CZECH TECHNICAL UNIVERSITY IN PRAGUE

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TECHNICAL UNIVERSITY IN BRNO

WORKSHOP 95

PRAGUE, JANUARY 23–26, 1995

PART I.

Mathematics – Physics – Chemistry – Engineering Informatics & Cybernetics – Computer Art – Fluid Mechanics

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These are the Proceedings of the Fourth Annual university-wide seminar WORKSHOP 95 which will take place at the Czech Technical University in Prague from 23–26 January, 1995.

The aim of the seminar is to present and discuss the latest results obtained by researchers especially at the Czech Technical University in Prague, Technical University in Brno and at collaborating institutions.

The organizing committee has selected a total of more than 420 contributions divided into 21 different areas of interest.

The program for WORKSHOP 95 consists of an introductory plenary session followed by four concurrent sessions: A, B, C and D.

Part I has contributions in the areas of:

- mathematics
- physics
- chemistry
- engineering informatics & cybernetics
- computer art
- fluid mechanics

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Section 1

MATHEMATICS

APPLIED MATHEMATICS IN ENGINEERING PROBLEMS

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Key words: finite element method, Maxwell equations, magnetic field, maximum angle condition, surface integral

1. In [1] the interpolation theorem for convex quadrilateral isoparametric finite elements is proved in the case when the condition $\varrho_K/h_K \geq \varrho_0 > 0$ is not satisfied, where h_K is the diameter of the element K and ϱ_K is the radius of an inscribed circle in K. The interpolation error is $O(h_K^2)$ in the $L_2(K)$-norm and $O(h_K)$ in the $H^1(\cdot)$-norm provided that the interpolated function belongs to $H^2(K)$. In the case when the long sides of the quadrilateral K are parallel the constants appearing in the estimates are evaluated.

In [2] two approaches in deriving the interpolation error for narrow quadrilateral isoparametric finite elements not satisfying the condition $\varrho_K/h_K \geq \varrho_0 > 0$ are presented. The first one, using the Bramble-Hilbert lemma, is successful only in deriving the $L_2(K)$-estimate. The nonapplicability of the standard approach via Bramble-Hilbert lemma in the case of $H^1(K)$-estimate is presented and a fully efficient method giving the optimum rate of convergence $O(h_K)$ in $H^1(K)$-norm is described. At the end the dependence of the interpolation error on the geometry of a quadrilateral is demonstrated by an example.

2. In [3] various triangular finite C^0-elements of the Hermite type satisfying the maximum angle condition are presented and corresponding interpolation theorems are proved. The simplest finite elements belonging to this family are polynomials of third degree. Nine of ten parameters uniquely determining these cubic polynomials are the same: function values and first partial derivatives prescribed at the vertices of a triangle. As to the tenth parameter there are several possibilities: a) the normal derivative $\partial p/\partial n$ prescribed at the midpoint Q_1 of the smallest side P_2P_3 of a triangle; b) the directional derivative $\partial p/\partial s_i$ prescribed at Q_1, where s_i is the direction parallel with the side P_1P_i ($i = 2$ or $i = 3$); c) the function value $p(P^*)$, where P^* is the point lying on the segment P_1Q_1 such that $\mathrm{dist}\,(P^*,Q_1) = \varepsilon\,\mathrm{dist}\,(P_1,Q_1)$ with $\varepsilon = (\mathrm{dist}\,(P_2,P_3))^2/(2\,\mathrm{dist}\,(P_1,Q_1))^2$. It is interesting that in the cases a) and c) the very general Jamet's hypothesis is not satisfied.

3. In [4] the finite element method for an elliptic equation with discontinuous coefficients (obtained for the magnetic potential from Maxwell's equations) is analyzed in the union of closed domains the boundaries of which form a system of three circles with the same centre. As the middle domain is very narrow the triangulations obeying the maximum angle condition are considered. In the case of piecewise linear trial functions the maximum rate of convergence $O(h)$ in the norm of the space $H^1(\Omega_h)$ is proved under the following conditions:

a) the exact solution $u \in H^1(\Omega)$ is piecewise of class H^4; b) the family of subtriangulations $\{T_h^A\}$ of the narrow subdomain Ω^A satisfies the maximum angle condition.

4. In [5] a special condition $\alpha \leq d(B\nu(B))/dB \leq \beta$ for magnetic reluctivity ν is introduced, α, β being positive constants. This condition guarantees the unique existence of both the generalized and the approximate solutions of the nonlinear stationary magnetic field equation, as well as a certain estimate of the error between these two solutions. This condition can be easily verified and is fulfilled for various magnetic reluctivity models used in electrotechnic practice.

5. In [6] a computional algorithm for modelling the periodicity condition is analyzed. This condition is very useful in electrotechnic applications because it enables us to reduce the domain of solution. However, it causes the loss of discretization system symmetry. The simplified way how to symmetrize the system again is presented. The paper is supplemented with numerical experiments.

6. In [7] the theory of surface integral including the Gauss-Ostrogradski theorem in a general form is developed without using the partition of unity.

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MATHEMATICAL MODELLING OF ENGINEERING PROBLEMS

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Key words: mathematical modelling, finite element method, equation of mathematical physics, plane elasticity, convection-diffusion problem, hyperbolic-parabolic problem, numerical integration, Czochralski flow, abstract operator equation.

In [1] the solution of the first problem of plane elasticity by an improved method of superposition is studied. The resultant stress function, which is a linear combination of the chosen biharmonic functions, is determined by/from the coincidence of all three components of the load resultant and the resultant of internal forces on the individual boundary elements. According to the Saint-Venant's principle, the inaccuracy of the solution is restricted to a thin strip along the boundary. The components of the resultants of internal forces acting on an arbitrary line segment can be expressed by means of stress function. The results of comparative examples prove the advantages of the proposed method.

Paper [2] deals with an explicit modified method of characteristics for the one-dimensional nonstationary convection-diffusion problem with dominating convection. A numerical method for the one-dimensional nonstationary convection-diffusion problem $u_t + pu_x - cu_{xx} = f$ is described and analyzed. The method is a combination of the method of characteristics and the finite difference method. Apriori local error estimate of the order $O(h_x^2 + h_t^1)$ has been proved, where h_x and h_t are the discretisation steps. The method is stable for $3\varepsilon h_t \leq h_x^2$ and it shows only a slight artificial diffusion. It takes advantage of some properties of the theoretical solution. This on the other hand causes difficulties in more dimensional problems.

In paper [3] existence and finite element approximation of a hyperbolic-parabolic problem is studied. The original two-dimensional domain is approximated by a polygonal one (external approximations). The time discretization is obtained using the Euler's backward formula (Rothe's method). Under certain natural smoothing assumptions on the data the existence and uniqueness of the solution and the convergence of Rothe's functions in the space $C(\overline{I}, V)$ is proved.

The effect of numerical integration in the case of narrow quadrilateral four-node isoparametric finite elements is studied in [1]. Let ε and b ($\varepsilon \leq b$) be the lengths of the short sides of a narrow convex quadrilateral K. Let h be the diameter of K. The following cases are analysed:

a) The case of parallel long sides: If $b = O(h^2)$ then an integration formula of second degree of precision guarantees the error of numerical integration equal to $O(h)$. If $\varepsilon = O(h)$ then we obtain the error $O(h)$ using an integration formula of fourth degree of precision.

b) Let one long side lie on the axis x and let a and b be the orthogonal projections of ε and δ on the axis y, respectively. If $|a - b| = O(h^2)$ then the same results hold as in the preceding case.

Contribution [5] deals with Czochralski flow. It is the flow of a silicon melt during production of *monocrystal* by Czochralski method. The axisymmetric model of the melt flow consists of the system of Navier-Stokes equations coupled with thermal convection-conduction equation, oxygen concentration convection-diffusion equations and an equation describing the effect of axial magnetic field. The problem is studied in the form used in literature dealing with numerical modelling, i.e. the flow is formulated in terms of stream function φ, Svanberg vorticity S and swirl Ω. Tension in free surface (Marangoni effect) yields special boundary condition. The weak formulation of stationary and evolutionary problems is introduced. Existence of the stationary solution is proved for small data, existence of the evolutionary solution is proved without restriction.

The solvability of operator equations is studied in [6]. The first part contains four abstract existence theorems for equations with operators being strongly monotone, monotone, weakly continuous or operators satisfying (M)-condition. The second part contains some examples of applications of abstract existence theorems to particular problems. The third part surveys auxiliary results that help verifying the assumptions.

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This research has been conducted at the Department of mathematics, Technical University Brno, Fac. of Mech. Engineering as part of the research project "Mathematical Modelling of Engineering Problems" and has been supported by TU grant No. C22/94.

MATHEMATICAL MODELS IN MECHANICS OF FLUIDS

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Key words: fluid mechanics, mathematical models, finite elements, Navier-Stokes equations, variational inequalities, turbine profiles

This contribution contains a brief description of some results which were obtained by the authors as a part of their research work in the year 1994. The referred papers will appear in various journals or proceedings of conferences in the next years.

J.Benda solved numerically the problem of subsonic flow of an ideal compressible fluid in a plane profile cascade. He developed a system of programs for complete solution by the finite element method. Convergence of the used iteration method for solution of the nonlinear system of grid equations was in details investigated in dependance on the used numerical method (SOR or the method of conjugate gradients) and on the Mach number. The method is applicable also to subsonic flows with Mach numbers which are arbitrarily near to one. The output data involve values of the stream function, velocity and Mach number in the flow field and the velocity and pressure distribution along profiles. Further details can be found in [1]. The work continues at the present time, it is oriented to design and program realization of the numerical method for optimization of profile shapes with respect to the velocity distribution.

S.Kračmar and J.Neustupa studied qualitative properties of variational inequalities of the Navier-Stokes type which simulate steady flows of viscous incompressible fluids in channels with the Dirichlet boundary condition on the input and the boundary condition

$$-p\mathbf{n} + \nu \frac{\partial \mathbf{u}}{\partial \mathbf{n}} = \mathbf{g}$$

on the output. (p is the pressure, $\mathbf{n}$ is the outer normal vector, ν is the coefficient of kinematic viscosity and $\mathbf{u}$ is the velocity.) Moreover, a one-sided condition restricting the backward velocity on the output was used. (This condition causes the necessity to formulate the problem by means of variational inequalities instead of partial differential equations.) The weak solvability was proved either for $\nu > \nu^*$ or for all $\nu > 0$ in dependence on the form of the one-sided boundary condition applied on the output of the channel. (ν^* is a positive number whose value can be concretely specified.) Uniqueness of solutions was proved under an apriori assumption concerning their regularity. Further, it was shown that the solution satisfies in a weak sense the Navier-Stokes equations and the inequality is reduced to the part of the boundary of the channel if the solution finds itself in an interior of a certain closed convex set whose form depends on the mentioned one-sided condition. More informations about this topic can be found in [2].

Š.Matušů dealt with equations of motion of viscous compressible fluids in the case of presence of singularities. She considered three types of singularities. At first, it is the case

when the density grows up without any boundedness. The second type corresponds to the case when the density vanishes and the third type occurs if the density has discontinuities like for example on a shock wave. The behaviour of perturbances and their propagation was studied in all three cases. (See [3] for more details.) Š.Matušů also studied a spherically symmetric motion of a viscous barotropic gas surrounding a solid ball. She proved stability of a steady equilibrium stage with a free boundary on the surface of the fluid.

It is known that the zero solution of differential equations in Hilbert or Banach spaces of the type

$$\frac{du}{dt} + Lu = Nu$$

(where L is a linear operator which is for example a generator of an analytic semigroup and N is a convenient nonlinear operator) is asymptotically stable if except other requirements which have more or less a technical character either $Re\,\lambda > \delta > 0$ for all $\lambda \in \sigma(L)$ or the operator L is essentially dissipative. The first condition is not satisfied for example in the case of many problems in exterior domains when the spectrum of L touches the imaginary axis and the second condition is too restricting, it is not satisfied if the symmetric part of L has some negative eigenvalues. J.Neustupa derived sufficient conditions for asymptotic stability which can be fulfilled in both these cases. (See [4] for more details.) The abstract differential equation introduced above can simulate among others a flow of a viscous incompressible fluid around a bounded body.

M.Machalický deals with a mathematical description and a graphical visualization of static and rotating parts of turbines. In frame of the cooperation with the enterprise Škoda Plzeň, he developed a set of new programs which respect boundary walls. The programs can be used for example to the design and control of shapes of channels between turbine blades from any view direction.

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PRECONDITIONED CONJUGATE GRADIENT METHOD AND ITS APPLICATION IN A FLUID DYNAMICS PROBLEM

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Key words: fluid dynamics, mathematical models, nonlinear algebraic equations, linear algebraic equations, condition numbers, ill-conditioned problems, preconditioned conjugate gradient method, finite elements, turbine cascades

This contribution is concerned with numerical solution of subsonic flow in a plane cascade. A corresponding mathematical model is a boundary value problem for a nonlinear elliptic partial differential equation. The finite element method has been used for a discretization of the differential equation and a system of nonlinear algebraic equations of the form $A(v) \cdot v = b(v)$ has been obtained. As the system is implicitly nonlinear, neither the direct solution nor the standard Newton's method can be used. Therefore a generalized method described below has been introduced.

$$
\begin{aligned}
\mathbf{w}^{(0)} &= \mathbf{v}^{(0)}, \quad \mathbf{w}^{(1)} = \mathbf{v}^{(1)} \\
\text{for} \quad k &\geq 1: \\
\mathbf{A} &= \mathbf{A}(\mathbf{w}^{(k)}), \quad \mathbf{b} = \mathbf{b}(\mathbf{w}^{(k)}) \\
\mathbf{v}^{(k)} &= \text{solution of} \quad \mathbf{A}\mathbf{v}^{(k)} = \mathbf{b}^{(k)} \\
\mathbf{w}^{(k+1)} &= \alpha \mathbf{v}^{(k)} + (1-\alpha)\mathbf{w}^{(k)}, \quad \alpha \in \langle 0,1 \rangle \\
k &= k+1
\end{aligned}
$$

An approximate solution $\mathbf{v}$ is then defined as a limit $\mathbf{v} = \lim_{k\to\infty} \mathbf{w}^{(k)}$.

In each step of this procedure it is necessary to solve a system of linear equations $A \cdot \mathbf{v} = \mathbf{b}$. A matrix of the system is symmetric and positive definite, but it is generally ill-conditioned. The fact that the values of the condition number were very large ($\sim 10^4$) drew our attention and so we decided to find a proper preconditioner for the matrix A to low the condition number of the system. A regular splitting $A = M - R$ of the matrix A has been defined and the matrix M - a regular part of this splitting has been used as a preconditioner. The closer the matrix M is to the matrix A the lower a value of the condition number of the "preconditioned system" is. Then instead of solution of the original system the modified system $M^{-1}Av = M^{-1}b$ has to be solved. This system has not been in fact constructed explicitly, a classical algorithm of the conjugate gradient method (CG) has been replaced by a preconditioned one (PCG) only. Comparing the two algorithms the difference between them is evident.

CG algorithm	*PCG algorithm*
$r_1 = b - Ax_1$	$r_1 = b - Ax_1$
$p_1 = r_1$	$p_1 = M^{-1}r_1$ (*)
$\alpha_k = (r_k, r_k)/(Ap_k, p_k)$	$\alpha_k = (r_k, p_k)/(Ap_k, p_k)$
$x_{k+1} = x_k + \alpha_k p_k$	$x_{k+1} = x_k + \alpha_k p_k$
$r_{k+1} = r_k - \alpha_k Ap_k$	$r_{k+1} = r_k - \alpha_k Ap_k$
	$u_{k+1} = M^{-1}r_{k+1}$ (*)
$\beta_k = (r_{k+1}, r_{k+1})/(r_k, r_k)$	$\beta_k = (r_{k+1}, u_{k+1})/(r_k, r_k)$
$p_{k+1} = r_{k+1} + \beta_k p_k$	$p_{k+1} = u_{k+1} + \beta_k p_k$

A distribution of the eigenvalues as well as the condition number of the matrix $M^{-1}A$ significantly influence convergence behaviour of the PCG algorithm. We need at maximum as many steps as a number of the equations to obtain a theoretically exact solution, but when the spectrum of the matrix of the modified system is "well distributed" we need very few steps only to obtain a good approximation of the exact solution.

Apart from *this the necessity to solve a system* $Mz = p$ *in each* step of the PCG arose. As the matrix M has been symmetric and positive definite, the Choleski factorization $M = L \cdot L^T$ and a following forward and backward substitution has been used. A reordering of the matrix M by a proper permutation matrix P has been done to minimize the fill-in in the factor L.

The procedure designed has been implemented into a program for the computation of subsonic flow in two typical turbine cascades used in Czech industry (Škoda Plzeň, profiles ST 101/80 and VO 1001/70).

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A FLOW-INDUCED INSTABILITY AND ITS NUMERICAL SOLUTION

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Key words: aeroelasticity, vibrations, stability, eigenvalue problem

The contribution deals with the theoretical and numerical methods for solution of a fluid-structure interaction problem. The study was concentrated on the dynamics and stability of an elastically supported flexibly-mounted body with 2 degrees of freedom vibrating in a rectangular channel conveying incompressible inviscid fluid. The problem was studied within the 1D and 2D linearized potential flow theory, including effects of boundary conditions at the inlet and outlet parts of the channel.

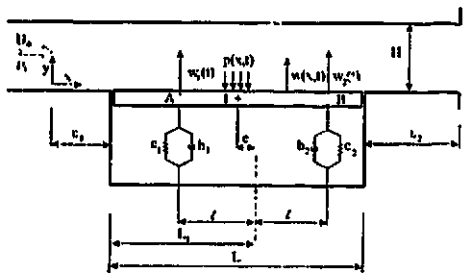

Fig. 1

The problem of finding the thresholds for the loss of stability of a flat flexibly-mounted rigid body (a plate) subjected to a parallel spacely confined 2D-fluid flow in a rectangular channel was recently mathematically formulated in [1]. The 2D problem can be considered as a semi-explicit system of Differential-Algebraic Equations (DAEs), where the algebraic part of DAEs, i.e. the discretized elliptic problem, solved by the finite difference method, is changed in each time step. The developed method of numerical solution was compared with a much simpler solution of the 1D-model of the fluid flow in a narrow channel. The first numerical results achieved within the 2D-model and 1D-model of the fluid flow were very close one to the other. The 2D interaction model was also partly described in the proceedings of CTU SEMINAR 94.

The paper [2] presented the numerical solution for an improved and more general 2D-model of the fluid flow in the channel when the inlet and outlet parts of the channel both upstream and downstream of the vibrating plate are taken into account. The critical flow velocities for the loss of static and dynamic stability of the system are evaluated from the numerical simulation of the motion of the plate. The results were compared again with the solution for the 1D-model of the fluid flow for various parameters of the system. Concerning the instability thresholds (the flutter or divergence) the considerable effects of the more general boundary conditions for the fluid flow were analyzed from the corresponding eigenvalues.

The elastically supported rigid body (a plate) with its upper flat surface of the length L subjected to the fluid flow in the channel of the height H is shown in Fig.1. The rigid body of the mass m and the moment of inertia I with an arbitrary position e of the centre of gravity T is supported by two springs $c_{1,2}$ and dampers $b_{1,2}$ at points A and B in the distance $l_1 \pm l$ from the upstream end of the body. The vibration of the body is described by the system of ordinary differential equations for the small displacements $w_1(t)$, $w_2(t)$ at A and B. The undisturbed mean flow velocity U_0 is now supposed upstream of the vibrating body in the distance ε_1 , and zero perturbation pressure is considered at the outlet of the channel in the distance ε_2 downstream of the body.

The 1D-problem for the potential $\phi(x,t)$ can be formulated with more general boundary conditions at the inlet and outlet parts of the channel:

$$\left.\frac{\partial\phi}{\partial x}\right|_{x=0} = 0, \qquad (1-\beta)\, p(x,t) + \beta\, \rho U_0 \left.\frac{\partial\phi}{\partial x}\right|_{x=L+\varepsilon_1+\varepsilon_2} = 0. \tag{1}$$

The 1D problem was studied by the classical methods of stability analysis. It was converted into an eigenvalue problem.

The influence of the parameters ε_1, ε_2 and β on the stability boundaries was studied more thoroughly. The boundaries for a fully symmetric damped system are very little influenced by the distance ε_1 considered at the inlet part of the channel. On the other hand the distance ε_2 downstream of the vibrating body was found very important. The longer the distance ε_2 was supposed the higher the hydrodynamic damping of vibration appeared, and the essentially higher mean flow velocity U_0 for the occurrence of the flutter instability of the system was necessary. Thus the dynamic behaviour and the stability of the studied system was found very sensitive to the choice of the boundary conditions for the flow field especially in the outlet part of the channel.

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NUMERICAL METHODS OF HIGHER ORDER

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Key words: spectral element methods, partial differential equations

The aim of our work was the development of some numerical methods, especially the so called spectral element methods, for solution of special problems represented by partial differential equations in the domain of evolution equations, in the domain of mechanics of fluid and in special problems of elasticity.

Spectral methods have been intensively developed over the last fifteen years. The progress in this field has been motivated by the need for a better accuracy in numerical simulation of more and more complicated scientific and technological problems. In the beginning a monodomain approach has been used. Later with the need to solve problems in more complicated domains the technique of domain decomposition has been used – thus the so called spectral element method appeared and was developed. These methods were developed especially by C. Bernardi, Y. Maday [1]. The idea of this methods is very close to the so called *h-p* version of the finite element method.

The basic characteristic of spectral element method is that discrete approximation is sought in the space of polynomials of high degree. The accuracy of the solution is then given by the regularity property of the exact solution. It is well known that the error of the approximation by polynomials of degree $\leq N$ descends exponentially with N.

Due to the domain decomposition approach the spectral element methods are very appropriate for parallel implementation [2], [3]. The development of these methods is in relation with the development of parallel computers which became accessible also in our conditions now. In our work we investigated the aspects of parallel implementation of the so called mortar element method which can be used in case of nonconforming, or sliding mesh [4].

As regardes to applications, we can mention the problem of the response of a simply supported bridge construction to a doubly sprung heavy vehicle going along the bridge.

This problem leads to the system of one partial and two ordinary differential equations for unknown functions $w(x,t)$, $v_1(t)$, $v_2(t)$, and was solved numerically by Ing. P. Pich and Prof. Karel Rektorys, DrSc., recently. The method of discretization in time was used and an ingenious programme developed, containing even such complicated cases as if the vehicle crosses an obstacle, jumps off and loses contact with the construction for a while, for example. Numerical results obtained by this method were quite satisfactory. However, the problem was so complicated that theoretical questions, especially that of convergence, remained unanswered. A different approach was suggested by Profesor Rektorys which seems to offer a better way of solving convergence questions.

The next technical problems we investigated were the problems of the elastic properties of the blood vessel and their replacement. A numerical model of contact "blood vessel-replacement" was made. This problem has been solved in collaboration with the Institute of Hydromechanics of Academy [5].

It is worth mentioning that this year the second deeply revised edition of the work K. Rektorys et al.: Survey of Applicable Mathematics, Dordrecht-London-Boston, Kluwer 1994, has been published, the preparation of which was also a part of our project.

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THE MATHEMATICAL MODEL OF A NONSTATIONARY FLOW WITH MIXED BOUNDARY CONDITIONS

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Key words: Navier-Stokes equations, mixed boundary conditions

In this contribution, we present the survey of the existence theorems for the system of the Navier-Stokes equations and the continuity equation with the mixed boundary conditions and for sufficiently small data.

1. Definition: *We suppose that* $\Omega \subset \mathbf{R}^n$, *where* $n = 2$ *or* $n = 3$, Ω *is open, bounded and connected domain,* $\Omega \in \mathbf{C}^3$ *and we suppose that*

$$\partial\,\Omega = \Gamma_1 \cup \Gamma_2, \Gamma_2 = \Gamma_3 \cup \Gamma_4, \Gamma_3 \cap \Gamma_4 = \emptyset.$$

$$meas\ \Gamma_i > 0, i = 1,2,3,4,\ meas\ (\Gamma_1 \cap \Gamma_3) = 0, meas\ (\Gamma_1 \cap \Gamma_4) = 0$$

2. Definition: *Let us define the space*

$$\mathcal{E}_\sigma(\Omega) = \{u \in [\mathcal{C}^\infty(\Omega)]^n;\ div\ u \equiv 0,\ \overline{supp\ u} \cap \Gamma_2 \equiv \emptyset\},$$

the Banach space H_σ *as the closure of* $\mathcal{E}_\sigma(\Omega)$ *in the norm of the space* $[L^2(\Omega)]^n$ *and the Banach space* $V_\sigma^{1,r}$ *as the closure of* $\mathcal{E}_\sigma(\Omega)$ *in the norm of the space* $[W^{1,r}(\Omega)]^n$, $1 < r < \infty$.

3. Definition: *Let* $f \in L^2(0,T,(V_\sigma^{1,2})^*)$, $u \in L^2(0,T,V_\sigma^{1,2})$, $u' \in L^2(0,T,(V_\sigma^{1,2})^*)$. *Let the function* u *satisfies the equality*

$$\int_\Omega u' \cdot v\ d(\Omega) + \int_\Omega \frac{\partial u_i}{\partial x_j} \cdot \frac{\partial v_i}{\partial x_j}\ d(\Omega) + \int_\Omega u_j \cdot \frac{\partial u_i}{\partial x_j} \cdot v_i\ d(\Omega) = < f, v > .$$

Then we say that u *is the weak solution of the Navier-Stokes equations with the right side* f.

4. Definition: *Let us define the Banach space*

$$X_V = \{u; u' \in L^2(0,T,V_\sigma^{1,2}) \cap L^\infty(0,T,H_\sigma); u'' \in L^2(0,T,(V_\sigma^{1,2})^*), u(0) \in D\}$$

with the norm

$$|||u|||_{X_V} = |||u'|||_{L^2(0,T;V_\sigma^{1,2})} + |||u'|||_{L^\infty(0,T;H_\sigma)} + |||u''|||_{L^2(0,T;(V_\sigma^{1,2})^*)} + |||u(0)|||_D.$$

Let us define the Banach space

$$Y_V = \{F = [f, u_0]; f' \in L^2(0,T,(V_\sigma^{1,2})^*), f(0) \in H_\sigma, u_0 \in D\}$$

with the norm

$$|||F|||_{Y_H} = |||f|||_{L^2(0,T;(V_0^{1,2})^*)} + |||f(0)|||_{H_n} + |||u_0|||_D.$$

5. Definition: Let us define the operator $\mathcal{N}_V : X_V \to Y_V$.

$$\mathcal{N}_V(u) = F,$$

where $F = [f, u_0]$ *and*

$$\int_\Omega u' \cdot v \, d(\Omega) + \int_\Omega \frac{\partial u_i}{\partial x_j} \cdot \frac{\partial v_i}{\partial x_j} \, d(\Omega) + \int_\Omega u_j \cdot \frac{\partial u_i}{\partial x_j} \cdot v_i \, d(\Omega) = < f, v >,$$

and

$$u(0) = u_0$$

for u, F *and every* $v \in V_0^{1,2}$.

6. Remark: It is obvious the function u is a weak solution of the Navier-Stokes equations with the right side f if and only if $\mathcal{N}_V(u) = f$.

7. Theorem: *There exists neighbourhood* U *of zero in* X_V *and neighbourhood* V *of zero in* Y_V *and* $\mathcal{N}_V$ *is one-to-one from* U *to* V.

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THE TWIST PATTERNS AND A FORCING RELATION

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Key words: pattern, forcing relation

Introduction: The aim of this note is to give more information about a forcing relation with respect to the set of twist patterns. These patterns have been recently discovered ([1], [2]) as the simpliest types of patterns forced by any ones. The terminology used here is mainly the same as in [3].

Let $P = \{p_1, \dots, p_n\} \subset R$ and $\varphi : P \to P$. Then (P, φ) is the periodic orbit (or cycle) if $P = \{\varphi^i(p_1)\}_{i=1}^n$ (φ is cyclic permutation of P). We will usually omit φ and we simply say that P is a cycle. Period of a cycle P is $\mathrm{per}(P) = n$. Two periodic orbits $(P, \varphi), (Q, \psi)$ are equivalent if there exists a homeomorphism $h : \mathrm{conv}(P) \to \mathrm{conv}(Q)$ such that $h(P) = Q$ and $\psi \circ h|_P = h \circ \varphi$. An equivalence class of this relation will be called a pattern. If A is a pattern and $(P, \varphi) \in A$ we say that the cycle P has pattern A (P is representative of A) and we will use the symbol $[P]$ to denote pattern A.

Let $\mathcal{I}$ be the set of all closed real intervals. We consider the space $C(I)$ of all continuous maps f, which are defined on some $I \in \mathcal{I}$ and mapping it into itself. A function $f \in C(I)$ has a cycle (P, φ) if $f|_P = \varphi$. In this case we shall say that f exhibits pattern $[P]$. A pattern A forces a pattern B if all maps in $C(I)$ exhibiting A, exhibit also B. By f_P we mean the P-linear map of P, i.e. $f_P \in C(I)$ ($I = \mathrm{conv}(P)$) such that $f_P|P = \varphi$ and for any interval $J \subset I$ such that $J \cap P = \emptyset$ we have that $f_P|J$ is linear. Obviously f_P is a piecewise linear map. The modality of f_P (P, $[P]$) is the number of local extremes in the interior of I.

A cycle (P, φ) has eccentricity m/n if for any map $f \in C(I)$ with cycle P there exists a fixed point $c \in \mathrm{Fix}(f)$ such that $\#\{x \in P;\ x \le c\}/\#\{x \in P;\ x \ge c\} = m/n$. Note that cycle $(h(P), h^{-1} \circ \varphi \circ h)$ where $h(x) = -x$ has eccentricity n/m and so we can define the eccentricity of pattern $[P]$ as the eccentricity of its representative such that eccentricity is greater than or equal to 1.

Definition. Pattern A with eccentricity m/n is a twist if it does not force any other pattern with the same eccentricity.

Of course, one pattern may have more different eccentricities. But as we have shown in ([1], Lemma 2.1) it is essential to consider the patterns with the unique eccentricity m/n only. For such a pattern we have used the notion of m/n-unipattern (m/n-unicycle for its representative). In what follows we shall always consider patterns (cycles) with eccentricity m/n greater than 1. Note that for an m/n-unipattern $[P]$ the relation $\mathrm{per}(P) = k(m+n)$ holds. Let us suppose a cycle P is written with a spatial labeling, i.e. $P = \{p_1 < \dots < p_{k(m+n)}\}$.

Definition. We shall say that an m/n-pattern $[P]$ is green if a map f_P has the following properties :

(i) f_P has a unique fixed point c ($p_{km} < c < p_{km+1}$),

(ii) if $p_i < p_j \le c$ and $f_P(p_i) > c$, $f_P(p_j) > c$ then $f_P(p_i) > f_P(p_j)$,

(iii) if $p_i < p_j < c$ and $f_P(p_i) < c$, $f_P(p_j) < c$ then $f_P(p_i) < f_P(p_j)$.
(iv) if $c < p_i < p_j$ then $c > f_P(p_i) > f_P(p_j)$.

The Theorems: The basic meaning has the following result.

Theorem A. Let A be a pattern with eccentricity greater than or equal to m/n. Then A forces some twist pattern with eccentricity m/n.
Proof. See [1].

The Theorem A shows why it seems to be useful to investigate the forcing relation and topological entropy with respect to the set of all twist patterns (see also [4]).

Theorem B. Suppose m, n coprime, p, q coprime and $m/n \geq p/q$. Then every twist p/q-pattern is forced by some green m/n-pattern.

Theorem C. Let m, n, p, q be positive integers. There exists a pattern $[P]$ with the properties:
(i) a modality of $[P]$ is greater than m,
(ii) a topological entropy of $[P]$ is greater than n,
(iii) an eccentricity of $[P]$ is greater than p,
(iv) $[P]$ forces only the twist patterns with modalities less than q.

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MULTIDIMANSIONAL DISCRETE SIGNALS AND SYSTEMS

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Key words: discrete signal, discrete system, partial difference equation

In most cases, discrete signals are mathematically represented by sequences of real or complex numbers and discrete systems are considered as mappings between sets of sequences. This approach is applicable both to one-dimensional and multidimensional signals. In the latter case by a multidimensional sequence we mean a mapping $x : \mathbf{Z}^n \to \mathbf{C}$.

Though any mapping T operating on any set of sequences $\mathcal{S}$ is a mathematical model of a discrete system, systems with reasonable properties require some specifications of the domain $\mathcal{S}$. In order to take into consideration linear systems, $\mathcal{S}$ must be a linear space; investigation of convolution systems require moreover, that a binary associative operation (usually called convolution) be defined on $\mathcal{S}$. Approximation and optimization methods, as well as another important property of systems, stability, impose further requirements on the mathematical structure of $\mathcal{S}$; these are associated with the concepts of convergence and boundedness and are typically met in a complete normed space.

A complete normed linear space $\mathcal{S}$ where an associative operation $* : \mathcal{S} \to \mathcal{S}$ is defined such that it is distributive with respect to addition in $\mathcal{S}$ and satisfies the relation

$$\|x * y\| \leq \|x\| \, \|y\| \quad \text{for any } x, y \in \mathcal{S}$$

is called Banach algebra.

It is therefore natural to employ Banach algebra techniques in systems theory; in particular, Banach algebras of sequences play an important role, either directly or indirectly, in a number of topics in the discrete systems theory. As examples we can take the principal stability criterion for multidimensional filters [1], deep analysis of the relationship between the cepstrum and the stability of multidimensional filters [2], theory of the asymptotic stability of discrete filters [3] or the recent results on the Λ-transform [4] and deconvolution [5].

In [6] it has been shown that all basic transformations of discrete signals - Fourier transform, z-transform and discrete Fourier transform - are particular cases of the Gelfand transform in the Banach algebras of absolutely summable sequences, causal absolutely summable sequences and periodic sequences respectively. Thus Banach algebras of sequences form a suitable mathematical framework for the discrete systems theory. This framework not only sheds more light on the known results but, as [4] and [5] show, opens ways to new mathematical models of discrete systems and has the potential to solve certain deconvolution problems and problems encountered in homomorphic signal processing.

Though the results in [4] and [5] are only one-dimensional we believe that the Banach algebra framework might help in obtaining their multidimensional counterparts. This idea is currently under investigation.

Models of linear systems are often represented by partial difference equations; either by input-output relations or by state equations. The existence and uniqueness (EU) of

their solutions have been formulated and solved for initial value problems and more general boundary value problems [10]. Special cases of mappings between sequence spaces have been considered in [7]. Here, the linear partial difference equations with periodic coefficients are investigated and EU conditions are formulated for the corresponding mapping between sets of periodic sequences.

The state space representation of linear n-D systems has been considered so far in special cases with the support of sequences in the first quadrant of Z^2. An attempt to generalize the concept of the local and global state of a general linear system has been made in [8]. The construction of the state is based on the recursive computation of the solution and enables the inclusion of n-D results into the framework of the general systems theory.

An attempt to contribute to the robustness of n-D systems resulted in a detailed study of convex combinations of 1-D Hurwitz polynomials [9]. Necessary and sufficient conditions for a convex combination of two Hurwitz polynomials to be again a Hurwitz polynomial, are given. Further research will, hopefully, lead to analogous results for scattering Hurwitz polynomials in n variables.

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QUANTUM LOGICS – A MODEL FOR GENERALIZED PROBABILITY

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Key words: noncommutative probabilistic models, quantum logic, states, Boolean algebra, measure theory

A *quantum logic* is a structure $(L, \leq, ', 0, 1)$ fulfilling the following conditions:

1. $\leq$ is a partial ordering on L with a least and a greatest elements, 0, 1;
2. $' : L \to L$ is a unary mapping on L with $(a')' = a$ for any $a \in L$;
3. if $a, b \in L$ and $a \leq b$, then $b' \leq a'$;
4. if $a, b \in L$ and $a \leq b'$, then the supremum $a \vee b$ exists in L;
5. if $a, b \in L$ and $a \leq b$, then there is an element $c \in L$ such that $c \leq a'$ and $b = a \vee c$.

A *state* on a quantum logic L is a mapping $s : L \to [0, 1]$ such that:

1. $s(1) = 1$;
2. $s(a \vee b) = s(a) + s(b)$ whenever $a, b \in L$ and $a \perp b$.

Thus, the classical probability model by Kolmogorov is a natural example of a quantum logic and the probability measures are just states on it. The difference between these two models lies in the formulation of the axiom 3 – in the probability theory one requires the existence of all joins, not only of the disjoint ones. In other words, in the probability theory the set of elementary events is to be a Boolean algebra, while in quantum logics it can be an orthomodular lattice, a more general structure. This might overcome a common problem with inadequacy of the probability model: in a natural situation it appears very often that two events are not comparable. The quantum logics have found a natural application in quantum theories and recently also in biology. I recommend [4] or [1] for a more detailed introduction to the field.

One of the basic problems in quantum logics is construction of examples and counterexamples. Even the simplest examples involve highly technical combinatorial problems. Hence, more advanced examples are usually "pasted" from simpler ones. This method was suggested by Greechie, who pasted Boolean algebras in a relatively simple, but surprisingly successful way. The problem is that a pasting of a collection of orthomodular lattices (or Boolean algebras) may, but need not result in an orthomodular lattice. Technically this means that one composes hypergraphs so that no "loop" of a small length was created. We found necessary and sufficient conditions for such pastings of orthomodular lattices and posets [3]. This paper presents the most general result concerning creation of quantum structures by pasting Boolean algebras together. Moreover, we developed a new method of a substitution of one atom by a whole quantum logic. Now the research is oriented at construction of ready-made components that could be used in the pasting. Our methods have been successfully applied to the theory – see [6] for a review of such results or the latest paper by Navara [2].

While we are usually interested only in one probability measure in the classical theory, in quantum logics we investigate the whole space of all (possible) states on L. The interplay of this *state space* and the orthomodular lattice L is studied intensively. The Jauch-Piron

property appeared to be very important, especially in quantum theories. Recently we studied the *subadditivity of states on L*. It is not obvious how to translate this notion from the classical theory into the quantum logics. We suggested several possible definitions and compared their consequences. Moreover, we proved that a quantum logic L tends to be a Boolean algebra if there are sufficiently many subadditive states on it - see [8]. This resembles a similar result for Jauch Piron states [5]. The interpretation of this fact can be that the properties of the state space may imply the distributivity of the quantum logic L which, in fact, means that L is the classical probability model.

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ON SUBDIRECT IRREDUCIBILITY

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Key words: subdirect product, variety of algebras, congruence

The subdirect product of algebras is one of the most important constructions of more complex algebras from a given collection of "simpler" algebras: one forms first a direct product of the given collection and then one considers any subalgebra of the direct product $\prod_{i\in I} A_i$ for which the i-th projection is the entire algebra A_i (for all $i \in I$). Algebras B which cannot be decomposed in this manner (i.e., those for which whenever B is isomorphic to a subdirect product, one of the projections is necessarily an isomorphism), are called *subdirectly irreducible*. These form the basic building blocks of any equationally defined class $\mathcal{V}$ of algebras because, by the famous Birkhoff theorem [1], every algebra in $\mathcal{V}$ is a subdirect product of algebras from $\mathcal{V}$. Thus, in order to understand the inner structure of an equational class of algebras, called a variety, it is important to know which algebras in it are subdirectly irreducible.

We have performed an investigation of subdirect irreducibility in the following two directions:

1. finding a structural description of subdirectly irreducible algebras in $\mathcal{V}$;
2. describing minimal congruences for an algebra in $\mathcal{V}$ (an algebra is subdirectly irreducible iff there is exactly one minimal congruence which is then the least non-identical one).

Algebras that are widely used in computer science are semigroups (i.e. algebras with one associative binary operation). Subdirectly irreducible commutative semigroups were described by B. Schein [7]. A full characterization of subdirectly irreducible semigroups with minimal left and right ideals was presented by M. Demlová and V. Koubek [2]. Minimal congruences for finite semigroups were classified by J. Rhodes [6], and minimal congruences for Green semigroups were fully described by M. Demlová and V. Koubek [3].

In spite of the results mentioned above there is no satisfactory structural description of subdirectly irreducible semigroups within all varieties of semigroups. One can ask what the reasons for this situation are. It has turned out that in some varieties there are too many subdirectly irreducible semigroups, so that a structural description of subdirectly irreducibles would involve a structural description of nearly all semigroups in the variety in question.

Definition: A variety $\mathcal{V}$ is said to have too many subdirectly irreducible algebras if every algebra in $\mathcal{V}$ can be embedded into a subdirectly irreducible algebra in $\mathcal{V}$.

Varieties of bands (i.e. idempotent semigroups) with too many subdirectly irreducibles were described by P. Goralčík and V. Koubek [5]. Varieties of nilsemigroups, varieties of commutative semigroups, varieties of completely regular semigroups with too many subdirectly irreducibles are characterized in [4].

In the future we plan a continuation of the research leading to characterizing subdirectly irreducible semigroups of some basic varieties, and to collecting evidence of varieties with too many subdirectly irreducible algebras.

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EXTENSIONS OF STATES ON OPERATOR ALGEBRAS

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Key words: von Neumann algebras, Jordan algebras, states on operator algebras, foundations of quantum physics.

The theory of algebra of operators on Hilbert space began in the 1930s with a series of papers by Jordan, von Neumann, Murray and von Neumann and by Wigner. The principal motivations of these authors were the theory of unitary group representations and certain aspects of the quantum mechanical formalism. They introduced and analyzed a family of operator algebras which are referred to nowadays as von Neumann algebras, C^*-algebras and Jordan algebras. Since its rapid development, the theory of operator algebras has become an important part of functional analysis, with applications in many other disciplines such as abstract harmonic analysis, spectral theory, non-commutative geometry, K-theory, quantum field theory, quantum statistical mechanics, quantum chemistry, etc.

Our research interest in this vast field is the general structure theory of operator algebras, in particular, extension properties of states. Below we summarize a few important results.

In papers [7,8] we deal with the extensions of states (probability measures) defined on projection logic $P(M)$ of a given Jordan-Banach algebra M. The central question of this field is the problem of whether or not all states of $P(M)$ extend to states (positive linear functionals) of an algebra M. This outstanding problem, known as the Mackey-Gleason problem, was posed some thirty years ago [9]. The positive answer would establish a relation between measure and state analogous to the relation between measure and integral in the classical integration theory (Riesz's representation theorem). The Mackey-Gleason question is highly non-trivial and has been answered in the affirmative for JBW-algebras, not containing type I_2- direct summand (generalized Gleason theorem). Studying the extension problem from a general point of view, we succeeded in proving that the Gleason extension property (the existence of the integral of a given measure) is, in fact, equivalent to the universal state extension property of the projection lattice (the existence of extension of a given measure to arbitrary larger orthomodular structure). This result strengthens considerably the generalized Gleason theorem and provides new insight into the Mackey-Gleason problem. In addition, we have shown the equivalence of the Gleason property and the Hahn-Banach extension property in the realm of order unit spaces of affine functions. Stated results are also of some importance for axiomatic quantum mechanics.

Paper [2] is devoted to extensions of Jauch-Piron states. (A state ϱ of $P(M)$ is called Jauch-Piron if its kernel is a sublattice in $P(M)$. It is commonly assumed in quantum physics that only Jauch-Piron states can qualify as being "physical" states.) Jauch-Piron states on one particular algebra do not usually extend to Jauch-Piron states on a larger algebra [1,5]. It is therefore surprising that, under some important circumstances relevant for both mathematics and physics, Jauch-Piron states possess remarkably good extension properties. Namely, we proved that every Jauch-Piron state on a JW-algebra M extends

to a Jauch-Piron on the enveloping von Neumann algebra $W^*(M)$. This result contributes to the structure theory of operator algebras and offers simplification of basic mathematical model of quantum mechanics [2]. Using the above stated result we can also show that all the results on the continuity of Jauch-Piron states obtained in [1,5,6,10] are valid also for Jordan algebras.

Finally, our research has been concentrated on the continuity of homomorphisms between von Neumann algebras, the commutative properties of states, and the geometrical properties of the state space [3,4,10]. The results of this part of our research are important contributions to the theory of von Neumann algebras and their applications.

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STATE SPACE OF AN ORTHOALGEBRA

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Key words: orthoalgebra, state space, pasting technique, extension problem, Boolean orthoalgebra, Hilbertian orthoalgebra

The logico-algebraic foundation of quantum theories, which has been pursued quite intensely recently (see [1,2,3,5,7,8,9], etc.), adopts for its underlying structure so called "quantum logic". A quantum logic is usually assumed to be an orthomodular poset. Certain philosophical, physical and mathematical considerations have suggested that the "right" logic of a quantum physical experiment be an orthoalgebra (OA). The OA is a partial algebra with a binary operation such that the orthomodular law can be derived as a consequence of the axioms imposed on the operation. Viewed from the mathematical standpoint, the OAs are generalizations of orthomodular posets (and therefore they generalize orthomodular lattices and Boolean algebras).

There seem to be (at least) two explicit advantages of OAs over the quantum logics used previously. The first reason is physical — the OAs (unlike orthomodular lattices) have come into existence on the ground of plausible physical assumptions based on the "test spaces" (see [2], etc.). The second reason is technical — the axioms of an OA are natural and simple and the algebraic theory of OAs seems to meet well the needs encountered in applications (see [3,4], etc.).

In this note we want to announce some recent results on states (=finitely additive measures) on orthoalgebras. The results will be published in [4] and [6]. A useful "pasting technique" to be applied in the state space considerations was developed. The orthoalgebras with rather interesting and "exotic" state spaces were constructed. Also, examples of orthoalgebras with preassigned state space properties were exhibited. A state representation theorem was obtained and an orthoalgebraic version of Shultz's theorem was established. A thorough analysis of the extension problem for states on orthoalgebras was carried out. A necessary and sufficient condition for "simple" orthoalgebras to allow extensions of states over larger orthoalgebras was found. It was also proved that all Hilbertian orthoalgebras as well as all Boolean orthoalgebras allow extensions of states.

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FUZZY QUANTUM SPACES AND BOOLEAN REPRESENTATIONS

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Key words: fuzzy quantum space, soft fuzzy σ-algebra, d^3-lattice, Boolean σ-algebra, σ-field, state, observable, representation

The notion of fuzzy set, introduced by Zadeh, has become frequently used not only in engineering applications, but also in biology, medicine etc. It enables us to describe our uncertain knowledge of the system. However, this uncertainty may originate also from the nature of the system, e. g. in quantum mechanics.

Besides numerous applications, the mathematical theory of fuzzy sets is proceeding. Recently, generalizations of the probability theory based on collections of fuzzy sets have been intensively studied. They allow for nonclassical situations encountered in the above mentioned areas. The notion of Boolean σ-algebra, crucial for the classical probability theory, is replaced by a collection of fuzzy sets. This collection has to be closed with respect to the operations of "fuzzy complement", "fuzzy union" and "fuzzy intersection" of countable subsets. Here we contribute to the theory of fuzzy quantum spaces [2,5] by clarifying the possibility of applications of Boolean techniques. We investigate this question in a more general structure — a d^3-lattice — using purely algebraic methods.

Let L be a σ-complete lattice with a unary operation $'$ (complementation). We call L a *d^3-lattice* [3] if it satisfies the following conditions:

(d1) L satisfies the distributivity condition $b \wedge \bigvee_{i\in K} a_i = \bigvee_{i\in K} (b \wedge a_i)$,

(d2) $(a')' = a$ for all $a \in L$ and $'$ is an order antiisomorphism (thus L satisfies the de Morgan laws),

(d3) $a \wedge a' \le b \vee b'$ for all $a, b \in L$ (*Kharat condition*).

All Boolean σ-algebras are d^3-lattices. Let us recall the definition of a fuzzy quantum space as an important example of a d^3-lattice.

Let X be a non-empty set. A *fuzzy quantum space* [2] (or *soft fuzzy σ-algebra* [5]) on X is a set $F \subset [0,1]^X$ satisfying the following conditions:

1. the constant zero function belongs to F,
2. if $a \in F$, then $a' = 1 - a \in F$,
3. if $\{a_i\}_{i\in K}$ is a sequence in F, then $\bigvee_{i\in K} a_i \in F$ (the symbol $\bigvee$ means here the pointwise supremum of functions),
4. the constant function $1/2$ does not belong to F.

In fact, d^3-lattices present a common generalization of Boolean σ-algebras and fuzzy quantum spaces. A d^3-lattice L is a Boolean σ-algebra iff $a \vee a' = 1$ for all $a \in L$. A fuzzy quantum space is a Boolean σ-algebra iff it is isomorphic to a σ-field.

Throughout this note L denotes a d^3-lattice. A suitable generalization of a random variable seems to be an *observable* on L, i.e. a σ-homomorphism of the Borel σ-algebra $B(R)$ into L. A *state* on L is a mapping $s : L \to [0, 1]$ such that

1. $s(a \vee a') = 1$ for all $a \in L$,

2. if $\{a_i\}_{i \in N} \subset L$ such that $a_i \leq a_j'$ for $i \neq j$, then $s(\bigvee_{i \in N} a_i) = \sum_{i \in N} s(a_i)$.

Particularly, a state on a Boolean σ-algebra is an ordinary probability measure. Now we may formulate the analogy between a d^3-lattice and a Boolean σ-algebra:

Theorem 1 [3]: *Let L be a d^3-lattice. There exists a* Boolean representation *of L, i. e. a Boolean σ-algebra B and a mapping $h : L \xrightarrow{\text{into}} B$ such that*

1. for each state s on L there is a state t on B satisfying $s = t \circ h$,

2. for each observable x on L the mapping $y = h \circ x$ is an observable on B.

Theorem 2 [4]: *Every Boolean σ-algebra is a Boolean representation of a fuzzy quantum space.*

As a consequence, there is a fuzzy quantum space admitting no states. This answers the problem of existence of states on fuzzy quantum spaces (see [1,2]).

Boolean representations usually are not σ-fields. Hence observables cannot be represented by measurable functions and they become "point free random variables". On the other hand, we achieve the maximum close correspondence between state spaces and between spaces of observables of a d^3-lattice and its Boolean representation.

It remains an open problem to characterize fuzzy quantum spaces among d^3-lattices. It is not clear which is the most general structure that admits a Boolean representation. Can (d1) be replaced with finite distributivity? Is the Kleene condition necessary for the existence of a Boolean representation? These questions are subject to further research.

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AN OBJECT-ORIENTED ANALYSIS FOR DECISION MAKING UNDER UNCERTAINTY

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Key words: object-oriented approach, optimization, stochastic programming, multi-stage models, blending problems, steel production

Typical problems studied for large-scale optimization relate with modeling approaches. An object-oriented methodology for multi-stage stochastic programming was presented in [1]. A separate encapsulation of solvers, data and models supports easy future modifications. Models, solvers and results can be stored in small databases based on streams.

The purpose of this paper is to present a mathematical model for the production process. Classical blending models are implemented for use at the beginning of the melting process. There are two questions usually asked. The first one is how to hedge against the influence of random losses during the process, and the second one is how to take advantage of the existence of more than one decision stage. The author will try to give possible answers to these questions using [1].

A main concept is an optimization element $\mathcal{O}_j$ defined in following way:

$$\mathcal{O}_j: \qquad ? = \underset{\mathbf{y}_j \in V_j}{\operatorname{argmin}} \{ f_j(\mathbf{y}_j, \xi_j, \mathbf{z}_j) \mid \mathbf{y}_j \in C(\xi_j, \mathbf{x}_j) \} \tag{1}$$

where bold characters denote following vectors: $f_j : \mathbb{R}^{N_j} \times \mathbb{R}^{K_j} \to \mathbb{R}^*$ is an objective function and $\mathbb{R}^* = \mathbb{R} \cup \{-\infty, +\infty\}$. $C(\xi_j, \mathbf{x}_j)$ is a feasible set, usually defined using a vector constraint function $\mathbf{g}_j : \mathbb{R}^{N_j} \times \mathbb{R}^{L_j} \to \mathbb{R}^{M_j}$, where $M_j \in \mathbb{N}$, $\mathbf{x}_j \in \mathbb{R}^{L_j}$ is a parameter, $L_j \in \mathbb{N}$. ξ_j is a random vector defined on $(\mathbb{R}^{S_j}, \mathcal{B}_j, P)$, $S_j \in \mathbb{N}$. $\mathbf{y}_j \in \mathbb{R}^{N_j}$ is a decision variable, $N_j \in \mathbb{N}$. $\mathbf{z}_j \in \mathbb{R}^{K_j}$ is a parameter, $K_j \in \mathbb{N}$.

Different elements are joined by rules defined by oriented graphs. Let $\Gamma = (V, E)$ be an oriented graph, where $V \subset \mathbb{N}$ is a finite non-empty set of nodes and $E \subseteq V \times V$ is a finite set of arcs. Let $\mathcal{O} = \{\mathcal{O}_j\}_{j \in V}$ be the set of optimization elements defined above. For each arc (i, j) of graph $\Gamma = (V, E)$ there are transformations $x_j^i = \phi_{ij}(y_i)$ and $z_i^j = \psi_{ij}(y_j)$. Models with ϕ_{ij} and ψ_{ij} mappings for the message exchange were also studied. These objects join different models and they create complex models especially the multi-stage models.

The first version of developed models was used in [2] for the special class of three-stage blending problems.

These results were generalized in the report [3]. Several deterministic equivalents were defined for given stochastic optimization problem.

Generalized randomness was discussed in [4]. A linearization of nonlinear terms containing random variables were studied in [5].

One of simple models was implemented in the CAM system used by the rapidly growing Czech steel producer ZDAS Zdar nad Sazavou and the revised simplex procedure is repeatedly used during the solution process [6].

Numerical results based on real data are presented in [7].

MSLiP solution procedure is defined in [8]. This procedure is based on the L-shaped algorithm using Benders decomposition for stochastic linear programming. Comparisons are based on the concepts EVPI, VSS defined by Kall and Wallace.

This approach was also used for analysis of the stochastic knapsack problem [9].

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USAGE OF REGRESSION METHODS IN MODELLING OF 3D INTERPOLATION SURFACES

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Key words: mathematical modelling, interpolation surface, patches, regression analysis, stepwise regression, method of least squares

Interpolation surface patches which are used in modelling of complex shapes, which is possible to be found in the technical practice, might be divided into two base groups:

(1) patches given by boundary curves

(2) patches given by boundary curves and tangential planes in the points of the boundary curves.

Each of this group above can be divide into two subgroups:

(a) patches determined by two boundary curves.

(b) patches determined by four boundary curves (Coon's patches).

Mathematical description of all the groups mentioned together with their advantages and disadvantages will be a part of my contribution. In short, patches of the group (1) are more convenient for computer programming, but it is not possible to create a model which enables large changes of their shape with respect to the given boundary. On the other hand, the patches from group (2) are reverse. The main advantage is a possibility of various shapes with respect to the given boundary. The disadvantage consists in more complex computer programming.

The choice of mathematical models for the boundary curve of interpolation patches depends on information about modelled curves we have at our disposal and request on their geometrical shape. For simplicity and with respect to the time needed we often use expression with polynoms.

In the use when the boundary curve is only known by individual points obtained by measurement, the best way is to create its mathematical model by means of regression analysis. The advantage of regression methods - with respect to the other interpolation and approximation methods - consists in the minimalisation of random errors of measurement.

A lot of regression methods how to find a mathematical model (equation) for the boundary curve are known. In comparison of evaluation of the regression methods and with respect to the simplicity and time consumption showed, the most efficient methods are:

the stepwise regression method

and

the method of least squares.

In the case of the stepwise method the power polynom with limited conditions is used. We introduced two types of linearised functions for the least square method. The required geometrical shape is reached by the choice of their optional constants. This choice is running automatically after the geometrical description of the curve in a computer. On fig. 1 a part

of surface is shown. This part consists of three patches. In my contribution will be shown the mathematical shapes of individual models together with their usage.

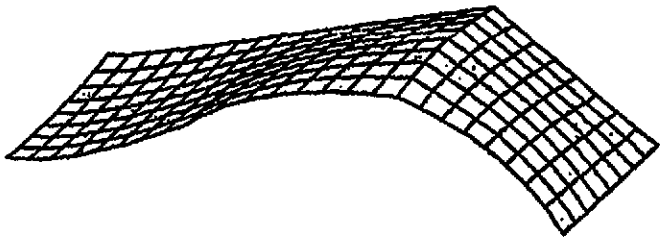

Fig. 1:

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VELOCITY AND CORIOLIS QUADRICS OF ROBOT-MANIPULATORS

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Key words: Robot-manipulator, velocity operator, Coriolis acceleration, velocity quadrics, Coriolis quadrics

This paper is a continuation of [3],where the basic properties of the velocity and acceleration fields of 3R robot-manipulators have been described. We shall show that both velocity and Coriolis acceleration operators are connected with quadratical surfaces.Let us have a 3R robot-manipulator determined by axes X_1, X_2, X_3, see Fig.1.Let us consider an instantaneous position Y_1, Y_2, Y_3 of these axes. Then the velocity operator Ω for this configuration is given by

$$\Omega = \omega_1 Y_1 + \omega_2 Y_2 + \omega_3 Y_3 ,$$

the Coriolis acceleration C is given by the formula

$$C = Y_1 \times Y_2 \omega_1\omega_2 + Y_1 \times Y_3 \omega_1\omega_3 + Y_2 \times Y_3 \omega_2\omega_3.$$

$Y_i \times Y_j$ is the cross product of Plücker coordinates,see [2]. The velocity operator Ω is always a linear combination of Y_1, Y_2, Y_3.This shows that we have to work in the 6-dimensional vector space V_6 of screws.It is the vector space of all pairs $(\vec{x};\vec{y})$ of ordinary vectors of the Euclidean space E_3. V_6 contains Plücker coordinates of all straight lines of E_3.Their image is called Klein's quadratical hypersurface K.

Let us assume that the direction vectors $\vec{x}_1, \vec{x}_2, \vec{x}_3$ of Y_1, Y_2, Y_3 are independent.All velocity operators Ω for the given configuration Y_1, Y_2, Y_3 generate a 3-dimensional subspace V_3 of V_6. The intersection of K with V_3 is a ruled hyperboloid Q_v.

Q_v is connected with the velocity operator and it is uniquely determined by the instantaneous configuration Y_1, Y_2, Y_3 of axes X_1, X_2, X_3 of the robot-manipulator.We shall call it velocity quadrics.

We have similar situation with Coriolis acceleration.According to (2) the Coriolis acceleration operator C for the given configuration Y_1, Y_2, Y_3 lies in the 3-dimensional space W_3 generated by screws $Y_1 \times Y_2, Y_1 \times Y_3, Y_2 \times Y_3$. Let us denote Q_c the quadratical surface obtained as the intersection of W_3 with K,we shall call it Coriolis quadrics. We can prove that the Coriolis quadrics Q_c is independent of the choice of screws Y_1, Y_2, Y_3 in the subspace W_3. Therefore the connection between Q_v and Q_c is independent of the choice of screws which determine them and we can choose screws corresponding to axes of Q_v. We show that Q_c and Q_v have the same axes. The equation of Q_v in canonical coordinates is

$$v_1x^2 + v_2y^2 + v_3z^2 + v_1v_2v_3 = 0.$$

Lengths a, b, c of axes of these surfaces are not in general the same.Relation between those quantities is the following:

$$Q_v : \qquad a^2 = v_2v_3 \qquad b^2 = v_1v_3 \qquad c^2 = v_1v_2$$

$$Q_c: \quad a^2 = (v_3 + v_1)(v_2 + v_1) \quad b^2 = (v_2 + v_3)(v_1 + v_2) \quad c^2 = (v_2 + v_3)(v_3 + v_1).$$

Classification of velocity and Coriolis quadrics is given according to different values of v_1, v_2, v_3.

1) $v_1 v_2 v_3 \neq 0$. Q_v is a one sheet hyperboloid. For Q_c we obtain the following possibilities:one sheet hyperboloid,two planes, one plane,empty set,

2) $v_1 v_2 \neq 0, v_3 = 0$. Q_v consists of two pencils of straight lines, Q_c is one sheet hyperboloid or Q_c consists of two pencils of straight lines.

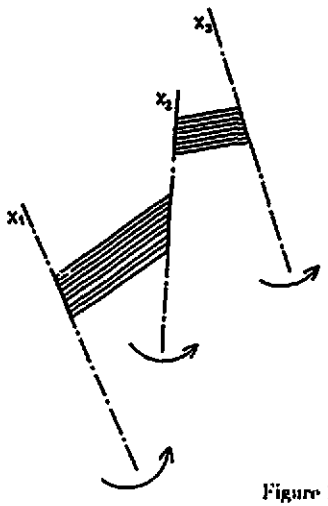

Figure 1.

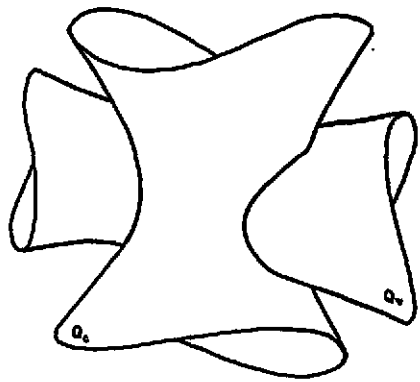

Figure 2.

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THE INDICATRIX OF DUPIN OF THE ENVELOPE CREATED BY DOUBLE ROTATIONAL MOTION

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Key words: double rotational motion, principal directions, principal curvatures, indicatrix of Dupin, envelope

The double rotational motion is a special motion in the space. It is studied mainly in the relation to the theory of gearing. The side of the tooth face is an envelope of the tool face or an envelope of the tooth face of the conjugate wheel.

During the design of the tooth wheel it is necessary also to take care about the form of the tooth face. By geometrical means the form of the surface can be described for example by the normal curvature at a point of the surface. Good information about the normal curvature gives us the indicatrix of Dupin (see [1]).

The articles [2], [3], [4] deal with the construction of characteristic curves and the visualisation of the special double rotational surface supported by computers.

This article is focused on the mathematical apparatus which leads step by step to the computation and visualisation of the indicatrix of Dupin of the envelope in its regular elliptic and hyperbolic points.

The double rotational motion is given by the rotation of the system ${}^1\Sigma$ across the axis ${}^1o$ with the angle velocity ω_{10} and the rotation of the system ${}^2\Sigma$ across the axis ${}^2o$ with the angle velocity ω_{20}. We suppose:

(I) Angle velocities ω_{10} and ω_{20} are constants.

(II) The angle between vectors $\vec{\omega}_{10}$ and $\vec{\omega}_{20}$ and the distance between axes ${}^1o$, ${}^2o$ is not changing during the motion.

The generating surface on which the double rotational motion is applied is fix joint with the system ${}^1\Sigma$. It creates a one-parameter family of surfaces. We suppose that the family of surfaces has its envelope.

The indicatrix of Dupin of the envelope is created in the tangent plane of the generating surface going through the contact point of both surfaces. If the principal directions and principal curvatures of the generating surface, the common normal vector and parameters of the double rotational motion in the contact point are known, the curvature of the envelope in the chosen direction can be computed.

Denote:

$\vec{n}$ - common unit normal vector of both surfaces,

$\vec{r}$ - position vector of the contact point,

$\vec{\omega}_{12} = \vec{\omega}_{10} - \vec{\omega}_{20}$,

$\vec{v}_{12}$ - vector of the relative velocity in the contact point of both surfaces,

κ - normal curvature of the generating surface in the direction of the vector $\vec{l}$,

$\tilde{\kappa}$ - normal curvature of the envelope in the direction of the vector $\vec{l} + \vec{v}_{12}$.

The relation between curvatures of both surfaces is given by the following formula (see [5]):

$$\kappa[\,\vec{l}+\vec{\omega}_{12}\,]^2-\kappa[\,\vec{l}\,]^2-[\,\vec{\omega}_{10},\ \vec{n},\ \vec{v}_{12}\,]+[\,\omega_{12},\ \vec{n},\ (2\vec{l}+\vec{r}\times\vec{\omega}_{10}+\vec{v}_{12})\,]=0.$$

Principal directions and principal curvatures of the envelope can be computed from projective properties of the regular central conic. Conjugate diameters of the conic create the involution of conjugate directions. Axes of the conic coincide with perpendicular pair of the involution. Lengths of semiaxes can be computed from the equation of the conic after suitable transformation of the coordinate system.

The algorithm has been used for writing programs for computing and visualisation of the indicatrix of Dupin of the envelope created by the motion of the rotational surface.

The generating surface and the part of its envelope is shown in fig.1. Fig.2. show the indicatrix of Dupin of the generating surface and of the envelope in its hyperbolic point.

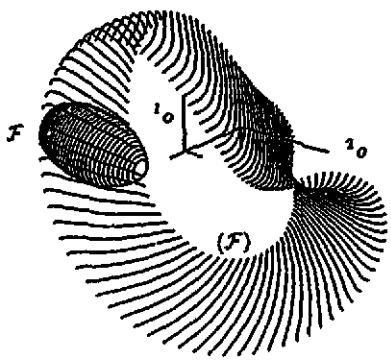

Fig. 1: Envelope

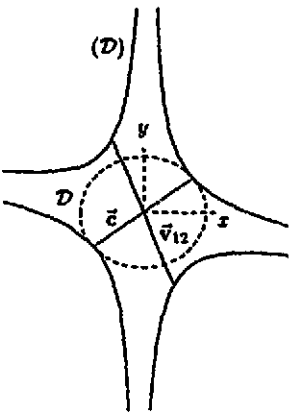

Fig. 2: Indicatrix of Dupin

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This research has been conducted at the Department of Technical Mathematics as part of the research project "Mathematical Methods in Kinematics of Machines and Robots" and has been supported by GA ČR grant No. 101/93/0447 (intern.no. 210 20).

MODELING SURFACES WITH "MATHEMATICA" SOFTWARE

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Key words: Mathematica, 3D ploting, surfaces

I. Introduction.

A very important tool in today's engineering world is the simulation. It is very important to introduce simulations into the curricula at technical universities, for example also into mathematics courses, statistics courses, numerical analysis, programming and geometry courses. The idea of using simulations in teaching is connected with a new approach to teaching in general. There are many studies concerning the use new technology in teaching supported by computers, also in teaching mathematics.

We can use the art of simulation in the area of geometrical modeling. For this purpose we have used a very flexible mathematical software called *Mathematica*. *Mathematica* is a general software system for doing numerical, symbolic and graphical computation. The work of the grant funded research group has concentrated on first year courses in geometry and programming. The main results of this work have been presented in [1] and [4]. These papers are the experimental manuscripts for students which will be used in the second semester of the school year 1994 - 95. More detailed information will be given at a seminar in January at the Department of Mathematics in the Faculty of Civil Engineering.

We present several topics from a part concerning modeling of surfaces in 3D.

II. Viewing by Mathematica

The standard screen view in Mathematica is the general perspective viewing. If we project a 3D object we join it with a system of coordinates in space. This system we can represent by a cube (*Viewing Cube*). The origin of this system is the center of this cube and the coordinate axes are sketched in Fig.1. Every 3D - object is immersed in another cube (*Object Cube*) which has the same center. The scaling on the coordinate axes are defined such that the edges of the *Object Cube* have parameter between −0.5 and 0.5. The viewing cube has an edge lenght equal to 2.

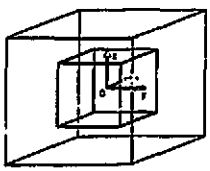


Fig.1

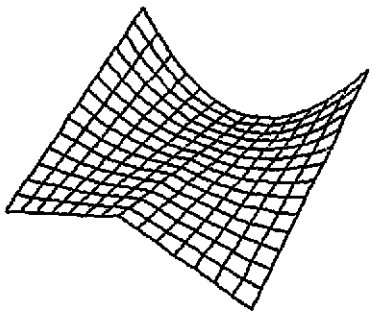
We can change using a special options the top - view, front - view, right - and left - hand side view. We can present an axonometric view too.

III. Modeling of surfaces.

The main result is the work on a gallery of surfaces. In this gallery we present, as well as known surfaces, also special ones. We use *Mathematica* for the sketching of simple vaults (e.g. cross – vault and cloister – vault) and simple roofs (slant and pyramidal roofs, see Example 1.). The three last parts of the manuscript present surfaces of revolution, quadratic surfaces and ruled surfaces (see Fig. 2).

Example 1.

```
In[1] := a[x_,y_] := 1 - Abs[x];
      := b[x_,y_] := 1 - Abs[2y];
      := c[x_,y_] := 7 - Max[Abs[7x], Abs[7y] ];
In[2] := rez[x_,y_] := Max[ a[x,y], b[x,y], c[x,y ] ]
In[3] := Plot 3D[rez[y,x], {x,-3,3}, {y,-2,2}, Axes -> False, Boxed -> False,
         Ticks -> None, PlotPoints -> 31, BoxRatios -> Automatic,
         PlotRange -> All, ViewPoint -> {1.3,-2.4,1.5}, Shading -> False};
```



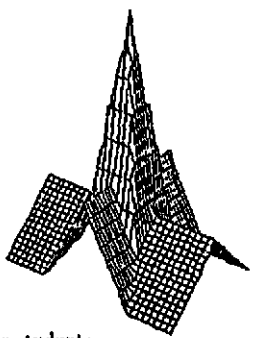


Fig.2

The manuscript [1] presents many similar examples for students.

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This research has been conducted at the Department of Mathematics of the Faculty of Civil Engineering CTU in Prague as part of the research project "Apple Computer Laboratory – Using software Mathematica in mathematics courses" and has been supported by Faculty of Civil Engineering CTU grant No. 2016.

TWO CONCEPTIONS OF THE DIDACTIC USING OF COMPUTERS IN TECHNICAL MATHEMATICS

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Key words: technical mathematics, teaching program, mathematically oriented software

Today, it is generally accepted fact, that the use of computers is an important part of mathematical courses at technical universities. This orientation was also acknowledged by the leading European mathematicians - authors of the well-known document [1]. In this paper, we want to discuss the two conceptions of possible didactic use of computers in technical mathematics and point out the necessity of the synthesis of these two conceptions.

Computer as a teacher.

A computer cannot, of course, substitute a teacher and take the responsibility for the process of education from him. But teaching programs can undertake some of the teacher's activities and allow the teacher to spend more time on creative pedagogical work. Computer aided instruction can have many specific advantages. This has been proved by fourty years' experience with programmed instruction and teaching machines. The most modern ways of computer aided instruction, for instance the use of multimedial teaching systems, build on this experience. In the field of technical mathematics we have contributed to this process by developing several teaching programs and finding out some new information. We have also understood the character of the obstacles which don't allow higher increase of the use of computers in the role of a teacher. First, the development of teaching programs is expensive. Moreover, when the content of teaching lessons or the teaching conception change, it is necessary to innovate the teaching programs. Generally, also the reluctance to change approach and habits on the part of the teachers, represents a great obstacle in making the teaching process more effective. Intensity of the control of student's learning process is still an open question. We find useful the teaching programs with graded help and with selfregulative branching nodes (i.e. adaptive programs, with less directive handling), destined mainly for the students of lower classes. [2] Now, our students in the first year of study use dozens of mathematically oriented teaching programs (video-programes or programes video-computer) in specially equipped laboratories at their own discretion outside their regular timetable.

This way of "automated consultations" seems to bee optimal in the present-day full-time study. Likewise, there are no doubts of using these programs effectively in extra-mural study and refresher courses, because it is also financially advantageous both for the students and firms.

Computer as a tool for mathematically oriented activity.

Together with the availability of powerful computing systems for educational purposes, a possibility for the students to run self-written, teacher-written or professionally developed programs has appeared. A qualitative change of this decade is represented by the tools of "mathematical software", developed professionally by world software producers. This kind of software include: Mathematica, Maple, Derive, Famulus and lot of others. They are noted for their high professional level, user-orientation when solving the problems of numerical mathematics, computer graphics and, most of them, also of symbolic mathematics. The introduction of these tools is a "shock", which, partially, distracts teacher's attention off other problems. It is understandable, because "mathematical software" brings about a change in the contents and aim of teaching technical mathematics, especially in theoretical knowledge, criteria of existence, uniqueness, convergence and others. This involves a great organizational and methodical effort. Our two-year experience [3] in teaching with the help of Famulus (and related experience of our colleagues with other systems) shows a lot of new possibilities, which these systems provide in teaching mathematics. At the same time, other problems appear. Comparing computer in a role of a teacher to the mathematical software systems, these don't demand anything from the students directly and they don't control and check their activity. The software systems represent so to say a set of "magic" offers of available mathematically oriented activities and it is left to the user what he will do whith them. We found out, that the students without guidance, try to play in a pointless way or to solve a given problem by "trial and error". Paradoxically, the following approach appears among the students: minimize mathematical theory and overemphasize the computer capabilities.

Conclusion.

Teaching programs on the one hand and tools of "mathematical software" on the other, can, with certain simplifications, represent the two extreme conceptions of controlled teaching - external control and auto-control. The prospects are in reasonable synthesis of the two conceptions. Now it is by the teachers interventions, when working in the computer laboratory with a small group of students. However, in the future, the teacher's capacity may not be sufficient. We should concern ourselves in anvance with the conception and development of such computer teaching programs that would take over this role of a teacher.

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Section 2

PHYSICS

PHOTOCHEMICAL PROCESSES IN Hg_2Cl_2 CRYSTALS

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Key words: mercurous chloride, luminescence, exciton, photodecomposition

Hg_2Cl_2 crystals are formed by linear chains of molecules Cl-Hg-Hg-Cl oriented parallel to axis c. The intramolecular bonding Hg-Hg is covalent while the bond of this core with the chlorine ions is ionic with a partially covalent character. The bond between adjacent molecules is of van-der-Waals type.

Hg_2Cl_2 crystals are photosensitive. If exposed to UV light at RT, they decompose into Hg and $HgCl_2$. The aim of this work is to study the formation of the luminescence centres responsible for infrared (IR) emission between 0.80 and 2.25 eV.

Measurements of photo-luminescence are performed on as-grown samples and on samples previously exposed to UV light at RT. Using a non-linear least-squares approximation, all emission spectra are fitted with linear combination of Gaussian curves. The parameters of Gaussians are found as follows: (1) maximal intensity at 1.72 eV (FWHM at 0.33 eV), (2) 1.51 eV (0.32 eV), (3) 1.39 eV (0.28 eV), (4) 1.23 eV (0.23 eV), (5) 1.06 eV (0.25 eV), and (6) 0.82 eV (0.21 eV).

If we consider the photodecomposition $Hg_2Cl_2 \rightarrow Hg + HgCl_2$ then the first candidate for IR emission could be $HgCl_2$ molecule. However, this model of luminescence centres is excluded in consequence of observed $HgCl_2$ molecule and IR luminescence disagreement.

The other possible photodissociation process can be described by the reaction

$$Hg_2Cl_2 \rightarrow (HgCl_3)^- + 3\,Hg + Cl$$

where Hg(I) is transferred to the Hg(II). Similar reaction can give rise to $(HgCl_4)^{2-}$ complex. Because of a large concentration of Br in Hg_2Cl_2 crystals, one can suppose that some chlorine ions are substituted by bromide ions to form complexes $(HgCl_xBr_{3-x})^-$ and $(HgCl_xBr_{4-x})^{2-}$. These complexes are serious candidates for the IR luminescence, consequently great variety of the IR emission spectra of Hg_2Cl_2 is to be expected, that is in accordance with our results.

Excitation spectra of Hg_2Cl_2 for as-grown crystals are shown in Fig.1. The interpretation of these spectra is complicated because a calculation of the electronic band structure of Hg_2Cl_2 crystal has not yet been performend. Kleier and Wadt [1] presented valence bond calculations for the ground states of Hg_2Cl_2 and Hg_2F_2 molecules only and estimated the excitation energies for some excited states of Hg_2Cl_2. These results support an interpretation of the observed spectra because in molecular crystals the electron levels of free molecule will emerge as excitons. Due to the crystal field, these electron levels will shift to the lower energies.

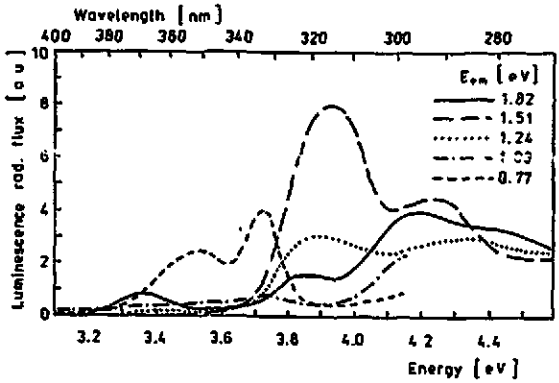

Fig. 1: Hg_2Cl_2 excitation spectra of as-grown crystal at 10 K taken for the emission photon energy indicated in the figure.

We have determined the exciton energies in Hg_2Cl_2 and Hg_2Br_2 crystals from the polarized excitation spectra for the blue emission. Comparison of calculated excitations, that give rise to dipole-allowed transitions in a free Hg_2Cl_2 molecule, with experimentally determined exciton energies in Hg_2Cl_2 and Hg_2Br_2 crystals is reported in Table 1.

Excitation	ΔE(molec) [eV]	E(Hg_2Cl_2) [eV]	E(Hg_2Br_2) [eV]	Polarization
$4\sigma_g \rightarrow 3\pi_u$	6.35	4.15	3.59	$\perp$
$4\sigma_g \rightarrow 4\sigma_u$	6.62	4.10	3.57	$\parallel$
$2\pi_g \rightarrow 4\sigma_u$	7.06	4.40	3.93	$\perp$

Tab. 1: Comparison of the calculated excitation energies for the low-lying states of Hg_2Cl_2 molecule ΔE(molec) [2] with experimentally determined exciton energies E(Hg_2Cl_2) and E(Hg_2Br_2) of the respective crystals. Directions of the transition moments are referred to the molecule axis.

Because Hg_2Cl_2 crystals contain a large concentration of bromine, the Hg_2Br_2 molecules are present in the Hg_2Cl_2 matrix and can be excited separately. It is concluded that centres responsible for IR Hg_2Cl_2 emissions can be excited through three different channels: (i) via excitons of Hg_2Cl_2 (4.10, 4.15, and 4.40 eV, corresponding to the $\sigma_g \rightarrow \pi_u$, $\sigma_g \rightarrow \sigma_u$, and $\pi_g \rightarrow \sigma_u$ transitions of the free Hg_2Cl_2 molecule, respectively), (ii) via excited states of the isolated Hg_2Br_2 molecules (near of 3.54 and 3.94 eV) present in the Hg_2Cl_2 crystals, (iii) resonantly in the specific excitation bands (3.35, 3.73, and 3.81 eV) of the defect centres.

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This research has been conducted at the Department of Solid State Engineering as part of the research project "Photochemical processes and radiation defect in halides and complex oxides single crystals" and has been supported by CTU grant No. 0848137.

TEST EQUIPMENT FOR MEASURING MINORITY CARRIER DIFFUSION LENGTH OF SI-WAFERS IN ACCORDANCE WITH ASTM F 391

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Key words: surface photo voltage, lifetime, diffusion length, minority carriers, semiconductors

The presence of lattice defects and contaminating atoms, especially of heavy metals, influences the lifetime of minority carriers, which may drop from the originall several thousand of μs in the as-grown monocrystal to only a few nanoseconds in wafers contaminated intentionally or accidentally by Pt, Au or other heavy metals.

The surface photo voltage (SPV) proved to be a very sensitive and accurate testing method, and was therefore included into the ASTM standard methods [1]. With SPV, light pulses impinging onto a silicon wafer are absorbed and they generate excess minority carriers. Those carriers that diffuse to the surface alter the surface potential by an amount called the surface photo voltage.

Surface photo voltage measurements to assess the diffusion length of minority carriers can be carried out either with constant photo voltage at various wavelengths, where the photon flux absorbed at the silicon surface is the measured quantity (method A in ASTM [1]), or with constant photon flux at various wavelengths, where the developed photo voltage is the measured quantity (method B in [1]).

The measuring set developed at our Department of Solid State Engineering uses method A. Monochromatic light through filters from an incandescent lamp is focused onto the surface of the investigated wafer through a glass plate, on which there is a conducting, but transparent film of indium-tin oxide (ITO), serving as capacitive input electrode for the preamplifier. Between the ITO electrode and the sample surface there is an adjustable small air gap to prevent direct contact of wafer surface and ITO electrode. The light beam is modulated with 70 Hz by a rotating light chopper, part of it being deflected by a 45° oriented glass plate as beam splitter onto a silicon photo diode for monitoring the light flux. In method A the light flux is controlled either by an adjustable aperture in the parallel beam, or by current adjustment of the light source in such a way as to achieve a constant photo voltage output at each selected wavelength from the filter wheel.

The basic relation used to evaluate the diffusion length L is

$$\Phi/U = const. \, (1 + sL/D) \, (1/\alpha + L)$$

If the absorbed photon flux Φ measured at an arbitrarily selected but constant photo voltage U is plotted against the reciprocal absorption coefficient $1/\alpha$ at the given wavelength, a straight line can be drawn through the measuring points, which intersects the x-axis at $-1/\alpha = L$. The inclination of this line depends on the surface recombination velocity s but

it does not alter the value of the diffusion length L_n even if the SPV is diminished by high s values. *It is the great advantage* of the SPV method that it is suitable to measure the diffusion length independently of the surface recombination.

The flux of the absorbed photons Φ_λ at the wave length λ may be computed by

$$\Phi_\lambda = k_\lambda \cdot U_{const} \cdot (1 - R)$$

where k_λ is the correction factor for evaluating the incident light flux from the photo diode response, (1-R) are the reflexion losses at the wafer surface and $U_{const.}$ is the surface photo voltage held constant by adjusting the light source. The correction factor k_λ must be experimentally evaluated before beginning of the measurement proper. By means of a type of Zeiss vacuum thermocouple the light intensity behind the ITO electrode was measured together with the response of the type IPP75 photodiode at the various wavelengths of the filters with constant lamp current.

As a first version the measuring set was designed for manual control, mainly to prove the feasibility of the method and to gain experience. It consists of an optical bench mounted on the cabinet containing the power unit, lamp current stabilizing system and digital panel voltmeters for reading Φ and U.

In routine measurements, the photo diode response U_λ at λ, measured at constant SPV, is fed into a computer with a program for graphic representation of the linear response curve, using linear regression, giving the diffusion length and the coefficient of determination r^2 to show the quality of the fit.

Surface etching in CP4 for obtaining low surface recombination and in consequence high SPV response, proved to be indispensable. Experiments with ground surface wafers were not successful,as the SPV was too low.

In the near future it is planned to use a smaller light spot to allow mapping of the whole wafer with an automatically moved X-Y stage and complete computer control of the whole measuring cycle.

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MEASUREMENT OF DEEP LEVELS IN POWER SILICON DEVICES USING TSC METHOD

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Key words: tsc method, deep levels, carrier lifetime

Deep levels in semiconductors are situated near to the middle of the energy gap band. They can be formed by local crystal lattice defects or by impurities such as Au, Pt, Pd, Fe etc. They have an influence on the lifetime of electrons and holes /1/. The recombination rate of electrons and holes determines the most important parameters of power silicon devices. The lifetime of carriers has a big influence on current-voltage characteristics and on the dynamic behaviour of devices. It is possible to reduce the carrier lifetime with appropriate impurities diffusion or with the creation of local defects by electron or ion irradiation. On the other hand, some centers may even cause deterioration of the reverse device characteristics.

Each local recombination centre may be described by one or more deep energy levels with the characteristic capture coefficient for electrons and holes and the concentration of centres. For measuring these parameters the methods of DLTS (deep level transit spectroscopy) or TSC (thermally stimulated current) can be applied. For the determining of a dominant deep level, another complementary method can be used [2]. With respect to the possibility of a complex measurement of all device characteristics including deep level diagnostics on a large area of structures of power semiconductor devices, the TSC method has been used in our research. The basic procedure of TSC measuring is the following. The sample is cooled down to the temperature of liquid nitrogen. The levels are filled with carriers with forward current. A reverse voltage bias is applied and we measure the current while the temperature increases. The captured carriers are released at a definite temperature, whitch results in a current peak. The position of the peak depends on the energy of the centre, the area is proportional to the concentration of centres in the space charge region. The shape of the peak depends on the rate of temperature rise. From the spectrum of peaks it is possible to determine the energy level and the capture cross of centers presented in the structure of devices.

A brief description of TSC measure instrument:

The examined sample with diameter up to 30mm is fastened to the basic copper board. On this board a small diode is also fixed for the measurement of the temperature. The sample is cooled down with liquid nitrogen. For heating there are slots in the board, through which flows dry nitrogen. The released gas also protects the device surface against wetting. The rate of temperature rise is regulated with the quantity and temperature of the gas. Batteries have been used as a source of reverse voltage bias and a voltage source for the input amplifier. In view of the fact that the input signal is very low (1–1000 pA), it is necessary to use large amplification and very good shielding. The sample must also be protected against light to remove the photovoltaic effect, which would form a background and make impossible to distinguish small peaks. The sample temperature and reverse current are measured

simultaneously using a multiplexor and a 12bit A/D convertor. Data collection is directed by a PC computer, in which further processing is possible.

The correct function of the appliance was checked by comparison to the levels measured by the DLTS method. An example of a measured TSC spectrum is demonstrated in the figure below.

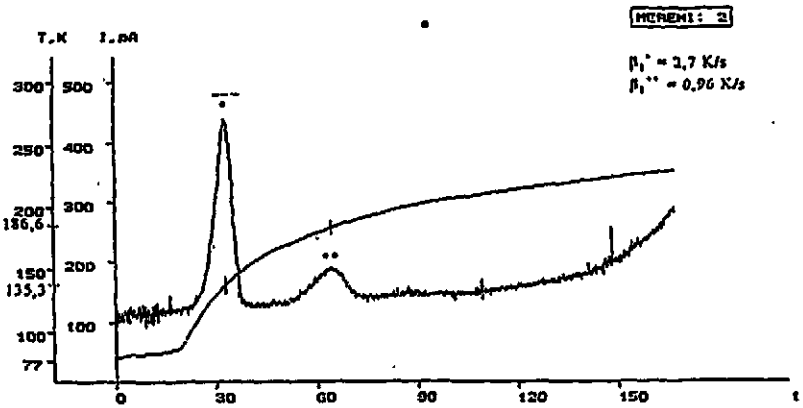

Fig. 1: The TSC spectrum of the diode structure diffused with Pd.

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This research has been conducted at the Department of Electrotechnology as part of the research project Recombination in power semiconductor devices and has been supported by GACR grant No. 102/94/1363.

COORDINATE DETECTORS OF ELEMENTARY PARTICLES

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Key words: microstrip gas chambers, semiconducting glass

Microstrip gas chambers (MSGC) have gained a lot of interest in the field of elementary particles detection due to their key features: good position accuracy, high rate capability and low cost. They are one of the main candidates for tracking in the experiments built at the new generation of accelerators, but there also exist a lot of promising possibilities of MSGC application in medicine, technology and other fields. The most serious problems of MSGC manufacturing technologies are obtaining stably operating detectors with suppressed ageing and charging up and availability of dedicated, high speed and high density readout electronics.

The MSGC consists of thin anode and cathode metal strips laid on insulating support at a distance typically between 100–200 μm and an upper drift electrode which defines a gas volume in which the ionisation to be detected is produced. When proper potentials are applied to the electrodes, the electrons released and multiplied around the anodes are collected and registered by the electronics. MSGCs show very promising features:position accuracy of an order of 10^1 μm, high rate capability, energy resolution of about 10%. fwhm for ^{55}Fe 5.9 keV X-rays and proportional gains up to 10^4.

The properties of the MSGC substrate materials are crucial for a stable operation of the detectors. The major characteristics are: moderate surface or bulk resistivity, high stability of performance under high voltage, good surface quality and metal adhesion properties and low cost. Previous experiments proved that commercially available insulators with good surface quality and high resistivity of an order 10^{16} Ω.cm had substantial gain instabilities during sustained irradiation. This effect is attributed to the modification of the electric field caused by substrate polarization and by the charging up of the insulator between the strips due to the accumulation of positive ions.It was also demonstrated that a stable operation of MSGC can be obtained by reducing surface resistivity to 10^{14}–10^{15} Ω/square. This moderate resistivity can be achieved by surface conditioning with ion implantation, by deposition of a thin film of semiconducting glass or by using material with low bulk resistivity.

Our work was concentrated on studying of deposition technology and physical properties of silicon polycrystalic semiconduting films (SIPOS). We studied two types of deposition processes: electron beam evaporation of silicon in an oxygen atmosphere (10^{-5}–10^{-4} mbar) and simultaneous evaporation of silicon oxide from a heated evaporation source and electron beam evaporation of silicon.

The thin films deposited by the first of the above mentioned methods showed an unacceptable reproducibility of their parameters. The main reason of this was the unstable evaporation rate of the silicon . Simultaneous evaporation of Si and SiO was performed under low pressure (less than 10^{-5} mbar) and therefore both high deposition rate and its good reproducibilty were achieved. The silicon deposition rate was 2–4 nm/min. The value of Si/SiO mass ratio was estimated by means of a crystal thickness measuring instrument and also by separate thickness measurement of Si and SiO thin films in properly shaded points on the substrate. Resistivity of the films was measured by means of the electrodes system evaporated on the substrate before Si/SiO film deposition.

In the Fig. 1 we present results for one group of the samples. Taking into account all our results, we can conclude that resistivity of the films is decreasing for growing content of silicon in the film and in case of samples with film thickness over 0.5 μm and higher Si/SiO ratio the resistivity could be of the order $10^{13}\,\Omega$/square.

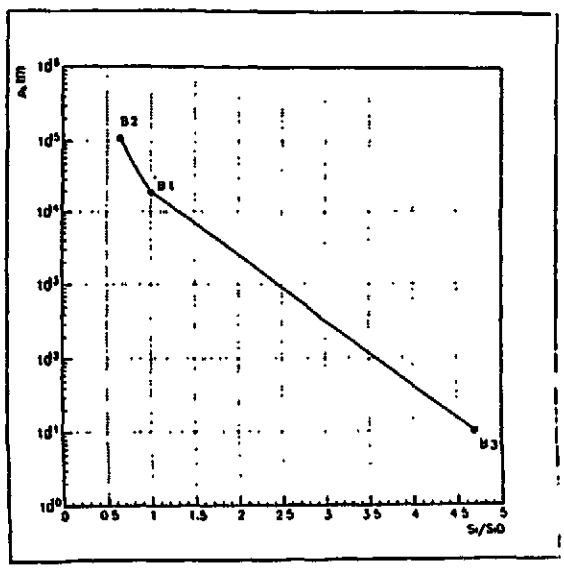

Fig. 1

This research has been conducted at the Department of Material Engineering, Faculty of Nuclear Science and Physical Engineering and at the Department of Physics, Faculty of Mechanical Engineering and has been supported by CTU grant No. 48213.

BULK GAAS RADIATION DETECTORS

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Key words: semiconductor, high-resistivity material, detectors, Schottky and ohmic contacts, technology

Bulk GaAs material, a wide bandgap semiconductor, shows potential as a room temperature detector. In order for semiconductor material to be useful as a radiation detector at room temperature, its bandgap must be enough wide to inhibit excessive leakage current due to thermal carrier generation. The bandgap of GaAs is sufficiently wide to allow for room temperature operation and its average atomic number is equivalent to that of germanium, the material widely used in gamma-ray and charged particle spectroscopy. Besides germanium, the silicon has been widely used in detector fabrication and it is used in the majority of charged particle operations. Both germanium and silicon have a considerable disadvantage of a small resistance against radiation damage. In addition, germanium must be operated below 150 K to eliminate the effects of thermally generated leakage current noise. In short, besides properties similar to those of germanium and silicon, GaAs has the following advantages:

- it allows for room temperature operation
- it can be used as a position sensitive device
- optoelectronic circuits can be integrated on chip
- it is highly resistant against any radiation, for example neutron bombardment.

The investigation of GaAs as a detector material dates back to the late 1960s and early 1970s [1]. At that time, epitaxial growth was the only means available to produce high quality GaAs layers, but the latter are generally limited to less than 100 μm, which is insufficient for the good function of detectors, especially for indicating highly energetic charged particles. At present, the high quality semi-insulating GaAs grown by LEC method has been developed. Using very high resistivity bulk material allows to achieve a sufficient thickness of depletion layer. The high resistivity (about 10^8 Ω.cm) is achieved by compensation of background impurities. The compensation is accomplished by the balance between residual carbon shallow acceptors and the native defects deep donor EL2.

Electric field

The electric properties of detectors are controlled by the intristic compensation mechanism and by the density of traps, impurities, and lattice defects in the bulk. The electric field in the detector is generated by the built-in and applied bias voltage and it depends on the concentration of donors, acceptors,and deep levels EL2. The deep levels EL2 are just below Fermi level [2] and are ionized when their energies stay below Fermi level. The electric field can be solved by using Poisson equation and in the case of presence of deep levels it shows two different regions in the depletion layer. The first one runs from Schottky contact and the electric field decreases with a constant slope. From this point where the

EL2 are completely ionized, the space charge density changes slowly to zero, and the same is true for the electric field [2].

To obtain the knowledge about the shape of electric field within the depletion layer, the measurements of the capacitance in the Schottky barrier have been used. As it is known, a plot of reciprocal capacitance squared C^{-2} vs bias voltage V yields a straight line when there is no gradient of impurities and their ionization is independent of the test signal frequency. When there are some deep level impurities in the bulk material, they contribute to the space charge density in the depletion layer. The change in applied bias voltage results in redistribution of the space charge due to the ionization of deep levels which are not able to respond to the test signal. Our measurements show that C^{-2} vs V curves are not linear and their slopes depend on the test signal frequency. This fact confirms the assumption about the double-triangular shape of the electric field in the detector. It can be concluded that the electric field decreases rapidly from Schottky contact, and that the diodes are not fully depleted.

Detectors fabrication

The GaAs material used for the experiments was obtained from Pegasus Ltd., The Slovak Republic, in the form of the wafers with thickness of 350 μm. The crystal, which the wafers were cut from, has a (100) orientation and it was undoped. Its resistivity was higher than 10^8 Ω.cm, Hall mobility about 6000 $cm^2.V^{-1}.s^{-1}$. Unfortunately, we have no knowledge about the lifetime of drift electrons on which the collection efficiency of detectors depends to a great extent. The latest detectors were made nearly in the same way as those mentioned in our last year's report [3]. To improve properties concerning excessively high leakage current the silicon nitride was used instead of silicon dioxide. The ohmic contacts applied were based on the solid state reaction between GaAs and AuGe and they were prepared in the same way as in [3]. The Schottky contacts were made again by evaporation of Ti followed by Pt and Au. The deep level concentration in the new material obtained was supposed to be lower than that in the material used last year. The measurements of charge collection efficiency and of capacitance C^{-2} vs V confirm the assumption concerning two ranges of electric field in the detector, and lower concentration of deep levels in the new material used.

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This research has been conducted at the Department of Solid State Physics, CTU Prague as a part of the research project "Semiconductor detectors" and has been supported by CTU grant No.8138.

INVESTIGATION OF GaAs RADIATION DETECTORS

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Key words: gallium arsenide, radiation detectors, ionizing radiation, protons, detector response

Semiconductor detectors of ionizing radiation which are solid state analogues of ionization chambers are versatile devices with perspectives in nuclear physics, high energy physics and their applications. Among III-V semiconductor compounds the most promising material at present is gallium arsenide (GaAs) [1], mainly because the GaAs detectors are the best candidates to survive in an experimental environment imposed by severe radiation in nuclear experiments. The presented results of GaAs program have grown from research which started in 1992 with the support of CTU Grant No. 8101 [2, 3].

Using technology available at FNSPE CTU a series of simple GaAs detectors were fabricated and tested with the aim to understand the properties and limitations of these simple, pad detectors. GaAs detectors were manufactured using improved quality substrate material (undoped material with significantly higher mobility of electrons which is equal to $6500\,cm^2V^{-1}s^{-1}$).

The main aim of the instrumental part of the research project is to investigate performance and limitations of produced single pad GaAs detectors and compare their spectroscopic and time characteristics with similar Si detectors. Their response and resolution have been tested with energetic protons and deuterons on a Van de Graaf accelerator. Some results of experimental tests of the GaAs detectors by the proton and deuteron beams are presented in Fig. 1 (amplitude spectra of 0.5 MeV and 1.5 MeV protons and deuterons) and in Fig. 2 (peak position as a function of proton energy and applied detector bias). These data are used for the description of mechanisms of the charge collection.

Overall goals of the project for 1995-1996 period can be summarized as follows:

- in cooperation with CERN RD-8 collaboration [1] to participate in the developing of convenient materials and technology for production of pad and/or strip GaAs detectors. The crucial technological problem in developing III-V compounds for detector applications is to provide strongly compensated materials with high mobility;
- to investigate parameters of produced detectors by standard and special spectroscopic techniques (determination of efficiency and resolution for charged particles and X-rays, charge collection, timing properties and noise studies with coincidence techniques). The results of the project are expected to be a contribution into the ATLAS experiment on LHC in CERN [4].

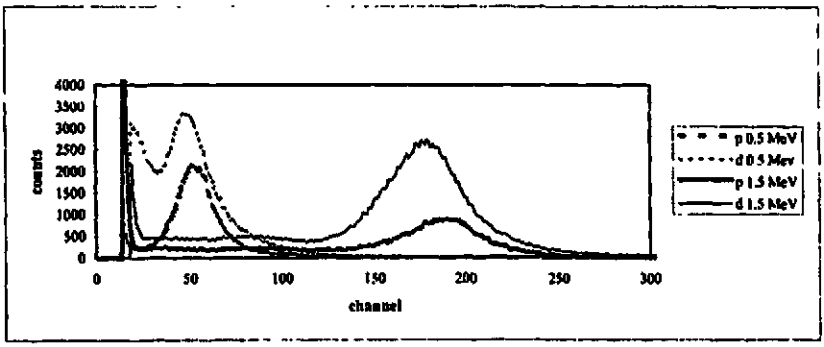

Fig. 1:

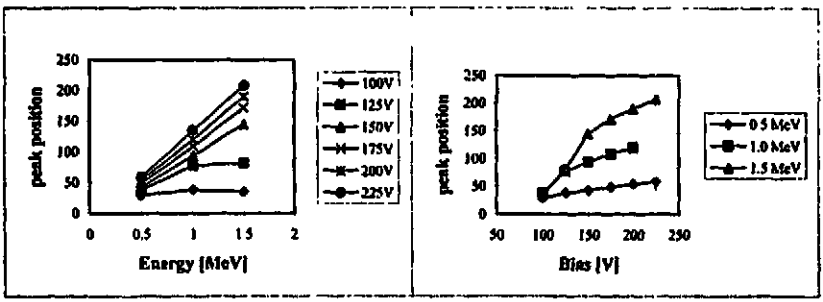

Fig. 2:

References:

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This research has been conducted at the Dept. of Physics and the Dept. of Solid State Eng. FNSPE CTU in close cooperation with the Nuclear Center, Faculty of Mathematics and Physics, Charles University. For the period 1994-96 the research is supported by the Grant Agency of the Czech Rep. ("Development of Radiation Detectors based on III-V Semiconductor Materials", GA CR No. 202/94/0901). In 1994 the GaAs research program has been also supported by the Ministry of Industry and Trade of the Czech Republic.

RADON AND THORON MONITORING METHODS

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Key words: radon, thoron, alpha decay, daughter products, electrostatic collection, air

During the last year work has been oriented to the following:
Spectroscopic method for determination of radon daughters in the air by means of short-time sampling was developed [1]. This method makes it possible to determine the state of nonequilibrium of radon and thoron gases with their daughters in the air.
- Prototype of multichannel analyser with dynamic memory controlled by microprocessor was built [2]. The apparatus was tested by continuous measurements of radon and thoron daughters using electrostatic collection on a Si detector (see Fig. 1).

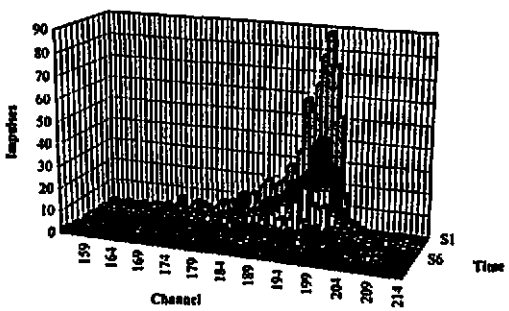

Fig. 1:

- Development of electrostatic collection method of the radon and thoron daughters continued. Electrostatic chambers with volumes up to 10*l* were built for continuous measurements with collection of the daughters directly on the surface of Si semiconductor detector. Electrostatic chamber (volume up to 1*l*) for single short-time sampling measurements of radon in soil air was designed and tested [3].
- Long-term continuous monitoring of radon and thoron daughters volume activity in the air has been carried out with callibrated continuous apparatus in a laboratory and in an underground room in the CTU FNSPE building. An example of one measurement is shown in Fig. 2. Superposition of daily activity variations on some long term changes can be clearly

observed. The comparison of these results with meteorological data records (temperature, atmospheric pressure, wind, etc.) will be performed. The value of *Rn* equivalent volume activity during the period May 94 - Sep 94 varied between $20 Bq/m^3$ and $150 Bq/m^3$, the average value is $62 Bq/m^3$. The ratio between ^{222}Rn daughters and ^{220}Rn daughters activities varied between 0.8 and 2.0, the average ratio is 1.62.

– Parallel monitoring of radon has been started on Kola peninsula (Russia) to investigate geophysical aspects of radon release. There, the equivalent volume activity of *Rn* varies between $30 Bq/m^3$ and $130 Bq/m^3$.

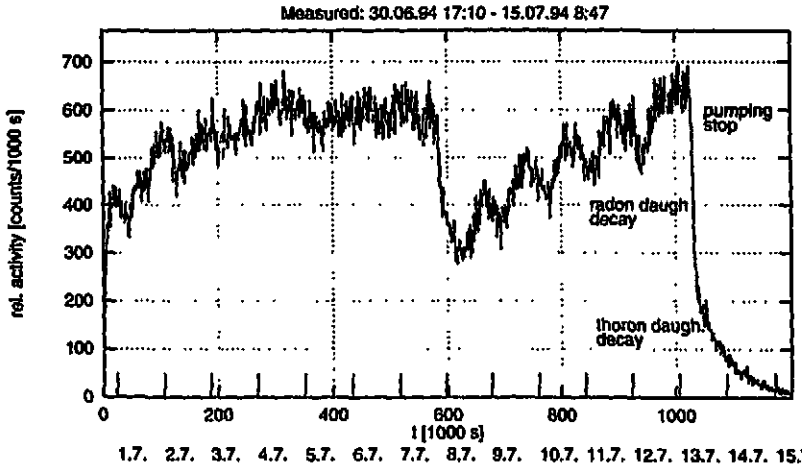

Fig. 2: Continuous measurement

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This research has been conducted at the Dept. of Physics, FNSPE CTU as a continuation of the research started in 1991 supported by CTU grant No. 8045 and in 1992-93 by CTU grant No. 8101 [4]. For the period 1993-95 the research is supported by GA ČR grant "New Methods for Measurements of Radon and its Progeny in the Air", No. 202/93/0392.

DEVELOPMENT OF ELECTROSTATIC COLLECTION METHODS FOR RADON DECAY PRODUCTS

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Key words: radon, thoron, alpha decay, daughter products, electrostatic collection, air

The development of methods for electrostatic collection of radon decay products continued [1]. Various technical arrangements of electrostatic collection chambers, including collection on detector surface and on electrodes maintained on high potential using capacitors, were devised [2]. The aim of these experiments was the development of instruments for radon activity measurements both in free air and soil air. For discriminating between radon and thoron products activity alpha spectrometry and decay characteristic measurements were used. An electrostatic field within the collection chambers was studied using computer modelling. A $500ml$ collecting chamber for Rn measurement in soil air was devised where radon decay products are collected on a circular electrode the potential of which was maintained using a high voltage capacitor.

As an example, results of the preliminary calculations of the electrostatic field are presented in Fig. 1. The fields have been obtained by numerical solution of the Poisson equation in cylindrical coordinates. Contour levels are plotted for values $U_0 = U_{el}$, $U_i = U_{i-1}/2$, $i = 1, \ldots$ in the left parts of the figures a, b. In the right parts of the figures contour levels have values $U_0 = U_{el}$, $U_i = U_{i-1} - \Delta U$, $i = 1, \ldots, N$, $\Delta U = U_{el}/N$, $N = 40$.

The dependence of the effectivness of electrostatic collection on collection voltage was determined by measuring the kinetics of RaA collection on the detector surface. Various voltages were applied to the chamber filled with Rn containing air. The results shown in Fig. 2 indicate that for voltages higher than $1500V$ a practical saturation of the collected activity is reached. To obtain information on absolute collection efficiency, count rates observed for air phase Rn+RaA without applied field were compared with that of electrostatic collection (see Fig. 3). Absolute air phase Rn counting was calibrated by establishing a reference to a standard alpha source. The dependence of electrostatic collection yield on chamber volume was determined.

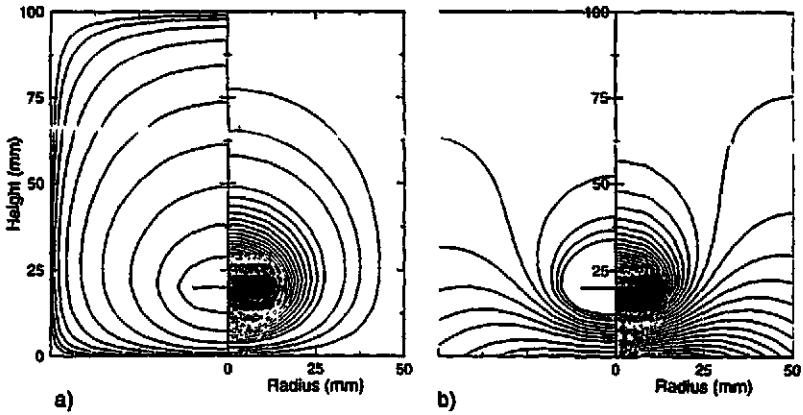

Fig. 1: Electrostatic field for two different configurations of electrodes: a) closed cylinder, b) circular electrodes in open space.

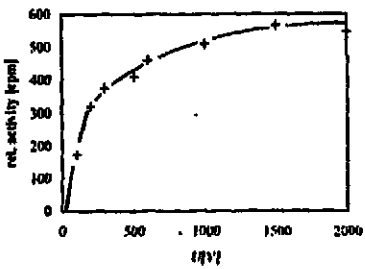

Fig. 2:

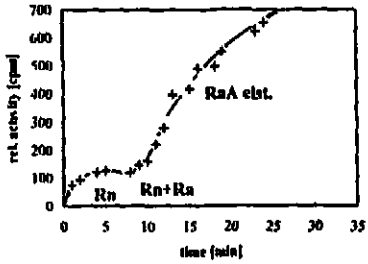

Fig. 3:

References:

[1] JECH, Č. - JANOUT, Z. - KONÍČEK, J. POSPÍŠIL, S.: *Detection of Radon and Thoron Daughters Using Electrostatic Collection*. CTU SEMINAR 94, Prague, Jan 17-20 1994. Part A-Physics, 117-118.

[2] POSPÍŠIL, S. JECH, Č. JANOUT, Z. KONÍČEK, J.: *Electrostatic collector of radioactive particles*. Czech patent document PV 1325-91, No. 02488/2151, Prague, 1994.

This research has been conducted at the Department of Physics FNSPE CTU and has been supported by GA CR grant "New Methods for Measurements of Radon and its Progeny in the Air" No. 202/93/0392, 1993-1995.

INVESTIGATION OF BETA-NEUTRINO ANGULAR CORRELATION IN FERMI BETA-DECAY OF SHORT-LIVED NUCLEI

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Key words: angular correlation, beta decay, neutrinos

According to the Standard Model (SM), the nuclear super-allowed β-decay is caused by only two types of weak interaction, namely V- and A- interaction, another two types (S- and T-) are assumed to be absent. On the other hand, the existing experimental upper limits [1] for the presence of these interactions are not better than 9% for T−interaction and 23% for S-interaction (at 95% CL). The goal of the present experiment is to search the admixture of S-interaction (which would be evidence of the SM breaking) or to reduce the last of the above mentioned limit to 5..10%. Measurement of the $(\beta$-$\nu)$ correlation coefficient with an absolute precision of 5% for a pure Fermi transition can improve the present limit.

The idea of the experiment is to detect γ-quanta coincident with β-particles emitted in some direction and to measure the Doppler shift of its energy δE_γ caused by recoil ion motion (fig.1). The origins of this recoil are the β-particle and neutrino, so that knowing the value of δE_γ and $\vec{p}$, one can deduce the angles $(\vec{p}, \vec{R})$ and $(\vec{p}, \vec{q})$ for each event and thus obtain the angular $(\beta$-$\nu)$ correlation coefficient. This technique should be used to investigate the $(\beta$-$\nu)$ angular correlation in the number of super allowed β-decay (including pure $0^+ - 0^+$ Fermi transition) of short-lived nuclei.

In 1993, after the preliminary off-line experiment [2] with long-lived ^{24}Na source, the first on-line test using the ^3He-beam of the Tandem accelerator (IPN, Orsay, France) was carried out in order to optimize the experimental set-up and measurement conditions. The $(^3He, n)$-reaction on the C, $(CH_2)_n$, B_2O_3 and SiO_2 targets was used in order to produce short-lived ^{11}O, ^{18}Ne and ^{30}S nuclei. For the detection of β and γ several types of Si(Li) and HPGe detectors were tested. The PC-based acquisition system connected with SUN-computer was also tested.

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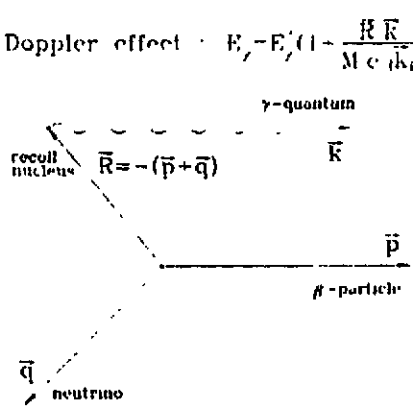

Figure 1: The idea of the experiment

As a result, the Doppler shift of 1011 keV γ-line following the $(0^+ - 0^+)$ β-decay of ^{18}Ne was observed and the numerous recommendations for the further improvement of the solid-target set-up, as well as on the development of the gas-target set-up, were obtained.

We plan to continue our experiments using two main techniques. The first is a solid target technique. The ^{18}Ne nucleus ($T_{1/2}$ =1.7 s, E^0_β=2.4 MeV (7.7%), E_γ=1.041 MeV) will be investigated. To obtain ^{18}Ne the B_2O_3 and Al_2O_3(50μm) will be irradiated by ^3He beam(10 MeV, 10..30 nA,ϕ=5 mm, external beam control). A new detector chamber has been prepared at JINR to improve this method. Fourteen cooled Si(Li) β-detectors are mounted in this chamber (instead of four as previously). Moreover, a new multi-target transpo system is coupled to that chamber in order to perform on-line measurements far away from the irradiation point thus avoiding the detector saturation during the beam burst.

The second main technique uses gas targets CO and CH_4 (0.1-1 atm) irradiated by ^3He beam (12-15 MeV, 10..30 nA,ϕ=5 mm,external beam control) to obtain ^{14}O nucleus($T_{1/2}$ =70 s, E^0_β=1.6 MeV (99%), E_γ=2.313 MeV). Using a gas target and gas transport system allows us to increase the distance between the points of target irradiation and sample measurement as well as to reduce the influence of recoil slowing-down before γ emission. Therefore it is possible to investigate Doppler shift of γ-lines deexciting rather long lived nuclear levels of recoil nuclei. In the particular case of ^{14}O, the half-life of such a level is 60 fs which prevents the investigation of this nucleus with solid targets.

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This research has been conducted at JINR Dubna in Russia.

THE MEASUREMENT OF DOUBLE BETA DECAY

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Key words: double-beta decay, calcium 48, molybdenum 100, radioactivity

Double beta decay provides a very good opportunity to study fundamental properties of the weak interaction. The neutrinoless double beta decay ($0\nu\beta\beta$) and two neutrino double beta decay ($2\nu\beta\beta$) are the second order weak processes which convert two neutrons in a nucleus into two protons. $2\nu\beta\beta$ is the normal weak process within the framework of the standard $SU(2)_L \times U(1)$ model. If the neutrino is a Majorana particle, a second decay mode is possible ($0\nu\beta\beta$) producing a neutrinoless final state. $0\nu\beta\beta$ is sensitive to the lepton number nonconservation, to the possible Majorana neutrino mass and to the possible right-handed admixtures in the weak leptonic current [1].

The high sensitivity double beta spectrometer TGV (Telescope Germanium Vertical) has been developed in cooperation with JINR Dubna, CSNSM Orsay and FNSPE Prague. TGV is composed of 16 HPGE detectors in the same cryostat, electronic part (NIM and CAMAC modules) and computer part (IBM PC). Each HPGe detector is a planar type, sensitive volume is 1200mm^2×6mm. Energy resolution for all 16 detectors varies from 2.6 keV to 3.3 keV (^{60}Co). The double beta decay source (e.g. ^{48}Ca, ^{100}Mo) can be inserted between neighbouring detectors. The electronic part consists of 16 identical channels. After registration of the first particle the time window 1μs is opened and at the end of this window each channel provides information about particle energy (pulse amplitude), type (pulse rise time) and detection time.

$\beta\beta$ decay is a very rare process, therefore special attention should be paid to the background suppression. The following measures are used in our experiment to suppress the background: i) Cu shielding (~20cm thick) + airtight box; ii) taking into account only the double events from neighbouring HPGe detectors; iii) distinguishing β particles and γ rays by different rise times of the detector pulses; iv) measurement in the underground laboratory (Modane, France).

Cu shielding protects TGV against the external background. The detector part of TGV has been set inside an airtight box against background due to Rn gas. Determination of the β particles and gamma-rays is based on the following principle [2]. Most of the electrons interact within the surface layer of the sensitive volume of HPGe detector and γ rays interact with the same probability within all volume of the detector. The rise time for the pulses of particles interacting in the surface layer of the detector is longer than that for pulses of particles interacting more closely to the center of the detector. A time window of

[1] At present on a long term stay at JINR

10ns duration is selected and during this period an input signal on charge sensitive ADC is integrated and digitized. The distinguishing γ rays and β particles provide the suppression of γ rays by factor 10-20 (depending on energy of the particle). TGV was transported to the Frejus underground laboratory, France (4000 m water equivalent), where the cosmic muon event rate is very low (4.2 $m^{-2}day^{-1}$ [3]).

Energy region [keV]	Kamioka undergr.lab.		Lab. Souterian de Modane, TGV			
			double		double with selection	
	Mode G	Mode A	1	2	1	2
500–600	$6.61 \cdot 10^{-2}$	$9.34 \cdot 10^{-3}$	$1.11 \cdot 10^{-2}$	$2.8 \cdot 10^{-3}$	$4.05 \cdot 10^{-3}$	$2.8 \cdot 10^{-3}$
1000–1100	$2.92 \cdot 10^{-2}$	$3.8 \cdot 10^{-3}$	$3.44 \cdot 10^{-2}$	$1.0 \cdot 10^{-2}$	$8.01 \cdot 10^{-3}$	$1.9 \cdot 10^{-3}$
1500–1600	$7.6 \cdot 10^{-3}$	$1.29 \cdot 10^{-3}$	$2.28 \cdot 10^{-2}$	$5.3 \cdot 10^{-3}$	$6.6 \cdot 10^{-3}$	$1.2 \cdot 10^{-3}$
2000–2100	$2.4 \cdot 10^{-3}$	$3.51 \cdot 10^{-4}$	$8.81 \cdot 10^{-3}$	$7.0 \cdot 10^{-4}$	$2.24 \cdot 10^{-3}$	$5.0 \cdot 10^{-4}$
2500–2600	$5.85 \cdot 10^{-4}$	$2.33 \cdot 10^{-5}$	$2.48 \cdot 10^{-3}$	$2.0 \cdot 10^{-4}$	$4.06 \cdot 10^{-4}$	$< 2.3 \cdot 10^{-4}$

Tab. 1: Comparision results of background measurements in Kamioka and Modane underground laboratories (in events/hour/cm^3) (Mode G = with nitrogen gas circulation, Mode A = anticoincidence with surrounding NaI detectors, 1 = with foils, 2 = without foils).

Several series of background measurements were carried out in Dubna and in Frejus underground laboratory (with and without Cu shielding, with and without foils made from natural Mo and Ca - to study the influence of foils on background). The total time of measurement at the end of October 1994 was 4293 hours. The purpose of these measurements was to estimate the level of background and to test methods for background suppression. Comparison of background level in TGV spectrometer and ultra low background β-γ spectrometer ELEGANTS [4] is shown in Table 1 and it shows that we achieved good background reduction without any special anticoincidence mode.

The main advantages of the TGV spectrometer are good energy resolution, stability, efficiency and low background. At present the measurement of background in Frejus underground laboratory continues. It is planned to start double beta decay measurement with an enriched source of double beta isotope (e.g. ^{48}Ca, ^{100}Mo) at the beginning of 1995. The result of background measurements made in Modane on TGV spectrometer shows the possibility to find half-life of $\beta\beta$ decay with total mass of source $\sim$4.5g (e.g. ^{48}Ca) in the range $T_{1/2} \simeq 10^{19} \div 10^{20}$years.

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This research has been conducted at JINR Dubna and in Lab. Souterain Modane and has been supported by GA CR grant No. 13/2201/0022.

ELECTRIC MODEL AND QUANTIFICATION OF ENERGY IN ATOMS

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Key words: model, quantification, energy, atom

Practically all our knowledge is based upon model formation. Apart from models acquired genetically we perceive the world through our senses and form models when storing the knowledge into our memory. We then correct our judgement using the stored models and comparing the past phenomena with the present ones. The correctness of our judgement depends upon our ability to determine the conditions of the presently contemplated phenomenon.

Each phenomenon depends upon the conditions under which it arose. These conditions determine its meaning, spatial distribution, energetic requirements, and its stability boundaries. Conservation and continuation of the phenomenon is dependent upon its protective system and upon the energy which is available in the particular space and time.

It is possible to find a striking proof as well as instructive example of general application of models even in the simplest of systems. It might be thought that it is possible to find such systems in the atomic world. This microworld, of course, is not directly accessible, but the present intensive research in the area makes possible certain hopes as to the final goal of complete understanding. It is to be emphasized, however, that even a single electron alone is a rather complex energetic system, about the internal structure of which we have only vague knowledge. A substantial barrier is the problem of quantum mechanics, which is still described (e.g. in ref. [1]) as a problem which it is possible to solve mathematically, but cannot be understood and explained. It is, fortunately, not necessary to accept this point of view thanks to the elucidating possibility offered by physical models, especially models based upon nonlinear electric circuits. In fact, it is even possible to explain the strange behaviour by motion of electrons.

The mutual relation between the classical and the quantum mechanics is a problem of a nonlinear oscillatory system. Some basic manifestations of this system are accessible to direct observations in nonlinear electric circuits.

The possibility of understanding may be interpreted as a possibility of verification of the phenomenon in question. It is then possible to assume that the model method of learning and understanding natural phenomena is applicable everywhere as long as the conditions for obtaining the necessary sensual perceptions are fulfilled. This does not mean, however, that we cannot understand a phenomenon which is not accessible to our senses. In such cases we use indirect models which are composed of simple, verifiable models connected together in a verifiable way.

In relation to the investigated phenomenon it is possible to assume the presence of the more important forces, which makes possible a certain simplification of the relations for the

description of the electron trajectory. In a relatively simple manner, it is possible to derive the equation:

$$\frac{K}{F} = \frac{a^3}{\cdot\cdot} - 3ae_x$$

where K - is the constant from the Coulomb law, conjugated with the charges in the investigated system.
F – is the magnitude of the force of an external field acting on an electron
a – is the amplitude of the basic harmonic, from the projection of the trajectory of the electron to the direction of the ellipsoid main axis. This represents the skin, upon which the trajectory of the electron may be found. The amplitude nears the length of the main semi-axis.
e_x – is the eccentricity, which is determined by the magnitude of the force F, mass of the electron, and its angular speed.

This equation assumes a specific motion of the electron on the corresponding skin. It requires an existence of a transversally oriented motion simultaneously with the longitudinal motion with the external field. This is no extraordinary requirement, it stems from an assumption of a wholly general motion in space at minimal transports of energy. It is therefore described by two oscillatory systems. As long as a motion of an electron in an atom exists, which can be described by the aforementioned equation, the behaviour of this system might be compared also with the behaviour of an electric model.

The linear energy-frequency relation and securing stability conditions are obviously the most important features of the derived nonlinear function, which represents the mystery of quantum mechanics. The shapes of the derived electron trajectories, the accordance with the derived spectra as well as with the Planck constant and with the ionisation potential, may be considered the verification of the correctness of this model.

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COMPARATIVE STUDY OF RADIATIVE CHARACTERISTICS OF HOT AND DENSE MATTER

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Key words: atomic data, radiative opacity, line profiles, high energy density

At present, several groups in different countries are developing radiative opacity codes. In view of the complexity of the physics involved, there is considerable interest in a detailed comparison of results calculated with different codes. A series of workshops provides a forum for such explicit comparison. The third international workshop of this kind (WorkOp-III:91) was organized in 1994 by the Max-Planck-Institute for Quantum Optics at Garching in Germany.

The meeting focussed initially on the comparison of selected cases, calculated by the various participants using different numerical codes representing a broad spectrum of approaches to the modelling of plasma opacities. We took part in this event for the first time using results obtained by a revised version of the opacity code RACHEL [1,2].

More than 150 MB of data, generated by 12 opacity codes, were provided to the organizating committee by participants. A synopsis of plots and tables of the submitted materials had been prepared several weeks before the meeting. The aim has been definitely more than just a "verification of codes"; in the workshop differences in calculated results have been traced back to the physics input so that their origin became clear.

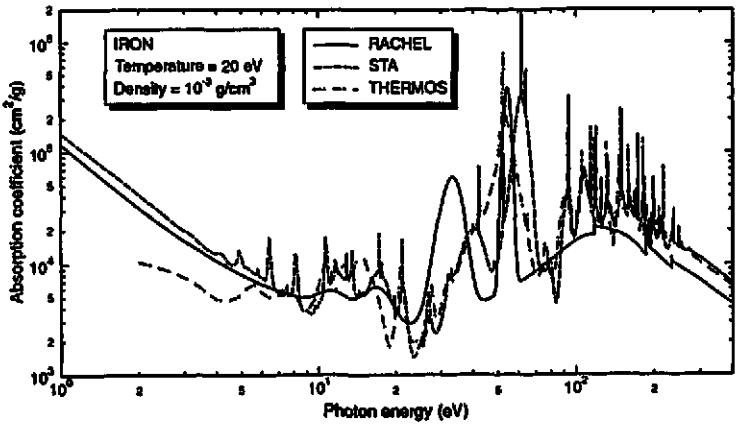

Fig. 1: Photoabsorbtion coefficient for iron

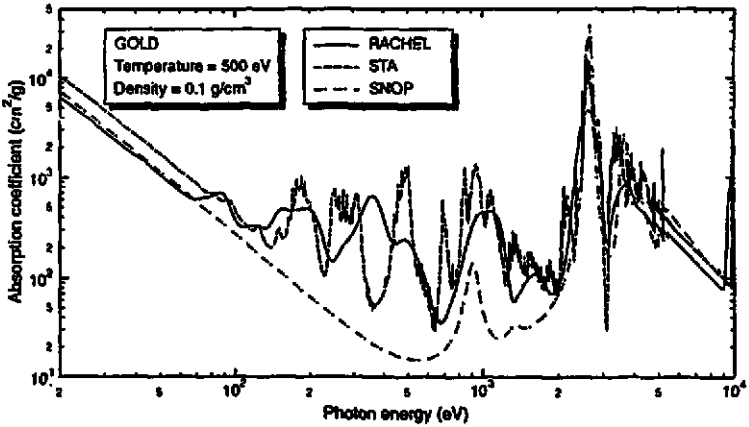

Fig. 2: Photoabsorbtion coefficient for gold

The cases studied and their motivation included: (1) opacities for stellar envelopes, (2) comparison with recent progress in opacity measurements based on laser experiments and gas gun experiments, (3) higher densities, up to solid density and beyond, (4) high-Z materials which are of interest in a wide range of areas (X-ray lasers), (5) non-LTE physics in complete steady state, optically thin approximation.

As a very small illustrative example of cases studied at the workshop, total photoabsorbtion coefficients for iron and gold as obtained by different models are shown in Fig. 1 and 2, respectively.

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This research has been conducted at the Department of Physical Electronics as part of the research project "Detailed Study of Spectral Lines of X-Ray Radiation Emitted by Highly Ionized Ions" and has been supported by grant No. 202/94/0710 of the Grant Agency of the Czech Republic.

SIMULATION STUDIES RELATED TO MAGNETIZED HIGH-PARAMETER PLASMA SYSTEMS

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Key words: magnetized high-parameter plasmas, high-density Z-pinch, controlled fusion, moving finite element method

We present concise information about our work which is oriented to the development of methods and implementation of simulation codes for studies of dense magnetized plasma systems with emphasis on hydrodynamic and radiation processes. The fibre-initiated high-density Z-pinch (HDZP) has been chosen as the first system for study.

HDZP [1] is a novel approach to a generation of high-parameter and nucleoreactive plasmas. In its applications to the study of controlled fusion a megavolt-range potential is to be applied along a thin filament of frozen thermonuclear fuel (deuterium/tritium), driving a megamp-range current through it, with the intention of heating the fuel to fusion temperatures in several tens of nanoseconds while stably confining it in its self-magnetic field.

Future use of the HDZP will show its application as a trigger for fusion detonations in cylindrical channels. Such systems [2] could allow the adoption of a clean working cycle based on advanced fuels (He^3, pure D, Li, Be, B) without the ecological drawbacks of the use of DT as nuclear fuel (radioactive material, high neutron fluxes). Another promising application of the HDZP (using a high-Z-material filament) is for the development of extremely intensive pulsed X-ray sources for physics and the development of new technologies.

Simulation of magnetized high-parameter plasma systems presents serious challenges *to existing numerical methods. Here we have applied a modern gradient-weighted (GW)* approach [3] to the moving finite element (MFE) method for solving the pinch dynamics in 1-D hydrodynamic approximation.

To begin with a reasonably complicated model of the high-parameter magnetized systems the fluid approach based on one-fluid form of Braginski's equations has been used. The work has been started with the implementation of the code PINCH [1], which applies the GWMFE approach to the study of 1-D fully ionized hydrogen systems.

Evaluation of ion distribution function is generally necessary for the calculation of thermonuclear yield in magnetized high-parameter plasmas. The detailed description based on Fokker-Planck equation is extremely complicated and a reasonable approximation has to be implemented for time dependent systems. The chosen approximation has been verified with the support of computer algebra tools. The simulation code for numerical solving this model has been automatically generated by the package FIDE [4], implemented in the computer algebra system REDUCE.

For the intended extension of the code to partially ionized high-Z systems with reasonably detailed modeling of radiation processes two supplementary studies, including the development of procedures for transport coefficients and radiation characteristics, have been

carried out. To evaluate transport coefficients of magnetized high-parameter plasmas several approaches have been tested and compared. To support calculations of the radiation yield and global spectra of X-radiation emitted by systems with high-Z plasmas results of the study [5] have been used.

For more realistic description of magnetized high-parameter plasma systems the extension of the study to 2-D models will be necessary. To master problems related to the development and application of multi-dimensional codes, the 2-D implementation of the GVMFE method for model systems and its eventual use on distributed computing systems have been studied.

Laser-driven systems using short and very-short pulses are one of the important future applications of the modeling of magnetized dense plasmas. It is expected that know-how from the studies described will be capitalized also in the research of interactions of ultraintense coherent radiation with solid targets in femtosecond region [6], where generation of enormous magnetic fields of the order 10^5 T is predicted [7].

The authors wish to thank Prof. Neil Carlson (Purdue University) for his excellent reports and GFMWE codes and Dr. Alan H. Glasser (Los Alamos National Laboratory) for his HDZP program and information about its 2-D version.

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This research has been conducted at the Department of Physical Electronics as part of the research project "Development of a model of thermonuclear burn with the aid of computer algebra" and has been supported by CTU grant No. 8210.

STUDY OF THE CONICAL ELECTRODE MAGNETIC FIELD CONFIGURATION

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Key words: magnetic pinches, nonideal plasma, plasma diagnostics

The new portable YAG laser with amplifier and conversion to the second harmonic with new power sources and pulse length 10-15 μs and repeat frequency 1 Hz was built and tested. The experiments at higher voltage 25 kV and the electrode configuration with outer circuit on the coat of the discharge tube were realized.

In the theoretical model of the stable structures the possibility of the α-effect, double layer and nonideal plasma influence were studied.

Experimental and theoretical results were published in [1] and presented in conferences abroad [2,3].

The most important results were obtained during a working stay in two departments of the Institute of Plasma Physics and Laser Microfusion in Warsaw.

In the newly built equipment of the plane lightning testing room (200 kV, 100 kA) the measurement with its own laser diagnostics was realized in spite of difficulties with synchronization in strong disturbance fields. A central dense and cold structure was observed with diameter 10 mm during 3-10 μs after the breakdown.

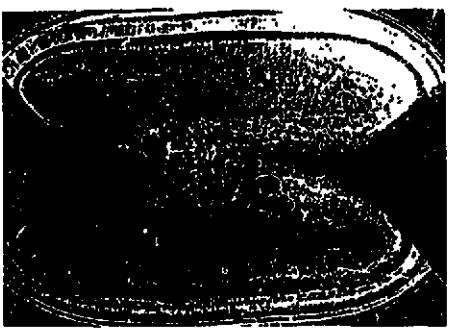

Fig. 1: The schlieren picture of the central structure in the discharge at atmospheric pressure in the air 6.0 μs after the breakdown.

In the Fig. 1 the schlieren picture is presented at time 6.0 μs, where the outline of electrodes and plasma anode (left) and plasma cathode (right) jets can be seen. The promising

results will enable the cooperation to continue in the next year with a current two times higher (200 kA).

In the equipment PF 120 the conical electrode configuration was installed on the coaxial electrode system. A construction feature of the condensator battery made preionisation impossible and we had difficulties with a breakdown in the surface of the insulators. The diagnostics of the discharge with a maximum current of 400 kA was realized due to CCD camera at wavelength 590 nm. At the CCD records, central and anode structures, Rayleigh - Taylor instabilities and axial filaments are presented.

At the Fig. 2 the record of the bremstrahlung of the dense central structure is presented with length 5 mm and width 10 mm.

Fig. 2: The CCD camera record of the bremstrahlung (590 nm) of the discharge at 2.5 kPa of argon.

The results are optimistic and allow further cooperation in dense plasma diagnostics in Warsaw and in Prague in the Department of Physics FEE CTU and in the Institute of Plasma Physics of AS.

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This research has been conducted at the Department of physics as part of the research project "Complex Physical Characterization of Z-pinch Plasmas" and has been supported by Grant Agency of the Czech Republic No. 202-93-1023.

COMPRESSION TIME OF THE GAS PUFF Z-PINCH

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Key words: z-pinch, gas puff

Gas puff device is a cylindrical column of plasma which is compressed to its axis by its own magnetic field (z-pinch phenomenon). A simple estimation of the compression time will be derived in this paper.

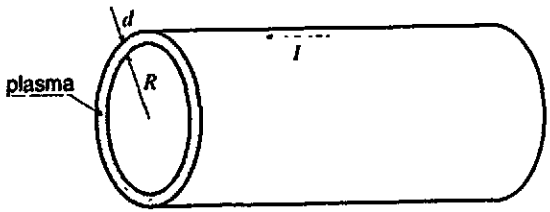

Fig. 1: Gas puff.

Let us denote $R(t)$-radius of the column; l-length of the column; d-thickness of the column; m-total mas of the plasma. See Fig. 1. The magnetic field on the column's boundary is given by Ampere's law

$$B(R) = \frac{\mu_0 I}{2\pi R} \ , \tag{1}$$

where $I(t) = I_0 \sin(\omega t)$ is the total current passing through the plasma column. For the Lorentz force density $f_L = -jB$ we can therefore obtain

$$f = -\frac{\mu_0}{4\pi^2} \frac{I^2}{R^2 d} \tag{2}$$

and the Lorentz force is

$$F = -\frac{\mu_0}{2\pi} \frac{l}{R} I^2 \ . \tag{3}$$

Consequently, the equation of the plasma column motion $md^2R/dt^2 = F_L$ can be rewritten as

$$R \frac{d^2R}{dt^2} = -\frac{\mu_0 l}{2\pi m} I_0^2 \sin^2(\omega t) \ . \tag{4}$$

Having introduced the nondimensional variables

$$\tau = \omega t \qquad \rho = \left(\frac{2\pi m \omega^2}{\mu_0 l I_0^2}\right)^{1/2} R \ , \tag{5}$$

the equation of motion

$$\rho \frac{d^2\rho}{d\tau^2} = -\sin^2 \tau \qquad (6)$$

can be solved numerically under initial conditions $\rho(0) = \rho_0$ and $d\rho/dt(0) = 0$. The numerical solution of the compression for various initial radii $\rho_0 \in < 0.1, 2 >$ is presented in Fig. 2. The times of compression were estimated numerically as well, and they are presented in Fig. 3.

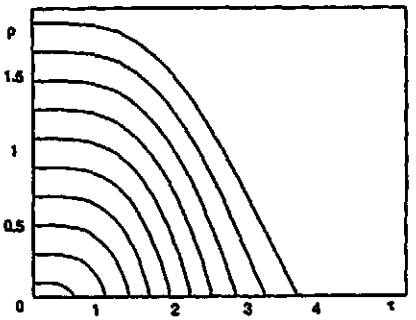

Fig. 2: Column radius versus time for various initial radii.

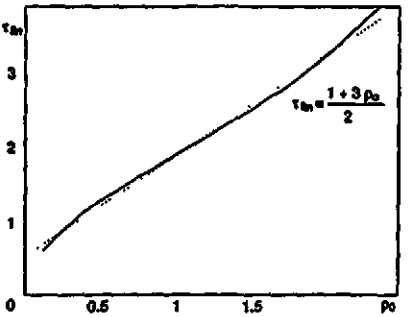

Fig. 3: Compression time versus initial radius.

The dependence seems to be almost linear and for the initial radii from the interval mentioned above can with good accuracy be written as

$$\tau_{fin} \doteq \frac{1 + 3\rho_0}{2} \ . \qquad (7)$$

Both numerical solution and this linear approximation can be compared in Fig. 3. Having transformed the nondimensional estimation (7) to the R and t variables we obtain

$$2\,\omega t_{fin} = 1 + 3\,(\frac{2\pi m}{\mu_0 l})^{1/2} \frac{\omega R_0}{I_0} \ . \qquad (8)$$

which is the sought relation for the t_{fin}.

Furthermore, under assumption that maximum compression occurs at the maximum current time ($\omega t_{fin} = \pi/2$), an optimal relation between the gas puff variables I_0, ω, m, l, R_0, can be derived

$$I_0^2 = \frac{18\pi}{4\mu_0} \frac{m}{l} \omega^2 R_0^2 \ . \qquad (9)$$

Both Eq. (8) and Eq. (9) can be very usefull in the design of the gas puff devices.

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This research has been conducted at the Department of Physics of the Faculty of Electrical Engineering as part of the research project "Complex investigation of the z-pinch discharge" and has been supported by ASCR grant No. 202-93-1023.

ATMOSPHERIC PRESSURE GLOW DISCHARGE IN AIR FLOW FOR ECOLOGICAL APPLICATIONS

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Key words: pollution control, non-thermal techniques, glow discharge in gas flow

Acid rain, the greenhouse effect, smog and ozone depletion are consequences of environmental pollution. Non-thermal plasma techniques based on the use of electric discharges are one of the ways for solving environmental problems.

Non-thermal plasma is characterized by the fact that the mean electron energies are considerably higher than those of the components of the ambient gas. Consequentially the very reactive radicals are produced; they in turn decompose the toxic molecules. This is in contrast to plasma furnaces or torches in which the whole gas is heated in order to break up the undesired molecules.

Non-thermal plasma techniques are based on

[1] silent discharge
[2] corona discharge
[3] energetic electron beam
[4] high frequency and microwave discharge
[5] glow discharge in a gas flow

Our research of the atmospheric pressure glow discharge in air flow was devoted to the study of stability and basic electric parameters of this type of the discharge.

The electrode system was formed by a set of parallel razor blades (cathodes) situated perpendicular to the plane anode. The electrodes were placed in a rectangular dielectric channel in which flowed the air. The distance between cathodes and anode was varied from 1 to 8 mm. The air flow velocity in the channel could be changed up to 120 ms^{-1}. DC power supply provided a voltage up to 50 kV. Each cathode was individually ballasted by a resistor 25 kΩ which was connected in a series with a central current limiting resistor 150 kΩ. The experimental apparatus is shown in Fig. 1.

Volt-ampere characteristics for the electrode system formed by one cathode against plane anode is shown in Fig. 2. The velocity of the air flow was 100 ms^{-1}.

It was observed visually that the structure of the discharge is not homogeneous along the whole length of the cathode; but, it depends on the gap between electrodes, the velocity of the air flow, and the applied voltage. In the stream of the air flow the current streamer first appears, followed by the region of the discharge which can be characterized by secondary emission. Negative space charge generated in the discharge is dragged by the air flow to distances much greater than the distance between the cathode and anode. This effect may play an important role for future ecological applications, because it allows an increase of the area of active radicals generation.

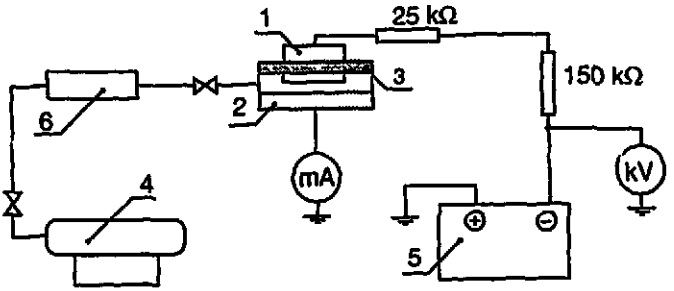

Fig. 1: Experimental apparatus: 1-cathode; 2-anode; 3-fixing glass; 4-compressor; 5- DC 50 kV source; 6-water and oil separator

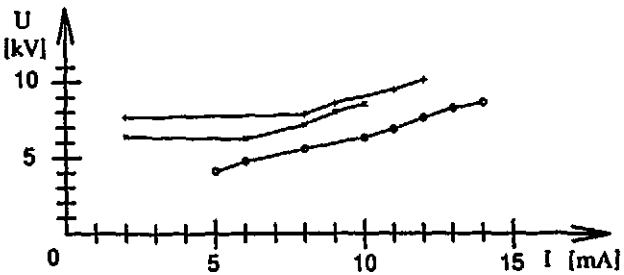

Fig. 2: Volt-ampere characteristics; gap between electrodes: + 4 mm; × 3 mm; o 2 mm

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This research has been conducted at the Department of Physics as part of the research project "Electric discharges for ecological applications" and has been supported by Universities Dynamic Development Fond grant No. 11 - 31042 .

VERTICAL ELECTRON TRANSPORT IN INFINITE SUPERLATTICE MONTE CARLO SIMULATION

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Key words: superlattice, miniband, vertical transport, diffusivity, simulation, Monte Carlo method, scattering

We studied the possibility of using a semiclassical model based on the Monte Carlo method for the superlattice vertical transport simulation. Our model deals with the ideal (perfectly periodical and infinitely long) superlattice. In this case the effective mass approximation is kept. This approach extends the area of semiclassical transport model applicability to nanometric structures. According to the actual superlattice material composition, wells and barrier widths and temperature, the conduction band offset is determined. E(q) dispersion relation in the superlattice miniband is computed using cyclic boundary conditions from the Kronning-Penney model. Effective mass and electron velocity in the miniband can be evaluated analytically from the dispersion relation [1].

The standard Monte Carlo transport simulation, including most important features of electron transport through the superlattice minibands is used. Inelastic acoustic phonon, polar optical phonon and ionised impurity scattering are considered in the bulk formalism. The Monte Carlo model has been applied on CdTe/CdMnTe superlattice simulation [2] with one miniband for conductance electrons (fig. 1). Temperature dependence and the variation of average values of velocity, energy and diffusivity with low electric field in the vertical direction were studied. Electrical field values were taken at a sufficiently low level to avoid disturbing the miniband structure and to keep the miniband transport.

The diffusivity dependence on the electric field is shown in fig. 3. Diffusivity at 2 K behaves as usualy in bulk material. After an almost constant value up to approx. 20 V/cm diffusivity drops down, due to the strong optical phonon scattering, which returns carriers to the bottom of the miniband after each emission process and causes electron motion to be more deterministic. Above the same value of electric field electron drift velocity and average energy start to saturate (figs. 2,4). Drift velocity drop at the highest electric field values may be caused by entering more electrons into the higher energy negative effective mass region.

The developed Monte Carlo model can be used for a rough estimate of electron transport parameters in the superlattice miniband. Information about electron energy, velocity and diffusivity is necessary in for example the superlattice laser design.

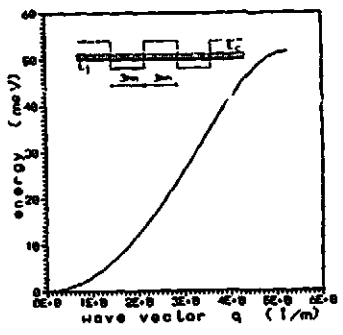

Fig. 1: Dispersion relation E(q) for electrons in the $CdTe/Cd_{0.82}Mn_{0.18}Te$ superlattice miniband.

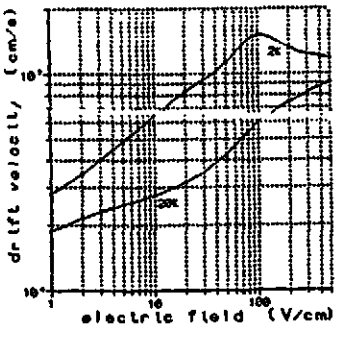

Fig. 2: Electron drift velocity dependence on the electric field in superlattice at 2 K and 20 K.

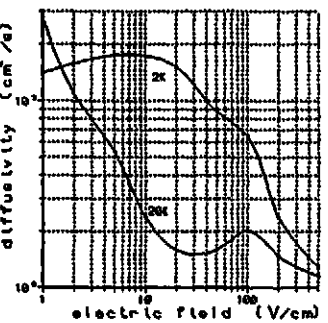

Fig. 3: Electron diffusivity as function of the electric field in the superlattice at 2 K and 20 K.

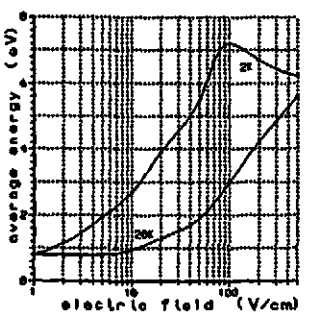

Fig. 4: Average electron energy as function of the electric field in superlattice at 2 K and 20 K.

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This research has been conducted at the Department of Microelectronics as part of the research project "TCAD Application for Semiconductor Heterostructures" and has been supported by Ministry of Education grant No.PV428/1994/VSAV.

NONLINEAR PROPAGATION OF WAVES IN HARD-WALLED DUCTS

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In many physical problems involving sound transmission in ducts, the sound pressure levels involved are so high that the problem of propagation and attenuation cannot be treated using the usual linear acoustic analyses. At these high sound-pressure levels, the nonlinear effects are of two types - the nonlinearity of the acoustic properties of the lining material and the nonlinearity of the gas itself. In this paper, we consider only the nonlinearity of the gas; that is, we consider waves propagating in hard-walled ducts. In addition we take into account only nondispersive waves. This criteria is satisfied in the case of plane waves. A complete system of equations which describes the propagation of these waves in thermoviscous fluids consists of the Navier-Stokes equation, the equation of continuity, the heat-exchange equation and the thermodynamic equations of state. Unfortunately, this system cannot be solved analytically. For this reason, in nonlinear acoustics, a common approximation is to neglect cubic and higher order terms in the equations, and to account for dissipative effects through linear terms only. The mentioned approximation leads to the well-known quasi-linear parabolic Burgers' equation which is a very good approximation of the exact equations of fluid motion when effects of dissipation and nonlinearity are not excessively large:

$$\frac{\partial v}{\partial x} - \frac{\varepsilon}{c_0^3}v\frac{\partial v}{\partial \tau} = \frac{b}{2c_0^3\rho_0}\frac{\partial^2 v}{\partial \tau^2} \tag{1}$$

where v is the particle velocity, $\tau = t - x/c_0$ is the retarded time, t is time, x is distance from a source, ρ_0 is density, $b = \frac{4\eta}{3} + \xi + \lambda(1/c_p - 1/c_v)$ is the dissipative coefficient, η , ξ are the shear and dilational viscosity coefficients, λ is the heat-conductivity coefficient, c_p and c_v are the specific heats at constant pressure and volume, $\varepsilon = 0.5(\gamma + 1)$ is the coefficient of nonlinearity for gases, $\gamma = c_p/c_v$. The suffix "0" is used to indicate equilibrium values. Inserting the values $V = v/v_m$, $s = \frac{x\Delta p_0 \varepsilon}{x_c}$, $y = \frac{c_0 \tau}{x_c}$, $G = \frac{2\rho_0 c_0 \Delta p_0 \varepsilon x_c}{b}$, we obtain the convenient nondimensional form of Eq.(1):

$$\frac{\partial V}{\partial s} - V\frac{\partial V}{\partial y} = \frac{1}{G}\frac{\partial^2 V}{\partial y^2} \tag{2}$$

where v_m is the peak particle velocity, $M = v_m/c_0$ is the peak Mach number and x_c is a characteristic distance. For pulses, it is convenient to take $x_c = c_0 t_d$ where t_d is the width of pulse in the time domain. The exact solution of Eq.(2) can be obtained by means of the nonlinear Cole-Hopf transformation $V = \frac{1}{G}\frac{\partial U}{\partial y}$ which transforms Eq.(2) to the diffusion equation:

$$\frac{\partial U}{\partial s} = \frac{1}{G}\frac{\partial^2 U}{\partial y^2} \tag{3}$$

The exact solution of Eq.(3) is given by the Poisson's integral

$$U(s,y)=\sqrt{\frac{G}{4\pi s}}\int_{-\infty}^{\infty}\exp[\frac{-G(y-s)^2}{4s}]\exp[\frac{G}{2}\int_0^z V(0,y)dy]dz \tag{4}$$

Then the exact solution of Eq.(2) is;

$$V(s,y)=\frac{\int_{-\infty}^{\infty}\frac{y-z}{s}\exp[\frac{-G(y-z)^2}{4s}]\exp[\frac{G}{2}\int_0^z V(0,y)dy]dz}{\int_{-\infty}^{\infty}\exp[\frac{-G(y-z)^2}{4s}]\exp[\frac{G}{2}\int_0^z V(0,y)dy]dz} \tag{5}$$

In our case, we assume the source condition

$$v(0,t)=v_m[at^2\exp(-bt)-ct\exp(-dt)]Heaviside(t); \tag{6}$$

where a,b,c,d are given constants. By means of the transformation, we can write:

$$K(y)=\exp\left[\frac{-G}{2}\text{Heaviside}(y)(\frac{a(b^2y^2+2by+2)\exp(-by)}{b^3}-\frac{c(dy+1)\exp(-dy)}{d^2})\right] \tag{7}$$

Using Eq.(5), we can write directly the exact solution; but, to solve the Poisson's integral analytically is rather complicated in this case. For this reason, it is necessary to solve these integrals numerically by means of the Simpson's method. The infinite integration range is not convenient for numerical computation. However, we can find based on the analysis of the function $N(z;y,s)=\exp(\frac{-G(y-z)^2}{4s})$ that the integrand is small except for values of z near y. Consequently, we can limit the range of integration to that region where the function has a value larger than the sufficiently small value κ:

$$V(s,y)=-\frac{\int_{y-d}^{y+d}\frac{y-z}{s}N(z;y,s)K(z)dz}{\int_{y-d}^{y+d}N(z;y,s)K(z)dz};\ \text{where } d=2\sqrt{-\frac{s}{G}ln(\kappa)};\kappa<1 \tag{8}$$

The solution can be shown graphically in the following figures:

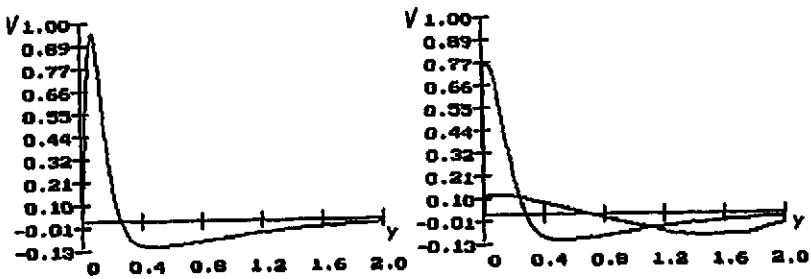

Fig. 1: The evolution of wave form at G=5000, s=0;0.1;25

Results of an experiment which will confirm the validity of the Burgers' equation are still in progress due to the fact that we need a sufficiently long waveguide in order to measure the evolution of wave forms.

This research has been conducted at the Dep. of Physics as part of the research project "Active control of aerodynamic noise" and has been supported by CTU grant No. 38187.

ANALYTIC SOLUTION OF THE VLASOV EQUATION IN THE FIELD OF A STRONG HIGH-FREQUENCY ELECTRO-MAGNETIC WAVE

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Key words: Vlasov equation, electron distribution function

In laser-pellet experiments and rf heating in tokamaks, large-amplitude high-frequency monochromatic electro-magnetic waves are launched into the plasma. Spatial modulation of the amplitude of these waves is crucial in changing the plasma equilibrium. In many problems of interest, the collisionless regime is appropriate and so the Vlasov equation can be used to determine the electron distribution function.

In this paper a general analytic solution of the Vlasov equation is presented for the case of plasma electrons in the field of such high-frequency monochromatic electro-magnetic wave with a large amplitude and a phase velocity appreciably higher than the electron thermal velocity (the case of non-resonant diffusion). Electric and magnetic vectors of this wave are supposed to be perpendicular to the plasma density gradient. The ambipolar potential is taken into account and the form of the electron distribution function on the boundary need not be Maxwellian.

The Vlasov equation relevant to our case can be written in the form

$$\frac{\partial f}{\partial t} + v_x \nabla f + \frac{e}{m_e} \nabla\varphi \frac{\partial f}{\partial v_x} - \frac{e}{m_e} \mathsf{A} f = 0 \tag{1}$$

with the following boundary conditions:

$$\mathsf{A}(0,t) = 0; \quad \varphi(0) = 0; \quad f(0, v_x, v_y, t) = f_0^{(0)}(v_x, v_y). \tag{2}$$

Here $-e$ and m_e are the electron charge and mass; $\varphi(x)$ is the ambipolar potential; $\mathsf{A}(x,t)$ is the differential operator in velocity space defined as follows:

$$\mathsf{A} = \mathsf{A}(x,t) = E_y(x,t) \frac{\partial}{\partial v_y} + B_z(x,t)\left(v_y \frac{\partial}{\partial v_x} - v_x \frac{\partial}{\partial v_y}\right), \tag{3}$$

where $E_y(x,t)$ and $B_z(x,t)$ are the electric and magnetic field of a high-frequency monochromatic electromagnetic wave with the angular frequency ω; ∇ denotes $\frac{\partial}{\partial x}$.

Using the method similar to that developed and successfully applied in the case of the plasma wave with a large amplitude [1] and confining our interest to velocities satisfying the condition

$$\left|\frac{\partial f_0^{(n)}}{\partial t}\right| \ll \left|v_x \nabla f_0^{(n)}\right| \tag{4}$$

we can arrive to the following system of recurrent relations:

$$v_z \nabla f_0^{(2n)} = \frac{i}{m_e}\left[-\nabla\varphi \frac{\partial f_0^{(2n-2)}}{\partial v_z} + \mathsf{A}(x) f_1^{(2n-1)*} + \mathsf{A}^*(x) f_1^{(2n-1)}\right], \tag{5}$$

$$f_n^{(n)} = \frac{ie}{nm\omega}\left(1 - \frac{iv_z\nabla}{n\omega}\right)\mathsf{A}(x) f_{n-1}^{(n-1)}, \tag{6}$$

$$f_m^{(n)} = \frac{ie}{mm_e\omega}\left(1 - \frac{iv_z\nabla}{m\omega}\right)\left[-\nabla\varphi \frac{\partial f_m^{(n-2)}}{\partial v_z} + \mathsf{A}(x) f_{m-1}^{(n-1)} + \mathsf{A}^*(x) f_{m+1}^{(n-1)}\right], \tag{7}$$

where $n \geq 1$, $m = n - 2k \geq 1$, $k \geq 1$.

Since $f_0^{(2n-1)} = 0$, $n \geq 1$, what we need to determine is a general formula for the term $f_0^{(2n)}$. This was found to fit the form

$$f_0^{(2n)} = \sum_{l=0}^{n} \sum_{k=0}^{l} \frac{1}{(k!)^2}\left(\frac{\psi}{2}\right)^k \frac{\partial^{2k}}{\partial w_y^{2k}} \frac{(-\phi\mathsf{M})^{(l-k)}}{(l-k)!} \frac{(\phi\mathsf{M})^{(n-l)}}{(n-l)!} f_0^{(0)}, \tag{8}$$

where we introduced dimensionless potentials

$$\psi = \frac{e^2\langle E^2(x,t)\rangle}{m_e^2\omega^2 v_T^2}, \quad \phi = \frac{2e\varphi}{m_e v_T^2}, \tag{9}$$

with the bracket $\langle \ldots \rangle$ denoting time averaging over the period of the oscillations; dimensionless velocities $w_x = \frac{v_x}{v_T}$, $w_y = \frac{v_y}{v_T}$; the electron thermal velocity v_T

$$v_T^2 \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f_0^{(0)} dv_x dv_y = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} (v_x^2 + v_y^2) f_0^{(0)} dv_x dv_y \tag{10}$$

and the differential operator $\mathsf{M} = -\frac{1}{2w_x}\frac{\partial}{\partial w_x}$.

Eventually the function f_0 itself can be expressed as

$$f_0 = \mathsf{L} f_0^{(0)}, \tag{11}$$

where L is the differential operator in velocity space which can be written formally as

$$\mathsf{L} = J_0\left(i\sqrt{2\psi}\frac{\partial}{\partial w_y}\right) e^{(\phi-\psi)\mathsf{M}} \tag{12}$$

and J_0 is a zero-order Bessel function. Slow time dependence of the function f_0 may be incorporated using the slow time dependence of the ponderomotive and ambipolar potentials respectively.

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This research has been conducted at the Department of Physical Electronics and has not been supported by any grant.

MATHEMATICAL MODELS OF QUANTUM SYMMETRIES

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Key words: quantum symmetries, quantum groups, nonlinear Schrödinger equation, representation theory

The investigation of mathematical models and physical applications of quantum symmetries carried out at the Department of Physics of the Faculty of Mechanical Engineering has been concerned with the representations of groups of symmetry, quantization on a discrete finite space and with the generalization of the nonlinear Schrödinger equation for irreversible processes.

I. The quantization on a discrete finite space was studied in connection with the possibility to construct coherent states over discrete phase spaces. Coherent states belong to most important tools in numerous applications of quantum theory. For simplest discrete configuration space Z_M (M points closed into periodic chain), with group of symmetry Z_M, i.e. cyclic group of order M, an overcomplete family of coherent states was constructed in [1]. In order to generate the family of coherent states we used the discrete Weyl group, which is an analogy to the Heisenberg-Weyl group in continuous case. Contributions at 14th Winter school Geometry and Physics (Srní, January 1994), $XIII^{th}$ Workshop on Geometry and Physics (Bialowieża, July 1994) and poster at XI^{th} International Congress of Mathematical Physics (Paris, July 1994) were presented on this topic.

A contribution to quantum groups theory was published [2], where operators of finite-dimensional quantum mechanics were used as an operator base for representations of q-deformed Heisenberg-Weyl algebras in the case, when q is a root of unity, i.e. $q^M = 1$.

In [3] the $\star$-product for symbols in finite-dimensional quantum mechanics was established. This investigation continues with the aim to find the analogy with the deformation of algebras of observables in continuous case. One possible way to quantize classical mechanics is to introduce noncommutative $\star$-product instead of the ordinary multiplication in the algebra of real smooth functions (classical observables) on the phase space. Thus the commutativity is deformed and the parameter of this deformation in classical limit goes to zero. In discrete case there is not such deformation in space of $M \times M$ dimensional matrices.

II. The nonlinear Schrödinger equation with a logarithmic term (NSE) reads

$$ih\frac{\partial\psi}{\partial t} = H\psi + \theta\psi\ln(\psi^*\psi),$$

where ψ is a complex function, H denotes the Hamiltonian operator for a system of N particles and θ a positive parameter. In [4,5,6], the stationary form of this equation was investigated and its solution was found. In 1994, the non-stationary NSE was generalized for the case when the quantity θ is a function of time and coordinates. A thermodynamic interpretation of this generalized equation was proposed; it can be used, in general, to describe irreversible macroscopic processes.

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This research has been conducted at the Department of Physics of the Faculty of Mechanical Engineering as a part of the research project "Quantum symmetries: Mathematical models and physical applications", and has been supported by CTU grant No. 8154.

QUANTUM SYMMETRIES: MATHEMATICAL MODELS AND PHYSICAL APPLICATIONS

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Key words: quantum theory, integrable models, quantum groups, contractions of Lie algebras, quantum scattering

Applications of symmetries in quantum physics and development of the corresponding mathematical tools were the subject of our research of 1993-94, in the following three main areas:

I. General quantization methods on non-trivial manifolds, particularly on homogeneous spaces: For homogeneous spaces of finite Abelian groups, the quantum description was derived in a way quite parallel to the continuous case [1]. The obtained formalization proved to form a suitable setting for representations of deformed Heisenberg-Weyl algebras in the case when the deformation parameter is a root of unity [2]. The application of quantization methods to systems with infinite-dimensional symmetry groups was considered in [3]. This problem arises in quantum gravity.

II. Contractions of Lie algebras, quantum and braided groups and their representations as a new type of symmetry of quantum models: A family of graded contractions of Lie algebras was systematically classified, and a relation to kinematical groups of spacetime was pointed out [4]. This result was extended to the conformal group of spacetime [5]. A new type of symmetry called braided groups was examined, including the relationship to quantum groups and supersymmetries [6]. It was shown that coherent states in the Perelomov sense can be introduced for quantum groups as well. As a consequence, one can construct representations acting in spaces of "holomorphic functions" in the spirit of Borel-Weil theory, analogous to the non-deformed case [7]. Boson realizations were derived and applied to the quantum groups B_l and C_l [8]. Quantum groups equipped with differential geometrical structure represent a new type of symmetric spaces [9]. Cyclic representations of quantum groups proved to be helpful when searching for eigen-values of quantum Hamiltonians [10].

III. Physical models, quantum Hamiltonians and scattering theory: The open chain of spins was studied, and efficient algebraic tools were developed to solve it [11]. A great deal of interest was paid to the application of new symmetries in quantum integrable models [12]. The scattering of non-relativistic particles in multiply connected domains was considered. In this problem, related to the Aharonov-Bohm effect, the fundamental group of the domain plays an important role as a discrete symmetry of the universal covering space. Using the Feynman path integral, the basic properties of the scattering operator were determined [13, 14]. The existence of resonances was proved for the Hamiltonian corresponding to a particle

moving in a curved quantum waveguide. This effect is related to the curved geometry [15, 16].

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ONE SEMESTER EXPERIENCE WITH THE COURSE OF CA SEMINARS OF PHYSICS

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Key words: computer aided seminars of physics, computer program, SW Famulus

Our contribution describes a one-semester experience with the newly-opened course CA Seminars of Physics at the Department of Physics, Faculty of Mechanical Engineering which accompanies physics lectures.

The graduates from technical universities and schools of similar types are supposed to gain not only enough wide and deep knowledge of the fundamental physical laws and principles which nature obeys, but they should know how to apply them in an active way. This knowledge should be used during their study of specialized subject in higher years of their university study, and consequently in solving of any practical problem of praxis when graduated. We understand that when passing the course of technical physics, the student has to have a certain amount of particular information concerning the knowledge of some facts, dates and also certain factual quantitative (numerical) imaginations. It is also very important to show the students methods of how to formulate a given problem, apply the laws and principles of physics, and the advantages and disadvantages of various methods which may be used, and to define the priority which leads to finding the most suitable method in a given case.

It is necessary, and it follows current trends to introduce the usage of such computer software which permits a solution of the problem during the class period. Comparing various commercially available SW from various points of view, we decided to use the Czech computer SW FAMULUS 3.5 (the English version). The author of the software (Dr. Dvořák) is a university physics teacher and so it was especially prepared to solve and simulate problems in physics and mathematics with respect to the teaching requirements.

We found the next advantages in computer and software usage:

- computer programs should help us in finding solutions, we were never able to discover using analytical mathematical methods alone. Especially, when trying to mathematically describe the behavior of the majority of non-linear systems, we need to use some simplifying conditions in most cases. That means we do not solve the original problem but its special case which may, or may not, be equivalent to the real problem.
- One can rapidly investigate system dependence on the input parameters of the system. In addition, the problem can be modified easily which allows us to investigate a wide

set of similar problems. Such modern and non-standard methods of inquiry should be a part of the educational process too and students must have the opportunity to be acquainted with, together with traditional solutions and analytical solution by means of computers.

- Passing Students have the opportunity to know the software together with new technique of investigation of problem.

The solution of the majority of technical problems and tasks depends not only on a detailed and extensive investigation of the particular problem from the point of view of practice. Substantial help with these problems can come from the knowledge in mathematics and physics. Additionally, many of the problems can be solved with the contribution from numerical methods in computer programs. To introduce such methods requires a substantially different view of the problem, many times accompanied by diffe rent formulation of the task. Moreover, the successful interpretation of the results and their application requires different approaches. d)As far as the teaching of physics itself, it should not only be based on the precise explanation and excellent intelligibility, but it must always be accompanied by application to a particular part of some practical problem. It is also necessary to make the student acquainted with an interpretation of the laws of physics together with an emphasis to all aspects concerning the topic. The major part of the work represents a choice of appropriate problems. Not only was it necessary to coordinate seminars with the lectures, but we needed to find some problems interesting for students and which are not easy to solve without computers. The problems can be divided into three main groups

- Problems which may not be solved using analytical mathematical methods (e.g. numerical derivatives, solution of elliptical integrals, non-linear algebraic or differential equations, sets of equations, usage of powerseries, matrix calculus), or when such methods are too time-consumptive and the results are too complicated to recognize the influence of individual quantities.
- Problems which can demonstrate some important physical concept, mutual relation among physical quantities, or such cases where the numerical values of variables are extremely important and interesting and worthy further technical courses at the university, and later, in practice.
- Computer-assisted-instruction in classical problems (similar to the textbook-examples) can serve as tools of self-study with student feedback. This type of program can also be used as a test of student knowledge.

The course was evaluated by both students and teachers as very efficient and interesting. It seems to fulfil the goals stated at the beginning of this paper. A substantial part of the work, concerning especially the exchange of experience at other universities, together with mutual cooperation, and with equipment of our computer laboratory was made under the umbrella of the TEMPUS program 2262.

COMPUTER AND LABORATORY EXERCISES IN PHYSICS

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Key words: laboratory excercises in physics, computer programs, SW Famulus 3.5, teaching of physics

Main Goals. We understand that when passing the course of technical physics, the student has to have a certain amount of particular information concerning the knowledge of some facts, dates and also certain factual quantitative (numerical) imaginations. It is also very important to show the students methods of how to formulate a given problem, apply the laws and principles of physics, and the advantages and disadvantages of various methods which may be used, and to define the priority which leads to finding the most suitable method in a given case. Laboratory exercises show them the way to this aim. We decided to introduce the up-to- date computer technique which allows fast and deeper insight into the particular experimental problem investigated.

It is necessary, and it follows current trends to introduce the usage of such computer software which permits a solution of the problem during the class period of laboratory exercise. Moreover, such computer programs should help in finding solutions, we were never able to discover using analytical mathematical methods alone. Especially, when trying to mathematically describe the behavior of the majority of non-linear systems, we need to use some simplifying conditions in most cases. That means we do not solve the original problem but its special case which may, or may not, be equivalent to the real problem. In some case, it is necessary to carry out preliminary numerical analysis of particular mathematical model of the given system to find real ranges of chosen parameters describing the system.

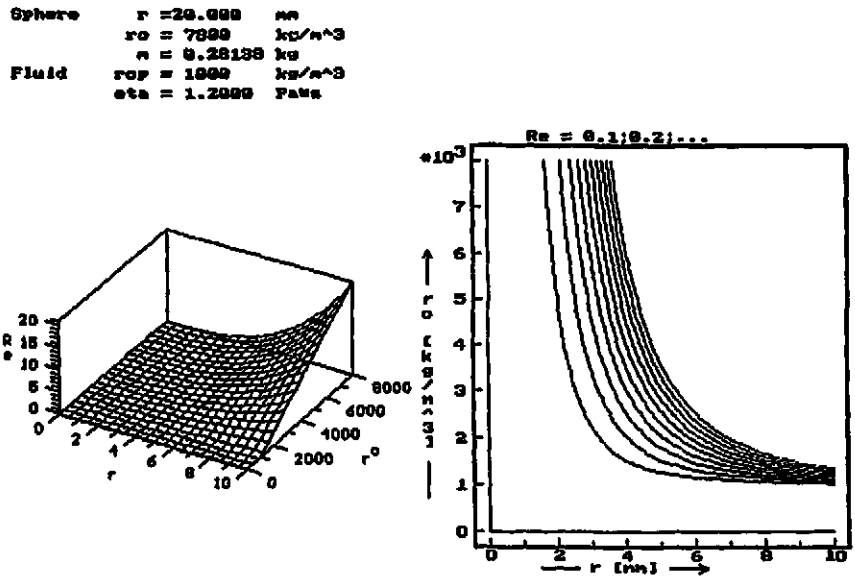
In laboratory exercises, it is also very useful and instructive to simulate and model the real problem measured. It allows the possible investigation of the whole set of similar problems and to become more familiar with the situation from the point of view of not only physics but also to gain quantitative imaginations.

Temoporary Achievements. The computer programs were prepared to support the next laboratory exercises:

- Measurement of resistances and capacitances
- Acceleration due to gravity
- Stokes' method in measurement of dynamic viscosity coefficient
- Investigation of electrical field
- Lenses
- D'Arsonval galvanometer

- RLC series electrical circuit
- Resonance curve in electrical circuits

An example of the computer screen of Stokes' method in measurement of dynamic viscosity coefficient:



The substantial part of the work was made within the Fund of University Development No.1169/1994 "Computer Usage in Laboratories of Physics" coordinated by the Department of Physical Electronic, Masaryk University, Brno.

ACOUSTIC EMISSION FROM STATICALLY LOADED TIMBER PANELS

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Key words: acoustic emission (AE), timber panels, static loading, AE signals

One of the tests which have been carried out in the frame of studies and prototype tests of timber panels for an AS-D 108 family house concerned the mechanical stiffness of the supporting structure and the bracing effect of a timber panel in the wall plane of the house on the structure as a whole.

Two test panels of dimensions 2.3 x 1.2 m^2 have been manufactured without horizontal rods and without inner plaster cardboard (thickness 12.5 mm). Only the basic supporting structure of the timber panel was tested, which consisted of a timber beam structure, jacketed on both sides by CETRIS boards.

The panels were positioned vertically. The acting force was horizontal and was generated by a hydraulic apparatus up to 250 kN . The force was measured by a strain gauge. The horizontal displacement in the force application point was measured by W50-HBM induction pickups. The data on the load and the horizontal displacement were fed via KWS 3073-HBM instrumentation amplifiers into a SERVOGOR X-Y recorder. The load was applied in steps up to the breaking strength.

The acoustic emission (henceforth AE) was measured in two channels. The AE pickups were placed in the middle of the panel. One of the pickups was used to detect the AE signals which after being processed in a counter served to generate the cumulative function (see Fig. 1). The other pickup signal was fed into a S/H circuit (DATALAB 912) and from it to a computer which made possible selective recording of the AE impulses during the test and also at any stage of the loading.

In both cases the CERES board wall casing broke down in critical regions of the panel corners. It was in this regions that they tore away from the panels, this phenomenon being due to local forces in the nailed joints. The CERES board skew fracture was due to enormous panel deformation which took place when the breaking strength was reached.

The tests proved that the rigidity of the nailed joints in the inserted beam region of the panel was insufficient.

The mentioned frame joint exhibited slippage which resulted subsequently in breakdowns in the wall board to timber frame joints. The horizontal beam displacement versus the applied load plot was measured separately for the left-hand-side and the right-hand-side supporting timber rod. The panel deformation at the breaking strength was as high as 80 *milimetres*. The *strain-stress plot is pronouncedly* non-linear, which indicated a strong mechanical compliance of the braced panel, which is evidently due to a poor design of the

mentioned joint. After the tests had been accomplished partial structure design modifications were put forward to the manufacturer.

All kinds of failure were documented by means of recordings of the accompanying AE signals. Selected charts are presented in the paper. The AE, although employed as a supplementary method, has proved to be extraordinarily sensitive. It gives evidence of the onset of a failure process much sooner than it virtually takes place and, consequently, does not lead to total destruction of the objects to be tested. Provided a detailed analysis of the sampled data has been carried out the AE method gives also a more detailed picture of the failure process.

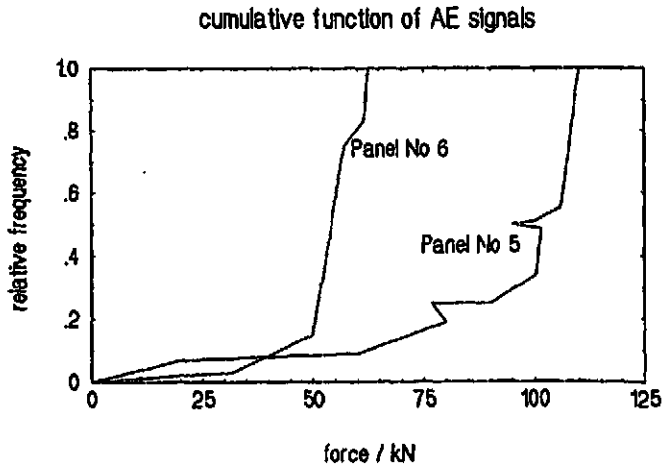

Fig. 1: Relative cummulation curve of AE signals from statically loaded timber panels

This paper has been elaborated in a section of the Department of Physics, Faculty of Civil Engineering, TU Brno, in the framework of and has been supported by a grant awarded by the Grant Agency of the Czech Republic, called "Acoustic Emission in Civil Engineering". Reg.No 103/93/2201.

SUBSEQUENT ACOUSTIC EMISSION FROM GLASS AND GLAZED CERAMICS

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Key words: acoustic emission (AE), glass, glazed ceramics peeling, acoustic emission signal correlation, subsequent acoustic emission (SAE)

The paper deals with acoustic emission that is generated in glasses and in glazed ceramics not only during stressing but also a certain time after the stress relief. This kind of acoustic emission can be termed as *subsequent acoustic emission*. We believe this term expresses the nature of this phenomenon better than, e.g., the term "secondary acoustic emission", which was used in [1].

The nature of the subsequent acoustic emission (henceforth SAE) is closely related to generation of cracks in the surface layers of the glass films after the stress has been removed, even in the cases that the original stress equaled one half of that necessary to generate a crack during loading, sometimes even less.

Crack nuclei arise in the glaze when a sharp indentor is indented into the glass or when tensile or compressive stress is applied to the glazing film.

The prevailing compressive bias in normal direction, however, will preserve integrity of the material. When a relief takes place then the surface layer which has been plastically deformated will keep a state similar to that of the previous loading. As there is, in fact, no more normal pressure a local thickening or even tiny residual tensile or shear stress (for example between the glaze and the ceramic body) are quite sufficient to produce a crack.

This crack need not always propagate up to the surface of the glass surface film. In the case of a stronger material (glass) springing-back or a weaker glaze-to-ceramic bond strength along with a simultaneous compressive stress in the glaze there appear small splinters or glaze chips peeling from the surface.

This process of gradual non-uniform strain field uniforming together with local degradation of the material (glass, glaze) integrity makes up real sources of the SAE.

Detection, recording and subsequent evaluation of the SAE signals can be employed for testing the quality of glass and glazed products directly in fabrication.

In the paper we present some results of our studies of SAE in selected civil engineering materials, such as: 5 mm thick sheet glass, glazed ceramic wall tiles, glazed covering, glazed ceramics.

The SAE signals from samples of the mentioned materials were assessed also from the point of view of the autocorrelation and cross-correlation with the intention to prove a unified physical nature of the phenomenon (see Fig. 1).

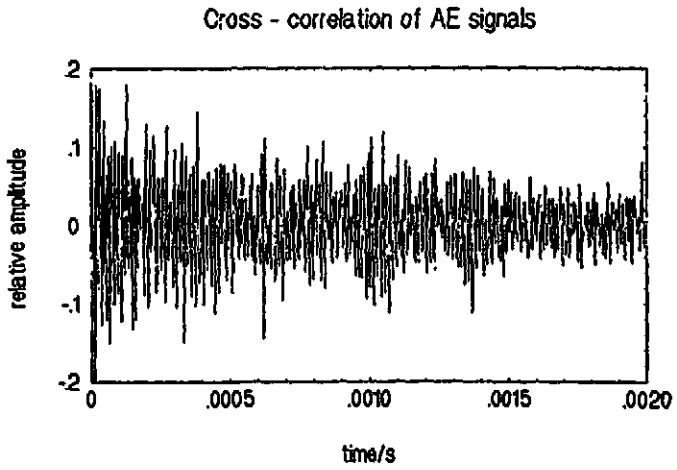

Fig. 1: Relative correlation function between AE signals from glass and glazed ceramic

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This study has been elaborated in a section of the Department of Physics, Faculty of Civil Engineering, TU Brno, in the framework of and has been supported by a grant awarded by the Grant Agency of the Czech Republic, called "Acoustic Emission in Civil Engineering, Reg.No 103/93/2201.

AERODYNAMIC NOISE IN DUCTS
Preliminary study for the ANC

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Key words: acoustics, noise, active noise control, spectras

Acoustic noise is recognized as a source of environmental pollution. Reduction of this problem is based on improvement of the design of the noise source and/or attenuation of the sound waves along their paths of propagation. The control of noise propagating through a duct is, due to a number of applications, a typical example of such a task.

There are two basic approaches: passive and active. The passive method consists in the use of various mufflers - sections of a duct whose walls have been shaped or treated to reduce the transmition of sound trouhg reflections and/or absorption or scatering of the sound waves.

Active noise control consists in adding a secondary wave created by artificial sources to the incident wave produced by the noise source, so that the superposition of these waves cancels the pressure downstream from the coupler. Active control of sound in ducts could be also realized by the active absorption of sound energy by a secondary source or sources [1].

For the purpose of ANC controler design, knowledge of noise characteristics is required. In our case, the noise is generated by a small axial fan. Resulting noise, propagating through the duct, is composed of the aerodynamically generated noise and the noise generated by a motor and gearbox. As the latter is dependent on the mechanical quality of the driving mechanism, the former, generated by rotating blades, is of primary interest.

Most of the recent progress in understanding aerodynamic sound generation by rotating blades is based on the acoustic analogy developed by Lighthill [2]. Recent developments in this field show that basic sound generation mechanisms are the same for axial and radial fans. From the detailed analysis presented by Neise [3], it follows that all monopole, dipole, and quadrupole types of sources can be found in the vicinity of the blades. Although monopole and quadrupole radiation can be important in some cases, the primary cause of the fan noise is the unsteady forces on the blades, vanes, and the fan casing which are generated by the interaction of these components with the turbulent flow. This mechanism of noise generation is called 'dipole noise' because the unsteady forces can be thought of as a distribution of moving acoustic dipoles. The blade forces can be periodic as well as random in nature, and, consequently, the resulting sound field usually has discrete and broadband components in its spectrum.

A number of measurements were carried out in order to find a characteristic noise spectrum in a duct produced by a fan mounted on the end of the experimental tube with a diametr of 0.1 m and a length of 2.5 m. The fan operated in two regimes. In the first one, the oposite end of the tube was closed and, consequently, there was no air flow going through the duct. In the other regime, the end was opened and the mean flow speed was measured to be about 4.5 m/s.

The typical experimental result for the first regime is shown in Figure 1. In spite of the special termination of the tube, the 'whistle effect' of the tube is evident (whose first harmonic is 34,5 Hz). The characteristic blade frequency is about 270 Hz, and, in the Figure 1, it is represented by the narrow peak of 85 dB. The corresponding result for the second regime is shown in Figure 2. The characteristic blade frequency is amplified by the fourth harmonic frequency of the experimental tube (for the open end whistle the first harmonic is 69 Hz).

Knowledge of the noise characteristics is necessary to provide the better understanding of the unsteady flow structure in the tube and to optimize the design of the active noise control system.

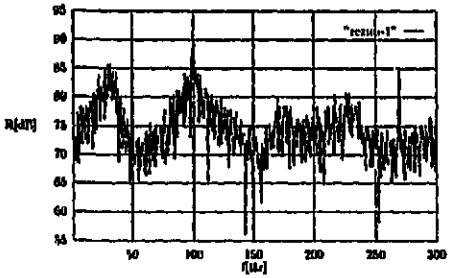

Fig. 1:

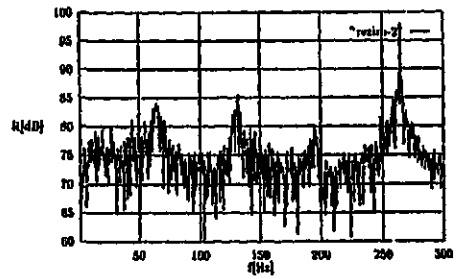

Fig. 2:

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This research has been conducted at the Department of Physics as part of the research project "Active control of aerodynamic noise" and has been supported by CTU grant No. 38187.

CALIBRATION OF SOUND INTENSITY INSTRUMENTS IN A ONE-DIMENSIONAL SOUND FIELD

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Key words: acoustics, sound intensity, calibration

Big attention is paid to the measuring of acoustic intensity today. The accuracy of this measurement strongly depends on the environment and on the quality of the measuring device. The most significant error when a two-microphone probe is used is a residual phase mismath. The intensitometers, which are based on computer-aided processing, can correct this phase mismath by the correction curve calculated from the calibration of the intensitometer. The laboratory method for calibration of intensity probes in a wave tube is described in this paper. The main goal was to prepare measurement equipment for the calibration of intensitometers.

The experiments were carried out on a wave tube located at the Department of Physics. The tube was made of steel, the inner diameter was 100 mm, the wall thickness was 5 mm, and the length of this tube was 2.5 m. There was one row of openings along this tube and another opening opposite them. These openings allowed measurement of the sound field near the tube wall or any distance from the wall. To obtain a one-dimensional sound wave in it, a 100 mm loudspeaker was used. A passive anechoic termination was placed opposite the loudspeaker. The absorber, which was used in these experiments as the termination of the tube and made of thin stripes of foam polyurethan and a cotton-wool slipped on a 750 mm wire, was measured under various frequencies.

The acoustic field in the tube was measured by a pair of B&K 4118 intensity microphones with B&K 2633 preamplifiers. Outputs of these preamplifiers were connected via a voltage amplifiers to a PC30-PGH plug-in card. This card can sample two channels at a sampling frequency of 100 kHz per each one.

Experiments to determine the phase shift between the two channels of the probe were performed in frequency range 100 Hz to 2000 Hz (the frequency limit of this tube). The microphones were required to be arranged in such a way that the signals on both microphones would be identical. To get identical signals on both microphones, they were placed opposite each other at the same distance of 540 mm from the loudspeaker. Signals from the A/D converter of the plug-in card were processed using the correlation function. The results show the phase difference, which corresponds to the delay at sampling the two measuring channels because this card has no sample-hold circuits. For frequencies above 200 Hz the delays were identical but at lower frequencies, uncertainty occurred with setting the phase difference because of big wavelengths of the signal. The correct removal of phase mismath between the channels at frequencies below 200 Hz requires an averaging of many values. However, in this case, even though the channels were at frequencies below 200 Hz, the correct results were got without the averaging (phase shift $< 1.1°$).

A number of experiments with different terminations were performed. The shape of the frequency curve closest to the ideal one was found when the length of termination was 400 mm, and a 1:1 rate of polyurethan and cotton was used.

The same microphone distances were measured for each frequency, but no influence of distance on measuring results occurred. Fig.1 shows the results for the microphone distance of 165 mm.

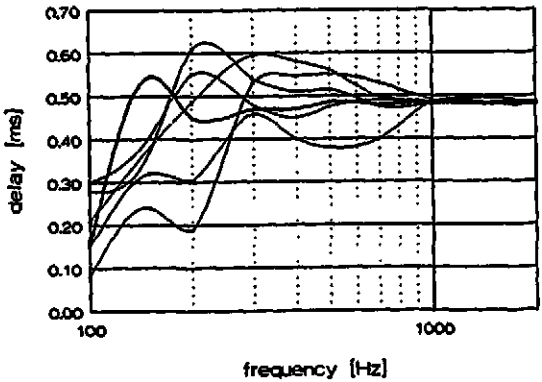

Fig. 1: Distance between microphones 165 mm (≈ 0.485*ms*)

From the experimental results it follows that intensity probe B&K with preamplifiers and voltage amplifiers enables precise measurement with a phase mismatch lower then 1.1° in all tested frequency ranges. The results are not dependent on th placement of the tested microphones (in the center of the tube with a 12 mm solid spacer or in the wall).

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This research has been conducted at the Department of Physics as part of the research projects "Active control of aerodynamic noise" supported by CTU grant No. 28187 and "Experimental equipment for measuring acoustic energy transfer in one-dimensional sound fields" supported by MECR grant No. 11-91041.

USING MICROWAVES FOR BUILDING MATERIALS MOISTURE DETERMINATION

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Key words: non-destructive measurement, moisture, building materials, microwaves

During the preparatory stage of the reconstruction and modernisation of the existing buildings, several problems have arisen. The main one is to find out the quality of existing structures which is determined by moisture content of materials, as well as by the condition of structures.

Water contained in building materials significantly changes their properties (mechanical, thermal, acoustic etc.), which determines the possibility of using a product in the construction and, in case of reconstruction, the possibility of maintenance, its technology and extent. Similarly, during manufacture of building materials, the concentration of water in raw materials and intermediate products decides on the quality of a final product. The complexity of the problem of finding a concentration of water in building structures lies in variability of materials used and in the fact that water exists in them in more forms (bulk water, physically and chemically bound water).

At present, there is no suitable method in this country for the determination water concentration in building materials which would satisfy the requirements of being exact, quick, non-destructive, easy to carry out and possibly a continuous one. These requirements are essential to bring such a method into practice. The standard method, suggested by the building codes and based on measuring the weight of water evaporated from a sample of a building material does not satisfy the above mentioned requirements (except the first one).

A solution can be offered by so-called indirect physical methods based on an interaction between a building material and some form of the physical field. The result of some of these interactions strongly depends on the volume of water contained in a material. Some of these methods are: electrical resistance, capacity, radiometric and ultrasonic methods. Despite of many advantages, these methods have also some disadvantages, in terms of requirements mentioned above:

- they require a direct contact with the measured environment,
- the results are influenced by the amount of salt substances contained in water,
- some of the methods do not have a sufficient range of measured values of water concentration,
- some others (radiometric, ultrasonic) are expensive and intricate in practice.

On the other hand, the use of the so-called microwave method for measuring water concentration in materials seems to be fairly promising. This method belongs to the group of electromagnetic methods based on the interaction between a moist substance and the electromagnetic field. It also benefits from the fact that dielectric properties of capillary-porous materials (most building materials) depends strongly on water concentration in them, especially on certain frequencies (microwave band) of the electromagnetic radiation. At the

Dept. of Building Design of FCE TU in Brno, the possibility of using microwave method were investigated in the following fields and the following results were obtained:

a) Determination of moisture content in building material samples.

We have determined the calibration curves of moisture dependence on attenuation of electromagnetic microwave radiation passing through the set of building materials (wood, chipboard, gas concrete, plywood, sand etc.).

b) Monitoring the cement mortar hydration process.

We have developed the guidelines for using electromagnetic microwave radiation passing through the hydrating cement mortar for monitoring the hydration process and using this way for finding the influence of admixtures (light ash) and other factors (temperature) on the hydration process time behaviour.

c) Finding the state of wooden ceiling structures.

Using models of wooden ceiling structures we demonstrated the possibility of using electromagnetic radiation passing through or reflecting ceiling structures for non-destructive determination of the position and width of the beams and for estimation of their condition.

d) Determination of moisture of the brick raw material.

We have determined the dependence of attenuation of the electromagnetic radiation passing through brick raw material on moisture content and temperature of the material at different stages of the technological process of its processing.

The 'open space method' based on the connection between the microwave radiation attenuation and the amount of water in a material is the most advantageous of the group of microwave methods as methods for non-destructive measuring of moisture content in building materials and structures.

During the interaction of electromagnetic radiation, which has a form of a plane monochromatic and linearly polarised wave, with a homogenous isotropic dielectric material, reflection, absorption and transmission of the radiation are observed. The quantity of the attenuation as a measure of radiant power absorbed in the material is defined as follows:

attenuation = 10 dB . log (incident flux density / transmitted flux density).

Using the above mentioned method we are able, by measuring in the open space, obtain the value of attenuation by means of the substitution method.

In case of using the microwave method for measuring moisture of wood its non-isotropic properties have to be considered. Wood could be roughly described as a layered dielectric environment. When monochromatic and linearly polarised electromagnetic wave passes through such an environment there is a difference between the propagation factor for the wave polarised parallel to the environmental layers and perpendicularly to them. In this case the attenuation of electromagnetic radiation passing through the wooden mass depends, besides its moisture, on the angle between the incident radiation and the wood fibres direction.

The conclusion based on the mentioned measurements is that the microwave method is highly suitable for measuring water concentration in building materials and can be used for non-destructive detection of wooden ceiling beams as well.

This research has been conducted at the Department of Building Design, Faculty of Civil Engineering, TU in Brno as part of the research project "Non-destructive determination of moisture content in building materials and composition of building structures by using microwave electromagnetic radiation" and has been supported by TU grant No. B-35/93.

ONE-POINT METHOD FOR MEASURING THE MOISTURE DIFFUSIVITY OF BOARD MATERIALS

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Key words: moisture diffusivity, board materials, one-point method

Methods for measuring the moisture diffusivity of porous materials have been the subject of both theoretical and experimental studies for years. The moisture diffusivity of many materials depends dramatically on the moisture content (sometimes within the range of several orders of magnitude) which makes its determination relatively complicated.

The steady-state method [1], and the non-steady-state methods by Matano [2], Drchalová [3], and Häupl and Stopp [4] belong among the most frequently used in determining the moisture diffusivity. All these methods have a common feature; they work with one-dimensional moisture transport, and calculate the moisture diffusivity from the spatial moisture distribution at one or several specified time levels. Therefore, they require rod samples where the moisture sensors are positioned along the longitudinal axis, and completely fail when only board samples are available. In this paper, we present a method which requires measuring the time history of the moisture content in only one spatial point, and therefore is suitable for board materials.

We consider the one-dimensional moisture conduction equation in the form

$$\frac{\partial}{\partial x}\left(\kappa\frac{\partial u}{\partial x}\right)=\frac{\partial u}{\partial t}, \tag{1}$$

where u is the moisture content, $u=(m_w-m_s)/m_s$, m_w is the mass of the moisten material, m_s is the mass of the dried material, κ is the moisture diffusivity,
with boundary and initial conditions of $u(0,t)=u_1$ and $u(x,0)=u_2$.

First, we use the Boltzmann transformation $\eta=x/2\sqrt{t}$, $w(\eta)=u(x,t)$. Then, assuming that we know in one spatial point, $x_o=const.$, the time history of the moisture content, $u=u(x_o,t)$, we employ the second transformation $t=(x_o/2\eta)^2$, $u(t)=w(\eta)$ with the result

$$\frac{4\sqrt{t}}{x_o^2}\frac{\mathrm{d}}{\mathrm{d}t}\left(\kappa t\sqrt{t}\frac{\mathrm{d}u}{\mathrm{d}t}\right)-\frac{\mathrm{d}u}{\mathrm{d}t}=0. \tag{2}$$

After integrating equation (2), we get

$$\kappa(u_2)=\frac{x_0^2}{4t_2\sqrt{t_2}\left(\frac{\mathrm{d}u}{\mathrm{d}t}\right)_{t=t_2}}\int_{t_1}^{t_2}\frac{1}{\sqrt{t}}\frac{\mathrm{d}u}{\mathrm{d}t}\,\mathrm{d}t+\frac{\kappa(u_1)t_1\sqrt{t_1}\left(\frac{\mathrm{d}u}{\mathrm{d}t}\right)_{t=t_1}}{t_2\sqrt{t_2}\left(\frac{\mathrm{d}u}{\mathrm{d}t}\right)_{t=t_2}}, \tag{3}$$

where $u_2=u(x_o,t_2)$ and $u_1=u(x_o,t_1)$.

Since the value of $\kappa(u_1)$ is not known, we have to express it in terms of the moisture flux, $j(x_o, t_1)$. Then after applying the same transformations to the moisture flux as to equation (1), and inserting the result into (3), we finally get

$$\kappa(u_2) = \frac{x_0^2}{4t_2\sqrt{t_2}\left(\frac{du}{dt}\right)_{t=t_2}} \int_{t_1}^{t_2} \frac{1}{\sqrt{t}} \frac{du}{dt}\, dt + \frac{\left(\frac{j}{dt}\right)_{t=t_1} x_o\sqrt{t_1}}{2A\rho_s t_2\sqrt{t_2}\left(\frac{du}{dt}\right)_{t=t_2}}, \qquad (4)$$

where $m(t)$ is the mass history of the moistened sample, A is the cross section of the sample (surface area of the board), ρ_s is the volume mass of the porous skeleton.

The newly developed method was tested by measurements on Dekalux (environmental friendly replacement material of the asbestos-cement based products, produced by EZA Šumperk, $\rho_s = 1800\ kgm^{-3}$, board thickness 5.6 mm). The test results are shown in Fig. 1. Moisture diffusivity first decreases with the moisture content and at about $u = 0.08$ it begins to increase.

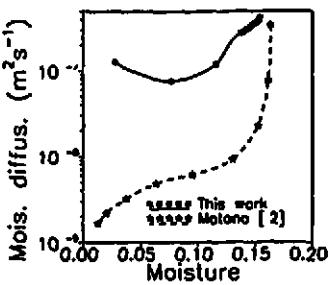

Fig. 1: Moisture diffusivity of Dekalux

The results of determining the moisture diffusivity by the one-point method were compared with those obtained by the Matano method [2] (rod samples $40 \times 5.6 \times 300\ mm$, cut from the material board). As shown in Fig. 1, the differences between both methods achieve one order of magnitude across the whole moisture range. This result provides evidence that the anisotropy in the two basic directions, along and across the board, is very important in measuring the moisture diffusivity of board materials, and has to be considered in the design of a building structure.

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This research has been conducted at the Department of Physics and has been supported by the grants of the Grant Agency of the Czech Republic No. 103/94/0140 and 103/94/0595.

UTILIZATION OF SUBNANOSECOND INTENSE PULSES OF SOFT RENTGEN RADIATION INDUCED BY IODINE LASER IN RADIATION PHYSICS

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Key words: soft x-ray radiation, thermoluminiscent dosimeters, laser-produced plasma, chemical dosemeters, Si PIN diode

Soft X-rays (SXR), have a number of applications, especially in radiobiology; which is given by the very high biological efficiency of SXR.The contemporary development of laser-produced plasma sources of intense SXR, gives a great opportunity to assist in tumour therapy. It requires the ability to characterize SXR sources (spectral brightness and exposition rate). Many types of semiconductor detectors (e.g. silicon PIN diodes) are in general use for SXR detection. In the case of SXR sources with low photon flux, like radionuclides and sychrotron sources to 10^9 photons/s, should the semiconductor detectors be acceptable because of their linear dose response. However their linearity is limited by photon flux of 10^{13} in sec while in the case of laser produced plasma SXR sources the detectors are irradiated by $10^8 - 10^{10}$ photons/ns. That is why it is necessary to develop detectors with such mechanisms of energy interaction and absorption, which allows us to presume their response dose linear despite the very high photon fluxes. This condition is fulfilled by chemical dosemeters and thermoluminescent dosemeters.

This work continues in the project which is based on the cooperation between Inst. of Physics of Acad. of Sciences and Dept. of Dosimetry and Appl. of Ionizing Radiation. Some results were presented at the last CTU seminar [1].

The iodine photodissociation laser system PERUN was used. This laser operates at wavelength 1315 nm up to 50 J of energy and about 350 ps duration. The laser beam was concentrated on a 30 μm thick Al foil target. At this point in our work we were mainly concerned about the thermoluminescent (TL) detector on the basis of aluminophosphate (Al-P) glass. The TL glow curve of this Al-P glass shows 5 peaks, which correspond to 5 types of traps [2]. By measuring the TL glow curves we obtained different kinds of irradiation sources (neutrons, gama rays and UV) we can assume different occupation of traps in dependence on photon energy. Simultaneously we can assume the independence of this occupation with the photon flux (dose rate). This effect we can use for measuring the photon flux as well as photon spectrum of SXR. Al-P dosimeters shielded by different foils were irradiated by SXR induced by incident laser energy varied from 9 to 27 J. Also the response of Al-P dosemeters placed in "sandwich" form (shielded by Be foil for UV elimination) were studied. Fig. 1 illustrate the TL glow curves of first (b) and second (c)

position of this "sandwich" arrangement. These dosemeters were irradiated by 15 J initial laser energy. The absorption of the Be foil as well as of Al-P glass were measured by a gamma-lines obtained from rentgenfluorescent spectra of some elements.

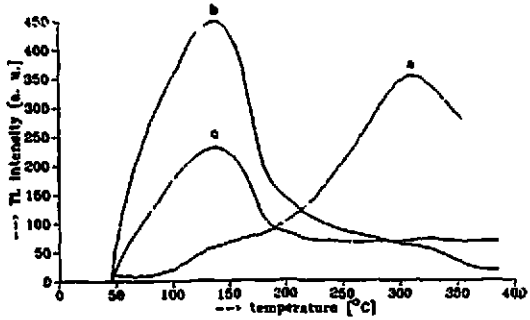

Fig. 1. TL glow curves of Al-P dosemeters irradiated

a) ^{55}Fe source
b) SXR – 1. dosemeter of 'sandwich' form
c) SXR – 2. dosemeter of 'sandwich' form (x 10^{-1})

Fig. 1:

The independence on the dose rate and very low fading allow us to calibrate these TL dosemeters by radionuclide sources. In Fig. 1 we can see the TL glow curve (a) after irradiation of 55Fe (5.99 keV). Responses of Al-P glass TL dosemeters were compared with responses of other dosemeters used in our experiments e.g. TL dosemeters and CaF_2:Dy TL dosemeters as well as responses of PIN diodes irradiated under the same conditions [3].

For absolute calibration of our measurements the Fricke solution was used. This chemical dosemeter relying on its tissue equivalence is a very suitable system for calibrating biological applications. Moreover, its radio-chemical yield is well known even for low energy photons and for high dose rates of radiation.

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This research has been conducted at the Department of Dosimetry and Appl. of Ionizing Radiation as part of the research project "Utilization of subnanosecond intense pulses of soft rentgen radiation induced by high power laser in radiation physic" and has been supported by CTU (TU) grant No. 48204.

Section 3

CHEMISTRY

QUANTUM CHEMICAL STUDY OF SMALL MOLECULES

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Key words: ab initio, SCF, MP2, IR, RAMAN, quantum chemistry

The goal of our work is an ab initio study of conformations and interpretations of IR/Raman spectra of small organic molecules. The first molecule under study was 4-azidobut-1-yne [1, 2, 7] that is the subsequent molecule from the series of small organic azides that were under study. Due to restricted rotation around C-C bond (gauche or anti) and C-N bond (gauche or anti) 4-azidobut-1-yne (HCCCH2CH2N3) can exist in five distinct conformations that are labeled GG, GG', GA, AG and AA, see Fig. 1. The first and second letters mark the conformations around the C-C and C-N bonds, respectively.

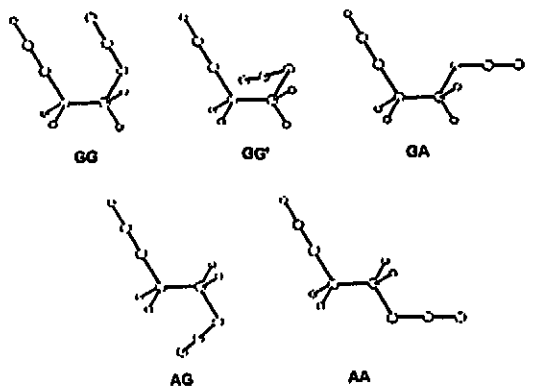

Fig.1. Five conformers of 4-azidobut-1-yne.

A problem of an interpretation and an assignment of bands of IR/Raman spectra was investigated. We carried out an ab initio SCF calculations to find optimal geometries of all possible conformers. Huzinaga TZP basic set was employed. The SCF optimized geometries were checked on nonnegative vibrational modes by vibrational analysis, and zero point vibrational energies were calculated. To improve the accuracy of ab initio energies, MP2 calculations were performed for all five conformers at the SCF optimized geometries.

From experimental investigations [2] by means of IR and Raman spectroscopy it follows that 5 conformers of 4-azidobut-1-yne form two groups. The first group consists of low-energy GG, AG and AA conformers; the second one is composed of GG' and GA conformers. These results are supported by our ab initio MP2/SCF TZP results that depict a similar dependence.

In order to obtain a complete description of the molecular motion involved in the normal vibration of our molecules, we have carried out a normal coordinate analysis. Ab initio SCF force field in Cartesian coordinate space was transformed to suitable internal coordinate space. Because of systematic overestimations of ab initio SCF force field, calculated force field in internal coordinate space was scaled.

The second molecular system under study was R1R2NCR3=C(CN)2, where R1, R2, R3= H, CH3 [3-6]. The goal of our study was similar as in the 1-azidobut-1-yne investigation. We used semiempirical MINDO3 and AM1 methods [3], ab initio MP2/SCF calculations [4] and IR/Raman spectra [5, 6] to investigate such molecular system. These molecules are intensively used in the organic synthesis and the intensive theoretical study of the physical and chemical properties of these compounds has not been carried out yet. A normal coordinate analysis was carried out to obtain description of vibrations. Ab initio SCF force field was scaled. A vibrational assignment was performed for some molecules [5, 6]. Our extended ab initio MP2/SCF (Huzinaga DZP basic set) calculations depict an interesting behaviour of molecules [3, 4].

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This research has been conducted at the Chemical Faculty as part of the research project "Quantum chemical conformational study of small molecules and a theoretical interpretation of IR spectra of these molecules" and has been supported by TU grant No. B 19/94.

PHYSICO-CHEMICAL PROPERTIES OF HYALURONIC ACID DERIVATIVES

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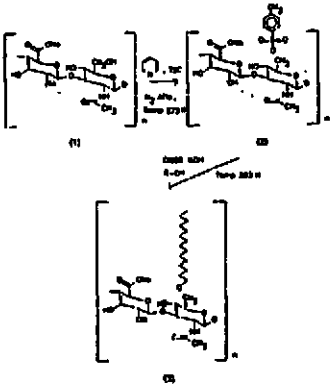
Key words: hyaluronic acid, micells, DSC, SEC, rheology, liquid crystals

Hyaluronic acid (or hyaluronate) (HA) is a linear carbohydrate occuring in the connective tissue matrix. Its disaccharide monomeric unit is built up of N-acetyl-D-glucosamine and D-glucuronic acid interconnected via β(1-3) and β(1-4) interglycosidic bonds.

HA macromolecule contain a considerable amount of regio- and stereo-chemical information, which are of substantial importance in selecting and directing processes on membranes. For all this potentials, it seems that HA and HA-crosslinked derivatives seem to be the top candidates for the construction of the new so called "smart" drugs or "smart" drug delivery systems. Such as systems are releasing the active drug or therapeutic agent as a response to a biological or an external stimulus.



Scheme 1. Reaction scheme of the alkylation procedure.

In the first stage of the inflammation proces, the enhanced capillary permeability permits the accumulation of polymorphonuclear leucocytes and other phatocytic cells at the inflamation site. These phatocytic cells can be activated by the immune complexes and other inflammation generating compounds, thus producing highly reactive hydroxyl radicals, which are acting as a bactericidal agent. These radical proceses are of a great importance in the strategy of the building the suitable drug delivery system based on the liberation of the active substance upon the radical induced degradation of the host matrix.

Our current interest is focused on the micelle-forming and liquid-crystal polymeric drug concepts. We are primarily interested in preserving the polymerization degree of the polymer, while maintaining the biologically and physiologically important side chain groups, i.e. the negatively charged carboxylic groups and the acetylamide. For this reason, for the

alkylation procedure, the selective method was used, where in the first step, alkyl sulfate and the polymer alkoxyde form an alcoxy-sulfonyloxy-complex. Under strict temperature control this reaction is selective for primary alcohols [1]. In the second step, the complex and the alcohol are added to KOH and stirred in DMSO for several hours [2] resulting in the alkylation of the polymer backbone. The synthetic procedure is schematically shown on the scheme 1. The synthesized new derivatives of HA, namely the pentadecyloxy-HA and hexyloxy-HA, and its solutions were characterized by the viscosity and the rheological measurements, by the size exclusion chromatography (SEC) as well as by differential scanning calorimetry measurements (DSC). The latter show the liquid crystal phase transition at the temperature of 5.57 °C for the pentadecyloxy-HA derivative as shown in Fig. 1.

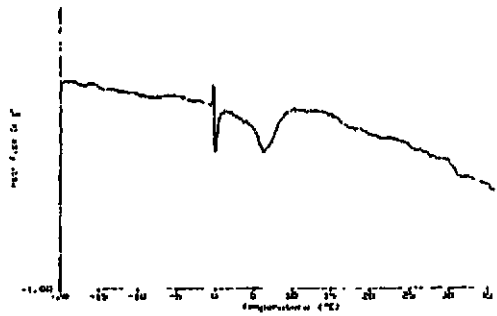


Fig. 1. DSC heating curve of the pentadecyloxy-hyaluronate.

The typical viscosity behavior of pure HA solutions which is characteristic with the high viscosity [3,4] and the simultaneous elasticity is after the mentioned modification lost due to the succesfull micelles formation. It seems that the liquid crystal phase transition process observed for the longer alkyl chains is induced by the micelles ordering process affected by the electrostatically induced temporary lattice formation in the solution.

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This research has been conducted at the Faculty of Chemistry of the Technical University of Brno as part of the research project "Modification of the physico-chemical and material properties of hyaluronic acid gels and solutions." and has been supported by TU grant No.D-8/93.

BIOPOLYMER MATERIALS FOR SPECIAL APPLICATION

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Key words: biopolymers, biocompatibility, polysaccharides, medical applications, low-temperature plasma

There was studied a process of surface hydrophobization of ceramics by the methods of theoretical and applied Physical Chemistry. Thin layer (SiO_2) models were prepared by chemical vapour deposition of SiO_2. The hydroxylic defects were generated by reaction of pyrolytic silicone dioxide with gaseous water. Total amount of Si-OH groups were determined by UV-VIS spectrometry after reaction of these with fluorescein isothiocyanate tetraiodine. Continual monolayer hydrophobic surfaces tightly adhered to the -Si(OH) surfaces were prepared by photochemically activated chemisorption of aromatic carbonyl compounds of alkyl benzenealdehyde on defected substrate. Quantum yield of photochemical reactions were determined experimentally by the experimental equipment constructed specially for this purpose. This equipment comprises: stabilised continual light source (Hg high pressure lamp), modulators of wave length and light intensity, temperated quartz cell compartment, and chemical detector of light intensity. For the sake of this study also the continual high frequency low-temperature physical plasma reactor with fluid zone for organic as well as inorganic particular materials was constructed . The parameters of this reactor were testified.

Solution properties of studied biopolymers (hydroxyethylcellulose, carboxymethylcellulose, hyaluronic acid) were studied in water solutions of different ionic strength. There was found that a degree of the polymer coil expansion is strongly depending on it in case of polyelectrolytes.

The diffusion processes of swelling and dissolution (in a dynamic regime) of the mentioned polymers were studied in temperature range of 20 to 50 °C. On the basis of this measurement the values of the internal diffusion coefficients, activation parameters of swelling, and dissolution were determined. It has been found that these values are strongly dependent on the thermal history of the polymer sample. Strong dependence of internal pressure in polymer swelling surface layer on the thermal history has also been detected. For the comparison of these phenomena with synthetic polymers at the same time the dissolution of fibrous polyesters were studied.

There are three papers in preparation for publication.

This research has been conducted at the Faculty of Chemistry of the Technical University of Brno as a part of the research project "Study of preparation, structure and properties of materials for special applications", and has been supported by TU grant No. A16/98.

THE STUDY OF PHOTOCATALYTIC DEGRADATION OF WATER POLLUTANTS

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Key words: photochemistry, photocatalysis, titanium dioxide, pollutant

Heterogeneous photocatalysis is capable of destroying many organic micropollutants in aqueous medium. Degradation of the organic waste materials (phenols, surfactants, aromatic and alifatic halocarbons) by irradiating their aqueous titanium dioxide suspensions is of increasing technological and scientific interests.

In our laboratory was built the photocatalytic instrument set consists of the immersion photoreactor with a quartz sleeve and a high-pressure mercury lamp, flow-in cells for continuous measuring of pH-value and conductivity and automatic instrument for evolved carbon dioxide estimation.

The quality of photocatalysts used for experiments was tested by the new developed method based on the photocatalytic degradation of 2,6-dichloroindophenol (DCIP) in aqueous suspension. Irradiation of titanium dioxide in aqueous suspension of 2,6-dichloroindophenol leads to a rapid decomposition of 2,6-dichloroindophenol. The rate constant and the apparent quantum yield were calculated. Some of the experimental results are presented bellow.

The photogenerated radicals in titanium dioxide powders and aqueous suspension have been studied by electron paramagnetic resonance. 5,5-Dimethyl-1-pyrroline-N-oxide (DPMO) was used as the spin trap.

Photocatalytic decomposition of p-cresol in the aqueous titanium dioxide suspension has been studied. All products of this reaction were studied by high performance liquid chromatography. It was proved that the following degradation products have been formed: p-hydroxybenzoic acid, p-hydroxybenzaldehyde, 4-methylcatechol, carbon dioxide. Based on the results obtained, the reaction mechanism of p-cresol photocatalytic oxidation in the titanium dioxide aqueous suspension was proposed.

Waste water from the pulp mills and the other industry often contains soluble saccharidic compounds and cellulose derivatives. We have focussed our research on the photocatalytic degradation of cellulose derivatives. We have studied first the hydroxyethylcellulose as a model compound. In addition to basic measurements of reaction products we have concentrated on the viscometric study of degradated polymer. The average degree of polymerization was determined. From the dependance of average degree of polymerization on the irradiation time and the other experimental data the mechanism of polymer chain degradation was suuested. These data support the existance of a raudom mechanism of hydroxyethylcellulose chain cleavage.

The solar photocatalytic degradation of hydroxyethylcellulose in aqueous titanium dioxide suspension were performed and the similar effects were observed.

A wide literature search for the methods of waste water purification were realized.

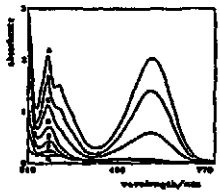

Figure 1.
UV-vis spectra of the DCIP solutions obtained during the photocatalytic degradation on TiO_2 (P25). Exp. times/minutes: A 0; B 2; C 4; D 6; E 8; F 10; G 15.

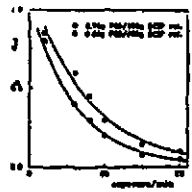

Figure 2.
The changes of the relative concentrations of DCIP during the photocatalytic degradation on TiO_2 (P25).

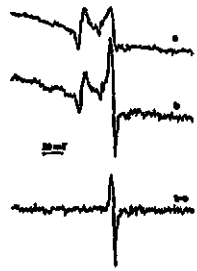

Figure 3.
EPR spectra of TiO_2 P25 powder:
a) non-irradiated
b) irradiated 1 minute
b-a) numerical subtraction of the spectrum a from spectrum b

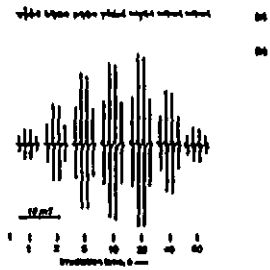

Figure 4.
EPR spectra of DMPO adducts observed in TiO_2 aqueous suspension after various irradiation times:
a) sample saturated with argon
b) sample saturated with air

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This research has been conducted at the Department of Consumer Chemistry, Faculty of Chemistry, Technical University Brno as a part of the research project "The Study of Photocatalytic Degradation of Water Pollutant" and has been supported by TU grant No. 09/93.

RADIATION INFLUENCE OF CATALYTIC PROPERTIES OF CuO-Bi_2O_3 MIXED OXIDES

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Key words: catalytic activity, ionizing radiation, hydrogen peroxide decomposition

Within the framework of systematic research of mixed oxide catalysts attention has been recently devoted to systems containing Bi_2O_3 oxide in interaction with the second component. Catalysts of this type are used in industry for various oxidative reactions [1]. Two selected systems (CuO-Bi_2O_3 and NiO-Bi_2O_3) were studied in detail from the point of view of chemical reaction and influence by ionizing radiation, using hydrogen reduction as a test reaction. The results of this study have been presented in earlier papers [2,3]. This contribution summarizes the results obtained in 1994 in the second field concerning the investigation of basic physico-chemical and catalytic properties of CuO-Bi_2O_3 mixed system and its sensitivity towards various kinds of ionizing radiation.

The CuO-Bi_2O_3 mixed catalysts of various compositions in the range 0-100 % were prepared from solutions of respective nitrates mixed in required ratios and coprecipitated with sodium carbonate solution. The precipitates were washed, dried and calcinated in air for 3 hours at 600 °C. The full decomposition of carbonates to the final oxides was confirmed by means of thermoanalysis. A part of each sample, stored in air at room temperature for a few months, was irradiated prior to its use with ^{60}Co gamma rays (doses of 0.5, 1.0 and 1.5 MGy) or with accelerated electrons (energy of 4 MeV) using a dose of 600 kGy. The catalytic activity of all samples was tested by the decomposition of the aqueous solution of hydrogen peroxide (1.2 mol/l) at different temperatures from 25 to 40 °C.

Various crystal structures of Bi_2O_3 oxide appeared in the samples of different composition and non-linear or non-monotonous dependences of specific surface areas and surface oxidative abilities on the composition give evidence of mutual influence of both oxides in the catalysts. This influence seems to be so strong that it stayed unchanged after a long period of storage of the samples as well as after their irradiation, except in the case of irradiation with the gamma rays dose of 1.5 MGy and with electrons. Because all applied doses lead to a decrease in the surface oxidative abilities of the samples one can assume that, in spite of the earlier studied pure CuO oxide, irradiation of CuO-Bi_2O_3 system leads to a reduction of metal ions probably by means of the hydrated electrons which are formed in the course of radiolysis of the moisture presented in the samples. Two opposite effects are probably occurring with the samples irradiated with accelerated electrons containing a high concentration of CuO oxide: the first is positive and unstable and the second is negative and rather stable. While the negative effect may also be due to the reduction by means of hydrated electrons the positive effect may be caused by direct ionisation of metal ions in the catalysts. The highly ionized ions recombine with unbalanced electrons during the storage of the catalysts and the oxidative abilities decrease.

Similarly, as in the case of surface oxidative abilities, considerable differences in catalytic activities between gamma-irradiated catalysts and the catalysts irradiated with accelerated electrons were found. In the first case the gamma-irradiation produces the defects influencing the interaction of both basic oxides in the catalysts which manifests itself by the new maxima on the non-monotonous dependency of the specific catalytic activity on the composition of the catalysts. The primary interaction of the components remains, at the same time, unaffected by irradiation. The interaction induced by the radiation is, of course, possible only at a certain composition of the catalysts and hence, the maxima were found at the same composition of the catalysts regardless of the applied doses of irradiation. The influence of accelerated electrons on the catalytic activity of the samples was found to be, unlike the gamma-irradiation, unambiguously negative and this kind of irradiation does not lead to the creation of new interactions between the components of the catalysts. The fact that the activities of irradiated samples are also decreased during their storage and the primary mutual interaction disappears proves that some post-radiation processes occur in this case. Comparing the influence of electrons upon the catalytic activities of the samples containing a higher concentration of CuO oxide with their influence upon the surface oxidative ability one can conclude that the surface oxidative ability of the samples does not determine unambiguously the catalytic activity of the catalysts in the test reaction. The modified activity may be due to activation of some new catalytic centres with a lower efficiency which is the same at all kinds of irradiation.

The partial results presented in this paper have already been published in more detail in Radiation Physics and Chemistry.

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NUMERICAL MODELING OF Ni SILICIDES SYNTHESIS INDUCED BY PULSED LASERS

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Key words: chemical reactions, silicides, nickel, excimer laser, mathematical model

We consider the following experimental situation: thin Ni film is deposited on the monocrystalline Si substrate by an evaporation technique, and the system then undergoes pulsed laser irradiation with a laser energy density which is not high enough to melt the surface of the sample. Due to the increased temperature, a solid-state chemical reaction is initiated on the Ni/Si interface.

Following the classical theory of solid-state reactions [1] and the previous experimental work on Ni silicides (see, e.g., the extensive reviews [2,3]), we suppose that the chemical reactions in the solid-state Ni-Si system are driven by diffusion effects. Thus, a chemical reaction can start, when Ni atoms diffuse into the Si bulk and/or Si atoms diffuse into the Ni layer. Since it is not yet known exactly how the reaction between Ni and Si runs when the system is irradiated by a laser, we choose an empirical treatment and assume that only some of the diffusing atoms can be trapped in the lattice of the majority compound to form a silicide, whereas the remaining atoms diffuse further. The type of reaction which actually runs in a Ni-Si system depends on temperature primarily. Therefore, the diffusion equations for Ni and Si have to be solved together with the heat conduction equation.

In every point we model the chemical reactions as follows: In accordance with [2,3] we assume that for $T < T_{cr1}$ the predominant chemical reaction is $2\,Ni + Si \rightarrow Ni_2Si$ and the only silicide formed is Ni_2Si. When $T > T_{cr1}$ but still $T < T_{cr2}$, we suppose that only NiSi is formed, either by $Ni_2Si + Si \rightarrow 2\,NiSi$ or directly as $Ni + Si \rightarrow NiSi$. Since the heat necessary for the former reaction is approximately 4–5 times lower than that for the latter (see [4]), it is apparent that for the formation of NiSi the first of the above mechanisms will be dominant.

After the temperature reaches T_{cr2}, we assume that only $NiSi_2$ is formed, either as $NiSi + Si \rightarrow NiSi_2$ or $Ni + 2\,Si \rightarrow NiSi_2$, eventually also $Ni_2Si + 3\,Si \rightarrow 2\,NiSi_2$, because there may still remain some Ni_2Si due to the rapidity of the process. The first mechanism is dominating again because the heat necessary for this reaction is almost 20 times lower than that for a direct formation of $NiSi_2$ from Ni and Si and approximately 4 times lower than that for the second of the above reactions.

To illustrate the performance of the model we present a brief description of the numerical experiments performed and some typical results of our computational simulations. We used the model to simulate pulsed-laser induced chemical reactions in a Ni-Si system with an

initial thickness of the Ni layer of 500 nm. The duration of the laser pulse was 28 ns FWHM (full width at half maximum). The energy density varied from 0.1 to 0.7 J/cm^2; these values are insufficient to melt the surface of the sample. In the numerical experiments, we simulated the development of silicides in the sample for 1 s.

Firstly, we performed numerical tests of the model. We varied the number of nodes and tried to choose them in such a way that certain characteristic values of concentration and temperature agreed with 0.1% accuracy on both the coarser and the finer meshes. We found that the optimum values from this point of view were cca 500 elements in the initial Ni layer and 1000 elements in the initial Si bulk. Similarly we investigated an appropriate time step for the computations. We found that to obtain 0.1% agreement as above the maximum allowable time step was 0.005 ns for the first 100 ns, whereas the time step could be significantly greater after 100 ns. The experiments were done on an HP 720 workstation and a typical simulation took approx. one hour under the single-user regime.

After performing the numerical tests, we then simulated the real experimental situation which we described above. The results obtained in this case were in good qualitative agreement with the real experiments. For instance, we observed that the whole 500 nm layer of Ni has fully reacted after one laser pulse, which is just the situation observed experimentally [5]. In general, we have found the model capable to simulate pulsed-laser induced solid-state chemical reactions in the systems under consideration.

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CONTROL DESIGN OF DELIMING PROCESS

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Key words: deliming process, numerical solution, network, control design, algorithm of control, optimization, system with distributed parametrs

In this paper I describe the construction of a mathematical model for deliming white hide materials. The mathematical model is proposed on the basis of the following presumptions: the mass transfer in the hide occurs by a diffusion mechanism. The diffusion occurs along the actual pore length. The model is very comprehensive and describes the evolution of concentration in the white hide. The system of non-linear partial differential equations describing the physical process, is solved numerically using a network [1]. Partial derivatives can be approximated by finite differences in many ways, depending upon accuracy requirements.

In this case numerical simulation helps us to observe the concentration field in the white hide and on the basis of the concentration field we can suggest an algorithm of control.

Deliming is an operation, its most important feature is the decrease in the Calcium hydroxide content of the raw hide material. Parameters which characterize deliming process, are the following:

- operating time,
- accurate consumption of water,
- temperature of the bath,
- type and accurate consumption of chemical agents,

For an algorithm of control design is necessary to solve the problem, which is the main purpose of an automatic gearchange.It may be achieving a suitable quality of product, minimum operating costs. Optimal control of the deliming process means a minimum of consumption of water or chemical agents, and also a minimum of operating time, which is directly connected with the consumption of electric energy for the propulsion of deliming equipment.

We can demonstrate a simple case of the deliming process, when we require removal of the content of Calcium hydroxide in white hide by using water in the bath. For an algorithm of control design We will choose economic criteria, meaning a minimum of operating costs. Consumption of water and operating time must be chosen so that the costs of water and electric energy is minimal. The same quality can be achieved by using a smaller consumption of water and a longer operating time, or by using more consumption of water and a shorter operating time.

The cost function is defined:

$$N = NE + NV \tag{1}$$

where NE = KE^*P^*t is the cost for consumption of electric energy, $NV = KV * V_0$ is the cost for consumption of water.

KE is the price of electric energy for kW/h [US/kWh],
KV is the price of water or deliming agent for m^3 [US/m^3],
V_0 is the consumption of water or deliming agent [m^3],
P is the power of machine [kW],
t is the time of deliming process [hod].

In the equation we can see that it is necessary to find out the optimal value (Vop,top), when the cost function is minimal. The problem is defined as extremum regulation [2].

In order to find out optimal value we have formulate mathematical models, which describe dynamics of deliming process in detail.

The deliming process is realized in the two phases, first one is deliming by water and the second one by chemical agents.There were two mathemathical models, which were formulated on the basis of analysing dynamics of the deliming process [3].These models are described by partial differential equations, from the point of theory of automation it is the question of the control system with distributed parameters. This task is a very difficult problem not only in tannery technology, but also in the connection of automation,because nonlinear-system with distributed parameters are very little executed. The task described by (1) means static constrained optimization by equations described in models [3]. For optimization we have suggested algorithm [6], which provide us to solve partial differencial equations of 2nd order (in this case We solved non-linear system numerically using a network) an then we have applied different known methods for optimization [7]. Because of complicacy of the system We have chosen a method not using derivates but only comparing coordinates.

Conclusion: Solution described in this paper enables us to save operating costs and along coefficients occurring in the system [3] we can approximately set the optimal input value for deliming process [4]. Because of resemblance of tanning operations we can apply these mathematical models for control design.

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Section 4

ENGINEERING INFORMATICS

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CYBERNETICS

AN IMPLEMENTATION OF GENETIC ALGORITHMS FOR FUZZY LOGIC CONTROL

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Key words: fuzzy logic control, genetic algorithms

The genetic algorithm (GA) proposed by Holland [2] is based on the principles of natural population genetics and natural selection. The algorithm is a sort of simulated evolution search algorithms to find the global optimal solution of the unknown nonlinear function $y = f(x)$. *The method belongs to the family of general purpose random search algorithms.* Recently, genetic algorithms have been combined with fuzzy logics to obtain a power tool for adaptive fuzzy logic controllers design. This paper presents one of possible implementations of genetic algorithms to identify a fuzzy logic controller (FLC). The aim is to tune the parameters (membership functions) and to derive fuzzy if-then rules (linguistic associative memory, LAM) from a given set of training data samples. This can even be accomplished simultaneously using the genetic algorithm we propose below.

GAs differ from conventional optimization procedures (e.g., error backpropagation) in five aspects:

- GAs operate with encoded parameters rather than with parameters themselves.
- GAs search from a set of points, *population*, rather than a single point.
- GAs evaluate only objective functions, *fitness functions*, and do not use any auxiliary information (e.g., derivatives).
- GAs guide their search with probabilistic transition rules.
- GAs proceed in parallel search on a potential set of solutions.

The general scheme of genetic algorithms can be described according to the following steps:

step 0. Choose an appropriate code for adjustable parameters and determine the string length. Define an analytical form of the fitness function.
step 1. Establish an initial string population.
step 2. For each string from the string population evaluate the fitness function.
step 3. Form a gene pool from strings with the lowest values of the fitness function. If the lowest value is less than or equal to the desired value or the number of iterations equals to specified ones, then STOP. Otherwise continue to step 4.
step 4. Apply standard operations for string reproduction to the gene pool to obtain a new string population and go back to step 2.

The only stage where the problem information is involved is the coding of parameters into a string and evaluation of the fitness function related to the string. There is no general rule how to encode adjustable parameters.

FLC internal structure. Let the plant be a system with n outputs (states) $x_1, \ldots, x_n$ and a single input y and $n_1, \ldots, n_n$ are different fuzzy input partitions, respectively. We

consider the maximal number m of rule antecedents i.e., $m = n_1 n_2 \ldots n_n$. Let m also be the number of all output fuzzy sets represented as singletons which can be obtained from a clustering procedure applied to output samples. Thus, we allow each rule to have its own unique conclusion. Positions of singletons are the adjustable parameters for us. So we have the *i-th* rule:

$$\text{IF } x_1 \text{ is } A_{i1} \text{ and } \ldots \text{ and } x_n \text{ is } A_{in} \text{ THEN } y \text{ is } b_i, \quad \text{where } i = 1, \ldots, m. \tag{1}$$

Coding. Each consequent part b_i of the previous relation belongs to a set of labels (i.e., $b_i \in \{0, B_1, B_2, \ldots, B_m\}$) where the symbol 0 denotes that the rule is disabled. B_i' s may be integer labels 1,2,...,m and they represent linguistic variables, e.g. *large, negative, approximately*, etc. which are placed at equally spaced positions on the output domain $[y_{min}; y_{max}]$. Labels can easily be transformed to real numbers as follows:

$$y_i = \frac{y_{max} - y_{min}}{m - 1} (B_i - 1) + y_{min} \tag{2}$$

Thus, we have a vector of grades of output membership functions which is to be deffuzified, e.g. by the COG method. Therefore, parameters are encoded into string the S, $S = (b_1, b_2, \ldots, b_m)$. Such coding not only allows us precise singleton positions but also determines the consequence links. Note that input fuzzy sets A_{ij}, $j = 1, \ldots, n$ are fixed triangular membership functions given by designers and just two sets can overlap.

Fitness function. The fitness function, F, which is to be mininized, tells us how good the string is. In many applications, we use the sum of squared errors as a measure of quality:

$$F(S_i) = \sum_k (y(x_k; S_i) - y^r(x_k))^2 + \alpha N_i \tag{3}$$

where x_k is a $k-th$ vector of training activation data, reference plant outputs, and y is a current FLC response which should equal to y^r, a reference reaction. N_i is the number of nonzero labels in the string S_i. The second term of the right-hand side in (3) is optional and penalizes an increasing number of fuzzy rules by a weighting factor α.

Genetics. Standard reproduction operations on strings are *selection, crossover, mutation and elite strategy*. These operations are problem independent.

Concluding remarks. The GA presented above works as a blind search algorithm with the fitness function describing the global behavior (error). We could spend a lot of iterations to obtain an acceptable solution. Possible improvements are advisable to make the algorithm faster. These improvements involve starting with a 'good' initial string population and also local evaluating behavior in order to fix the 'correct' labels and reproduce only those 'bad'. It is also necessary to generate a new population after several iteration steps; otherwise strings converge.

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NONLINEAR CONTROLLER DESIGN BASED ON FUZZY MODELLING

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Key words: fuzzy logic control, fuzzy-neural networks, clustering, backpropagation

The paper presents fuzzy modelling as a tool for design of nonlinear controllers. Fuzzy logic-neural networks (FLNN), providing general nonlinear input-output maping and incorporating learning ability, are used as a basis for building up nonlinear vector functions for discrete time diference models. Unsupervised and supervised identification techniques are described as well as results from data driven identification of a controller.

Fuzzy logic controller (FLC) is generally a nonlinear dynamical system and its often reported success in applications is namely due to the nonlinearities introduced. We regard nonlinearity as a synonym for intelligence. There is an extensive number of parameters to be adjusted and it is not easy to decide which of them and in what manner they have to be tuned in order to get the desired performance of the control system. This paper presents a systematic approach for fuzzy model identification and controller design. A fuzzy system including fuzzification and defuzzification interfaces is a nonlinear mapping f from an input space X to an output space Y in the form of difference equation

$$y(t) = f(x(t-1), x(t-2), \ldots, y(t-1), y(t-2), \ldots) \qquad (1)$$

The mapping f is not defined analytically but as relations between reference points i.e., training samples, obtained for instance from experienced human operator. These points are logically linked by if-then rules and stored in a linguistic associative memory (LAM).

Fuzzy Logic-Neural Network

Architecture. A Fuzzy Logic-Neural Network (FLNN), proposed by Lin [3], is a particular implementation of a fuzzy system equipped with fuzzification and defuzzification interfaces. FLNN is principally built of five neuron layers and its internal representation is highly modular, but restricted in fuzzy rule consequences. Our desire is to keep the function of the FLNN transparent, interpretable and fully parametrized. FLNNs meet these goals.

Identification techniques. The problem of a FLNN identification is generally constrained nonlinear optimization problem. We recognize unsupervised and supervised techniques for the FLNN model identification. In the unsupervised case the FLNN is activated from both sides by correlated reference data in order to set initial parameters (membership functions) and to derive fuzzy rules (consequences). Thus the FLNN does not play an active role. The supervised identification techniques work either off-line or on-line. The FLNN works in the operation mode and generates outputs which are then compared with the reference ones. This error is used for the adaptation of the FLNN and we can easily introduce an explicit criterion to describe model quality. Two groups of methods were tested, genetic algorithms (GA) and the error backpropagation method.

Fuzzy clustering. FUZZY C-MEANS, the classical algorithm of data clustering, is applied for automatic generation of input/output reference fuzzy sets.

Error backpropagation. Supervised identification based on backpropagation gradient technique is used for the local search. The supervision is governed by the criterion

$$I = \frac{1}{2} \sum_t (y^r(t) - y(x(t);\theta(t)))^2, \qquad (2)$$

where y is the net output, y^r is the corresponding reference output and x is a node activation input, θ may be parameters of membership functions as well as weights of synaptic links between layers.

Experimental results and comments. FLNN identification techniques were tested on one input - two outputs plant data. Experiments proved the validity of ideas given above and showed some coloraries and limitations. The most appropriate membership functions of input fuzzy sets are those with triangular (or trapezoidal) shapes and overlap parameter equals to two. The reason is that these membership functions approximate 'continuously' while others (e.g., bell-shaped) approximate 'stepwise'. Without lost of generality we used in operating mode singletons as output fuzzy sets. Each fuzzy set, dividing into seven linguistic terms (labels) as $\{LN, MN, \ldots, LP\}$, was defined on medium density discrete domain. Firstly, output and input data were clustered by fuzzy C-means algorithm, i.e. we obtained positions of membership function peaks. This preliminary step saves much work latter. Secondly, fuzzy rule consequences were derived using backpropagation. Here we found weights of synaptic links between two layers in two phases. Initially weights were incremented (from zero) by values of multiplication of fuzzy antecedent and fuzzy consequences (Mamdani's implication). Then these weights were updated in backpropagation phase where samples with small errors were not far considered in the training set. Finally, the link with the maximum weight for each rule antecedent must be choosen in order to keep consistency. If this value is small enough that rule can be deleted. Updating ouput singletons in the backpropagation algorithm has no effort and even due to gradient descent approach applied to 'nonstandard neural functions' singleton positions may be deteriorated. Therefore these positions were fine-tuned by the well-known method of least squares. However, manual design of FLNN topology and its parameters dominates in the engineering practice at present. Designers prefer using rather their experience then data driven algorithms of automatic tuning. The main reason is that bad reference data may lead to incorrect model as is often the case in training of neural networks. It is advantageous to combine the both design approaches and this is a challenge for the software tool developers nowadays.

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RULE-BASED FUZZY CONTROL SYSTEMS

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Key words: fuzzy, control, rule-based

A fuzzy controller is a nonlinear dynamic system with special mapping of input/output variables. In its structure, its parameters and, sometimes, also in its input data, human experience can be involved in a human-oriented "fuzzy" way. There are several classes of fuzzy regulators, based on different kinds of fuzzy sets representation.

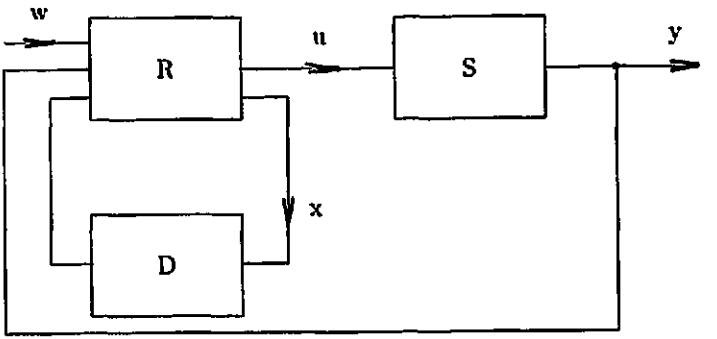

Fig. 1: Rule-based fuzzy control system

Our article deals with a special class of such systems which can be characterized by a formal scheme shown on Fig. 1., where R is a fuzzy regulator, S is a controlled system, H is a (zero order) hold and D is a one-step time delay. The system variables are: x ... regulator internal state variable, u ... regulator output variable (as well as controlled system input variable), y ... control system output (including sometimes general system performance), w ... regulator external input (including desired value of y, measured external disturbances and eventual human expertise). The regulator can be described by

$$x(k+1) = f[x(k), y(k), w(k)] \tag{1}$$

for state variable development (k is a discrete time variable) and by

$$u(k) = g[x(k), y(k), w(k)] \tag{2}$$

for the regulator output. Some sophisticated control systems improve their performance essentially if human experience is involved in the control system in an atypic way. For example, flame length control in a rotating kiln [1] could be notably improved by changes in

the system configuration (the opening or closing of kiln observation windows, the connecting or disconnecting of selected classical control loops, the opening or closing of the building main door etc.) in dependence on a kiln working point and indirectly observed atmospheric conditions (smell of the smoke, personal feeling, precipitations, sky observation, etc.). This example shows both types of possible human experience involvement in a fuzzy control system: what is to be done in certain conditions (functions f and g in the controller), and fulfillment of such conditions (human expert generated component of the external input w).

If the functions f and g are based on rule-based information propagation similar to that of PROSPECTOR, FEL-EXPERT or NUCLES [2] expert systems, we obtain a structure which can be easily programmed and put in operation. Such a structure can be characterized by an oriented graph consisting of edges representing signals and by nodes representing signal transformation functions. While in the classical PROSPECTOR-like expert system the majority of signals can be taken as (apriori and aposteriori) probabilities, in control system more emphasis is put on physical significance of signals. In consequence, many nodes described by distribution function can be expected in its structure.

Typical examples of signal - probability transformation in a rule-based fuzzy control system are the nodes GAUSS (Gaussian multidimensional distribution), GOR (formally described by a group of one-dimensional Gaussian distribution function nodes, followed by a fuzzy OR), UNI, UNOR (similar functions characterized by an uniform distribution), and EXPO and EXPOR (exponential distribution) which are used in NUCLES expert system. All these functions can be characterized either as a transformation of the set of signals to a (subjective) probability of occurrence of some phenomenon or as a transformation of such set of signals to another somehow significant signal. The general problem of involvement of human experience in the regulator structure and parameters is in this case facilitated by its relative transparency. The rule-based structure of the above mentioned functions f and g has another important advantage thanks to their similarity to the Nilsson's Φ machine: in case of having available a significant set of input/output data (which can also be acquired from human experience), their parameters can be adapted ("trained") by the methods described in [3].

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AUTONOMOUS MOBILE PLATFORM

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Key words: autonomous mobile robot, trajectory planing, trajectory tracking, onboard navigation system

This paper shortly describes the construction of an original autonomous mobile platform development. Our interest is aimed at the area of control systems of mobile robots, methods of sensor data fusion, and navigation of mobile robots in inaccurate indoor environment.

It was necessary to design a development environment and onboard navigation system which have to be used for teaching purposes and research work. The development environment which makes up the mobile robot mechanical platform contains motor motion controllers, odometry measurement sensors, and an onboard communication net. The onboard navigation system is a hierarchical control system which allows for the low-level control (i.e. to move the vehicle from a given initial state to the desired state).

Mobile Robot Platform. The vehicle is a rectangular platform 0.5x0.45m driven by two DC motors coupled to 2 driven wheels and two additional swivel wheels. The driven wheels are interconnected with motors by the 1/25 worm gearing. The total load of 100kg is assumed.

The Architecture of the Control System. The problem of designing the control system can divided into the task of control algorithm design, and to the design of the hardware architecture for this purpose.

The theoretical basis of the "2D vehicle motion control system" is described in [1]. It solves the problem of the trajectory planning and trajectory tracking. From a theoretical point of view, the control problem can be classified as a multidimensional multicriterial nonlinear one. Such a task can not be solved by a simple feedback controller - the system has a too complicated and nonlinear structure. A hierarchical approach has to be used:

- At the highest level, trajectory parameters are set in the form of point of desired trajectory ([position in 2D, velocity vector]).
- At the intermediate level, desired local trajectory parameters are computed.
- At the bottom level, a simple local PID controller is used to compare desired and actual local trajectory parameters and to compute the control action.

The control schema shown in Fig. 1. The onboard navigation system comprises a reference-state generator ($\vec{sv}$ = [*position, velocity vector, mov.time*]), an error-feedback controller (the current state is input = [*position, velocity vector*], and vehicle location sensing using odometry.

Requirements on the communication net of the vehicle (onboard net) come from computation intensivity of each module and from the quantity of data which is transferred among these modules.

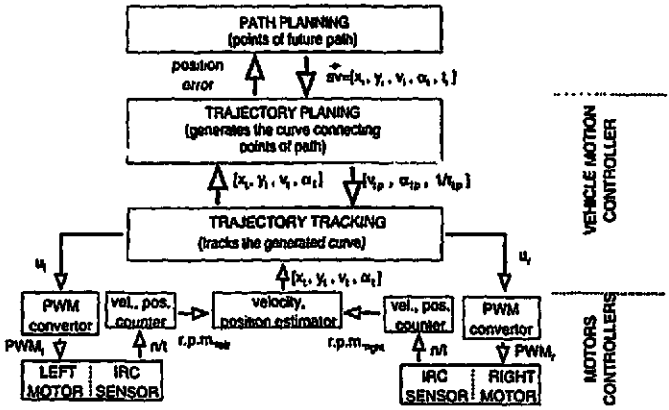

Fig. 1: Hierarchy of the control system.

The organization of the onboard communication and the corresponding hardware devices comes from the chart (Fig. 1). Three micro-controllers 80C552 are used for the vehicle motion controller and the motor controllers. The two of them are used for the control of the two DC motors and for the scanning of the revolutions and positions of motors from IRC sensors.

The IIC bus provides communication among *motor controllers, vehicle motion controller* and the other devices on the vehicle (that means the onboard communication net). The PC computer is an onboard arbiter of the IIC bus and it provides connection to the higher level of the control system by Ethernet or serial link.

Future Work. The onboard control system for the 2D mobile robot navigation, is undergoing testing at present. Next we want to use the control algorithm for 2D vehicle control. It will be used as the developing system in the area of mobile robotics and robot navigation.

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This research has been supported by the Czech Ministry of Education grant No. V359 /1994, the Copernicus Grant No.5855 and the Grant No. 102/95/0954 of the Czech Republic Grant Agency.

COOPERATIVE CIM SYSTEMS

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Key words: expert systems, computer integrated manufacturing, control systems, artificial intelligence, distributed parallel processing

The CIM applications of real size are currently testing the limits of software engineering because of their extent, the amount of data to be handled and specialized knowledge to be embodied. Monolithic solutions are becoming non-realistic and difficult to engineer into reliable software products. Moreover, there are many diverse software packages working efficiently as stand-alone programs that need to be integrated into a global software solution. This is definitely true in the companies with geographically distributed units (e.g. if the technology development department, administration headquarters and manufacturing facilities are located in different towns/countries). The only way out of these software development problems seems to be the highly distributed multi-agent software architecture.

Methods of Artificial Intelligence, especially the theory of multi-agent systems, have been explored to design the CIM distributed architecture. The approach is philosophically based on Hewit's actor model. The philosophy of actors (or agents) leads to the possibility of considering agents as structures that combine both procedures and data into a single entity - an object.

Suppose that the CIM task should be solved at various geographical sites. The decomposition of the entire CIM task is usually already given by the location of the facilities (workshops, design centers, etc.) and very specific well-defined functions of these facilities. According to the functionality, many typical units can be found (e.g., selling agencies, business coordination unit, manufacturing units, technology development units, etc.). In the real-world tasks also accounting, maintenance of resources, legal affairs, and marketing activities have to be supported.

The presented facts show that the CIM task decomposition and the allocation of subtasks are usually *functionally pre-defined* and do not create a *substantial* problem.

Communication plays a dominant role in distributed systems. Every functional unit (module, node) of the distributed system may be considered as a computational process that consists of two parts:

- a domain-dependent problem solving part (task) which have no knowledge about the other nodes or about the overall system,
- a domain-independent part (agent) responsible for communication and coordination activities. The agents contain all the knowledge about the rest of the distributed system.

There are two basic possibilities of inter-agent communication on the implementation level: client-server and peer-to-peer. The CIM requires that the communication connections

are organized as symmetrical peer-to-peer links. The current platforms usually only support the client server connection.

This problem - by our practical experience - can be solved in the UNIX environment in the following two ways:

One possibility is to directly use some low level communication protocol to organize the peer-to-peer connections. The main disadvantage here is the unsafe communication. The message in this protocol can get lost or duplicated and the time ordering of the messages can be changed. It means that the implementation of some additional specific algorithms (acknowledgment passing, Lamport's clock, etc.) to avoid these unwanted features is highly desirable. This makes the multi-agent system implementation more complicated.

Another possible approach is to organize the communication so that the peer-to-peer behavior is observable from the outside, but the internal implementation is based on the client-server connections. In this case, there is a star-like structure used on the implementation level. It consists of a central node (server or hub) which provides the connection service among the nodes (clients) in tips. The behavioral level resembles a set of peer-to-peer connections. This topology has several advantages. It enables the addition of new agents during the multi-agent system operation, to control the communications states, broadcasting of messages, etc. It was proved that this solution may be efficiently supported in the Internet by the parallel virtual machine (PVM) [1]. The main deficiency of this topology is that when the hub fails, the entire multi-agent system also fails.

The other important subproblem being solved concerns the design of intelligent user interfaces for CIM. A specialized model-based user interface has been designed and partially implemented.

The role of qualitative modelling in CIM tasks was deeply studied in detail.

The results of the projects:

1. A very detailed analysis of the geographically distributed CIM systems elements has been done.
2. Two types of distributed system architectures (based on the low-level protocols and PVM, respectively) have been designed, implemented and tested in the UNIX environment.
3. Intelligent interfaces for the CIM system were studied and designed.
4. Three contributions were presented at international congresses/conferences, and two detailed technical reports are available.

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This research has been conducted at the Department of Control Engineering as a part of the research project "Cooperative CIM Systems" and has been supported by CTU grant No. 8190.

INTELLIGENT CONTROL SYSTEMS

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Key words: computer integrated manufacturing, control systems, real-time control, artificial intelligence, planning

The implementation of computer-integrated manufacturing (CIM) systems involves the application of computer technologies across all aspects of the manufacturing process, including design, materials planning, plant logistics/scheduling, storage, and delivery. A central component of such system is the actual manufacturing subsystem which produces the finished product. The extent to which a CIM system achieves its goals is inevitably dependent upon the use of effective and robust decision making at the production control level. Existing control systems rely most often on decisions devised and tested through prior off-line analysis. Comparing these systems with CIM technology, it is obvious that CIM greatly enhances the capabilities of the entire manufacturing process. Three main elements can be recognized:

1. the ability of the computer to provide on-line, variable-program (flexible) automation of manufacturing activities and equipment,
2. the ability to provide on-line, moment-by-moment optimization of manufacturing activities and operations,
3. the ability to integrate all of the various constituents of the entire manufacturing process into a system - a system, that can be flexibly automated and moment-by-moment optimized as a whole.

The CIM system is a closed-loop feedback system in which the prime inputs are product requirements (needs) and product concepts (creativity) and the prime outputs are finished products (fully assembled, inspected, and ready for use). It is comprised of a combination of software and hardware, the elements of which include product design, production planning, production control (feedback, supervisory, and adaptive optimizing), production equipment, and production processes.

In the following part of the paper, let us concentrate on the problems of control systems which constitute an important subsystem of a CIM system. Over the past few decades, a variety of procedures for analysing distributed systems and for designing control strategies have been invented. These procedures may be classified into 3 types [3]:

- procedures for modelling dynamic systems,
- procedures for describing qualitative properties of system behavior,
- procedures for controlling system behavior.

Almost all of them rest on the common presumption of centrality. However for a CIM system, which per se implements decentralized decision making, distributed computation and hierarchical control, the main task is obtaining global coherence with decentralized

control. Controller nodes must cooperate to exploit and coordinate their responses to interdependent subproblems, but with limited internode communication. The coordination task is linked with the problem of uncertainty: each cooperating agent (= controller) must effectively deal with:

- environmental uncertainty which results from absence of accurate view of the number and location of processors, affectors, sensors, and communication channels,
- data uncertainty which results from incomplete and inconsistent local data at a node,
- control uncertainty which results from absence of a complete accurate model of activities in other nodes.

Problems connected with uncertainty processing have been solved mainly in the area of knowledge-based systems and we rely on the research results already achieved.

Regarding manufacturing complexity and uncertainty, the control system is designed as distributed and hierarchical. The basic control task is reduction of the distance between desired goals and achieved results of activity units, thus keeping optimum performance. Let us specify the control actions: monitoring (of controlled units), interpretation (of data and information), modelling (of unit state), simulation (of unit dynamics), diagnosis (of critical events), action planning (to restore optimum - generation of alternative plans, plan selection), action triggering. Almost every action can be effectively supported by artificial intelligence (AI) systems. We have identified AI methods applicable to the control systems. These methods are extensively studied and further developed.

The following results in the area of CIM education and research have been reached within the frame of the project in 1994:

1. The courses "Distributed AI and Control Systems" and "Planning, Scheduling, and Control" were included in the curricula of PhD students at the Faculty of Electrical Engineering.
2. The distributed control system developed in 1993 in the frame of the UDF Grant No. 0457 was implemented in the laboratory equipped by Allen-Bradley, A Rockwell International Company. Now it is regularly used for experimental work of both undergraduate and postgraduate students.
3. Experiments with fuzzy control systems and physical models of real systems were successfully performed.
4. The results and experience from CIM education were presented on two international conferences [1], [2].

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GENETIC ALGORITHMS

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Key words: genetic algorithms, computer integrated manufacturing, control systems, artificial intelligence, planning

The target of the project on genetic algorithms (GA) has been a study and experimental investigation of GA's performance in a range of optimization tasks. The main interest concerns the use of GA for discrete combinatorial optimizations. These tasks have not been researched and tested to a sufficient and satisfactory extent anywhere in the world.

Currently, there are a lot of publications and articles that mention experimental results for particular tasks. However, these articles do not give full view on how the problems were solved. Information is restricted to only what representation and what genetic operators were used and, at most, what was the population size and how many generations led to the published results. Unfortunately, important data on values of GA parameters (probability of crossover and mutation, population size, etc.), information about the replacement strategy used, about the selection type, and about the form of the scaling function are usually missing.

Thus, the primary target of our endeavor has been to investigate a collection of typical discrete tasks and to do a sufficient amount of experiments with these tasks. The experiments include performance tests of GA for different types of problem representation, watching sensitivity of convergence on different parameter values, etc. All those results will provide some practical experience and knowledge on the GA's behavior, as the theoretical interpretation is very difficult and has yet to be elaborated.

GAs are search algorithms based on principles of natural selection and genetics. They are probabilistic algorithms which maintain a population of candidate solutions (individuals). The individuals are reproduced in accordance to their fitness values (objective function, goodness) and they undergo crossover and mutation operations (recombination). Each individual has its own fitness value which is the value of the function according to which we want to find the optimum. For GA purposes, each individual is represented by a string of symbols from a finite alphabet.

A simple GA is composed of three operators - reproduction, crossover and mutation. GAs work with populations of individuals and by reproduction, crossover and mutation of individuals create new, hopefully better, populations.

Reproduction is a process in which individuals are selected to be crossed later. Individuals are selected according to their fitness values in the way that strings with a higher value have a higher probability of contributing one or more offspring in the next generation.

After reproduction, the pair of selected strings undergoes a cross-over operation yielding two new individuals. The mutation operator plays a secondary role in GAs. It is the occasional random alteration of the symbolic value of a string at a randomly chosen position. In this way, a new set of individuals is generated. These new individuals must replace some selected individuals in the old generation. The rules for this selection form the replacement strategy. All these steps are relatively easy for the case of continuous optimization space.

The major difficulty associated with the use of GA for combinatorial optimization tasks is the appearance of intrinsic constraints. The research was focused on the Traveling Salesman Problem (TSP) and the Job-Shop Scheduling Problem (JSP). TSP is a classical example of an NP-hard problem and the JSP is one of the hardest known NP-problems. These tasks impose a great number of constraints upon a feasible solution. In the case of TSP, the constraints are: any city can appear on the tour only once, and the tour must contain all cities. There are even more constraints defined for the JSP. The key approach, how to cope with these constraints, is the choice of a suitable problem representation.

For an experimental evaluation, three publicly available benchmarks for 30, 50, 75 sized TSP were used. Cities are given by their coordinates and the distance between cities is calculated as Euclidian distance. A series of ten experiments for each task was performed. GAs are probabilistic, thus the judgment of their performance must be done from a statistical point of view. The results obtained were surprisingly good. A new optimal path for the 30 cities problem was found which is even better than any of those published before.

The second task solved by GA was the JSP. The JSP belongs to extremely hard combinatorial problems and it was chosen because of its practical importance. The use of a conventional GA has been tested. It was very interesting to examine whether such a hard problem can be tackled using conventional GA. It means by using the simplest crossover and mutation operators. The solution here was achieved by a clever problem representation taken from literature. There is a well-known benchmark for a 6-machines - 6-jobs JSP. The results achieved in our tests are very close to the known optimal solution which is very encouraging for further investigations.

Results of the project:

1. A very detailed analysis of the use of GAs for the TSP has been done.
2. A set of experiments with one of the practically interesting and very difficult problems - JSP - has been worked out.
3. An informal cooperation has been established with the University of Essen (D) where the JSP problem is being studied.
4. A detailed technical report has been prepared and two contributions were presented at international conferences (see Ref.)

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This research has been conducted at the Department of Control Engineering as a part of the research project "Genetic Algorithms" and has been supported by CTU grant No. 8189.

AN INTELLIGENT DECISION SUPPORT SYSTEM FOR TRANSPORTATION MANAGEMENT

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Key words: distributed artificial intelligence, transportation management, knowledge, co-operation, multi-agent systems

Freight transport is a significant part of each country's economy. Therefore the logistics and planning in this area become more and more important both for economical and ecological reasons. Many of the problems which must be solved in this area, such as the Travelling Salesman and related scheduling problems, are known to be NP-hard. Moreover, since just-in-time production has became popular, planning must be performed under a high degree of uncertainty and incompleteness. The classical Operations Research approach cannot cope with the dynamics of this domain. In reality, these problems are far from being solved. As it has been published many times in newspapers and other mass media, a lot of trucks in the streets of the Czech Republic (and other European countries as well) are driving without a carriage.

In this paper, we try to answer the question why it is adequate to use AI techniques and more specifically DAI approaches to tackle the transportation problems. One reason is the complexity of the scheduling problem. However there are more pragmatic reasons: Both global and local knowledge are necessary to solve the scheduling problems effectively. Global knowledge includes general knowledge (taxonomical, topological, temporal, or expert). Local knowledge encompasses knowledge about the capabilities of the transportation company as well as knowledge about competitive/cooperative companies. Moreover, since a global view is impossible (because of the complexity), there is a need to operate from a local point of view and thus to deal with incomplete knowledge with all its consequences. The last aspect leads to the DAI arguments:

1. The domain is inherently distributed. Hence it is very natural to look at it as a multi-agent system.
2. It is very difficult to centrally maintain and process the knowledge about the shipping companies, their vehicles, and behaviour. Moreover, knowledge is often not even centrally available. Therefore, modelling the companies as independent and autonomous units seems to be the only acceptable way to proceed.
3. In real business, companies usually solve capacity problems by contacting partners who might be able to perform the problematic tasks. The basic model of this activity is negotiation.

The main, long-term goal of this research is to develop a prototype of an Intelligent Decision Support System for Transportation Management. The following main topics were investigated within the introductory study in 1994:

1. The overall control strategy of the system enabling the cooperation of distributed agents. The principles of communication among these agents were studied. Let us briefly describe the considered task: Let us have a group of shipping companies whose goal is to deliver a set of dynamically given orders, satisfying a set of given time, vehicle capacity, route, and cost constraints. The complexity of the orders may exceed the capacities of a single company. Therefore, cooperation between companies is required in order to achieve the goal in a satisfactory way. The common use of shared resources, e.g. train or ship, requires coordination between the companies. Although each company has a local, primarily self-interested view, cooperation between the shipping companies is necessary in order to achieve reasonable global plans.

2. Analysis of functions and knowledge of specific entities in the transportation domain was performed. Based on this analysis, it was possible to divide agents in two large groups, namely so-called system agents, which perform tasks such as the representation and interpretation of the simulation world, and domain agents, which correspond to shipping companies and trucks. Defining trucks as individual agents brings the advantage of delegating problem-solving skills to them (e.g. route-planning and local plan optimization). Communication between agents is enabled by direct communication channels.

The company agent is responsible for the disposition of the orders that have been confided to him. Thus, it has to allocate the orders to its trucks, while trying to satisfy the constraints provided by the user as well as local optimality criteria. The shipping companies can be regarded as experts for cooperation and cooperative problem solving. They are equipped with additional global knowledge which is needed for cooperating successfully with other companies.

The truck agents represent the means of transport of a transportation company. Each truck agent is associated with a particular shipping company from which it receives orders. Given an order, the truck agent does the planning of the route according to its geographical knowledge and it will inform the shipping company agent about the deliverance of the goods. Furthermore, the truck reports remaining capacities, planned routes and it is able to estimate the effort (and the effects) that are caused by an order.

3. Based on the functional analysis, some methods for cooperation of individual agents were suggested. The general idea of the solution is based on the paradigm of self-organization, which is applied to a society of knowledge-based systems [1]. The messages passed between the agents are structured into negotiation protocols.

4. Tasks for continuing research were defined, namely planning of individual agents, forms of cooperation, mechanisms for task decomposition, and design of knowledge representation structures.

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INSTINCTIVE AUTONOMOUS MOBILE MINIROBOTS IN EDUCATION ON THE CTU

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Key words: biomechatronics, mobile instinctive autonomous minirobots, distributed control, instinctive behaviour

These are many tasks in the field of mobile robotics, such as collision-free movement in a natural unconstrained environment, orientation of mobile robots (mobots), etc. All of these tasks are easily performed even by very simple animals and mostly much better than by traditional mobile robots. An animal does not consciously plan what to do next, nor does it have an explicit internal representation of the world. It is controlled by a set of simple reactive behavioural patterns. Each of them responds instinctively to a particular stimulus, and the resulting global behavior of the animal is merely a resultant of those single patterns merged together using an appropriate mechanism. More complex behaviours, which may really seem to be consciously planned, are mostly nothing but a chain of successively performed instinctive actions. Successive behavioural patterns are released by stimuli that are results of the activity of preceding behavioural patterns.

These are the main reasons for our decision to build two mobots equipped with a non-symbolic and non-representational control system. The control system of these biomechatronic devices is not decomposed into serially arranged functional units (sensing, planning etc.) as in classical robotics, but into many autonomous instinctive units. Each of them is a subsystem responding to a particular stimulus. These units work in parallel; it is neither possible nor reasonable to use a separate processor for each of them in a real implementation. Our instinctive robots prefer local sensor data and tend to avoid the use of stored internal information using its environment as its own best model instead. "Intelligence" of a system like this is thus not carefully planned and prepared in advance; rather, it is an emergent property, emerging only during the interactions between the system and its environment.

The following robots are used as test beds for this architecture:

- a car model with built-in servos, infrared proximity sensors and a simple control system based on the 8051 microcontroller. This robot has already been successfully equipped with lower levels of control, endowing it with the ability to move about in relatively general environment without hitting objects.
- a six-legged insect-like robot. Since the robot is primarily intended as a test bed for various versions of the control system and not for the study of kinematics of walking mechanisms, the simplest variant of kinematics with two degrees of freedom (DOF) for each leg has been chosen. Each of them consists of two segments, one horizontal and one vertical. The two segments are connected with a revolute joint about the horizontal

axis, with the horizontal segment being connected to the body with revolute joint about the vertical axis. This mechanical design only enables wave gait and requires an almost plain surface. Practical experiments confirmed our expectations about the gait type, the mobility and its limitations. This device was built with limited funds and the main goal was gathering experience. On this basis, an improved version of a mobot with legs with 3 DOF, which will enable walking on rough terrain and application of free gait, is projected now.

The robot uses tactile sensors and will be equipped with infrared sensors and possibly with sonars. Since a control system of this kind does not require huge computational power, we have investigated whether it is able to perform requisite tasks with one cheap Z80 microprocessor. We have actually achieved some interesting results with this control system. The robot is able to walk and to avoid obstacles. However, since the control of six-leg locomotion in itself is quite a difficult task, the addition of more complex control layers would be impossible within this system. For this reason, a new system using the 32-bit MC68332 microcontroller, is currently being built. After it has been equipped with basic control structures endowing it with the ability to move about in a general indoor environment, our research concern with this robot will primarily be focused on higher control structures enabling it to be oriented and to move about purposefully and obviously without hitting (moving as well as static) obstacles in real unknown and unconstrained environments. In particular, we will examine problems of the possible hybridization of this architecture, which means the connection of instinctive lower levels, securing the necessary level of autonomy and reactivity with higher control structures based on symbolic reasoning.

Besides the potential future applications (farms of robots etc.) the work has already had and will have a substantial pedagogical impact because it involves many undergraduate and graduate students. Moreover, both robots are currently being used as teaching aids in several subjects such as Robotics, Mobile Robots and Robot Control at the Faculty of Electrical Engineering and will be used in corresponding subjects (e.g. Mechatronics, Applied Mechanics, Fundamentals of Technical Cybernetics) also at the Faculty of Mechanical Engineering on the CTU Prague.

The goal of this project has been successfully achieved as our idea has been experimentally verified and shown to be interesting in attractive applications.

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This research has been conducted at the Department of Control Engineering of the Faculty of Electrical Engineering and has been supported by the CTU-grant FRVS 0816 "Instinctive Autonomous Mobile Minirobots in Education".

MODERN CONTROL METHODS IN MECHATRONICS

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Key words: mechatronics, fuzzy control, H∞-theory, sensitivity functions, model

Mechatronics is a balance between mechanical, electronic and computing technologies. All of these areas also include control. In regards to this project,we studied modern control methods that are prospective in mechatronics.

One of the most prospective methods is fuzzy theory that was devised for the purpose of enabling machines to handle subjective human ideas and operate based on advanced knowledge as well as applications of human beings intricate experiences. In other words, fuzzy theory allows for the development of truly user-friendly machines.

With the help of fuzzy theory, we controlled swings of the load hanging on a crane. The swing changes are caused by the load inertia.

The system consists of a crane motion trajectory, crane construction, a crane drive, a load swing angle sensor and a fuzzy controller.

The controller receives three input signals: set crane velocity (V_s), swing angle (b), and angular velocity (db/dt). The motion velocity (V) is the output signal of the controller.

It is necessary to create four membership functions for the three output and one input values. We defined five levels for the set velocity and three levels for the swing angle as follows:

NM ... Negative Medium
NS ... Negative Small
ZR ... Approximately Zero
PS ... Positive Small
PM ... Positive Medium
PL ... Positive Large

and created 15 rules. The following rule is given as an example.

If ((b=NS) and (db/dt=ZR) and (V_s=ZR)) then (V=NS)

We also concentrated our research activities on H∞-theory, especially on the so-called standard H∞ - optimal regulator problem.

We introduce the standard problem by considering the mixed sensitivity function in the configuration of Fig. 1.

The diagram shows V as a shaping filter for the disturbance, and W_1 nad W_2 as frequency dependent weighting functions for the control system output and the plant input, respectively. The signal w is an external input that drives the disturbance shaping filter V.

It is easy to check that the Laplace transformation of the weighted control system output z_1 and the weighted plant input z_2 are given by the following formula:

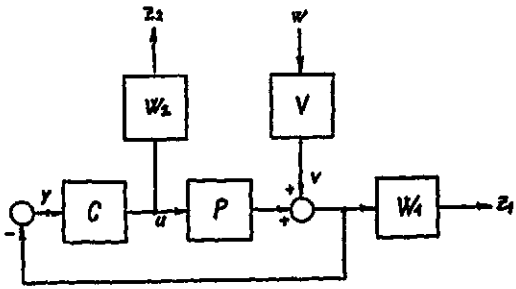

Fig. 1: The mixed sensitivity problem

$$z_1 = W_1 S V w, \tag{1}$$
$$z_2 = -W_2 U V w, \tag{2}$$
$$\tag{3}$$

so that $z = \mathrm{col}(z_1, z_2) = \mathbf{H}w$, with

$$\mathbf{H} = \begin{pmatrix} W_1 S V \\ -W_2 U V \end{pmatrix} \tag{4}$$

Hence, the mixed sensitivity problem amounts to the minimization of the ∞-norm of the transfer matrix from the external input w to the composite output z. The freedom available in the minimization problem consists of the choice of the compensator C.

By isolating the compensator, we get the configuration for the standard H_∞-optimal regulator problem.

In regard to this project, some other tasks and experiments were solved. Some of them will be used for mechatronic studies.

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FUZZY ESTIMATION OF THE ANGLE OF A CRANE

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Key words: mechatronics, fuzzy logic, estimation

To improve the tracking accuracy of the crane, it is necessary to remove a load oscillations induced by the pendulum effect. To actively dampen the oscillations, one has to know the angle of the pendulum. However, in an industrial environment, this angle is difficult to measure. An alternative involves using a state observer which reconstructs the angle of the pendulum from the displacement of the carriage. In my work in ULB Brussels, the possibility of estimating by using fuzzy logic was demonstrated.

The fuzzy estimator has a structure that is derived from a Mamdani type fuzzy controller.

The goal of the fuzzy estimator is the estimation of the system trajectory in a state space. A sequence of rules forms the so-called linguistic trajectory which should be very close to the system trajectory. The difference between these curves is an error of estimation ε which can be taken as the Euclidian norm.

To construct the fuzzy estimator, the following steps are recommended:

- identification of variables and their values, sorting dependent and independent variables
- determination of universes of discourses and membership functions
- creation of a rule base by using some methods
- tuning of fuzzy estimator

From all the selection possibilities of the input variables, the following combination was taken after analysis of the system behavior

$$\left[\frac{d}{dt}\theta\right]_{t_i} = f\left(\int_0^{t_{i-1}} \theta dt, dx\right), \tag{1}$$

where

$\left[\frac{d}{dt}\theta\right]_{t_i}$: change of the angle θ at time t_i

$\int_0^{t_{i-1}} \theta dt$: a definite integral of the angle θ from the time 0 to t_{i-1}

dx: change of the position (velocity)

The formula is computed recurrently by using feedback.

The inputs to the fuzzy estimator are the change of position (velocity) dx and a definite integral of the angle θ from the time 0 to t_{i_1} . The output of the fuzzy estimator is the change of the angle $\frac{d}{dt}\theta$ at time t_i.

For all three variables, we have to determine universes of discourses and membership functions. In the first step, we can take intervals in which these variables appear during a simulation as universes of discourses. This approach is possible because of the necessity of tuning the results in the last step. For our task, we can use triangular and trapezoidal membership functions.

The linguistic variables "velocity" and "sum of angles" are divided to 1 trapezoidal membership function in the surrounding of the steady states (the dead zone) and 5 triangular membership functions. Using the dead zones decreases the influence of the disturbances to fuzzy estimation for the steady states (for the velocity). The linguistic variable "change of angle" is divided into 7 triangular membership functions.

All membership functions except the side ones for the linguistic variables "velocity" and "sum of the angles" are symmetrical with overlapping factor 0.5.

The universes of discourses are divided among these membership functions in a regular manner. This property will be important for the construction of the rule base.

After defining the membership functions, we need to develop a knowledge base (KB) which consists of rule structure and content.

The structure of the rules for our task is derived from the general formula. The idea in the construction of a knowledge base is the following: We assume that it is possible to describe the behavior of our system as a relation between the velocity and the integral of angles . In the cases where these variables are in equilibrium, the change of the angle is null. For the other states, the change of the angle is proportional to the "deflection" from the equilibrium stage.

The rules are built from the characteristics of the step response as follows: if the result of fuzzy inference is far away from the equilibrium point, a large output — the change of angle — is expected, whereas a small output is acquired if the result is near the equilibrium point.

By using this linguistic approach, we can make the base of fuzzy rules. For simplicity, this can be created in look-up table form.

After creation of the fuzzy rules, the final step is the tuning of the fuzzy estimator. Because of the complexity of this process, we only tune our fuzzy estimator for one couple of parameters (the mass and the length of pendulum).

By using the described method, we made the fuzzy estimator. In this stage of our investigation, we only simulated results with MATLAB. For this task, we used functions from FUZZY TOOLBOX v. 3.0. (Humusoft, Czech republic) and some new functions of ours.

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This research has been conducted at the Department of mechanics and robotics, Free University Brussels, Brussels and has been supported by TEMPUS JEP-4143-93.

NEW CONTROL STRUCTURES FOR MECHATRONICS

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Key words: real-time control system design, DSP, parallel processing

Mechatronic systems (e.g. machine tools, robots, flexible manufacturing systems) are typical as systems with tightly coupled mechanic and electronic parts. The control of these systems is quite complex task. One possible solution is the distribution of control systems, algorithm parallelisation and the use of the parallel computing systems. A problem with the simulation of a multilayer neural network on **transputer** array was investigated in this project with a link to [2][3]. The decomposition and mapping on the given architecture was proposed also with a simple message passing scheme. The time complexity analysis and a comparison with a classical algorithm were done as well as measurements on parallel computers [5].

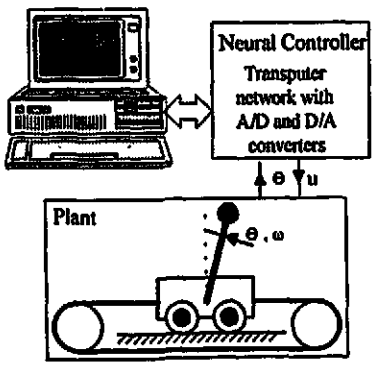

Fig. 1: Inverted pendulum plant

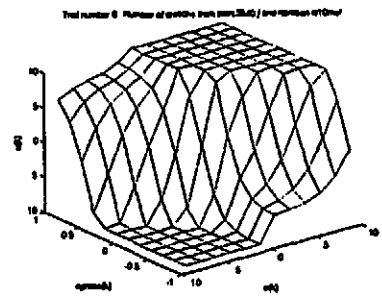

Fig. 2: Neural controller characteristics

Besides the performance measurement, the neural network controller was implemented. Experiments were done on an inverted pendulum physical model. The task was to stabilize the pendulum in an upright position having information about pendulum angle Θ and angular speed ω. Figure 1 shows the experimental environment schematically.

Useful hints for setting neural network architecture and tuning neural networks parameters were summarized in [4]. Then neural controller was designed and the criterion function was defined for the given control problem. Assuming the learning procedure had already stopped, the neural controller could be seen as a non-linear static function with two inputs

and one output as shown in Figure 2. Its behaviour is very similar to the conventional linear PD controller with saturation.

Other work performed in this project was done with Programmable Multi Axis Controllers. This system is a high-performance servo motion controller capable of commanding four axes of motion simultaneously. Through the power of a **Digital Signal Processor** (DSP), PMAC offers a good price-performance ratio for multi axis control that was not previously available. Motorola's *DSP 56001 is the CPU for PMAC, and it* handles all the calculations for all axes. Any version of PMAC may run as a stand-alone controller or it may be commanded by a host computer, either over a serial port or a bus port. As a general purpose controller, PMAC can serve in a wide variety of applications. Our intention is to use it as a controller of machine tools and driving plotters.

The cooperating axes can be closely associated for completely coordinated motion; each axis can be put in its own coordinate system for completely independent operations; any intermediate arrangement of axes into coordinates is also possible.

The task of PMAC is executing sequences of motions given to it in a motion program. When told to execute a motion program, PMAC works though the program one move at a time, performing all the calculations up to that move command to prepare for the actual execution of the move. PMAC is always working ahead of the actual move in progress, so it can blend properly into the upcoming move, if required.

The sequential nature of the motion program is well suited for commanding a series of moves and other coordinated actions; however, these programs are not good at performing actions that are not directly coordinated with the sequence of motions. For these types of tasks, PMAC provides the capability for users to write "PLC programs". These are named after Programmable Logic Controllers because they operate in a similar manner, continually scanning though their operations as fast as processor time allows. These programs are very useful for the tasks asynchronous to the motion sequences.

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This research has been conducted at the Department of Control Engineering as part of the research project "New control systems structures for mechatronics" and has been supported by FRVS grant No.0831.

POLE PLACEMENT FOR LINEAR MIMO TIME-VARYING NON-LEXICOGRAPHIC-FIXED SYSTEMS

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Key words: Pole placement, Linear MIMO time-varying system, Non-lexicographic-fixed

The paper deals with the pole-placement for MIMO time-varying linear systems which are not lexicographic-fixed. Generally the pole-placement for time-varying systems has a different meaning and its solution is more demanding then for time invariant systems (Nguyen, 1987). The pole placement for MIMO time-varying linear systems is now becoming important for mechatronic systems as treated as linearized nonlinear systems. For the solution of pole placement of non-lexicographic-fixed systems we have used the idea of augmentation scheme of (Chai et al., 1991) which is generalized and improved.

Formulation of the problem. Let us study the MIMO time-varying linear system

$$\dot{\mathbf{x}} = \mathbf{A}(t)\mathbf{x} + \mathbf{B}(t)\mathbf{u} \tag{1}$$

with state variable $\mathbf{x}(n\times 1)$, control variable $\mathbf{u}(m\times 1)$ and state matrices $\mathbf{A}(t)(n\times n)$, $\mathbf{B}(t)(n\times m)$ The controllability matrix $\mathbf{U}(t)$ is defined as

$$\mathbf{U}(t) = [\mathbf{J}_A^0(\mathbf{B}), \mathbf{J}_A^1(\mathbf{B}), \ldots \mathbf{J}_A^{n-1}(\mathbf{B})] \tag{2}$$

where the matrix operator $\mathbf{J}$ is defined as

$$\mathbf{J}_D^0(\mathbf{M}) = \mathbf{M}, \quad \mathbf{J}_D^1(\mathbf{M}) = \mathbf{MD} - \frac{d}{dt}\mathbf{M}, \quad \mathbf{J}_D^{i+1}(\mathbf{M}) = \mathbf{J}_D^1(\mathbf{J}_D^i(\mathbf{M})) \tag{3}$$

The system (1) is controllable (Chen, 1981) iff the controllability matrix $\mathbf{U}(t)$ has full rank n for all times $t \in [0, \infty]$. The controllable system (1) is lexicographic-fixed (Nguyen, 1987) iff there exists a unique $(n \times n)$ submatrix of $\mathbf{U}(t)$ that is non-singular for all times $t \in [0, \infty]$.

System augmentation scheme. For time $t = 0$ we construct the reordered controllability matrix $\mathbf{R}(0)$

$$\mathbf{R}(0) = [\mathbf{J}_A^0(\mathbf{b}_1), \ldots, \mathbf{J}_A^{\mu_1-1}(\mathbf{b}_1), \ldots, \mathbf{J}_A^0(\mathbf{b}_m), \ldots, \mathbf{J}_A^{\mu_m-1}(\mathbf{b}_m)]_{t=0} \tag{4}$$

where μ_j are controllability indexes and $\mathbf{b}_k$ are columns of the matrix $\mathbf{B}$. The controllability indexes can change and are dependent on time t of selection process. Because the system is controllable we can find the finite maximum of controllability indexes $\nu_k = \max_i \mu_k$. Because the system is non-lexicographic-fixed it is $n_g = sum_{k=1}^{m} \nu_k > n$. We define the generalized reordered controllability matrix

$$\mathbf{R}(t) = [\mathbf{J}_A^0(\mathbf{b}_1), \ldots, \mathbf{J}_A^{\nu_1-1}(\mathbf{b}_1), \ldots \mathbf{J}_A^0(\mathbf{b}_m), \ldots, \mathbf{J}_A^{\nu_m-1}(\mathbf{b}_m)] \tag{5}$$

Instead of system (1) we shall study the augmented system

$$\dot{\mathbf{x}}_y = \mathbf{A}_y(t)\mathbf{x}_y + \mathbf{B}_y(t)\mathbf{u} \tag{6}$$

$$\mathbf{x}_y(n_y \times 1) = [\mathbf{x}, \mathbf{x}_1]^T, \quad \mathbf{A}_y(n_y \times n_y) = [[\mathbf{A}, \mathbf{A}_2]^T, [\mathbf{0}, \mathbf{A}_1]^T], \quad \mathbf{B}_y(n_y \times m) = [\mathbf{B}, \mathbf{B}_1]^T \tag{7}$$

Now the matrices $\mathbf{A}_1(t), \mathbf{A}_2(t), \mathbf{B}_1(t)$ will be determined such that the augmented system (6) is lexicographic-fixed. Because the generalized reordered controllability matrix $\mathbf{R}(t)(n \times n_y)$ has rank n we can extend this matrix to the controllability matrix $\mathbf{R}_y(t)(n_y \times n_y)$ of the system (6) having rank n_y. The main **Theorem** is

If the system (1) is controllable but may not be lexicographic-fixed on $t \in [0, \infty]$ then there exists an $(n_y - n)$-dimensional auxiliery system

$$\dot{\mathbf{x}}_1 = \mathbf{A}_2(t)\mathbf{x} + \mathbf{A}_1(t)\mathbf{x}_1 + \mathbf{B}_1(t)\mathbf{u} \tag{8}$$

such that the augmented system is controllable and lexicographic-fixed on $t \in [0, \infty]$.

Pole placement. The pole placement problem is now solved for the augmented lexicographic-fixed time-varying MIMO linear system according to the technique presented in (Valasek and Olgac, 1993). We obtain the feedback gain vector $\mathbf{K}_y(t)$ by which we compute the control action

$$\mathbf{u} = \mathbf{K}_y(t)\mathbf{x}_y = \mathbf{K}_y(t)[\mathbf{x}, \mathbf{x}_1]^T \tag{9}$$

Conclusions. The results of this paper together with the results of (Valasek and Olgac, 1993) have finally removed all restrictions on the solution of pole placement problem for time-varying MIMO linear systems. The property of being lexicographic-fixed is the last restriction which remains for the pole placement of linear time-varying systems besides to be controllable.

This paper deals with one part of the research realized under the CTU Grant, the other part dealing with fuzzy and H_∞ control is reported separately.

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SOFTWARE TOOL FOR DESIGN OF ADAPTIVE CONTROLLERS

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Key words: self-tuning control, recursive least squares identification, PID control, pole placement control

In control of complex multivariable technological processes, a challenge of using advanced control algorithms offers, as they can attain better technical and economical parameters. It is matter of fact, that this opportunity is rarely used. The relation between demanding theory and industrial reality is unsatisfactory all over the world. This situation is caused by objective complexity of the design procedures and by the increased risk of unsuccessful application, if the design was not realised in qualified way.

One of the promising directions in the advanced control, in some extent capable of overcoming the problems with controller setting, is adaptivity. Even here the problem of prior tuning cannot be avoided; it is characterized by the following tasks: problem formulation, analysis of information available, system structure and parameter identification, control synthesis, initial condition setting, estimation of control efficiency etc.

The research team was composed of three parts: university group (Faculty of Technology Zlín and Faculty of Electrical Eng. TU Brno), academical group (Institute of Information Theory and Automation, AS CR Praha) and practical oriented group (Firm ALCOR a.s. Zlín). The character of work corresponded mostly with the division: theoretical, laboratory and practical with possibility of the commercial use of the research results.

The research work of the team from the AS CR Praha aimed at providing consistent theoretical grounds and reliable algorithms for preliminary design ensuring good transients and optimal operation of multivariable LQG adaptive controllers.

However "recent surveyes in the process industries have shown that up to 90 percents of the closed-loop control algorithms used are PID" [1]. These types of controllers are more convenient for users owing to their simplicity of implementation, which is generally well known. In the case of a correct choice of their parameters they can control a considerable part of continuos technological processes. However, the tuning procedure is often nontrivial and it may be very difficult to find values of the parameters which give a desired closed-loop behaviour. For this reason, groups of the Faculty of Technology Zlín and of the Faculty of Electrical Eng. Brno are long-term devoting with automatic setting and implementation of the digital PID controllers.

The software firm ALCOR a.s. Zlín developed the object-oriented system Control Panel for generating of industrial monitoring and control programs. This system contains self-tuning PID [2] and pole placement [3] controllers.

For the computer aided design of the adaptive PID and pole placement controllers has been developed MATLAB-Toolbox STC PID PP (Self-Tuning Controllers PID and Pole Placement). This Toolbox is determined for designing, testing and simulating in real-time

of these controllers. The proposed software is entirely written as MATLAB m-files (version 4.2) using of the functions of the Control System Toolbox. This Toolbox includes tools which facilitate following:

1. Simulation of the control process in the form of continuous model, discrete model or model which has been obtained using the recursive identification from measurable process dates.
2. Recursive identification using the least squares method with directional forgetting.
3. PID [2],[3],[4] and pole placement [3],[5] controller design.
4. Real-time control.

The designed self-tuning control algorithms which are included in this MATLAB-Toolbox are simple, sufficiently robust and suitable for control a large class of controlled systems (proportional systems with minimum or non-minimum phase, integral systems and with time delay ones). For this reason, the Toolbox can be preferable used for supporting the project of the self-tuning industrial controllers. The individual designed controllers are programmed in the form of the C++ functions for the industrial applications too. The PID self-tuning controller [4] derived for the third order model is being verified for the control of a 200 MW power plant [6] and pole placement self-tuning controller [3] has been used for temperature control of a thermo-analyzer [7].

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This research has been conducted at the Department of Automatic Control Faculty of Technology Zlin and at the Department of Automation and Measuring Faculty of Electrical Eng. TU Brno as part of the research project "Software tool for design and preliminary tuning of adaptive controllers" and has been supported by TU Brno grant No. B 29/93.

COMMUNICATION SUBSYSTEMS ON THE FIRST CONTROL LEVEL

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Key words: fieldbus, ASI bus, bridge

In the laboratory of Control Systems of the Department of Automation and Measurement Engineering the first bridge between two industrial fieldbuses has been developed. Attention was given to the new west European standard ASI bus and another two fieldbuses managed by a simple communication protocol of the firm Omron and the French industrial standard FIP. The ASI bus is a simple, cheap fieldbus for connecting binary sensors and actuators. It has been developed by leading European firms producing sensors and actuators. The physical connection is two-wired, control is of the type Master- Slave. The typical configuration of one fieldbus segment is 1 Master and 31 Slaves. A maximum of 124 passive binary sensors and actuators can be connected to one ASI-Master. The maximum response time of the segment is 5 ms. The Omron bus is a correct fieldbus for connection of Omron programmable controllers and industrial regulators. The communication rate is 19,2 kbps by 31 Slaves. Its control is of the type Master-Slave. The architecture of the bridge is shown in Fig.1. ASI-Master has been developed by means of the COP member, connected by RS 232C interface with a PC/386. Because the Omron-Master has been built by means of a PC program, the bridge has been also devised as a program on PC/386. This solution enables a simple realization of an interconnected heterogeneous fieldbus-system, on the other hand, the configuration limits the rate of data transfer. In the future a compact microcomputer oriented bridge will be realized. In the initialization phase of the system each user should define the data flow from ASI - Slaves to Omron - Slaves and vise versa. Also the period of data transfer should also be defined. According to a list of data to be transferred and according to the periodicity of their transfer, the bridge will periodically transfer the data. To each transferred data unit , the bridge will affect a date-of-next-transfer. The bridge periodically checks if a date-of-next-transfer has expired and performs a transfer of all data, attached to that date. Than a new date-of-transfer for each transferred data is calculated. One of the most important features of the bridge is timing management. Because of DOS, the period of clock is about 55ms. To perform a periodic data transfer, the bridge uses a PC timer. The RS 232C interface between the ASI bus and the Omron bus builds the main restriction of the bridge. The implementation of the bridge is based on the idea that not only a bridge between the ASI bus and the Omron bus will be developed. The program was divided into two tasks: - the user's interface - the stream handler The function of the user's interface includes configuration of the bridge and automatic recovery of a former configuration at the start. An interruption from the timer periodically stops execution of the user's interface and calls the stream handler. This program gives curret time and transfers all data. After that it returns the execution back to the user s interface. The user's interface also warns the user when an error occurs during a communication. The *stream creates the principal brick of the application. The stream respects the period in* which it can be activated and inactivated. When the stream is inactive, it exists in the PC

memory only and no data is transferred. In the active phase, the data flow is performed. The stream is a *virtual object* and *contains* all mechanisms important for any other bridge performing periodic data transfer. The user's stream inherits all characteristics of the virtual one and depends on the specific fieldbus. For any fieldbus a new procedure "Stream" has to be developed. The most important information for the development of a new bridge are source and destination addresses and an instruction how to deal with each fieldbus. To create a periodic stream means to define the information to be transferred, the destination address and the period.

The program contains a user-friendly environment, using Turbo Vision libraries. For purposes of system configuration by means of a window, a user can define a new stream and edit the existing ones. The period, addresses and the read/write definition of the transfer can be changed.

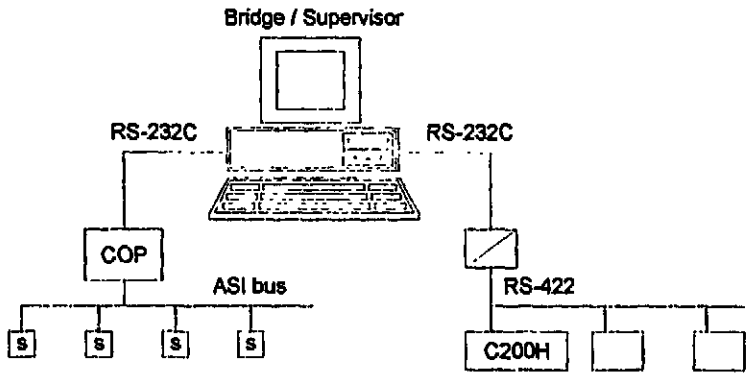

Fig. 1: System architecture

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This research has been conducted at the Department of Automation and Measurement Eng. as part of the research project "Communication subsystems on the first control level" and has been supported by TU Brno grant No.B3/VUT.

VIRTMED – A PROJECT FOR 3D MEDICAL DATA PROCESSING AND VISUALIZATION

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Key words: 3D medical data, visualization, image processing, knowledge based segmentation, virtual reality, 3D interaction

The examination of complex data becomes more and more important problem at the present stage of medical diagnosis techniques development. Namely three dimensional scanners like CT (X-ray Computer Tomography) and MRI (Magnetic Resonance Imaging) generate large amount of image data. In present (especially in Czech Republic), the exploiting of such datasets is limited to direct viewing of 2D scans on a tomograph screen (Console), followed-up by their recording onto a film and direct viewing of films against the flat lightbed.

CT and especially MR tomograph is an expensive equipment. For that reason a lot of people work on making the most out of provided information. That means especially improving of the conclusive evidence of medical examination, acquisition time shortage and radiation dose reduction. Three dimensional reconstruction of examinated organs is usefull for communication with another physicians - not radiologists. It has also a great importance for surgical or radiation treatment planning.

In the past, physicians had to be satisfied with raw data for their diagnosis - e.g. in the form of X-ray photographs - without additional computer analysis. The requirements for such analysis were to high for solving them by at that time available computers. In present the computer technology development reached such a level, that the computers can process tasks, which go beyond common possibilities in contemporary medical praxis.

Also our computer graphics group started a research in this field. Cooperation with Purkyne Military Medical Academy in Hradec Králové was established. The basic idea of the project is to put together the pieces of knowledge from fields such is medicine, computer vision and computer graphics towards improving the medical diagnosis.

The first stage of the project is concentrated on the study of current situation:

- obtaining information about special medical software yet available,
- trying to compare accessible general visualisation systems (like IRIS Explorer, AVS, Khoros) and to judge their usability for medical data exploitation,
- testing the basic image processing algorithms implemented by students in student semestral projects,
- testing the possibilities of increasing the interactivity during large data sets visualisation using the GL library on Silicon Graphics workstation (in student diploma theses).

In next stages, we would like to specialize in three fields:

- investigation of algorithms for 3D datasets exploatation using the methods of artificial inteligence,
- developing of methods of interaction in 3D space using 2D input devices,
- introducing the methods of Virtual Reality in operation planning.

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LOADBALANCING FOR DISTRIBUTED RAYTRACER

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Key words: distributed, visualization, raytracing, loadbalancing

Fast visualization of 3D scenes became one of the main subjects of research in the modern computer graphics. Many new algorithms were introduced in the last several years and some of them have been implemented into computer hardware. The quality of the output must be sometimes sacrificed in order to achieve high speed of visualization. The extreme case is a suppression of some attributes of visualized objects. For example it is impossible to simulate optical effects on lenses using hardware Z-buffer. This is one of many reasons why our research team decided to investigate computationally expensive parallel rendering algorithms for scientific and CAD/CAM visualization . One of those algorithms is raytracing which allows generating photorealistic images fully reflecting the complexity of light behaviour in a non-trivial scene.

The effort for decreasing the time of rendering using the raytracing algorithm corresponds very often with decreasing the number of tested intersections between the ray and objects of the visualized scene. This can be done by implementing different speedup algorithms based on the space partitioning and building redundant tree-like data structures. To achieve a good speedup, the data structure (Octree, Binary Space Partitioning tree) has to be rather large. The memory requirements for complex scene usually exceed the memory capacity of nowadays workstations. To achieve the high speed for large data sets rendering so needed for scientific visualization, the parallelization of the raytracing algorithm is necessary. Previous research had shown that the best speedup can be accomplished using the parallelization based on object-space partitioning [1]. It is somewhat similar to the algorithmical speedup methods mentioned above. The difference is that the space cell created by the partitioning are assigned to the processor one by one. The drawback of this technique is the necessity of the mutual communication among the processors. The exchanged messages represent the light rays travelling through the space.

The distributed system consisting of communicating *cells* (processor assigned a space partition) has to be controlled in such a way that each cell is kept working and does not become idle. Control mechanisms of this kind are called loadbalancing strategies and are well-known in the field of parallel computing. The loadbalancing strategies can be divided into two groups:

1. *static* - executed only once as a part of pre-processing phase
2. *dynamic* - executed during the computation run whenever necessary

Dynamic loadbalancing methods appear to be adequate for 3D rendering since objects of the scene may be moved or new objects can be generated during the computation.

The measure for the loadbalancing in our system is the Local Load Factor (*LLF*) of cells. The value of LLF mostly depends on the number and complexity of the objects enclosed in the cell and also on the number of messages received from the neighbouring cells. There are two different ways to influence the LLF during the computation:

- changing the geometrical shape of the particular cell
- processor farming

The first approach described in detail in [2] is not suitable for the parallelization of the raytracing algorithm based on the space partitioning. The main reason is the tree-like data structure in each cell used to achieve the algorithmical speedup. Creating such a data structure is very time consuming and it is usually a part of the pre-processing phase. Any change to be made in this data structure implies to building a new one.

The process farming is based on the fact that there are more processors available in the parallel system than space partitions. There are three levels hierarchy of processes. First level consist of the Control Process which regulates the loadbalancing mechanism. The second level consist of processes which represent the space cells (*VBoxes*). The main task of these processes is to communicate with neighbouring cells, to generate initial rays and to compute LLF.

The processes performing the actual raytracing (*RTCore*) belong to the third level and can be further divided into two subgroups:

1. *native* RTCores
2. *spare* RTCores

The number of native RTCores equals to the number of VBoxes. Only the spare RTCores can be used as free computational resources for the loadbalancing based on assigning one of them to the VBox with the highest LLF. If LLF of the VBox drops under certain limit (there is no work for the spare RTCore), it notifies the Control Process which then finds another VBox with the highest LLF and the situation repeats. It is obvious that high number of spare RTCores allows better loadbalancing.

We don't have any concrete results yet since the loadbalancing strategy is still being implemented. We solving the problem of reloading the local scene of a cell by a spare RTCore in case that this RTCore is assigned to the VBox as a result of loadbalancing activities. The partitioning of the scene should be improved because it influences the number of VBoxes and number of native and spare RTCores. We suppose that the number of available processors in the system is fixed and limited. Last but not least the trashing effect at the end of the computation when the LLF of majority of the VBoxes drops and many available spare RTCores are searching new job has to be solved.

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VISUAL TEST BED FOR OCR MACHINE DEVELOPMENT

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Key words: automatic testing, synthetic image generation

The Project. The Visual Test Bed is the first development project solved in the Computer Vision Lab for Allen-Bradley. This project started cooperation between the Computer Vision Lab and A-B Company represented in our country by the Allen-Bradley Research Center, Prague.

The Allen-Bradley is a large American producer of industry control systems. Part of the control system is module CVIM2 designed for processing images captured by CCD cameras. CVIM2 can be plugged in a control system and used as a source of optical information required for industrial process control. The CVIM2 can be used either as a sensor measuring object positioning and properties or as a optical character recognition (OCR) machine (different software packages).

The Visual Test Bed. The Visual Test Bed (VTB), developed within the project reported here, is a system for automatic testing of OCR machines. Results from VTB should be used for evaluating properties of OCR algorithms and for their improvements. The VTB system will be also used for comparing OCR machines from different producers.

The VTB system consists of the following parts: the VTB program, a PC compatible computer, an image capture card (installed in PC), the OCR machine and necessary cables. The image capture card is able to convert digital (pixel) images into the signal which a CCD camera produces. The signal enters the camera input port of the OCR machine (CVIM2). Moreover, the OCR machine is connected with the PC by a RS 232 link that serves for communication between the PC and OCR machine.

The VTB system generates a series of testing images, according to user requirements. The testing images are converted to a CCD camera signal and enter the OCR machine. The OCR machine processes each image and sends the results back to the PC computer. The acquired results are compared with expected results and stored in a table for later analysis.

The VTB Structure. The VTB program is composed of two cooperating parts: the Image Generator and the Image Sequencer. The Image Generator provides access to the data structure Testing Image Pattern (TIP), which stores all information necessary for generating a series of testing images. The Image Generator (IG) interacts with the user when TIP is being created and cooperates with the Image Sequencer when a series of testing images is being generated. The Image Sequencer controls the process of testing image generation (in IG), controls and communicates with the OCR machine, and accumulates and processes test results.

The Testing Image Pattern. The TIP is a set of graphical objects. It can contain the following objects: lines, rectangles, ellipses, polylines, polygons, bitmaps and texts. Properties of the objects are described by attributes. Attributed properties are those ones which will vary in testing images. The user creates the TIP by placing objects and defining their attributes.

Attributed object properties simulate local object distortions. There are several attributed properties common for all objects: a position, rotation, size, object gray level. Distinctive objects have also specific attributes based on their nature. Since the program is designed for testing the OCR machine the most complex graphic object is a text.

The text object can either print standard text using True Type Font (TTF) technology or can simulate a dot jet printing (DJP) which is widely used in industry. In both cases, the letter height, width and spacing is attributed. In a DJP mode, additional properties are attributed: dot size, dot column spacing, dot row spacing. It is also possible to define printing distortions like a dot size variance, dot position variance, column position variance (these distortions have a normal distribution). Not only text parameters but also text string is a attribute. It can change in the series of testing images.

Image and Object attributes. The program uses two attribute types: numerical attributes and text strings. Based on user selection, numerical attributes can vary in three ways during the generation of testing images: (1) absolute, the value does not change, (2) random, the value is selected randomly from a given interval, (3) exhaustive, the value is selected from a given interval with a given step so that all possible combinations of all exhaustive attributes from TIP might be used. The text string is generated either from a text file or using a metacharacter string (grammar rules).

Besides object distortions, the IG simulates also entire image distortions like: noise, image deformations (projections), light variations, etc. Image distortions parameters are attributes so they may vary as well.

Usage and Implementation. Having defined the TIP, the user switches to the IS, enters a number of required testing images and IS will start controlling the IG to generate images and acquire results from the OCR machine. The results can be then processed in other programs (a spreadsheet, statistical package). Conclusions can be used for OCR algorithm improvements.

The program is implemented in C++ and compiled for Windows NT. We hope that this is the beginning of our cooperation with AB Comp. and more scientifically oriented projects will follow.

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KNOWLEDGE BASED CADASTRAL MAPS INTERPRETATION

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Key words: image analysis, vectorisation, geographic information systems

The aim of the project. The aim of this two year project is to reduce the amount of errors in conversion of raster to vector images by the order of one or two. We propose to use a knowledge-based approach for that purpose. We developed the automatic vectorisation system without knowledge earlier [1] and extended it to be usable within the project reported here. As the general line drawings comprise complex knowledge, we restricted our attention to simple cadastral maps.

The second aim of the project was to stimulate research in the Bayesian estimation theory applied to CAD systems and geographical information systems particularly. These issues are partly reported in [2].

Automatic vectorisation. An automatic vectorisation system was developed [1]. It is able to process large scanned maps. It is typically used for maps of size A0. The process consists of preprocessing, thinning, and raster to vector conversion. Our practical experiments have shown that conversion is quite robust for simple maps, e.g., those used in forestry. On the other hand, the automatic conversion has difficulties when use for complex maps as the image segmentation process itself is difficult. It seems that a knowledge-based approach might be a good solution.

The first approach might use knowledge on the level of image segmentation where individual objects are identified. The second approach that we have chosen in this project, could use a vectorised version of a potentially oversegmented image and tries to build a correct interpretation using the knowledge.

Proposed knowledge-based interpretation module. The automatic vectorisation module takes the raster image and produces a set of vectors that correspond to lines in the original image. Vectors have a distinct topological structure (i.e., their adjacency to other vectors) that is important to represent. The metric properties of vectors (i.e., line length or width) are important as well. We decided to separate these qualitative (topological) properties from quantitative (metric) properties to ease automatic reasoning.

This thought led us to the representation of the drawing by an attributed graph. The graph itself represents topology and the attributes represent metric or other qualitative knowledge. Vectors correspond to graph edges and vector endpoints correspond to graph nodes. The graph nodes thus represent the adjacency between vectors. The graph nodes are attributed.

The knowledge about all drawings of the same type is formally represented as a language describing their topology and geometric properties. The interpretation of a drawing can be viewed as a translation from the *topological* language to another, *functional* language by performing a semantical labelling. The language is modelled by a formal grammar. A grammar has been created for the simplified case of cadastral maps. The desire was to test if this approach is plausible.

Grammar symbols and rules. The terminal symbols of the grammar are divided into two groups. Symbols from the first group correspond to initial geometric labelling: END represents a hanging line, VERTEX represents a join of just two vectors, FORK represents a join of three or more vectors.

The second group consists of the following semantical labels: SIGN represents a special symbol on a cadastral map that means two grounds are registered together, TEXT corresponds to alphanumeric text, BOUNDARY corresponds to a boundary of a ground.

The translation then replaces symbols from the first group by the symbols of the second group while maintaining the structure of the graph. Typically, only adjacent nodes are taken into account. The representative rule looks like the following ($N(s)$ is the set of nodes adjacent to the in question s):

$$\begin{aligned} &\text{if} \quad (\text{label}(s) = \textsc{vertex}) \wedge \\ &\quad (\exists t \in N(s) : \text{label}(t) = \textsc{boundary}) \wedge (\forall u \in N(s), u \neq t : \text{label}(u) = \textsc{vertex}) \\ &: - \ \text{label}(s) := \textsc{boundary} \end{aligned}$$

The interpretation of the map can be outlined as follows: The initial state (symbol) of all nodes in a graph is first set according to the number of edges joining in this node. The new symbol is evaluated for each node of the graph. The symbol evaluation process is repeated until there is no change in symbols assigned to graph nodes.

Conclusion. The above-outlined method was implemented and tested on a simple subproblem from the domain of cadastral maps. The preliminary results are promising.

There are still several problems to be solved. We created the grammar rules manually in an ad hoc manner. Even that the inference of the grammar from the training set is extremely difficult, we may try to semiautomize it. The convergence of the above-outlined algorithm also remains an open question.

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OPTIMIZATION OF COLOR FILTER FOR RAINBOW RANGE FINDER

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Key words: computer vision, range finder, accuracy analysis

The rainbow range finder is a device for the acquisition of three-dimensional (3-D) information about surfaces. It uses active illumination for the extraction of information missing in two-dimensional image. The 3-D coordinates of the points on the measured surfaces are determined by triangulation. In contrast with similar approaches, the illumination pattern is a continuous rainbow with parallel strips of constant monochromatic color. The rainbow illumination is produced by a projection of light passing through an interference filter using a commercial slide projector. At a point in the image the observed color is used for the monochromatic color light plane identification. The intersection of the plane and the beam passing through the focal point and the position in the image plane locates the surface point in space.

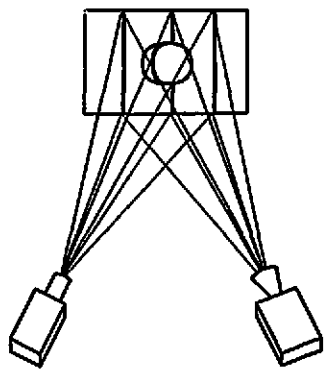

Fig. 1: Basic principle of rainbow range finder.

Problem. The position uncertainty of the surface point is bounded by a hexahedron. Four sides of the uncertainty hexahedron are determined by the camera pixel sides projected through the focal point. Two rest sides are determined by the monochromatic color planes passing through the projector. The angle between these planes is influenced by the uncertainty in the color determination.

The color determination is influenced by several factors. Among the others, we can mention:

- The quality of the rainbow light source.
- The color, reflectance properties and the shape of the observed surface.
- Color resolution of the color camera.

Solution. An important effect influencing the precision of the color determination is the camera color resolution. The color discrimination capability of a camera is not constant over all wavelengthes. For some dominant wavelengthes, the color discrimination error is significantly higher than for others. This is not convenient for many applications. The end user usually prefers a lower maximum error when the average error is kept constant. The aim of this contribution is to decrease the maximum value of the error caused by the mentioned effect.

The task is to find the relationship between the dominant wavelength of the light plane λ and the position of this plane in space parametrized by the angle α. The criterion is to minimize the maximum value of the uncertainty in the light plane position determination. All needed functions are known in a nonparametric form (measured on the system) and the numerical solution of the task is possible.

When the function $\lambda(\alpha)$ is known, the interference filter with the required properties can be manufactured.

Conclusion. The above described method allows us to decrease the maximum error of the position measurement without increasing the cost of the system. When specific requirements on the behavior of the error function are laid down, the appropiate changes in the method can be rendered to satisfy the user. This and other methods can avoid the main disadvantage of the rainbow range finder which is its relatively low precision.

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PHYSICALLY BASED LOCAL SHADING ANALYSIS

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Key words: computer vision, image understanding, shape from shading

One of the central issues in computer vision is how the properties of intensity image constrain the imaged surface shape. This "inverse problem" is important since computer vision deals with extracting relevant information about the world from images. Shape is a natural feature of real-world objects, it is therefore important for object recognition and geometric reasoning.

Local Shading Analysis (LSA) aims at looking for a *direct* relation between surface differential properties and local properties of its intensity image. The general advantage of LSA is that it can provide surface-related data for higher-level vision algorithms from single monocular 2-D intensity images *without reconstructing the surface* in an explicit depth form. This is possible because the intensity image is strongly related to local surface orientation [7]. The surface normal vector and the shape operator ("curvature matrix") are thus natural shape descriptors *obtainable from intensity image* by means of a local computational operation. The research reported here was motivated by looking for *qualitative shape from shading*. This is an important issue, since (1) qualitative shape may be sufficient for recognition and geometric reasoning, which leads to an increasing interest in qualitative shape from X [1,8], and (2) intensity image is a natural source of visual information.

Previous Work. The following factors are assumed: the Lambertian diffuse reflectance model, uniform surface albedo, and known positions of infinitely distant illuminant and viewer. The presence of interreflection among surface patches is excluded. These are standard assumptions in "shape from shading."

Pentland [6] strongly restricts the surface class in his fundamental work on LSA: it is to be a *sphere*. Then the surface normal vectors up to a convex/concave case, the surface albedo, and the incident light direction can be estimated from image data *without knowledge of the illuminant position*. If the qualitative illuminant position is known, the ambiguity can be resolved. When the assumption about the surface is violated, the estimates degrade very fast. The solution need not exist in the case of parabolic surfaces.

Later, Lee and Rosenfeld [4] provided an alternative solution to the problem. They still assume the surface is spherical. The general drawback of both of these approaches is that the recovered normals need not model a smooth (integrable) surface because of the heuristic assumptions about the surface.

Oliensis [5] assumes that a surface point neighbourhood can be approximated by the *osculating paraboloid* at that point. Then, the surface normal parameters, the principal curvatures, and the surface albedo can be estimated. Although correct, this approach to LSA is rather poorly tractable because of the complexity of the mathematical description.

Our Contribution: We employed a special surface parameterization uniquely generated by the surface reflectance isocurves that project on isophotes in an image. Then, the LSA problem becomes *well-tractable* with *no a priori restriction on the surface form* in the

sense of restricting the surface type like Pentland in [6], Lee & Rosenfeld in [4], or Ferrie & Levine in [3], or the surface order like Arnspang in [2], or assuming an explicit local surface approximation like Oliensis in [5]. The generality of the proposed approach allows further analysis of image events. The theory is presented in [7] in full detail. The main theoretical results may be summarized as follows:

(1) The surface normal vector and Gaussian curvature can uniquely be estimated along occluding contours in the image, (2) the surface normal vector can uniquely be estimated along self-shadow contours in the image if the position of the illuminant is known, (3) LSA outside the occluding contour is only possible when the surface is non-developable, (4) the surface normal vector and principal curvatures up to their signs can be estimated at image singular points due to critical points of the surface reflectance function, (5) isophotes are always parallel to zero-curvature principal direction irrespective of illuminant position, (6) outside the image singularities, four solutions for surface normal vector and principal curvatures can be computed by means of a simple and closed-form estimator requiring up to second-order image derivatives.

Open Questions. *There are two fundamental questions remaining to be answered: (1) Can the surface normal vector and the shape operator be specified at other singular image points? (2) In order to infer the qualitative shape from shading, the local ambiguity problem must be solved: a mechanism for propagating unambiguous surface interpretation from loci of unique qualitative solution (occluding boundary) has to be found. This works well in biological vision systems if enough unambiguous (sparse) cues are available. The question remains which mechanism is to be left behind.*

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ENHANCING RADIOMETRIC POSSIBILITIES OF THE CCD CAMERA

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Key words: computer vision, radiometric measurement, dynamic range enhancement

Problem statement. This work aims to show that the expensive CCD camera with 12-bits quantisation of light intensity can be replaced by the 8 bits camera. The computer vision laboratory carry out the project with the Oncological Department of the First Faculty Clinic of Charles University in Prague. The check of a ray emittor characteristic is needed for safety and quality irradiation of patients in the irradiation treatment. One of the possible methods of emittor characteristic measurement is based on evaluating the optical density of the photosensitive film irradiated by a ray emittor. The optical density is defined :

$$D = \log \frac{E}{X},$$

where D is optical density, E is intensity of a light source, X is intensity of a light passed through.

Our aim is to measure the intensities of E and X by CCD camera. The relative error of computed density D is in the best case :

$$\delta_D = \left| \frac{\log(\frac{(E+\Delta_b)\times 10^{-D}}{E\times 10^{-D}-\Delta_b})}{\log(E)} \right| \times 100\%,$$

where δ_D is relative error of density computed from CCD camera measured data,
Δ_b is quantitative error of light intensity sampling.

The measured range of optical density should be $\langle 0, 2.5\rangle$ in our application.. The relative errors should be lower than 1%. These requirements are fulfiled by 12-bits CCD camera. *We will deal with the problems of using the 8-bits CCD camera by extending its dynamical measurement range.*

Solution. We can measure density up to a value of 1.2 with relative error less than 1% by the 8-bits CCD camera. We have developed a new method which can measure density higher than a value of 1.2 with the same relative error limitation.

We suppose that the output of the CCD sensor works in a linear part of its characteristic. This characteristic can be written simply (1) and assuming the lighting E_e = constant (2).

Let us assume $U < U_{max}$, where U_{max} is maximal output voltage in linear transmision characteristic of CCD sensor.

$$U = k \times \int_0^{t_{int}} E_e(t)\,dt. \tag{1}$$

$$U = k \times E_e \times t_{int}. \tag{2}$$

where U is output voltage, k is transmission constant, t_{int} is integration time.

Using the CCD camera with an electronic shutter, we can make two measurements with E_e = constant, but with two different shutter times. We can extend dynamical measurement range in that way. As some pixel output can be saturated while measuring with longer shutter time the next required feature of CCD camera is an antiblooming. *This method is strongly limited by proper functionality of the antiblooming gates.* The relationship between the two measurements is expressed :

$$\frac{U_2}{U_1} = \frac{T_{int2}}{T_{int1}}.$$

The extension of dynamical measurement range depends linearly on the integration time.

The CCD camera should work in linear *mode*. It means that automatic gain control and autoiris should be switched off, gama correction should be set to 1. We would again point out that the lighting E_e has to be constant, in the best case the source of light should be supplied by stabilized direct current. A frequency spectrum of the light source should be out from the infrared range or IRcut off should be used.

Result. The method was verified with an one line CCD sensor Fairchild CCD191 and is currently tested with 2D Philips camera LHD 0703.

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RENDERING REAL WORLD OBJECTS WITHOUT 3-D MODEL

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Key words: computer vision, 3-D objects rendering, combination of characteristic views, image matching

Methods which are able to capture a real object and render it from an arbitrary different viewpoint usually use a 3-D model of the object. The bottleneck of these methods is the 3-D model creation. It is a substantial problem which has not yet been solved for objects of complex shapes. Our approach involves representation of the object by a *set of primary 2-D views*, rather than by its 3-D model. Any view not contained in this set is obtained as a combination of a small number of the closest primary views. The advantage of this new approach is that objects of more complicated shapes can be handled and that the access to views is faster than in the case of rendering the 3-D model. The result of our survey of the state of the art is that no information has been published so far about any system which is able to capture and render real-world objects using a similar approach, though there are several inspiring papers (e.g., [4]).

The *idea of the method* is as follows: A set of primary views covering the whole surface of the object is captured. These views can be accessed directly; only intermediate views are missing. If information about the correspondence of the primary views were available, we could obtain any intermediate view by interpolating between a subset of primary views close to it.

To proceed, the following problems must be solved: (1) Determining the position and intensity of a pixel in the interpolated view using positions and intensities of n corresponding pixels in n primary views. (2) A visibility problem for the pixels in the interpolated view. (3) A correspondence problem for n-tuple of the primary views. (4) The choice of the minimum but sufficient set of the primary views. In our research up to now, we have found promising approaches to solve (1), (2) and (3). Of these, the approaches to (1) and (3) have been supported by successful experiments. We have shown that the position of a pixel in the interpolated view can be approximated by the *linear combination* of positions of corresponding pixels in the primary views, assuming the proximity of the views. We have outlined the solution to the visibility problem in the interpolated view under the condition that every point on the object's surface is visible from at least n primary views (n given typically 3 or 4). We have proposed the method for acquiring the correspondence, based on the already published work [1]. We have not dealt yet with the difficult problem of the choice of the minimum but sufficient set of the primary views.

We have conducted *experiments* with the construction of the interpolated view from a pair of primary views. In fact, this state of our research is already sufficient to render a real-world object from any view lying on the circle around the object (see the figure).

Fig. 1: Two primary views of the object (a linen towel), rotated around a vertical axis by 0° and 10° (*left and right*), and the interpolated view viewed as if rotated by 5° (*middle*).

In further work, we plan to improve the correspondence algorithm, to make the analysis of the error due to the linearization of the problem of finding the position of a pixel in the intermediate view, and to find at least a partial solution to the problem of selecting the minimum but sufficient set of primary views.

At the end of our research, we intend to construct a prototype of a device able to render a captured real-world object from an arbitrary viewpoint, lying on a sphere around the object. The rendering algorithm in this prototype should be implemented on the multiprocessor-multidisk system [3]. We expect this will make possible a frame generation rate high enough to achieve the impression of the real-time moving of the object on the screen.

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CURVATURE VIA CONVOLUTION WITH THE GAUSSIAN REVISITED

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Key words: image analysis, computer vision, discrete geometry

Curvature of the Digital Curve via Convolution with the Gaussian. The improvement of computing curvature of the digitized curves was presented in [1]. Its extended summary is presented here. The newly proposed curvature computation method can be used in computer vision in various curved objects' descriptions. We use it in our projects[1] concerning 3D curved object recognition.

The standard scheme of computing curvature using convolution with the truncated Gaussian kernel was studied. First, we showed that systematic bias caused by curvature smoothing can be removed. Second, we demonstrated that a large portion of the error has roots in other phenomena (anisotropy of the raster, limited size of the Gaussian, numerical integration of the convolution, and discretization). We have applied performance analysis and the discrete nature of the data has been considered. The proposed method proves to be better than the best method proposed in the survey paper [3].

Let us briefly review current approach [2]. Suppose we have a curve in the parametric form $\mathbf{x}(t) = (x(t), y(t))$. The basic idea is to obtain a smoothed curve $\mathbf{X}(t) = (X(t), Y(t))$ by the convolution (denoted $\odot$) of the original curve $\mathbf{x}(t)$ with the Gaussian filter $G_\sigma(t)$, i.e. $\mathbf{X}(t) = G_\sigma(t) \odot \mathbf{x}(t)$. Derivatives of the smooth curve can be computed via convolution with the derivative of the Gaussian kernel; the second derivative can be computed as follows: $\mathbf{X}''(t) = G_\sigma(t) \odot \mathbf{x}''(t) = G''_\sigma(t) \odot \mathbf{x}(t)$. The parameter σ is related to the scale at which the operator G_σ acts.

Lowe [2] computes the curvature using derivatives estimated according to the previous equation. It has been observed that a curve is shrunk towards the centre of curvature in the process of smoothing. The side effect is that the estimated curvature κ is significantly biased. Lowe shows that for original $1/\kappa \gg \sigma$, the estimated $\kappa \approx \|x''\|$.

A circle of radius r passing through the origin and centered at $(r, 0)$ has been used instead of the general $\mathbf{x}(t)$ to ease the development of the degree of shrinkage. The coordinate function $\mathbf{x}(t)$ for a path length parameter t/r is $x(t) = r(1 - \cos\frac{t}{r})$, $y(t) = r\sin\frac{t}{r}$.

Bias elimination. Our aim was to find a formula that compensates for a good deal of the curvature computation error as a function of the σ of the Gaussian.

We wanted to discriminate the error caused by smoothing from other error sources (anisotropy of the raster, limited size of the Gaussian (e.g. 3σ), numerical integration of the convolution, discretization). Therefore, we decided to compute the equation for the curvature κ analytically, obtained by the convolution of the Gaussian in a continuous case. To ease the computation, the curve was locally modelled by its osculating circle.

By evaluating $\kappa(t)$ at $t = 0$, we get: $\kappa_m = \frac{1}{r}t\frac{d^2}{d\sigma^2} = \kappa e^{\frac{\sigma^2\kappa^2}{2}}$, where κ_m is the theoretically computed curvature, r is the radius of the circle, $\kappa = 1/r$ is the curvature of the osculating circle and σ is a standard deviation of the Gaussian.

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Once κ_m and σ are known, unbiased κ_{mu} can be computed from the following equation: $\kappa_{mu} = \kappa_{mf} \cdot e^{\frac{\sigma^2 \kappa_{mu}^2}{2}}$. We can restrict ourselves to $\kappa_{mu} \geq 0$ because $\kappa_{mf} = f(\kappa_{mu})$ is an odd function. The right-hand side of the previous equation is a monotonically decreasing function from κ_m to 0 and the left-hand side is a monotonically increasing function from 0 to $+\infty$. This implies that there exists just one solution. It can be computed numerically.

Conclusion. It is evident from the equation for computing κ_{mu} that for *recognition purposes via hashing, no shrinkage correction has to be performed.* The biased curvature κ_m is in one to one correspondence with κ. It implies that κ_m has the same descriptive power as κ itself.

We conducted exhaustive experiments [1]. They imply that we can measure curvature of a circle with an error varying between 8 to 24 %. The remaining error is still significantly biased. Further improvements could be achieved if other phenomena like Gaussian kernel truncation, numerical integration, and violation of common parametrization of $G_\sigma(t)$ and $\mathbf{x}(t)$ were investigated. The local model of the curve also plays a role: in highly curved parts of the curve, the osculating circle is not a sufficient model.

The experiment with the clothoid curve [1] teaches us that for small σ compared to the radius of the osculatory circle the results are strongly influenced by raster anisotropy. This effect is for $\sigma = 1$ and $\kappa \in \langle 0, 0.15 \rangle$ of at least the same importance as the error caused by curve shrinkage.

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THE SIMULATION OF THE REAL CAMERA FOR THE RENDERING

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Key words: computer graphics, rendering, camera, ray-tracing, optics

The most popular rendering methods in computer graphics for three dimensional scene are ray-tracing and radiosity and their combinations. They are characterized by simplified approach to capture the depth of space. This increases the quality of the rendered images. Method using the spread point function depending on the distance of object from camera in the space was described in 1981 by Potmesil and Chakravarty [2]. This method provides quite good results, but it fails in certain cases. One of them is a problem of overlapping objects, and the second one is visualizing objects in a mirror.

That is why we have proposed different approach of capturing the depth of space. We have implemented a model of a camera, which solves imperfections mentioned above. It even enables to simulate optical faults in a real camera.

Model of a camera. Camera model is based on the main optical axis. A path of a ray through lenses can be described in two different ways. The first one uses simple expression based on the focal distance. The second one simulates refraction surfaces (a part of a sphere or a plane). Both methods can be combined together. The computer model allows also to create such an optical system which cannot be built in the real world.

Processing of rays. The size of a blur on a film cannot be described functionally. That is why we use the *generation area*. For every pixel on the film frame we generate a set of rays casted from the evaluated pixel through *generation area* to the optical system. The rays pass through and enter the 3D scene, where standard ray-tracing algorithm is used for their evaluation. The color of pixel is evaluated as an average value of the set of rays. The shapes for generation areas can be *circle*, *ellipse* or *rectangle* (n rays for one pixel), or five or nine points *supersampling* or *jittering* methods.

To speed up the whole rendering, adaptive method of ray generating is suitable. We can take into account any of the methods described above and add an adaptive approach to all of them. The principle preserves the property of blur and speeds up the rendering $n:2$ comparing to non-adaptive method. A similar method can be used also for antialiasing effect, especially in the sharply visualized areas.

Camera preprocessor. The aim is to design the optical system as a preprocessor for commonly used ray-tracers (see Figure 1). The ray-tracer must accept the definition of input rays (the origin and the direction) from our preprocessor. After evaluation of input ray, the resulting color must be returned to a preprocessor. This condition can be satisfied for almost every ray-tracer, if it is available in a source code, not as a standalone program.

The model presented in this paper is based on idea of generation area. The quality of image depends on the right size of the generation area and its position. These values are important parameters of the system. There is no easy way to set all parameters correctly.

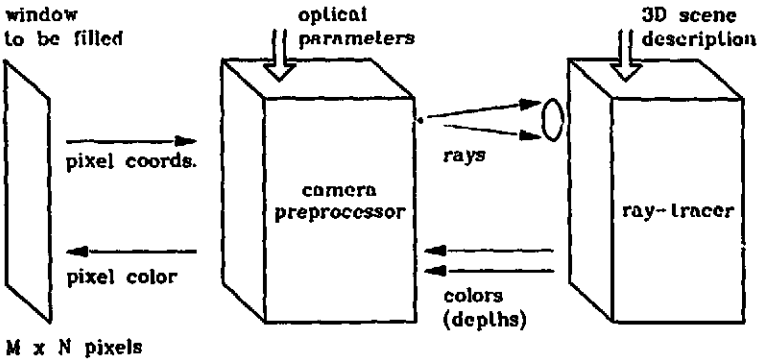

Fig. 1: Connection of camera preprocessor with other processes

The optical system can be designed arbitrary by user, so the only suitable method seems to be the iteration. We have implemented set of different methods for setting the optical system:

Set Sharpness, Set Sharpness From To, Focus At, Focus Infinity, Autofocus.

We have implemented also the tool for finding the focal distance of created optical system. This method is used for experiments concerning design of appropriate parameters of optical system.

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RULES INDUCTION FROM EXAMPLES FOR FUZZY CONTROLLERS

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Key words: fuzzy control, rules induction, rules evaluation

The aim of the intelligent controllers is usually to find a substitution for anthropomorphic control procedures realized by a human operator. Fuzzy controllers may utilize the operator's experience in linguistic form. In many cases, the operator is unable to formulate all his decision rules explicitly. One possible way to obtain the rules in these cases is to observe the operator's activities and to try to induce the rules from measured data. The method submitted provides a tool for this purpose.

Most of industrial control processes, where the application of classical control approaches is problematic. Let us take as an example biotechnological processes. They are usually nonlinear and nonstationary in nature, and most of the variables describing these processes cannot be directly measured on line.

For these reasons, most biotechnological processes are manually controlled and the operator of these processes usually has a good idea of how their charges will behave under most operating conditions. On the other hand, manual control of these bioprocesses is a challenge for fuzzy control application. There are many successive control systems for biotechnological processes utilizing a fuzzy approach. The most popular example is using fuzzy controllers for wastewater purification processes.

The crucial problem in the design of a fuzzy controller is speciffyingf the rules in linguistic form. The actual methods for finding these rules are mainly oriented to the acquisition of human knowledge. An experienced expert or skilled operator is interviewed and asked which rules he uses in specific situations to obtain a successful decision. But often a successful operator is not able formulate the rules explicitly. In this case one possible method is to observe an operator's activity, to store all initial conditions and corresponding decisions and then to try to find corresponding rules by analyzing the data.

In this paper, a method based on the information theoretic approach is submitted. The method utilizes an approach known as a General System Problem Solver (GSPS) suggested by G.J.Klir [1]. The dimensions of state space of the considered process is estimated by the GSPS. The control action depends on state variables. Some of them are not directly measured. They may be reconstructed with the help of other variables which are directly measurable. Let us consider that we measure all the variables of the process which can probably carry information for the necessary state variables. Some variables may be redundant and therefore must be excluded. Once accomplishing these measurements, we obtain data which may be arranged into the matrix form. The rows of this matrix, called an activity matrix, correspond with individual variables (control action and state variables) and columns correspond with sampling periods. (Let us assume that the sampling frequency is optimal) [2], [3]. Our aim is now to find all variables and their delayed values (because the system is assumed to be dynamic) which carry information for control action. Formally it means we must choose entries of an activity matrix with the help of a specific matrix called

"mask". The elements of a generative mask are zero, negative, or positive, meaning "neutral element", "generating element", and "generated element", respectively. The generating element corresponds with the control action, generated elements are founded and neutral elements have to be excluded as redundant.

To find the entries carrying maximal information for control action, i.e., the mean mutual information is used. We gradually check the mean mutual information between the control action and actual and delayed values of all variables and all their meaningful combinations. During this process, the redundant variables are excluded (they carry no additional information) and finally, we obtain the group of variables carrying maximal information for control action. In other words we obtain the dimension of the state space [1], [5].

The following step is an appropriate partition of the state space for cells associated with linguistic terms used in the rules in linguistic form. There are different approaches to choosing the number and shape of relevant membership functions in common use. We may define membership functions apriori, or we may define only the desired number of fuzzy sets and estimate their membership functions with the help of some clustering algorithm using the available data. (Algorithms like ISODATA , fuzzy C-MEANS etc.) [6].

Having the partitions the connections between individual cells and relevant control actions must be specified. These connections may also be evaluated by means of mean mutual information. For any cell of the state space, the strength of the connections with any degree of control action may be estimated. A connection associated with the higher degree of mean mutual information corresponds with the founded rule.

The method submitted here is not so complicated and provides information on the quality of available data. (If the data are sufficiently rich to cover all relevant cells of the state space and to allow an inference of all relevant rules).

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USAGE OF FUZZY LOGIC FOR COMBUSTION ENGINE IGNITION CONTROL

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Key words: internal combustion engine, spark advance control system, fuzzy control

Recently, people have changed their view on Combustion engine control systems in automobiles. Before that they had considered them as necessary engine equipment. With the help of the evolution of information processing and semiconductor technology, it is now possible to design complex electronic control systems . The systems are both sufficient in reliability and affordable. Automotive electronics has developed very dynamically in the last ten years. At this time, the price of the automobile electronics represents 20 — 35 % of the whole price of the new constructed cars and this trend will undoubtedly increase. Even though there are a lot control systems in cars (air-conditioning control system, brake system control, information and navigation systems, etc.), we will concentrate on the engine ignition control systems in our article. In regards to the long cooperation of the Department of Control Engineering with the car industry (Škoda, Tatra, PAL and Tesla Sezam) we have obtained a lot of information about requirements and targets in the area

Over the last three years, we have been engaged in cooperative research (internal CTU grant no. 8008/91,92,93) with the Faculty of Mechanical Engineering (Department of Combustion Engines) and the Technical University of Liberec. In this cooperative project, we designed and constructed several interesting versions of modern electronic ignition control systems and developed several algorithms for spark advance control to reach optimal operation parameters in regards to exhalation limits. Electronic digital ignition systems enable to control turboboost engines that work under the lean burn regime. These engines essentially reduce the amount of nitrogen oxides NOx and simplify the problem of exhaust gas catalytic purification. To reach a similar effect that is typical for engines controlled in the area of the stechiometric ratio $\lambda = 1$, it is possible to use a one way catalyzer that is much cheaper. To use engines under the lean combustion regime, it is necessary to design a special ignition control system that generates sparks of high energy and works with optimal timing all the time. In this case, the optimal spark advance seems to be a very complicated multivariable function and the control system that would be able to control the engine according to the function under all working conditions can only be a digital system. This kind of system most often works as a memory. The data for all operational conditions are located in the system memory (system map). The engine is equipped with sensors of the variables that have the biggest influence on the advance (angle velocity, load torque, coolant temperature, etc.). The variables are periodically measured and the optimal spark timing is chosen from the system map. Sparks are generated with the help of an actuator.

The control system that we developed for gas engines with lean combustion also works this way. This system uses the MH 1210 customer integrated circuit, which was developed

in Tesla Rožnov according to the author's design. As a result of the project, a prototype series of the ignitions control systems for gas engines in ecological city buses was produced.

The method we used causes very quick system responses and is more advantageous than other feedback systems. Even though the developed system is successful in practice, we can not omit several shortcomings caused by the direct control method we used. This method only provides optimal control when the coincidence between the system map and the real engine properties exist. The system map is created according to the etalon and the real engine properties can be different from the etalon and changes in the progress of operation. Another problem of the method is that only several variables which have an essential influence on the spark advance are measured. The variables that are not measured can cause inconvenient timing of spark generation.

Although the grant project has already finished and the results are fully used in the automobile industry, we continue with our research. We are creating a new control algorithm for the designed control system hardware to remove all the disadvantages we mentioned above and to maintain quick responses during accelerations. This combined system will be controlled according to the map during acceleration and deceleration. Other algorithms will be active during steady conditions. This feedback algorithm will maximize a quality function in the work point given by the map value in this point. From the practical point of view, the most advantageous way is to maximize the engine torque. If the load is constant, the engine torque changes causes angle velocity changes of the engine. It is very easy to measure them. The designed regulator will maximize velocity by the spark advance changes and substitutes the original map value with the new value. The regulator maximizes the thermodynamical efficiency of the engine. Sometimes it is more important to control the exhausted gas composition. This kind of control must to be based on other principles.

The main reason for designing mentioned control systems is pollution control. But variables characterizing the degree of pollution are not usually measurable on line. The conventional feedback controller is usually designed as a state controller. The unmeasurable state variables are typically estimated with the helps of a state observer or Kalman's filters. It is very problematic under condition such as low precision of the sensors (high noise) and nonlinear nature of the combustion process. One prospective method for solving this problem is using of nonlinear controller designed as a fuzzy controller. This type of controller may utilize only the measured state variables.

The final results of this research must be postponed until next year and we assume that the research will be continued as a grant project next year.

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A LEARNING PARADIGM FOR NLP

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Key words: learning, tagger, part of speech, lexical/contextual rules

Many tasks in natural language processing are based on proper identification of the role of words in a text, their tagging. It can be derived using complex linguistic knowledge, which is very difficult to lay down explicitly, in an exhaustive way and without loss of consistency. That is why there is an increasing tendency to use different learning techniques for its extraction.

There are Markov-model based stochastic taggers which use the probability to find a word tagged with *Tag* in the text *P(word/Tag)* along with the probability *P(Tag/previous n tags)*. These stochastic taggers are able to reach very high accuracy. Nevertheless, information is not represented in a directly understandable form. The rule-based tagger created by Eric Brill [2] keeps the high rate of stochastic taggers, but unlike them it captures the relevant knowledge in a small set of rules. The basic idea of that tagger is to use a learning strategy (Transformation-Based Error-Driven Learning), so that sets of lexical and contextual rules are extracted from a pretagged corpus (the user can choose his own set of tags). There are only a few transformations (metarules) which describe the features relevant to the part of speech as: the tags on both sides of the word, the first/last characters of the word, or the possibility to find in the corpus such pairs of words that one can be derived from the other.

In real applications, there is an urgent need to handle unknown words. The stochastic taggers usually introduce the same probability *P(Unknown Word/previous n tags)* for all unknown words into the model.

On the contrary, the rule-based tagger is able to extract lexical rules based only on word prefixes/suffixes, so that it can make some hypotheses about words even if they are unknown. The performance of such a tagger when unknown words could appear in the text is still very impressive. For instance, an accuracy of 97.2% was achieved for 600,000 words from Penn Treebank Corpus [1].

The method on which Eric Brill's tagger is based is not language dependent. Nevertheless, there is no experience with efficiency of that algorithm in the case of languages with a rich morphology. Our first experiments with an Italian legal domain corpus show that even a text of limited size (2,700 tokens) is enough for finding some important traditional-grammar-like rules. The corpus has been tagged in a semi-automatic way by an experienced linguist using the help of specialized software (Morpho-analyzer of ARIOSTO [1]). It is important to keep in mind that the final tagging of an unknown word is reached after the application of *all* possible rules in their proper order, so that each rule only partially restricts the number of candidates for a particular tag.

One of the derived rules is the following: "Tag a word as PA (prep.art.) whenever the addition (deletion) of the string "la" on (from) the end of word results in a word that can be found in the text." For instance: "del <-> della, nel <-> nella" and so on. The comparison between contextual rules that have been learned from an Italian text and those learned from

English Brown corpus shows many similarities. For instance: "Change the tag from *common noun* to *trans. verb* if the previous word has the tag *adverb of place*.(Italian)"; "Change the tag from *common noun* to *verb* if the previous word has the tag *adverb*.(English)". According to this rule, the word *work* will be tagged as *verb* in the next sentence: "They always/*adverb* work/*verb* with energy" even when *P(work/common noun) > P(work/verb)* if we do not care about the context.

Evident parallels between the contextual rules and the rules of the traditional grammar can also be found. For instance, our first Italian rule distinguishes transitive from intransitive verbs by the occurrence of an object or its determiner at their right side.

During the learning process, a simple lexicon containing all words from the corpus and their possible tags is being created. No concept of word paradigm is applied and there are no rules how to connect the forms of the flexible words with their basic form. Such an approach is in a certain way an alternative to the morphological vocabularies. A great deal of a linguistic experts' work to capture the peculiarity of the language in an exhaustive set of rules is replaced by the less expensive and much more intuitive task of "choosing the right tags for the learning corpus".

Nevertheless, many applications still use the concept of the morphological vocabulary [1], [3]. Their advantage is a relatively compact list of basic forms of words when compared to the very large lexicon of Eric Brill's tagger. The biggest advantage of the strategy using morphological vocabulary is that the same semantic value is associated with all forms of the same word. The price we pay for that is the boring manual work to describe the relevant subset of rules for each word.

Keeping this in mind, it could be worth trying to merge the benefit from the morphological vocabulary with the lower cost of the learning strategy. Normally, for the purpose of the part of speech tagging, words with different flexion are tagged by the same tag if they have the same part-of-speech role. This situation is common for several languages, for instance, there is one part of speech *Verb* with 82 different patterns (*aimer, placer, manger, peser,* etc.) in French. Similarly, there are several patterns for Czech nouns (*hrad, pán, muž, stroj...*) and for Italian verbs (*amare, credere, capire, partire*). If we use tags referring to morphological patterns of words instead of the part-of-speech tags, it could be possible to guess the pattern of an unknown word found in the text. Even more, Eric Brill's tagger can return multiple tags for a word, so that the operator should choose the right tag from the few most probable. Based on this idea, the results of our experiments with the Czech language will be reported in the near future.

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HUMAN ERROR DETECTION

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Key words: human error, man-machine systems

A human operator controlling a process can perform various control tasks. Skill-based control, such as minimizing control errors, represents the lowest level tasks and has been studied intensively during the last several decades. Supervisory control of complex systems comprises higher level operator tasks, namely system fault detec- tion, diagnosis and recovery. In the cognitive engineering approach, hig- her level tasks are denoted as rule-based and knowledge-based. Error detection and diagnosis for these task categories have been intensively investigated in last years.

The first methods of human error description have been based on a be- haviouristic approach. Only the consequences of human errors were ac- counted for. The task performed was classified as a success or a failure. The analysis of human errors requires the knowledge of human cognitive mechanisms. This reason has stimulated research in modelling cognitive and decision making activities of operators. Cog- nitive classification of human errors should respect knowledge orga- nization, cognitive control and characteristics of the environment where the performance takes place. On the skill-based level, human error can be denoted as slip, meaning intention correct and action not carried out as planned. On the higher level, a rule-based mistake means faulty application of well known rules or procedures both in identi- fying a situation or in adopting a plan. On the highest level, a know- ledge-based mistake means selected plans do not fit with the problem to be solved.

There are two basic approaches to error detection: the signal-ba- sed and the model-based methods. In the case of the former, proper symptoms are derived from the measured signals to detect errors. Ty- pical symptoms are the magnitude and the derivatives of the measured time function, limit values and some statistical characteristics. The latter make use of the operator behaviour model. Construction of such a model is the crucial point of the method. While for direct control tasks, the operator behaviour can be modelled by the use of analytical models, for higher level tasks qualitative or knowledge- based models are necessary. Examples of advanced models of this kind are described in [1] and [2].

The simplest method of fault detection in continuous tasks consists in a threshold test. If constant thresholds are used, the problem of effects of noises and other unknown inputs arises. If the threshold is too small, false errors will occur, if the threshold is too large, small errors can not be detected. Especially for human error detection this method brings several disadvantages, which can be avoided by the use of the fuzzy approach.

One way is in the introduction of an adaptive threshold as descri- bed in [3] and [4]. The input measured values are converted to linguis- tic terms by applying fuzzy sets. Now fuzzy rules are introduced for the evaluation of error symptoms and other error influencing factors. The following defuzzification produces a numerical value giving the threshold for error detection.

Another approach is based on fault fuzzy definition appearing in reliability theory. In [5], a method for fuzzy fault detection is proposed which detects faults by comparing

measured values to fuzzy simulated ones. The measured value can also be introduced as a fuzzy quantity and so no threshold or special detection procedure is needed.

The fuzzy concept for human error detection was tested on a simulated horizontally moving pendulum of variable length (a crane) controlled by a human operator. The crane was simulated by the use of an analytical model and fuzzy rules enabled various error definitions derived from pendulum angular deflection. The human operator error was indicated as membership values for three linguistic variables.

Further research will be oriented on human operator behaviour modelling for simple tasks and under the consideration of behaviour influencing factors. These models should serve for human error detection.

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MATHEMATICAL METHODS AND COMPUTER SUPPORT OF THE DECISION ON INNOVATIONS

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Key words: innovation, project, mathematics, decision, optimization

Some of the results, which were achieved in solution of the research project E-1, are briefly described in this paper.

Deciding on the innovations, mathematical methods are applied (and in our research they are prepared for industrial and pedagogical use) e.g. in modelling of innovation life cycle (rise, development, propagation and diffusion of innovations), as well as in innovation project management. In the computer support and mathematical modelling of innovation project management [1] our attention has been concetrated mainly upon

a) the selection of Research and Development Projects

b) the scheduling of the innovation projects

c) the chronicling with contemplating the deviation of the actual state of innovation projects from the scheduled state

The present situation in Czech enterprises signalizes that there are no program systems available (by now) which would make us possible to carry out effectively multicriterial selection of hundreds of projects simultaneously, with tens of criterion functions including non-linear ones, and tens of resource limitations by means of personal computers.

This is why a decision support system [2] has been created for solving the following problem at the computer PC AT: To choose for the plan some of the s from innovation projects. Let i be an index of project ($i = 1, 2, ..., s$). The goal of the solution is to find for all i the values bivalent variables δ_i for which $\delta_i = 1$ if the project is selected for the plan, $\delta_i = 0$ in the opposite case. Main requirements of the solution are the following:

a) to satisfy the resource limitations of type

$\Sigma_i a_{ij}\delta_i \leq b_j \qquad (a_{ij} > 0,\ b_j > 0, \quad j = 1, 2, ..., m)$

b) to make every effort to maximize the criterion functions $z_j \quad (j = 1, 2, ..., p + q)$. Here $z_j = \Sigma_i c_{ij}\delta_i \quad (j = 1, 2, ..., p)$ (criterion functions of gain),

$z_{p+k} = (\pi_k - \Phi_k)/[l(\Phi_k - \pi_k) - \pi_k] \in [-1; 0] \qquad (k = 1, 2, ..., q)$

(criterion functions of balance),

$\Phi_k = (\Sigma_{i \in S(k)} \mu_i \delta_i)/\Sigma_i \mu_i \delta_i \quad (k = 1, 2, ..., q)$ is the ratio of the manpower allocated to projects belonging to category k to total manpower needed for the solution of all projects that will be selected for the plan. The projects may belong to different categories which need not be mutually disjunctive. Simultaneously $S(k)$ = the set of projects falling into category k, μ_i = *manpower used by project* i, π_k = *ideal value of quatity* Φ_k,

$l(x) = 0$ for $x < 0$, $l(x) = 1$ for $x \geq 0$. To solve this problem we have created algorithms

[3] based upon the principle of reference point [1],[5], allowing the introduction of heuristic iterations, with agregative scalarizing criterion function and a dialogue regime. Having carried out the optimization, the user may, for example decide which of the criterion functions satisfy him and which do not, after which the system in the dialogue with him gradually improves the solution.

The innovation projects which have been selected should be scheduled [6], [7], [8], [9]. A multiproject scheduling program system has been created based on heuristic priority rule for shifting of the innovation project activities in the case of limited resources, adapted for a well-comprehensible communication with the user and having a graphical output [10]. This system has been applied in the industrial enterprise [8].

The third program system created is based on the so-called SSD-graph [11] which combine advantages of Gantt charts and Petri nets. This program system contemplate the deviation of the actual course of projects from the demanded scheduled state and mapped it into a 5-element scale. It is an useful tool for praxis of the innovation project implementation. All the program systems are adapted for an associated unique common database system.

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FUNCTIONAL ANISOCHRONIC STATE ESTIMATORS FOR FAULT DETECTION IN HEREDITARY SYSTEMS

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Key words: model-based fault detection, delays, state space, hereditary properties, delay functionals

The principle of so-called model-based fault detection methods consist in the use of state estimators or filters for analyzing data measured on monitored plant or control system, evaluating how far they correspond to the expected standard model function. By means of special information procedures the model allows to provide the so-called analytical redundancy and to generate residuals (deviation signals) which serve for detecting system faults. The method is well elaborated [1] for the models based on standard state space, i. e. described by system of ordinary differential state equations. These models are well suited for mechanical and electrical systems with concentrated parametres, however, they are not very suitable for the systems where substantial delays and aftereffects appear. The classical state space model of this kind of systems requires to introduce artificially a higher number of state variables so that most of them can not have corresponding properties on the monitored object.

In previous author's papers [4], [5] a so-called anisochronic state space model has been introduced and investigated, being marked by substantially lower number of state variables and ability directly to express any form of system hereditary properties (delays, latencies, aftereffects). Linear form of anisochronic state model results in the following functional differential equations set

$$\frac{dx(t)}{dt} = \int_0^T dA(\tau)x(t-\tau) + \int_0^T dB(\tau)u(t-\tau), \quad y = C \cdot x \tag{1}$$

where x, u, y are the vectors of system state, input and output respectively, and $A(\tau)$, $B(\tau)$ are the respective functional matrices assigning not only the gain coefficients but also the appropriate delay distributions. Only the real accumulations on the plant are described by the left-hand-side derivatives $\frac{dx}{dt}$. Due to this, as a rule, almost all of the state variables x are measurable and may be considered as system outputs too.

A state estimator for the anisochronic system (1) may be designed in an analogous way to the standard one, i. e. as a parallel model with a special feedback from the measured output y. It can be expressed by the functional equations

$$\frac{d\hat{x}(t)}{dt} = \int_0^T dF(\tau)\hat{x}(t-\tau) + \int_0^T dG(\tau)u(t-\tau) + \int_0^T dH(\tau)y(t-\tau) \tag{2}$$

where $\hat{x}$ is an estimate of the state vector. To build up a convergent state estimator, it is necessary to select suitable functional matrices satisfying the following conditions

$$G(\tau) = B(\tau), \quad F(\tau) = A(\tau) - H(\tau) \cdot C \tag{3}$$

The feedback matrix $H(\tau)$ is to be select in a similar way as in standard estimators, i. e. with the aim to assure a good convergence of $\hat{x}$ toward x even if the model matrices $A(\tau)$, $B(\tau)$ are identified not very exactly. It is purposeful to design $H(\tau)$ as a functional matrix too, since then is it possible to eliminate some of the delays from the estimator dynamics this way.

The task how to perform the synthesis of $H(\tau)$ or the synthesis of anisochronic system in general is a rather new problem in control theory. Two ways of approaching this problem have been followed and employed:

a) system representation by its characteristic function in complex domain and its following shaping

b) $H(\tau)$ design with the aim to get an almost delayless system of the same order as (1).

The first approach has been developed in a general extent, i. e. for any control or dynamic problem which can be considered as a task of parameter assignment. The main results have been presented in [5]. The latter is an approach suitable particulary for setting up an estimator feedback. A well-proved option of this way of solution is as follows. By setting-up $H(\tau)$ it is aimed to get an estimator matrix $A(\tau) - H(\tau) \cdot C$ which is near to a target dynamics with n-times repeating zero $-\frac{1}{T_e}$ so that

$$det[p1 - \int_0^T dH(\tau)e^{-p\tau}] \quad \longrightarrow \quad (p + T_e^{-1})^n \tag{4}$$

where T_e is a suitable time constant. It is necessary to select an optimal value of T_e providing an enough fast estimate convergence of (2) without threatening estimator stability. The main achievements of anisochronic functional state estimators are the following

- plants with hereditary properties may be followed by models with relatively low number of state variables
- most of state variables are introduced as physical real properties and are measurable as a rule
- anisochronic state approach distinguishes between delay and accumulation dynamics; it means a more natural and true principle of modelling for thermal processes, chemical reactors, biological phenomena etc.

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COMPUTER-AIDED MODELING AND OPTIMIZATION OF MECHATRONIC SYSTEMS

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Key words: computer-aided engineering, mechatronics, modeling, optimization, design

The aim of using software design tools is not only to make the design process faster, cheaper and more comfortable. Even more important is to achieve higher level of functionality and better quality of the designed products. Reducing the need for experimental verification using real product prototypes, which is inherently slow and expensive, by computational techniques allows for asking many 'what if' questions which cannot be answered by experimenting in principle.

The ultimate goal of any computer-based design system is to proceed from the given product specification up to the product manufacturing and testing automatically. Despite of the large number of engineering software tools available in the market already, the actual situation today, however, is to still have just 'islands' in the design space, mostly unlinked. Existing tools for direct synthesis are applicable just to very few classes of engineering problems. This underlines the importance of simulation and optimization. In the case of mechatronic products, the simulation and optimization methods as well as tools should be applicable to all the engineering disciplines, design levels and design descriptions involved in the design process of the products.

There exists a wide variety of simulation tools for physical design level, some of them very sophisticated. These tools, however, are mostly dedicated to one engineering discipline only. For this reason, designers of multidisciplinary systems still commonly resort to deriving the system equations 'by hand', and to solving them using a block-oriented simulator. The block-diagram oriented simulation programs are well suited for the design levels of higher abstraction only. Using these programs for the physical design level is tedious and error prone.

To use computers for simulation efficiently means to use them both for formulation as well as for solution of the system equations. The programs for symbolic computations are of a rather limited significance in the case of engineering system equation – only a marginal variety of engineering problems posses an analytical solution. Therefore, the engineers have to stick mostly to the numerical modeling and simulation procedures.

The first author has developed a novel methodology for multipole modeling and automatic equation formulation of equations for mixed-energy-domain systems on the physical as well as on higher design levels. This approach has proven to be considerably more efficient and user friendly than that based on block diagrams or bond graphs. The approach allows for setting up models of multidisciplinary systems from submodels of the system components in a kit-like way isomorphic with the structure of real systems. At the same time,

the approach is applicable to system modeling on different levels of their abstraction using different design descriptions.

The second author has contributed considerably to the mathematical theory of numerical minimization, especially in the area of variable metric methods for unconstrained minimization. Based on his unifying approach he has extended the applicability and computational efficiency of these methods. He has also developed several minimization methods of his own. His effort resulted in multipurpose and robust optimization packages SPONA and UFO.

It was just quite natural to combine both authors' approaches complementing each other to achieve objectives of the project. The combined approach has been implemented in a prototype software and demonstrated in the case of several design problems. The developed methods has been published, and specification of the developed software is readily available for further upbringing to its commercialisation.

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VALIDATION AND GENERATION OF SYMBOLIC-NUMERIC ALGORITHMS

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Key words: algorithm validation, code generation, symbolic computation, computer algebra, exchange integrals for atomic collisions

For the solution of many problems from physics and other fields (see e.g. [1]) it is necessary to combine numerical computation and symbolic, algebraic computation with formulae. Symbolic processing of formulae on computer is most naturally done by one of the available computer algebra systems (CAS), but these are slow for numerical computations. Splitting the computation into two environments, numeric and symbolic, would most often lead to problems with information exchange between them. Further, such combined computations would be useful in cases where only a particular type of mathematical objects, e.g. polynomials, are processed and where algorithms faster than the general ones implemented in CAS can be applied for these objects. It is thus desirable and already proved to be useful [1] to implement algorithms manipulating symbolically specific type of formulae in the numeric environment. However, such implementations meet other difficulties, since the algorithms dealing with formulae are complicated and their formulation in the numeric environment is tedious and error prone. To overcome this difficulty we propose a method allowing validation of these algorithms by their comparision with algorithms already implemented in CAS. Automatic code generation then guarantees that the resulted implementation is error-free. To distinquish the algorithms which perform symbolic operations in the numerical environment from other methods we call them symbolic-numeric algorithms.

The method for development of symbolic-numeric algorithm performing operation O on formulae of type TF can be shortly described by the following steps:

1. the symbolic implementation SI of the operation O in a CAS in which formulae from TF are represented as standard formulae; this implementation is usually very simple and we assume error-free
2. propose the representation R of functions from TF in numerical arrays
3. the symbolic-numeric implementation SNI of the operation O in the CAS in which formulae from TF are represented by the representation R; this implementation is typically much more complicated than the implementation SI
4. compare the results of the implementations SI and SNI on chosen input data for the operation O; comparison is done in the CAS; in the case of different results follows correction of bugs in the implementation SNI
5. automatic generation (by CAS) of numerical implementation of the operation O from the CAS-validated implementation SNI

In this method we are using the computer algebra system REDUCE with the numerical code generation package GENTRAN and numerical programming language FORTRAN.

The described methodology has been used for the development of validated symbolic-numeric algorithms for computations of two quantities used in atomic collision theory. The first, matrix elements of Coulomb interaction between two bound hydrogenic states needs evaluation of integrals

$$\frac{1}{R^{l+1}}\int_0^R P_1(r)e^{-ar}\,\mathrm{d}\,r + R^l\int_R^\infty P_2(r)e^{-ar}\,\mathrm{d}\,r, \qquad (1)$$

where $P_i(r), i = 1,2$ are polynomials in r originating from the radial hydrogenic functions. The developed symbolic-numeric algorithm includes subalgorithms for symbolic integration of the above integrals, calculation of the radial hydrogenic functions and manipulations with polynomials. The developed symbolic-numeric algorithm implemented in FORTRAN is about 300 times faster than the symbolic one implemented in REDUCE. The symbolic-numeric algorithm is much faster because it uses floating point representation of polynomial coefficients, works only with a specific type of formulae and it is compiled with static arrays. It lacks the symbolic absolute precision, not relevant for the applications.

The second, three-dimensional overlap exchange integrals for heavy particle collisions, have the form

$$\int \psi^*_{n_1 l_1 m_1}(\mathbf{r}_1)\,e^{(a_1\mathbf{r}_1+a_2\mathbf{r}_2)}\,\psi_{n_2 l_2 m_2}(\mathbf{r}_2)\,\mathrm{d}\,\mathbf{r}_1. \qquad (2)$$

where ψ_{nlm} are hydrogen like wave functions with the quantum numbers n, l, m. Shakeshaft [2] has shown how these integrals can be transformed into one dimensional integrals. For symbolic-numeric algorithm calculating the exchange integral (2) we have derived [3] a closed form formula based on the method of ref. [2]. The presented methodology has been used for checking the correctness of the closed form formula and implementation of the symbolic-numeric algorithm which transforms (2) into one dimensional integral integrated numerically.

The methodology and its applications to matrix elements (1) and exchange integrals (2) are described in more detail in [4], which also includes a fully treated simple example.

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GEOMETRIC TRANSFORMATIONS FROM THE BAYESIAN VIEWPOINT

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Key words: geometric transformation, Bayesian approach, image processing, XLISP-STAT

Geometric transformation is a very common operation in image processing. It is necessary for fitting images of different sources (e.g. aerial photos, remote sensing scenes of various spectral bands, scanned or digitized maps etc.); or, generally, for finding correspondence of objects in an image with the reality. It has even more general theoretical background, because geometric transformation is actually a special case of so called Inverse Problem.

Geometric transformation is, generally, described by the equation

$$x = T_q(\dot{x}), \tag{1}$$

where

$\dot{x}$ ... coordinates of a point in an image

x ... coordinates of a point in a required coordinate system

T_q ... transformation model; $T_q : \dot{X} \to X : \dot{x} \mapsto T_q(\dot{x})$, $\dot{X}, X \in E^2$

T_q is given by a set of parameters $q = [t_1, \ldots, t_m]$ that can be computed with the aid of the set of pairs $\mathcal{X} = \{[\dot{x}_i, x_i] \mid i \in I\}$, which represent coordinates of tick points in both coordinate systems.

The research focuses on the problem of accuracy of transformed points and its dependence on the configuration of tick points. The transformation model T_q is supposed to be known in advance. The objective of the research is to estimate the probability distribution of transformed points x for the arbitrary configuration of tick points and their probability distributions. The fundamental principles of such an approach are applicable to the variety of common transformation models (congruence, similarity, affinity, projective transform, polynomial transform etc.)

The main task is to determine mapping

$$\Psi_{\mathcal{X}} : \dot{f} \mapsto f,$$

where $\dot{f}$, resp. f stands for the probability density of coordinates $\dot{x}$, resp. x. The symbol $\Psi_{\mathcal{X}}$ includes a set of probability densities $\{[\dot{f}_i, f_i] \mid i \in I\}$ which correspond to the set of tick point coordinates $\mathcal{X}$. The mapping $\Psi_{\mathcal{X}}$ can be obtained by several ways.

By the simplest way, the density f can be computed with the aid of the vector of parameters q, whose probability distributions are evaluated by solving the overdetermined system of equations

$$x_i = T_q(\dot{x}_i), \; i \in I \tag{2}$$

by means of Bayesian inference. This way has to be used when the prior probability distributions of the transformation parameters are available. This case is significant when the geometric relation between both coordinate systems is controlled and the values of parameters has been kept in predetermined ranges (eg. remote sensing, photogrammetry, map digitizing etc.). The expected position of the point being determined (x) can be expressed in the form of probability distribution and used in the Bayesian procedure as well.

There is a remarkable consequence of using the prior probability distributions. It is connected with the reliability of the results of transformation, that is dependent not only on the number of degrees of freedom of transformation equations, but also on the informativeness of prior distributions. In the classical least-squares adjustment of transformation parameters the reliability is given only by the number of parameters, when the tick points are already established. By means of the prior distributions, the Bayesian approach provides a finer tool for setting up the rate between reliability and adequacy of the transformation model. This advantage can be easily shown in the problem of scale distortion of digitized image. The distortion can be neglected if a material of the digitized sheet (paper, film) has a high stability in size. Then all the measured coordinates are used for computation of the remaining parameters (translation, rotation). Including the scale factor in the adjustment reduces the number of degrees of freedom. It makes the results less reliable, especially when the distorsion is non-uniform and different scale factors have to be introduced in different axes and in different areas of an image.

With the least-squares method, the better adequacy of the transformation model can be reached only to the detriment of the reliability. The application of the Bayesian approach with prior distributions restrains the decrease of reliability. The more informative the prior distributions, the less decrease of reliability is caused.

Prior information is available for the positions of captured points ($\hat{x}$, $\hat{x}_1$, x_1) as well. Constrained areas where the tick points are expected to fall in are known in advance. Therefore the special probability distribution was considered for the densities $\hat{f}$, $\hat{f}_1$, f_1. The main features of that distribution are described in [1].

The mentioned advantages must be proved in some special transformation models (congruence, similarity, affinity) before this approach would be generally recommended. The most convenient software tool for such numerical experiments is a statistical computational environment XLISP-STAT. This environment is based on the XLISP programing language, which supports functional and object oriented programing styles. Besides a variety of statistical functions, XLISP-STAT includes a package for approximate Bayesian computations.

Application of Bayesian the inference in geometric transformations makes a useful connections with other operations in image processing using the Bayesian approach: classification, interpretation based on a knowledge system with Bayesian decision rules (eg. vectorization).

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QUALITATIVE OPTIMIZATION BY MEANS OF MATROIDS

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Key words: Expert fuzzy qualitative model, fuzzy AND/OR networks, structural redundancy, generalised concept of Basis, matroid structure, greedy algorithm

The synthesis of Expert Fuzzy Qualitative Models and of Qualitative Control Algorithms results in many cases in non optimal products [1]. The situation can be improved in some cases by tuning of models [2] (using special methods) but the principal problem (redundancy or non completeness) there is not solved. The theoretical line of our research programme there has been devoted to optimization of Expert Fuzzy Qualitative Models (which have been designed by Knowledge Networks composed of fuzzy AND/OR elements). In this context there has been investigated the generalized concept of Basis induced by Matroid structure [3].

Definition 1: Matroid M is a pair $(N, \mathcal{J})$, where N is a finite set (set of matroid elements) and $\mathcal{J}$ is a system of subsets (of independent elements) on N with the following properties:

a) $\mathcal{J}$ is a non empty *heriditary* system:

$$((N \in \mathcal{J}) \wedge N'(N' \subseteq N)) \Rightarrow (N' \in \mathcal{J}) \qquad (1)$$

b) If N, N' are two elements from $\mathcal{J}$ and $\#N < \#N'$, then exists an element $x \in N' - N$, and holds $N \cup \{x\} \in \mathcal{J}$.

The principal importance in our development there has been represented by the definition of Independence of functional elements.

Definition 2: $\mathrm{and_i}, \mathrm{and_j} \in N$,

$$\begin{aligned} \mathrm{Ind}(\mathrm{and_j}, \mathrm{and_j}) &\Leftrightarrow ((OUT(\mathrm{AND}(\mathrm{and_j})) = 1 +/- \epsilon) \\ &\Leftrightarrow (OUT(\mathrm{AND}(\mathrm{and_j})) = 0 +/- \epsilon)), \end{aligned} \qquad (2)$$

where **AND** represent fuzzy operator elements, OUT symbolises values of their outputs and *epsilon* is a real tolerance of extreme values on interval $L \subset R$. The symbols $\mathrm{and_i}, \mathrm{and_j}$ represent vectors of inputs to fuzzy **AND** elements.

The *formation of the Basis* has been realised in the following steps :

S1: The formation of covering Cov of set N by subsets $N_k \subset N$, k = 1,...,q of independent objects.

S2: *The formation of Matroid* $(N, \mathcal{J})$ *by means of objects from covering* **Cov** *using operations* of Definition 1.

S3: The search of the Basis by means of Greedy Algorithm [4].

After the formation of the initial Basis (deductive Basis) there has been constructed its inductive extension. This semi-formal procedure has been realised with help of Neural Network (BrainMaker v2.5) which had been prepared before and trained for the same modelled process [7].

The principle of qualitative optimization is non numerical in substance. The fragments of the structure are combined by determined optimal way. In our investigation there has been applied the structure of *vector matroid* (as a prototype of a "building block structure") for the optimization of fuzzy AND/OR networks. The research line has been directed mainly by ideas of Knowledge-based approach to fault detection systems design (mainly to exploration of qualitative modelling background for the Knowledge-based observers). Nevertheless - in more general disciplines , e.g. in the field of structural optimization and in the Design Theory , the use of "tree matroid structure" seems to be very promising [5],[6].

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This research has been conducted at the Department of Automatic Control , Faculty of Mechanical Engineering , as a part of the project "Computer Aided Fault Detection in Complex Control Systems " and has been supported by CTU grant No.08 28180.

THE GENERATION OF TYPICAL NONSINUSOIDAL WAVEFORMS FOR TESTING OF SAMPLING METHODS OF MEASUREMENT

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Key words: plug-in card, sampling, dynamic measurement

The essential subject of the project "*The Investigation of Algorithms for Dynamic Measurement and The Specification of Methods for Estimation of Errors of These Measurement with Use of PC plug-in board Systems*" follows from its name. When, however, the algorithms are developed, the tools for their testing in practical applications have to be at hand. One of these tools is the generation of typical waveforms (not only in the digital form for a simulation of sampled waveforms, but also in the real analog form) with the known parameters. Besides the simple waveforms (sinus, triangle, squerewave) there are also the voltage waveforms, which are ofen used for a pulse control of drivers (Fig.1.,2.) and can be digitally generated. The current waveform is derived simultaneously from them (Fig.3.,4.) for the defined parameters of a load (R,L).

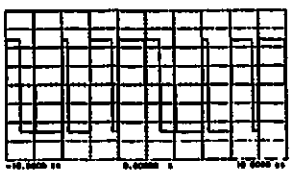

Fig. 1: The pulse width modulation

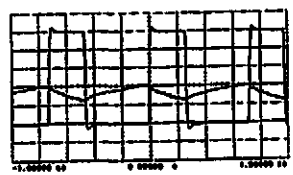

Fig. 2: The pulse controlled DC motor

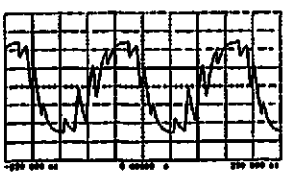

Fig. 3: The current waveform A

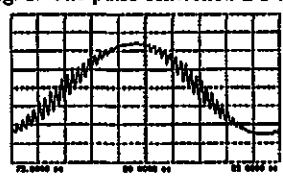

Fig. 4: The current waveform B

In the case of simple thyristor control it is composed of the sine function and of the exponential function. In another case (the pulse-controlled DC and induction motor) it is a numerically defined impulse course. The current courses are in this instance made up of the

exponential parts. It is necessary for a stable status of current course to use several steps of iterations.

The average and RMS value of both the modelled waveforms and the active power are simultaneously computed.

Then the waveforms in a digital presentation have to be converted to the analog form. The two-channel *arbitrary* programmable generator (plug-in board) Keithley-Metrabyte's PCIP-AWFG/2 is used for this purpose. The parameters of the generator are as follows: *Output voltage 0 to +5V, 0 to +10V, -5 to +5V, -10 to +10V; 12-bit resolution; 5 MHz sampling frequency; 2 x 32kSa waveform memory*

Theoretical estimated errors of the defined power and of the RMS values should be lower than $2/2^{(12-1)} = 0.1[\%]$ from the ADC range (see [1]). The real errors of RMS value were measured using two *different multimeters* - HP3401A (0.15%+0.01%), HP3455A (0.05%+0.05%) and the power analyser Norma D5135 (0.2%+0.2%) in AC+DC mode. Some of the results are listed in Table 1., where the parameters of the generated waveforms are also shown.

VOLTAGE		Num.	Measured values					
f [Hz]		resul.	U ef [V]			Errors [%]		
Maked	Pulses	Uef[V]	HP3440	HP3455	D5135	HP34401	HP3455	D5135
5	50	5.000	4.959	4.997	4.993	0 82	0.06	0.14
10	50	5.000	4.959	4.997	4.993	0.82	0.06	0.14
10	5000	5.000	4.991	4 999	4.983	0.38	0.02	0.34
100	500	5.000	4.997	4.997	4.986	0.06	0 06	0.28
100	5000	5.000	4.990	4.997	4.978	0 20	0.06	0.44

CURRENT			Num.	Measured values					
f [Hz]		R/L	resul.	I ef [A]			Errors [%]		
Maked	Pulses	[ms]	Ief[A]	HP34401	HP3455	D5135	HP34401	HP3455	D5135
5	50	10	3.474	3.472	-	3.478	0.06		-0.12
10	50	5	3.721	3.711	3.720	3.715	0.27	0.03	0.16
10	5000	5	3.451	3.451	3.453	3 448	0.00	-0.06	0.09
100	500	5	1.053	1.053	1.053	1.050	0.00	0.00	0.28
100	5000	1	2.990	2.991	2.990	2.983	-0.03	0.00	0.23

Tab. 1: The measured errors

The differences between computed and measured values are in all cases smaller than the errors of the used instruments. The parameters of the two channel mode of waveform generation (power measurement) are measured at the real time.

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INFORMATION SYSTEM OF DIGITAL SIGNAL PROCESSORS

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Key words: digital signal processor, information system, database

An information system of digital signal processors (DSP) allowing one to find out or to compare the parameters of the different DSP. The system is composed from the database of DSP parameters, and the program (written in Clipper 5.2) to edit and search through this database has been created in the Departement of Mesurement.

The group of the parameters of each DSP is displayed simultaneously on one screen, so the user can look at the information card of the DSP. Therefore the information of any DSP is compact. The program allows the user to file the cards under the chosen criteria and find out the DSP with the best parameters. The user can naturally delete any information and write in a new one. There also exists the possibility to create a completely new database with the same structure, for example to create a database of some special DSP.

The user drives the program choosing from the menu. The use of the menu follows the rules used in contemporary programs. So it is easy to get through. On the last line of the screen the information text is placed showing the user the list of functions in the chosen part of menu. It shows more detailed information about the chosen function. The user can get all the information about the program from the wide text program (help). The database of the terms (vocabulary) used in the DSP technology is also included.It is also possible to edit this vocabulary and write in new terms.

The DSP have the following parameters written in the database: the firma, the type, tho fixed or floating point, the word length, the description of the multiplier,the structure and the size of the internal program memory, the structure and the size of the internal data memory, the structure and the size of the external program memory, the structure and the size of the external data memory, the technology of the production, the parallel I/O, the serial ports, DMA channels, instruction cycle, power supply, number of timers, the type of the package, the price, the source of the information, the software, the date when the information was acquired, information about the aplications of the DSP and other notes.

Currently we have in the database of the DSP, information about 143 DSP from Texas Instruments, Motorola, AT&T, NEC and ADSP.

The information system is accessible via the server MERENI, typing the word MESBASE and choosing alternative 2.

DETERMINATION OF PERIOD TIME FOR PULSE WAVEFORMS

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Key words: pulse waveform, virtual instrument, signal processing, digital filter

Pulse controlled drives are frequently used at the present time. The electrical parameters of their supply (Power, RMS, etc.) are often measured using sampling methods [see 1]. Instead of some special instruments, plug-in cards with suitable software support can be used as the 'Virtual Instruments'. The software for realisation of a virtual wattmeter, a RMS voltmeter, a phase shift meter, or a vectorvoltmeter on the base of PC plug-in cards has been created by the Department of Measurement [see 2]. The most important condition, and the first neccessary step for using the supply quantities computing algorithms, is to define the period time of a sampled pulse waveform (especially in the case of low speeds, when it is not advisable to use the method of a moving average).

The determination of the period time is often not a simple matter, particularly in the case of voltage waveforms of pulse controlled induction motors. For these, pulse width modulation (PWM) or other types of pulse modulation are usually used. The voltage waveforms have several zero-level crossings in one period. Sometimes the signal may be deformed by overshoots and accompanied by additive noise. Therefore the period time cannot be defined directly from the time points of the zero-level (or another defined level) crossings. It is necessary to preprocess the sampled signal to recover a "smooth" waveform with the dominant basic harmonic.

- Theoretically four basic methods can be used for this purpose:
  - autocorrelation
  - digital filtering using FIR or IIR filters
  - spectral analysis using FFT
  - cepstral analysis or Hilbert transformation

All four methods were analysed and examined using "Matlab" and "Numeri" software packages with the following results:

1. The **autocorrelation function** is not a "smooth" function for the majority of examined pulse waveforms. Although the period of a basic harmonic may be well visible, there are still pulses and it is not adequat for defining a comparison level for the period determination without further digital processing.

2. The **FIR filters** of a higher order (> 40) can be used to separate the signal with a dominant basic harmonic.The system function $H(z)$ of a causal FIR filter is represented by

$$H(z) = \frac{B(z)}{A(z)} = \frac{b_0 + b_1 z^{-1} + \ldots + b_N z^{-N}}{1 - a_1 z^{-1} - \ldots - a_M z^{-M}}, \qquad (1)$$

where the coefficients $a_i = 0$ $(i = 1,...,M)$, and $b_N \neq 0$. This means that the FIR filter is always stable and the length of the transient time is *equal to the filter length.*

The DFT and windows method was used for the design of the filter. There are two contradictive demands in this case - the time of the signal processing, and the quality of the filtering. Therefore, compromise values of filter parameters have to be used. Moreover, the recommended ratio of a sampling frequency and a cut-off frequency of filter is not kept, because the number of samples cannot be smaller to achieve the demanded precision of the measurement.

The **IIR filters** have *none* of the above mentioned disadvantages. However, there is a danger of instability and a great sensitivity to the change of parameters. The system *function H(z) of an IIR filter* is represented by equation (1), where coefficients a_i, b_j are real numbers and $a_M, b_N \neq 0$. The frequency transformation method was used for the derivation of the demanded filter from prototype filters. The results are comparable with the results of a FIR filter, but the order of the needed filter is smaller than the order of a FIR filter, thus the computing time is much shorter. The most serious disadvantage is the undefined transient time.

3. **FFT** is not suitable for this purpose, because the number of samples per period recomended in this case is 2^N. Thus the period must be known, otherwise the resulting spectrum will be "blurred". Knowledge of the period of the basic harmonic can improve the FFT results [see 3].

4. The use of **cepstral analysis and Hilbert transformation** was also simulated. However, the results were not satisfactory, and these methods are not suitable for the determination of the period in the case of the discussed pulse waveforms.

Conclusion: Digital filters are suitable for determination of the period of pulse wave forms which occur in the pulse control of induction motors. The most precise results were achieved using FIR filters. The processing time for IIR filters was much shorter; but, because of the undefined transient filter time, it is difficult to determine the start point for searching the defined level crossings needed to compute the signal period. As a result the possibility of error can be higher. The concrete results for both modelled and real signals and the consequences of errors in RMS value, power and frequency spectrum measurement will be discussed in the W95.

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This research has been conducted at the Department of Measurements as part of the research project "Investigation of Algorithms for Dynamic Measurements and Specification of Error Estimate Methods of These Measurements Using Plug-in A/D Modules", and has been supported by CGA (TU) grant No. 102/93/0907.

LABORATORY FOR INTERDISCIPLINARY STUDIES OF MECHATRONICS

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Key words: mechatronics, fuzzy control, knowledge base, membership functions, rules, model

In regards to this project, a specialized laboratory for mechatronic studies has been established. This laboratory consists of two independent parts, one of them is located at the Department of Control Engineering, Faculty of Electrical Engineering, and the second one at the Department of Mechanics, Faculty of Mechanical Engineering, CTU Prague.

During the first period, we concentrated on experiments with the OMRON FZ 001 fuzzy logic unit which is a subpart of the OMRON C200H programmable controller. Our first target was to use this system to control two-conveyor-belts for product packing. The products were carried on a conveyor belt A at random intervals, but at a fixed speed. The boxes were carried at regular intervals on a conveyor belt B, which ran parallel to conveyor belt A, so that the boxes arrived at the same time as the products. To create the knowledge base, it was necessary to make a decision about input data, membership function forms and creation rules. The input data for the product/box offset were taken from the relative product/box position (E) calculated as shown below:

$$E = (\text{count from rotary encoder A}) - (\text{count from rotary encoder B}).$$

The input data for the rate of change of the offset (DE) is simply the difference between the most recent value of E (E_n) and the previous value of E (E_{n-1}) as shown below:

$$DE = (E_n) - (E_{n-1})$$

For both of the inputs, we chose a triangular membership function. On the bases of our past experience, we created 25 rules of the following form (as an example we chose the rule Nr.1):

If ((Box is ahead) and (Box is faster)) then (Slow box a lot).

If the input data are the following:

product/box offset: E
offset rate of change: DE

and the output data:

conveyor belt B speed adjustment: VB,

then the expressions can be converted as follows:

DE \ E	NL	NS	ZR	PS	PL
PL	NL	NL	NS	PS	PM
PS	NL	NM	NS	PS	PM
ZR	NM	NS	ZR	PS	PM
NS	NM	NS	PS	PM	PL
NL	NM	NS	PS	PM	PL

where:

NL	...	Negative Large	PS	...	Positive Small
NM	...	Negative Medium	PM	...	Positive Medium
NS	...	Negative Small	PL	...	Positive Large
ZR	...	Approximately Zero			

The system model is constructed at this time.

In the next experiment, the OMRON E5AF temperature fuzzy controller was used to control an electric furnace model. As a result of this task, the control circuit behavior under the PID control and fuzzy control were compared.

We also designed and constructed a two-cylinder waterplant model for the laboratory of mechatronics. The PIDEQER software packet (a PID controller with an expert advisor in the feedback) cooperating with the real system with the help of the CTRL control board developed by the ÚTIA ČSAV, Prague, was used to control the level in one of these cylinders. In the process of developing the control circuit, we found several software defects that we immediately adjusted. Recently, the model and the control system were fully prepared for teaching in the laboratory.

The next experiment was prepared at the Department of Mechanics. We tried to control a drive model with typical nonlinear and dynamic elements that cause problems in practice very often. Backlash, friction, compliance and weight were chosen as the typical elements. All of them are adjustable from the minimal value up to the maximum. It is possible to simulate many model situations that enable professors to demonstrate a lot of practical problems to the students.

In regards to this project, some other tasks and experiments were prepared. All of them will be used for mechatronic studies in the new laboratory.

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This research has been conducted at the Department of Control Engineering in cooperation with the Department of Mechanics CTU Prague and has been supported by FRVŠ grant No. G11-31045.

EFFECT OF QUANTIZATION AND LEAKAGE ON FREQUENCY SPECTRA

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Key words: digital spectrum analysis, quantization error, spectral leakage

Frequency spectra are measured for periodic waveforms or for stochastical (noise) signals. In the latter case, the spectral composition of the signal is described by means of the power spectral density of the signal [1].

An important feature of digital measuring of frequency spectra (using the Fast Fourier Transform - FFT - algorithms) is the possibility of *spectral leakage*. Spectral leakage means the leaking of energy from one frequency component of the spectrum to other frequency components. It leads to new spectral lines in the frequency spectrum, which do not correspond to the frequency composition of the original signal. Spectral leakage thus causes deformation of the spectrum. It is encountered if the signal period is not an integer multiple of the sampling interval. Spectral leakage can be excluded by the synchronization of the signal to the sampling frequency. If this synchronization is not possible, spectral leakage can be limited by multiplying the measured signal by a suitable *window function*. Some examples of this phenomenon are shown in [2].

At our department we would like to evaluate the imperfections of plug-in boards on various measured parameters and characteristics of a signal, e.g., on RMS value, on average power, or on frequency spectra of periodic signals. The basic imperfection of the ADCs used in plug-in boards is their *quantization error*. The effect of the quantization error of the measured signal can be simulated on a computer. Its influence on the frequency spectrum can be very well demonstrated in the case of a harmonic signal. The spectrum of this signal consists, in ideal case, of one spectral line only. In the case of a sampled harmonic signal the spectrum consists of one spectral line in the frequency band from 0 to $f_s/2$, where f_s is the sampling frequency. Since the number of quantization levels of an ADC is limited, the harmonic signal is expressed as a sort of staircase signal in the time domain, and its frequency spectrum consists of a basic spectral line and higher-order harmonic components. The amplitudes of these components depend on the number of bits of the ADC used and on the type of bit number limitation used (rounding or truncation).

Computer experiments were performed to evaluate this phenomenon. SNR (signal-to-noise ratio) expressed in dB was used as a measure of the integral evaluation of the quantization effect on the harmonic signal. When experimenting with a physical harmonic signal using a plug-in card, it was found that there were high demands on the test signal quality - both in its frequency accuracy and stability and in its spectral purity. If there is not an integral number of sampling intervals equal to the test signal period, spectral leakage can mask the effect of quantization. To prevent spectral leakage, the following equation must be fulfilled:

$$T_s N / T_{sig} = f_{sig} T_s N = m$$

where N is the number of the points of FFT, f_{sig} and T_{sig} are the frequency and the period time of the measured signal respectively, T_s is the sampling interval, and m is a positive integer.

The demands of frequency accuracy depend on the number of bits of the tested ADC. These demands were found by numerical experiments simulating the numbers of bits of the usually used ADCs and the various ADC's input voltages. Frequency synthesisers were found to be suitable test signals sources for lower resolution ADCs. For high-resolution ADCs, spectral purity of the test signal must be extremely high; otherwise the test signal imperfections will be reflected in the measured spectra at a level that cannot be disregarded. We have found, numerically, how the demands of the test signal frequency accuracy are dependent upon the number of bits of the used ADC.

Because of possible spectral leakage, methods of finding the signal period time in the case of complicated periodic signal are very important in digital spectrum analysis. A presentation at this workshop is devoted to this topic [3].

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This research has been conducted at the Department of Measurements as part of the research project "Investigation of Algorithms for Dynamic Measurements and Specification of Error Estimate Methods of These Measurements Using Plug-in A/D Modules", and has been supported by CGA (TF) grant No. 102/93/0907.

THE PROCESSING OF THE LDA MEASUREMENTS OF THE FLUID FLOW WITH THE NONSTATIONARY CONTENT OF THE MACROPARTICLES

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Key words: fluid flow, turbulence, macroparticles, velocity histogram, fluctuation energy

At the equipment of the Chemical Engineering Department at the Ohio State University, Columbus, OH, USA we got the LDA records, generated by the fluid flow with the macroparticles. The aim of the experiment was to answer the question whether and how the macroparticles influence the turbulence of the flow.

Measurements were carried out in the vertical column, in upgoing stream. The diameter of the column was 4" (101.4 mm), the length was 1010 mm. The index refraction match technique was used: the index of the refraction for the fluid – paracymene ($\varrho = 860\,\mathrm{kg/m^3}$, $\mu = 1.023\,\mathrm{cP}$) was the same as that for the macroparticles, beads - colorless transparent spheres of PMMA ($\varrho = 1130\,\mathrm{kg/m^3}$). The experiment was arranged as the set of the individual runs: after the beads had set on the bottom of the column the pump was turned on and by opening the inlet valve of the column the run was started. The beads rose up, dispersed and escaped by the sequal with the fluid from the column to the bead collector, from where they were returned after finishing the run. It follows, the presence of beads in the measuring point was only transient. The fluid velocity was measured by means of the microparticles of china clay ($d = 5\,\mu\mathrm{m}$), which are used as the tracers. The beads have two sizes: 1/8" and 3/16", the falldown velocities in the paracymen are 0.165 m/s and 0.209 m/s respectively.

There have been arranged runs with only microparticles, with only beads and with both kinds of the particles. If we consider the microparticles as the first factor and we assign their absence and presence to 0 and 1 resp, and do the same for the beads as the second factor, we get the runs 01, 02, 10, 11, 12, which may be further distinguished by the followed component of the velocity (axial or radial), the superficial velocity (set by the number of turns of the inlet valve) and the position of the point in the column. The nonstationary runs (x1, x2) have been terminated after 30 seconds, the run 10 lasted 100 seconds.

All runs (but 10) are transient, therefore our first task was to find the time regions, where the flow conditions are almost constant. Our second task was to eliminate the possible reflections on the beads as we only want to register the fluid velocity. The first problem was solved through dividing the whole runtime period to the subperiods (I to IV). We supposed to solve the second problem by means of the runs 0x - runs without the LDA particles. If

there were really no such particles, all the records would be caused by the reflections on the beads and it would be no problem to find their characteristics and to eliminate them from the runs 1x. The occurence of the records in the region IV, where no beads are present (and not only this) indicates, the previous idea is not accessible, the removing of the tracers is not perfect and in the region I to III the reflections as well as the velocity records are possible. We have tried to solve the problem by means of the double filtration: to find the characteristics of the tracer velocities from the region IV and by means of them to eliminate the records of tracer in the regions I to III. Then we suggested to repeat the procedure: to find the characteristics of the remaining records and to eliminate them from the runs 11, 12. We have had no problem to accomplish the first step, but we have not succeeded in repeating it: the only characteristic of the remaining data was the high value of the autocorrelation function for the smallest time shift 0.5s; the mean velocity was significantly lower and the standard deviation higher than that in region IV, the shape of the distribution was not reproducible. We can only estimate the part of data in runs 1x caused by misreading, because of the same number of the beads in the runs 0x.

Each run x1, x2 was split into regions I to IV, in each of this regions the histogram number of record - velocity was evaluated. The results were extremly dispersed, when we used the original physical coordinates, we have achieved the concentration by the normalisation of velocity by the formel $(v - v_{IV})/s\ v_{IV}$ where the values for the normalisation were taken from the region IV of the same run, where undisturbed flow occurs. All the presented results are expressed in this normalised velocities.

As the additive quantities, the total and fluctuation energies have been evaluated. The fluctuation energy has been calculated in two manners: in respect to the mean of the actual region (internal f. energy) and to the mean of the region IV (external f. energy). All these numbers are evaluated as the sum of the squared velocities or differencies of them, and are corresponding to the common measuring of turbulence intensity; we relate our numbers to the total processed runtime, our numbers are the rate of energy, dimension $m^2/s3$.

Fluctuation energy in respect to the local mean shows the turbulence intensity and its spread to the upper and lower velocity band, the external fluct. energy points out the shift of the mean velocity between the regions.

The comparing of the fluct. energies shows, that the registred flux of energy for beads only (runs 0x) is much less than that for runs with beads and particles (runs 1x). Moreover, in runs 02 only 50 to 60% records are due to missreading, caused by the reflection and present in the same amount in the records of the runs 12.

All calculations are presented in the tables. It can be seen that the local fluctuation energy for both bands - lower and upper - has the maximum in the region I to II, then decrease significantly. External fluctuation energy is almost constant for the upper band, independend of the presence of beads. We conclude that most of the changes caused by the beads are concentrated into the lower region of the velocities. If this is true, the ratio of the fluctuation energy for lower and upper bands shows the changes in the turbulence intensity: the value greater than 1 indicates the increased turbulence intensity and inversely.

This research has been conducted at the Department of the Chemical Engineering of the Mechanical Faculty of the Czech Technical University and at the same department of the Ohio State University as part of the research project "Research of Turbulence in the Flow with Macroparticles" and has been supported by grant No. 132 1014 of Gu CR.

ICOSYM INFORMATION AND CONFERENCE SYSTEM FOR MECHATRONICS

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Key words: mechatronics, information system, conference system, computer network

ICOSYM is an open information and conferencing system for educational activities within the area of Mechatronics supported by the Internet computer network and developed at the Computing Centre of the Czech Technical University in Prague. ICOSYM is to address the needs for information transfer on a cross-discipline base (mechanical, electrical, control and software engineering), on a cross-sectorial base (schools, industry, research, associations), and also on an international base.

A special branch of ICOSYM will also provide a survey of EU TEMPUS Program activities with the Czech participation to increase their efficiency, both in their implementation and result dissemination periods.

Mechatronics is a new interdisciplinary area of engineering aimed at the optimal design of *mecha*(nical-elec)*tronic* systems, which range from cameras and precision instruments up to industrial robots, machines for building industry and agriculture, transportation means, and other contemporary electronically controlled machines.

Recognizing the importance of Mechatronics for enhancing both the functionality and quality of machine industry products, and to cope with the Japanese and U.S. competition, many West European universities have already started courses in Mechatronics educating engineers capable of communicating with each other across the traditional engineering disciplines. As machine industry plays an important role in the Czech economy, also the Czech technical universities are developing similar courses.

As mechatronics is based on a close cooperation of mechanical, electrical, control and software engineering specialists, and also on a close cooperation between universities and the industry, the exchange of information coming from diversified sources is vital to it.

The objective of ICOSYM development is in intensifying international cooperation among universities and in increasing its effectiveness, in facilitating their access to information, in enhancing university-industry cooperation as well as continuous and distance forms of education, and last but not least, in helping East European Universities to overcome the exchange-rate barrier which still makes telecommunication fees, not to speak about traveling costs, too expensive for them.

As ICOSYM is based on the Internet computer network which is already well established all over the World and operates free of charge, ICOSYM is easily accessible to teachers and students from virtually any university.

It is hoped, that once the system is established, it will attract attention of East as well as West European universities to such an extent, that it will grow into a pan-European cost-effective system supporting cooperation in Mechatronics related education. (Despite the fact that Mechatronics is among the priority themes of the ECC, no similar activity

exists so far to our knowledge.) It can be also envisaged that the system will serve as a pilot project for other educational areas.

The information part of ICOSYM should allow its users to explore, search and retrieve the following kind information:

- survey of courses, final theses, doctoral dissertations, research projects, reports and other publications of individual schools offering study in the area of Mechatronics
- student exchange and placement programs, distribution of application forms
- directories of educational, research and industrial enterprises active in the area
- announcements of international activities in the area of Mechatronics
- surveys of library, patent, and other relevant information resources
- surveys of ISO and other international standards
- information on new components, software tools, books, etc.
- interdisciplinary library of mathematical models for dynamic system components and phenomena *)
- survey of TEMPUS JEPs with the Czech participation

The conferencing part of ICOSYM aimed at interactive sharing of knowledge and exchange of views will allow for:

- structured receipt and transmission of messages
- self documented discussions/conferences on specific subjects
- communication in a group environment
- taking part in an established conference or initiating and moderating a new conference by any participant
- establishing a conference as a public one or as limited to a specified group of participants

The working language is English. The system is based on international communication standards for transfer of textual and graphical information data. Besides other network resource tools, ICOSYM will utilize the hypertext-controlled multimedial World Wide Web. The ICOSYM information and conference segments can be accessed at the following WWW and e-mail addresses respectively:

`http://icosym.cvut.cz/icosym/main.htm` `icosym@vc.cvut.cz`

This research has been conducted at the Computing Centre of the Czech Technical University as a part of the research project "ICOSYM – Information and Conference System for the Czech TEMPUS and Mechatronics" and has been supported by the TEMPUS grant CME-94-CZ-1003.

**) The interdisciplinary library of mathematical models has been established as a part of the research project "Interdisciplinary system for computational modeling" supported by the FRVŠ grant No. 659/1994.*

Section 5

COMPUTER ART

RITA – A NEW PROGRAMMING ENVIRONMENT

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Key words: object-oriented programming, algebraic specification, programming language, inheritance, type checking

This article describes a new programming environment RITA, which has been designed and developed at the Department of Computer Science, FEE CTU.

RITA is a configurable problem-oriented language. It has a fixed syntax of declarations, expressions and structured statements, but its typing mechanism, type checking, semantics of operations, syntax and semantics of simple statements are free. It is designed for two levels of programmers: application and system. The system programmer configures the language by writing a specification and implementation of an appropriate set of operations and simple statements. The application programmer writes applications in the language prepared by system programmer. Thus RITA comprises two languages in one: a specification language and an application language.

RITA's specification language is based on sorted algebras. A set of sorts is defined together with signatures of operators on these sorts. The syntax of unary and binary operations is fixed, while syntax of simple statements (started with an identifier) is free. The form of a specification is similar to that used in algebraic specifications (see [2]). The semantics of specified operations is defined operationally, i.e. in C++.

RITA's application language depends on specifications and supports three different programming styles: simple statements starting with a keyword (à la Basic), operational (à la C++) and procedural (à la Pascal).

An application in RITA is translated into C++, the language supporting object-oriented programming (see [3]). The resulting module is linked with the library prepared by the system programmer and is ready to be executed. The RITA translator generates project files for Borland C++ project manager and thus supports all the features provided by that environment (such as built-in editor, symbolic debugger, linker, project manager etc.).

RITA provides the user with a powerful and flexible typing mechanism. Only two basic types are defined: numbers and strings. There is a structured data type, called bag, which in various modifications implements ranges of numbers, dynamic one-dimensional arrays of items, ordered sets of keys and tables of items with sorted keys. Further types can be introduced by the system programmer. No new types can be defined by the application programmer. RITA's type-checking is strict although more flexible type-checking is possible. The typing mechanism could be extended in three ways: introduction of inheritance of types by means of order-sorted algebras, releasing of type-checking by introduction of untyped items, and support of generic types and operations. These new features involve some interesting theoretical aspects that will be discussed in more detail.

Introduction of ordering on sorts leads to searching for a proper operation. There arise some problems with this search as follows:

```
types T1 < T2              // two sorts, T1 is subsort of T2
operations
      T1 + T2 -> T1        // binary operation +
      T2 + T1 -> T1
declare T1 a, b            // declaring two objects of sort T1
```

then how to resolve the expression a + b? There are at least two way of answering this question: to *forbid* the situation or to resolve the types in lexicographical ordering (e.g. from left to right).

There are two ways in coping with the release of type-checking. The type of an operation can be resolved dynamically (in run-time) or dynamic binding of C++ can be employed. While the first way needs dispatch tables to be created, the second way is more elegant although a lot of code is generated.

Generic types and operations increase the power of a language. At the implementation level they are supported by templates (in C++) and so it is useful to support these at the specification level as well. This again affects the process of type resolution.

Future work includes incorporation of the above mentioned features into the language.

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TYPE SYSTEMS IN GRAPHS

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Key words: compilers, graph grammars, semantic models, type checking

Current compiler construction techniques are at the stage when there is a very good theoretical basis for the implementation of at least the analytical phase of the compilation. Problems arise in the area of semantic definition and code optimization and generation. To find some uniform approach it is necessary to develop some computational model that could be used both for the formal description of the language semantics and for the specification of a compiler. The approach that seems to be very promising and that has already been widely used in the area of functional languages, uses a graph as an internal structure of the program model in the compiler [2]. The graph can be transformed according to some rewriting rules that are more complex and also more powerful than linear string grammars or term rewriting systems. The graph approach has several advantages compared with classic techniques - the most important of them is the possibility of splitting the process of rewriting into several independent transformations that can be performed by different processors.

There are several languages supporting graph transformations and the languages differ in their definition of a graph and in their support for user-friendly applications. As for an example of an advanced system we can mention the PROGRES environment, based on a syntax-directed editor. At the Department of Computer Science and Engineering, TU Brno, the programming language aLeaN has been developed as a tool for expressing graph rewriting rules and graphs with attributes [1]. The first version of the language worked without types and it has proved insufficient for greater projects. The main disadvantage of the first version was in a very weak type checking that allows the programmer to write inconsistent grammar rules. Introduction of types is promising in two directions: as a tool for expressing more semantics that can be statically checked in compile-time, and for improving the graph unification algorithm using type information. When only untyped graphs are used, the unification algorithm has to check in run-time the compatibility of matched subgraphs and to try out all relevant rewriting rules. These checks can be partially moved to the compile-time as static semantic rules.

The working definition of the graph is based on *rooted graphs* (also called *term graphs*) as graphs with one distinguished node — the *root* of the graph [3]. Each node of the graph is bound to a specific structure of *attributes* and *successors*. Types of attributes are specified using some domain types (integers, reals, strings, etc.) and successor nodes are specified using label types.

If we want to construct a graph, some type compatibility rules should be applied: types of successor nodes should be compatible with the type of the original node. The *type compatibility* is a very important concept in typed graphs, because it restricts the possible shapes of graphs that are allowed to be constructed. In fact, we can distinguish three levels according to the existence of polymorphic types: *monomorphic typing*, where all types are monomorphic, *weak polymorphic typing* with one distinguished node type that is compatible with all other node types, and *strong polymorphic typing*, where each type is compatible

with some specified group of types. The monomorphic typing is not usable in practice because there isn't any possibility to construct recursive node types (lists, trees, general graphs). The weak polymorphic typing allows some successors to be of any type, so the type checking is, in fact, switched off for them and we are not able to restrict the allowed types in any way. So the last level creates the opportunity to specify stronger or weaker restrictions on any successor type.

The way how to make groups of related node types is to introduce a partial ordering among types. The ordering is specified as a relation between a parent node type and child types that satisfy the following condition: the child type inherits all attributes and successors of its parent and adds its own attributes and/or successors. Starting point of the type hierarchy is the type *Node* representing a class of nodes without any attributes and successors. The strong typing allows the successor of any node to be of the specified type or of any of its descendant types.

The new version of the aLeaa language [4], implemented at the Department of Computer Science and Engineering, is a slightly more powerful incarnation of the previous principles. This version of the system is able to work with typed graphs; it converts the graph specification into a binary form and generates a C++ source for the rewriting rules. After rewriting the output graph can be converted back into the textual form or it can be further processed applying other set of rewriting rules. The system is supported with the GRB generator for string-to-graph grammars, allowing to build a graph of the parsed linear source code according to some string-to-graph grammar [3].

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PRACTICAL USE OF TEMPORAL PETRI NETS FOR PARALLEL SYSTEM MODELING

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Key words: Petri net, temporal logic, temporal relation, eventuality, fairness, temporal Petri net, timed Petri net, parallel system, concurrency

Petri Nets have been introduced and used as a model of parallel systems. This model can express and analyze certain aspects of concurrency and synchronization of actions, causal relations between events and conditions of parallel systems. However, sometimes time relations between events and time-dependant conditions are necessary to be modeled in order to verify real system behaviour. Petri nets have been extended to many types of so called *Timed Petri Nets*, [2],[3] or *Modified Petri Nets*, [4], with the time requirements associated with either places or transitions. Disadvantages with this introduction of time are found in the field of verification of the modeled system - analytical methods are unsuitable, only simulation methods are commonly used, [1], [2], [3]. In addition some of the fundamental properties of concurrent systems such as eventuality and fairness are not possible to represent or to analyse.

Another class of Petri Net extension is the temporal Petri Net (TN) in which timing constraints are represented by the operators of temporal logic, [1], [2], [3]. Temporal Petri Nets can describe clearly and compactly causal and temporal relationships between events of a system, including eventuality and fairness.

A temporal Petri Net (TN) is defined to be a pair $TN = (PN, f)$, where PN is a Petri net and f is a formula of the language L for describing temporal restraints.
The language formulae are built up from atomic propositions:
(p has a token) - abbreviation p is used,
(t is firable) - abbreviation tok,
(t fires) - abbreviation t where p and t are places and transitions of the Petri Net;
Boolean connectives AND, OR, NOT, $\Rightarrow$ (implication) and
temporal operators $\bigcirc$ (next), $\Box$ (henceforth), $\Diamond$ (eventually), $\cup$ (until).
$\bigcirc P$ states that proposition P becomes true in the next state.
$\Box P$ states that P continues to be true in all future states.
$\Diamond P$ states that P eventually becomes true in some future state.
$P \cup Q$ states that P will continue to be true at least until the first time when Q becomes true.

f can be interpreted as a restriction in the firing sequences in PN; only firing sequences satisfying f are allowed to occur. (e.g. Formula $\Box(t \Rightarrow NOTp)$ means that a transition t fires only if a place p is token-free, and therefore temporal Petri nets can simulate Petri Nets with inhibitor arcs, which have the modeling power of a Turing machine.) For more details and an exact definition see [1], [2], [3].

Our aims in the studying of temporal Petri nets (TN) were the following:

- implementation of temporal constraints (formulae f of the language L) - a regular TG grammar and nondeterministic finite machine were built, [1];
- inclusion of the temporal model to some existing software system for modeling, analyzing and simulating Petri nets - the system Pesim from VUT Brno was used and extended to include temporal relations;
- study of the relationship between the Petri net structure and temporal rules;
- study of the possibilities of formal analysis of temporal Petri net properties.

We have arrived at the following conclusions:

Temporal Petri nets require both the semantics of Petri nets and the semantics of temporal operators. However the combining Petri nets and temporal formulae might be advatageous: a net structure is suited for the representation safeness properties while liveness properties are very difficult to analyze by classical Petri net analysis methods. On the other hand liveness properties can be represented naturally by temporal formulae. The representation of safeness properties by temporal assertion alone can be quite cumbersome.

Petri nets are commonly used mostly because of their ability to visually and naturally express parallelism. Most of the basic properties such as liveness, reachability, boundedness are NP-complete problems. But it is possible to solve them for *simple or not very complex Petri net structures*, therefore we tried to simplify the Petri net's structure by *defining* temporal relations describing this structure. The result was; it was not possible to determine a Petri net structure unabiguously only by temporal relations but sometimes the simplification of it is straigthforward. The last conclusion for practical use of a temporal Petri net is: you must choose a model with the right balance between net structure and temporal relations with the help of a good software tool which makes it possible to analyze both structural properties and temporal properties.

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UNIFORM HOMOMORPHISMS OF DE BRUIJN AND KAUTZ NETWORKS

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Key words: homomorphisms, parallel computing, de Bruijn digraphs, Kautz digraphs

De Bruijn and Kautz (BK) digraphs have been studied recently as promising underlying topologies of interconnection networks for massively parallel computer architectures since they form a family of digraphs with asymptotically the largest number of vertices for a given degree and diameter and have several graph-theoretical properties that are useful for designing interconnection networks. Particularly, they enable simple and optimal routing and broadcasting, have optimal connectivity and fault-tolerance, and contain cycles and trees as subgraphs.

However, BK digraphs are neither vertex symmetric nor hierarchically recursive, i.e., larger-diameter instances do not contain smaller-diameter instances as subgraphs. This makes the design of parallel algorithms for them more difficult.

Given two digraphs G and H where the size of G is larger than the size of H, a homomorphism of G onto H is a surjective and arc-preserving mapping of the vertex set of G onto vertex set of H. A homomorphism is vertex-uniform if each vertex of H is loaded with the same number of vertices of G. We can similarly define the arc-uniformity. A vertex- and arc-uniform homomorphism is uniform.

If there is a uniform homomorphism of G onto H, a parallel computation running on the larger G can be optimally emulated on the smaller H, since the computation and communication load is uniformly distributed among the resources of the smaller network. If G and H are (di)graphs of the same family, such an emulation enables a larger computation to be squeezed optimally into a physically smaller parallel machine with the same interconnection topology. See [1] for some results on uniform adjacency-preserving mappings of several popular interconnection networks.

In this paper, we focus on uniform homomorphisms of BK digraphs.

Let $\mathcal{Z}_d = \{0, 1, \ldots, d-1\}$ denote an alphabet of d letters and $\mathcal{Z}_d^n = \{x_1x_2\ldots x_{n-1}x_n \mid x_i \in \mathcal{Z}_d\}$ the set of all d-ary words on $\mathcal{Z}_d$ of length n. Let $B(d, D)$ and $K(d, D)$ denote de Bruijn and Kautz digraphs, respectively, with in-degree and out-degree d and diameter D. Then [3,4]

$$V(B(d,D)) = \mathcal{Z}_d^D$$
$$A(B(d,D)) = \{(x_1x_2\ldots x_D, x_2\ldots x_Dx_{D+1}) \mid x_i \in \mathcal{Z}_d, 1 \le i \le D+1\}$$
$$V(K(d,D)) = \{x_1x_2\ldots x_D \mid \forall i : x_i \in \mathcal{Z}_{d+1}, x_i \ne x_{i+1}\}$$
$$A(K(d,D)) = \{(x_1x_2\ldots x_D, x_2\ldots x_Dx_{D+1}) \mid \forall i : x_i \in \mathcal{Z}_{d+1}, x_i \ne x_{i+1}\}$$

Our results for de Bruijn networks are as follows:

Theorem 1 *For every homomorphism f of $B(d,D)$ onto $B(d,D-1)$, $D \geq 2$, there exists a binary operation $\diamond$ on $\mathcal{Z}_d$ such that f can be defined as*

$$f(x_1x_2\ldots x_D) = (x_1 \diamond x_2)(x_2 \diamond x_3)\ldots(x_{D-1} \diamond x_D).$$

Lemma 2 *Let $\diamond$ be a binary operation on $\mathcal{Z}_d$ satisfying at least one of the following two properties (B) and (B'):*
$\forall a \in \mathcal{Z}_d$, the mapping $x \mapsto a \diamond x$ is a bijection on $\mathcal{Z}_d$. (B)
$\forall a \in \mathcal{Z}_d$, the mapping $x \mapsto x \diamond a$ is a bijection on $\mathcal{Z}_d$. (B')
Then for any $D \geq 2$, homomorphism f of $B(d,D)$ onto $B(d,D-1)$ defined by

$$f(x_1x_2\ldots x_D) = (x_1 \diamond x_2)(x_2 \diamond x_3)\ldots(x_{D-1} \diamond x_D)$$

is vertex- and arc-uniform.

As a corollary, we get uniform homomorphisms $V(B(d,D))$ onto $V(B(d,D-1))$ already known from the literature, for example,

$f_1(x_1x_2\ldots x_D) = x_2x_3\ldots x_D$,
$f_2(x_1x_2\ldots x_D) = x_1x_2\ldots x_{D-1}$,
$f_3(x_1x_2\ldots x_D) = (x_1 \oplus_d x_2)(x_2 \oplus_d x_3)\ldots(x_{D-1} \oplus_d x_D)$, where $\oplus_d$ is + modulo d.

Homomorhisms induced by binary operations with Property (B) are especially important for computation-contention optimal and communication-contention free emulations of tree based D&C computations on de Bruijn networks [2]. However, Property (B) or (B') are not always necessary for an operation $\diamond$ to induce a uniform de Bruijn homomorphism.

Theorem 3 *For d non-prime and $D \geq 2$, there are binary operations $\diamond$ without Property (B) and (B') inducing a uniform homomorphism of $B(d,D)$ onto $B(d,D-1)$.*

The proof is constructive. For example, for $d = 4$, the multiplication table of a binary operation $\diamond$ constructed by Theorem 3 is as follows.

$\diamond$	0	1	2	3
0	0	3	3	0
1	3	1	1	3
2	0	2	2	0
3	1	2	2	1

Similar results hold for Kautz digraphs (see [2] for more details).

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RANDOMIZED ALGORITHM FOR DYNAMIC EMBEDDING OF BINARY TREES INTO HYPERCUBES

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Key words: randomized algorithm, embedding, hypercube, dynamic tree

The *embedding problem* for parallel computers is defined as the problem of optimal mapping of a *task graph* describing parallel computation onto a *processor graph* describing a parallel computer. Quality of an embedding is very often expressed by five parameters, called *expansion*, *load*, *dilation*, *edge-congestion*, and *node-congestion* (see [2,3] for definitions).

If a task graph G and a processor graph H are given and an embedding of G in H is defined before the computation starts, then we speak about *static* or *off-line* embedding. But very often either the structure or the size of the task graph depends on the computation and the embedding changes in the course of the computation. In this case, we speak about *dynamic* or *on-line* embedding.

In many cases, the task graph has a *tree structure* and the processor graph has a *hypercube structure*. Since these structures have different properties, the problem of embedding trees into hypercubes is difficult in general.

Several results have been published during the last few years on dynamic embeddings of binary trees into hypercubes. In [2], a simple randomized algorithm which embeds an M-node binary tree into an N-node hypercube with a dilation $O(\log\log N)$ and with a load $O((M/N)+1)$, with high probability, is presented. In [3], two randomized *flip-bit* algorithms are described. The first algorithm achieves dilation 1 and, with high probability, load $O((M/N)+\log N)$. The second one achieves dilation $O(1)$ and, with high probability, load $O((M/N)+1)$ and edge-congestion $O((M/N)+1)$.

Similarly, as in [3], we present, here, a modified flip-bit algorithm for dynamic embedding binary trees into hypercubes with dilation 2. We use the *flip-bit* and *track number*, but the strategy for embedding tree nodes into hypercube nodes is different.

Let Q_n be an n-dimensional hypercube with $N = 2^n$ nodes. Let T be a rooted binary tree of size $M \leq N$. Each node x of T is assigned its *level*, $l(x)$, equal to its distance from the root (the root itself has level 0). The randomized algorithm proceeds as follows:

The embedding of children of an already embedded tree node x is controlled by a random *flip-bit*, denoted by $\mathrm{fb}(x)$. It is a random function generating a value from $\{0,1\}$. Each node x of T at level $l(x)$ is assigned a *track number* $t(x) = (l(x) \bmod (n-1)) + 1$. Assume that x is an already embedded node of T whose children are to be dynamically embedded. (The algorithm does not specify the order in which the already embedded tree nodes are selected for embedding its children, hence it can be done in parallel). The children of x will be embedded as follows:

if fb(x) = 0 **then**
{ embed left_child_of(x) (if exists) with dilation 1 into dimension ($l(x)+1$);
embed right_child_of(x) (if exists) with dilation 2 into dimensions ($l(x)+1$) and $l(x)$; }
else
{ embed left_child_of(x) (if exists) with dilation 2 into dimensions ($l(x)+1$) and $l(x)$;
embed right_child_of(x) (if exists) with dilation 1 into dimension ($l(x)+1$); }

Clearly, the dilation of this randomized algorithm is 2. It is not difficult to prove that the described algorithm embeds a complete binary tree of height $(n-1)$ into optimal hypercube Q_n with load 1, dilation 2, average dilation 1.5, edge-congestion 2, and node-congestion 4.

For arbitrary M-node binary trees, we proved that the expected value of load of a hypercube node is less than or equal to $1+2M/N$. The algorithm was implemented and tested on a variety of binary trees of various sparsity. The experiments have shown that the load, edge- and node-congestion is $O(1)$ with high probability, that the probability of the maximum value of embedding measures is very low, and that the distribution of embedding measures is almost independent of both the dimension of the hypercube and the shape of the tree. See Figure 1 for sample results.

We are currently in the process of proving these cost-measurements. Also, we are trying to apply the randomized algorithms for embedding k-ary trees, $n \geq k > 2$, into the n-dimensional hypercube.

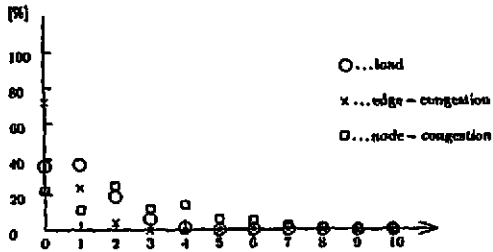

Figure 1: Distribution of measures of embedding 510-node binary trees into Q_9

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THE LINDA LANGUAGE IN DISTRIBUTED ENVIRONMENT

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Key words: parallel programming, generative communication, Linda

The parallel and/or distributed programming is based on several communication and synchronization principles. Several mechanisms related to these principles were developed in order to introduce the principles into the real programming. The communication mechanism called *generative communication* (GC) appeared at the Yale University in the middle 80's. It is better known as the *Linda* language which was the first implementation of the mechanism. It is based on a notion of an abstract, globally shared, and a process independent data space called *tuple space* (TS). *Tuples*—the data structures stored in tuple space—consist of one or more typed elements, and they are content addressable (associative memory). TS is also an environment for the parallel execution of processes. Every process has an access to TS, but tuples are not bound to processes. Tuple space is a persistent object.

Six basic operations for handling the TS and tuples were defined in [1]. In implementations of the GC mechanism (Linda-like systems) six functions or procedures perform the operations. However, the semantics of two of them was proved to be problematic, so that only four operations can be generally accepted: placement of a tuple to TS — `out()`, reading a tuple from TS — `rd()`, reading and removing a tuple from TS — `in()`, and parallel evaluation of a tuple with its consequent placement to TS — `eval()`.

As stated above, the tuple space—the heart of the GC mechanism—is a global, shared data space. The GC mechanism says nothing about the implementation of TS. Experimental implementations of a Linda-like system can use only one computer to simulate parallel cooperation of many processes; however, more than one processor should be considered to take advantage of their joint power — the main argument for building any parallel programming tool. Unlike what one could expect, the majority of Linda-like systems is implemented in a distributed environment, i.e. in an environment with multiple interconnected processors but with no physically shared memory. The main reasons are certain technical problems of the multiprocesor systems with shared memory, and the cost of such systems too. We have chosen the ready to use and cheap environment of several workstations interconnected by the local area network (LAN). The main goal is to make the distributed environment transparent for all Linda operations, and the main problem is how to do it efficiently.

The simple Linda-like system was implemented on workstations running the Unix operating system. It is based on cooperation of *the so-called TS servers* that manage their local, disjoint parts of TS. The *Name server* is a central authority that makes decisions where a tuple is to be placed, and that coordinates TS servers. The *Reliable message passing system* (RMP) was developed on the top of TCP/IP protocol suite [4]. The motivation was to adapt the well known set of communication protocols for efficient use in real-time conditions. It is possible to write simple Linda applications in the C language. However, the way how the application has to be written is very experimental (not user friendly), and the applications were built mainly to test the communication subsystem. The applications

helped us to prove that *the communication is a very* important part of the Linda-like system implementation. The MPI standard is studied now to be used for next implementations as a communication basis.

In the theoretical part of our research we are searching for a formal model that could be used for *uniform* description of the commonly used primitives for interprocess communication, process synchronization, and data sharing.

The *interaction point* was defined as the basic interaction object. The simple interaction primitives are those that can be modelled by a *single interaction point*. These include primitives such as shared variable, semaphore, monitor, asynchronous channel, and asynchronous mailbox. Similarly, compound interaction primitives are those that can be modelled by using two or more interaction points. This class includes synchronous channel, synchronous mailbox, remote procedure call, rendezvous, and barrier synchronization. An interesting conclusion is that the hierarchy of both simple and compound primitives gives a lattice diagram. Some of the results were published in [2].

Another direction of the theoretical research is based on the experience that the original GC mechanism is *not* suitable for solving all problems. Having very nice features for the building of some sort of applications, the original GC mechanism lacks other properties. The fact that tuples can be accessed only associatively makes the implementation of some algorithms inefficient. The problem of implementation of the graph structures and algorithms led to a proposal of the extension of the GC mechanism [3] that is based on the unique identification of each tuple. New operations allow direct access to uniquely identified tuples via the mechanism that resembles *memory pointers*. The proposed extension is transparent to the original operations. Features of the extension are expected to be useful also for building applications that must work independently in one tuple space without any interference. Development of the extension goes on.

We were successful in establishing collaboration with the Aalborg University in Denmark, the birthplace of AUC C++Linda implementation of the Linda-like system on the Transputer network. It is expected that the collaboration will boost our implementation activities and that the experience thus gained will prove helpful for both parties concerned.

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PARALLELIZATION OF PROGRAM STRUCTURES

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Key words: parallelization, vectorization, optimization, compile

Developing parallel code is an effective and economical way to create high performance computer software. In most cases, in order to achieve maximum performance, programs must respect the particular hardware platform and use hardware dependent routines. Consequently, the code differs from machine to machine. Moreover, most currently available software, which has been developed for single processor machines, is virtually useless because its effective implementation for a parallel machine is difficult. Usually, the software would have to be completely rewritten in order to take full advantage of more processors.

Parallel code can also be achieved by leaving the burden of program parallelization to the compiler. The software created in this way is usually less effective, but it is well balanced by the savings during software development.

The main concern of this contribution is the specification of program structures suitable for parallelization by the compiler and methods as to how it can be achieved. The two types of parallelization are dealt with. Vectorization of code for SIMD machines and parallelization for MIMD machines are discussed. Individual statements and program sections are separately investigated.

The simplest case is the parallel execution statements for copying or filling segments of memory. Parallelization of arithmetic and logic expressions significantly improve the code speed of large numeric computations. Algorithms for the parallel optimization of these expressions reduce the computational tree by taking advantage of comutativity and associativity.

Simultaneous processing of more program statements in parallel usually gives better performance than sequential processing of individual program statements, each of them treated in parallel. Program statements are split in program sections. A special case of these sections is *linear program sections* which include only assignment statements.

The parallelization of linear program sections consists of two main parts, namely data dependent analysis and scheduling of CPU instructions that can be executed simultaneously. This contribution deals with data dependence analysis only.

Three categories of data dependence are introduced for two statements S and T, where S precedes T in forward flow sequential program execution [6]. The first is *data dependence* of T on S, where there exists a simple variable v such that S assigns value to v and T fetches the value of v. The second is *antidependence* of T on S, where there exists a simple variable v such that T assigns value to v and S fetches the value of v. And, lastly, *output dependence* of T on S, where there exists a simple variable v such that both S and T assign value to v. The construction of the data dependence graph is described, and the influence of dependencies to parallelization is investigated. The *variable renaming* method is used for removing output dependencies and antidependencies.

Insertion of *goto* statement, conditional statement or switch into linear program sections deals with significant modifications of the data dependence graf. The possibility of parallelization in that case is discussed in this contribution.

Program loops are the most important objects for parallelization. The same program statements are repeated many times. If all these iterations are scheduled in parallel, the execution time drops to the time necessary for one iteration only. The space of all iterations of a loop is similar to that of the linear program section. The dependence graph is extended only by dependencies between different iterations, and it is constructed using methods similar to those for linear program sections.

The scalar variable, used in the loop body, invokes dependencies between all iterations. These dependencies can often be removed by *scalar expansion*. Scalar expansion substitutes all occurences of the scalar variable with the vector variable (array) of the same name, indexed by number of iteration.

The scheduling of statement occurences in a loop iteration on MIMD machines is the same as the scheduling of statements of linear program sections. Specific methods are used for vector optimization on SIMD machines. Only the single nested loop can be transformed into vector instructions. This means that only the innermost loop nest can be vectorized. The *loop distribution* is used to extract single nested loops from a multiple nested loop. The statements from an outer loop are separated from an inner loop and separately vectorized. The *loop interchange* method changes the innermost loop to achieve maximum performance of the vectorized loop.

Multiple nested loops with index expressions invoke more complicated dependence graphs. The methods, described above, have insufficient power to vectorize such loops. *Dependence uniformization* [2] can be used to transform such loops into vector instructions.

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PROBLEM SOLVING WITH PARALLEL PROCESSING

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Key words: parallel computation, message passing, transputer arrays, parallel neural networks, genetic algorithms, parallel solution of ODE

The research described in this short communication has been oriented to application based parallel computing in the areas of artificial neural networks, dynamic system simulation and physical design of computers. Even though the testing of some algorithms started on sequential machines, porting them to parallel system has been or is being done. At present transputers are the only existing computing platform for affordable parallel computing and for embedded or real time applications which we are interested in. Algorithms are being implemented on a network of up to 7 transputers with application-specific topologies. The goal is to find the architectures and algorithms with minimum communication overhead, sufficient speed-up and scalability.

Before any effort in parallel computing actually started, we had tried to understand and classify parallel algorithms suitable for message-passing architectures generally [1]. This study helped us to parallelize efficiently several ANN paradigms: MLP (a multi-layered perceptron), CNN (cellular NN) and Hopfield nets. The first MLP algorithm for forward operation has already been implemented in Occam language [2] with a good speed-up and scalability for large NN. There is still some room for improvement of the processing speed, which is yet to be explored. The work on CNN and Hopfield nets is being carried on. Parallelization of a learning phase of MLP is also under consideration, even though this is not of primary importance in real time applications.

Yet another NN paradigm, Sparse Distributed Memory - SDM, has been analysed to asses its properties [8]. Mathematical formulas have been found for setting up optimal parameters of this NN. The theoretical results have been tested on a program model (using 512 bit- wide address and data buses). However, its parallel implementation is not feasible due to a large operating memory required in this model.

In the area of dynamical system simulation a modern Taylor series method is being parallelized for transputers [3],[4]. To ease this task a TKSL/TRANSP language has been developed which uses block description and diagrams known from analogue computing technique. Occam procedures created for individual analogue units communicate mutually over Occam channels. The language TKSL/TRANSP accepts simulation tasks in a form of a textual description of the given analogue net and compiles them into Occam programs, so that no debugging of Occam programs is required. Placement of analogue elements on transputers effect the communication overhead. Therefore an optimizing tool for automatic placement is planned, which would minimize the amount of communication.

The TKSL/TRANSP and the related TKSL/ORCAD languages have been on exhibitions during international conferences [4] and [5]. Some difficult simulation problems in the area of stiff systems [6] and hyperbolic partial differential equations [7],[9] have been addressed and a sequential solution (running in TKSL/386 environment) is now ready for

parallel implementation as well. During this investigation the original hypothesis about resulting errors being almost exclusively caused by converting PDE into ODEs and not by the Taylor series integration method itself, has been proved.

Finally genetic algorithms (GA) have been used in the area of design automation, namely for the search of an optimal mapping from the elements of the logic diagram (represented by the nodes of a hypergraph) into a regular mesh of positions (2 D array). Within a diploma project a program PGPLACE in C++ with a user-friendly interface has been developed [10], which enables a wide class of experiments via interactive menu for setting main parameters of genetic optimization. Extending this tool for parallel implementation of GA on a given specific transputer network (a farm) will be explored in the following phase of research.

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PARALLEL ALGORITHM FOR SOLVING THE STEINER TREE PROBLEM

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Key words: graph algorithms, parallel algorithms, Transputer programming

One of the most important problems of combinatorial optimization is the *Steiner tree* problem. Although the *Steiner tree* problem belongs to the class of NP-complete problems, it could be solved for realistic graphs on multiprocesor computers in a reasonable time. The algorithm described bellow gives theoretical background for implementation of an algorithm for solving the *Steiner tree* problem on a *Transputer network*.

Transputer networks consist of *Transputers*, i.e. processors having own RAM memory and own programs connected by a switching device. The switching device is usualy not reconfigurable during the time of computation. Existing networks are composed from 32 to 1024 *Transputers*.

The formulation of the *Steiner tree* problem is as follows. Let $G = (V, E)$ be a connected undirected graph with edge cost function $cost : E \to R^+$ defined for each edge (x, y) from E. Let R be a subset of V. A *Steiner tree* $T = (V_T, E_T)$ for $R \subseteq V$ is a subtree of G that contains all vertices of R, i.e. $R \subseteq V_T$. Our goal is to find a *Steiner tree* for R with minimal total cost, i.e.:

$$\text{MINIMIZE}\left(\text{cost}(T) = \sum_{(x,y)\in E_T} \text{cost}(x, y)\right)$$

The *Steiner tree* problem is a direct translation of the routing problem for a single multiterminal net into the context of graphs. The figure on the next page shows an undirected graph an its minimum *Steiner tree* T for $R = \{A, B, C\}$.

For solving the *Steiner tree* problem there exist a number of algorithms. For obvious reasons, only approximate algorithms are of practical interest. However, all reported algorithms [1] have two major disadvantages: the computation time is rather high and/or the quality of results is rather poor.

We propose a new algorithm suitable for solving the *Steiner tree* problem with input data reflecting the bounds of typical routing problems from integrated circuit design. The routing algorithm consists of finding a *Steiner tree* of a graph with $|V| \gg 100$. The algorithm is proposed to run on a *Transputer* multicomputer with $n > 10$ processors in reconfigurable interconnection topology.

The principal (and the most time consuming step) of the proposed algorithm will compute the sum of costs of shortest paths $p(x, u), u \in R$ for some vertices x from V, i.e.:

$$h(x) = \sum_{u\in R} \text{cost}(p(x, u))$$

Obviously, the function $h(x)$ may be computed in parallel.

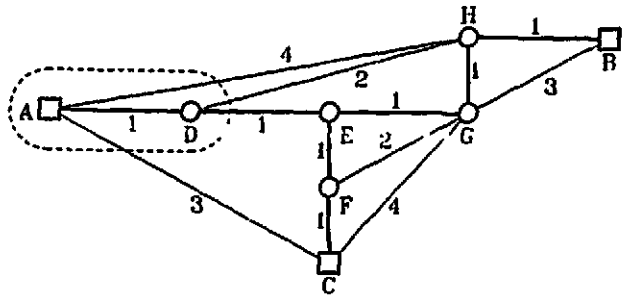

Fig. 1: *Steiner tree* in a graph. $R = \{A, B, C\}$,
$T = (V_T, E_T) = (V, \{AD, DE, EF, FC, EG, GH, HB\})$ $V_2 = \{D, F, G, H\}$
$h(D) = 7$, $h(F) = 8$, $h(G) = 8$, $h(H) = 9$, $R' = \{\{A, D\}, B, C\}$

The values of $h(x)$ of a processed graph may represent a landscape with *valleys* and *hills*. A *Steiner tree* can be computed as a tree connecting all required vertices of *valleys* with maximal depth. Notice that the vertex with the minimal value of $h(x)$ is always a part of a minimum *Steiner tree* if $|R| \leq 3$.

Let $V_2 \subseteq V$ denote the set of neighbours of R in G (see figure). Let us assume that the values of $h(x)$ are known for each $x \in V_2$. The proposed algorithm proceeds as follows:

- a vertex $x \in V_2$ having minimal value of $h(x)$ is identified (see figure); notice that at least one of the vertices from V_2 must belong to the minimum *Steiner tree*
- the vertex x together with its neighbours $\{u_1, u_2, \ldots\}$ from R is taken as one vertex in a modified graph G' (coupling, see figure); in fact it means that a part T' of resulting *Steiner tree* has been generated, in our example $T' = (\{A, D\}, \{AD\})$
- the set R is modified to a set R' where $|R'| \leq |R|$ (see figure).

The whole process is repeated until $|R'| = 1$.

The time complexity of the proposed algorithm is $O(|V|^3)$ provided that a sufficient number of processors is available.

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PROCEDURAL COMMUNICATION STRUCTURES

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Key words: distributed computation, remote procedure call, stub

This contribution presents principles of the Castor programming environment that was designed to support programming of distributed applications. The aims of the design were: the simple structure and its implementation and the flexibility required for educational use.

Introduction. Programming of distributed applications is a complicated task. Two main sources of difficulty are: the implicit complexity of distributed computation and the general lack of high level implementation tools. The practice is frequently based on communication (message passing) and thread libraries that must be used very carefully. As an example we can present the TCP/IP and the Lightweight Process libraries for UNIX (and SunOS) environment. Any support tool that further lowers the implementation complexity is useful. Procedural communication tools (RPC, rendez-vous) are commonly accepted as a solution to the problem. Procedural mechanism reflects the asymmetry of a distributed application that consists of client and server entities.

A typical client-server implementation tool (RPC generator) permits to define a client-server interface as a set of procedures that are called by a client and performed by a remote server. The outputs of the tool are: a client stub that transforms a client's call and its parameters into a message and a server stub that accepts messages and transforms them into server procedure calls. The programmer joins the generated stubs with a client process (at the client's side) and with server procedures (at the server side). The SunOS RPC generator, the DCE environment and the OMG CORBA Request Broker are examples of this approach.

Symmetrical Procedural Interface. The inherent disadvantage of stub generators is their excessive orientation to the asymmetrical client-server schema. Applications that require a more complicated interaction among distributed components can scarcely profit from their use and generally use lower level message passing. However, the substitution of message passing by procedural mechanism can be even more important here than in a simple client-server case.

Symmetrical procedural interfaces were studied in the framework of the Castor programming environment. Castor is based on the execution model that can be classified as a Passive-Object Model. Passive objects form an environment for concurrently running threads. Any thread can pass object boundary by calling a method in another object. The execution of each thread can be viewed as a sequence of fragments executed in different objects. The approach can be applied even when objects are distributed over the architecture and share no physical memory space. Passive objects can be characterized as persistent ones, they preserve their states between entries of active threads. More threads can run inside one object at the same time, their synchronization has to be done by internal synchronization tools, semaphores and conditional guarded sections.

The symmetrical RPC stub has the following form in Castor:

```
Rpc class cname
  {
  public:
    [virtual] rtype mname ( parameters )
      { ... } ;
    ...
  }
```

The prefix **Rpc** of the **class** keyword declares the previous construction as a "template" for the stub.

The implementation scheme based on the front-end of a C++ compiler was inspired by the μC++ system [1]. The front-end converts the previous construction into the appropriate definition of the stub class. Each method declared within the **Rpc** construction has the corresponding counterpart in the stub (virtual or abstract method).

The connection between one of the ends of the ("empty") stub and the object that inherits it is done by overriding virtual functions. Object-specific definitions of the stub code can be different at different ends of the stub.

Asynchronous invocation. As standard procedural interfaces are synchronous, concurrent RPC invocation requires to divide client execution into several concurrent threads. Such a forking can be hidden by asynchronous invocation of an RPC. Asynchronous RPC differs from the synchronous one in the interface, its specification is prefixed by the **async** keyword.

Asynchronous RPC invocation can be viewed as an atomic form of procedural communication. More complicated communication structures (e.g. a standard and symmetrical stub) can be constructed from asynchronous RPCs using thread synchronization. This strategy results in simple procedural communication tools useful even for programming of microcontrollers on fieldbuses.

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MONITORING AND ANALYSING THE NETWORK TRAFFIC UNDER THE UNIX OPERATING SYSTEM

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Key words: computer networking, operating systems, network security, network monitoring

The worldwide intensive application of computer networking has pushed forward th development of software tools for monitoring and analysing of data transmitted on compu r networks. *UNIX*, the most popular multiuser and multitasking computer operating system, has integrated many useful networking tools, but the low level network monitoring is not possible in a standard *UNIX* environment.

Most of the *UNIX* based networks are connected by *Ethernet*, originally developed by Xerox company. *Ethernet* soon became worldwide standard and it has been specified by *IEEE 802.3* standard. The well known family of *TCP/IP* communication protocols was developed to serve as a basic communication tool in networks connecting computers running *UNIX* and these protocols are now the most frequently used means of communication for data transmission on the *Network* and *Data Transmission* layer of the *ISO/OSI* protocol model. The data flow in the network subsystem is shown in the figure on the next page.

There are serious reasons for network traffic monitoring and analysis. The first is the efficiency of network traffic (especially routing). The experimental data from traffic monitoring can provide us with more valuable information for routing optimization than theoretical formulae are able.

The worldwide computer interconnection into wide area networks has faced new problems in computer security. Using computer network traffic monitoring we are able discover data missuse.

The development of application software running in the network environment could be made more efficient when based on the knowledge of the real data transferred on the network.

A software for efficient network analysis is developed in the Department of Computers. The package is written in the C programming language which guarantees portability among various versions of the *UNIX* operating system.

The collection of the raw network data (packets) is sampled from the network adapter device driver included in the file system of *UNIX* (e.g. */dev/pf* - packet filter in the *4.3 BSD UNIX*). The packet flow on the network could be analysed on-line or could be redirected to a file for further processing. For security reasons, only the system administrator is allowed to run the program for analysis of all network data.

On the *Network-interface* layer of the *ISO/OSI* model, the program provides the user with the information about the sending and receiving addresses. The supported formats

of the frames on the mentioned levels are *DIX* (DEC, Intel and Xerox), *FDDI* (Fibre Distributed Data Interface) and *IEEE 802.3*.

On the *Network layer*, the program interprets the data sent by *ARP* (Address Resolution Protocol), *RARP* (Reverse Address Resolution Protocol) and *IP* (Internet Protocol) protocols, on the *Transport layer* we have *ICMP* (Internet Control Message Protocol), *TCP* Transmission Control Protocol) and *UDP* (User Datagram Protocol).

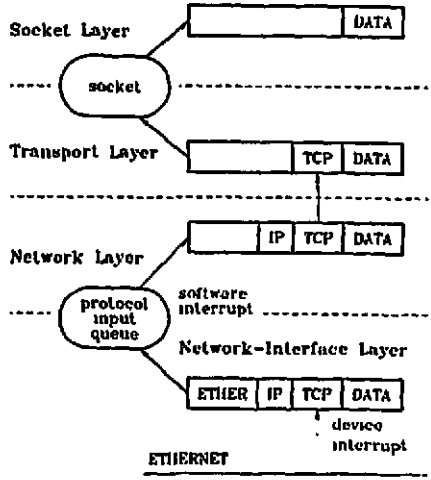

Fig. 1: Layers of the *ISO/OSI* protocols in *UNIX* based network

The amount of data transmitted through the network could be huge. For efficient procesing of this data we need to analyse only the valuable data. To achieve this goal, the data flowing on the network is filtered and only the data satisfying specified conditions are piped for further processing. The conditions are given in a text file and processed by a simple compiler. The specified conditions could form a logical expression described by context-free grammar.

The above described monitoring and analysing software was developed on *VAX 11/780* computer running *Ultrix*, a derivate of *BSD 4.3 UNIX* operating system.

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DIAL-UP IP ROUTER

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Key words: IP connectivity, ARP router, SLIP

This contribution provides an overview of a dial-up IP router solution based on PC technology. The router was developed as a student diploma project at the Department of Computer Science.

Background. Connecting home personal computers to global Internet network has become a very hot topic after successful establishment of the internet infrastructure in our country. A lot of users who access internet services from university or company local area networks would like to use them from their home computers, too. Traditional solution based on UNIX-box terminal line with terminal emulation on PC is not appropriate for client-server applications with graphical interfaces. Using internet protocol allows to run the same internet programs on home PC and on PC in your office. An X-window emulator makes a real workstation from a home PC giving it access to many X-based applications running somewhere else in the network. All these sophisticated applications are based on TCP/IP protocol suite and that is why it is so important to extend internet from office all the way to the home computer. The main aim of this work was to solve this problem with special respect for poor telephone services in our big towns.

How does dial-up IP work? Dial-up IP is a service provided by a server to clients. A server is connected to the campus local area network and allows to reach it by clients using one or more attached phone lines. A client on the PC uses an IP address dedicated to LAN although it is not directly connected to it. From the point of view of other computers connected to the same Ethernet segment a PC with its own IP address shares the server's Ethernet address. The router responds to ARP (Address Resolution Protocol) request containing an IP address of any connected SLIP client. This technique is called Proxy-ARP routing. Establishing a connection between a dial-up client and a server consists of several phases:

1. A home computer connects to the server located in the office using modem and switched phone line. After negotiation of transfer speed between modems the data link is established and character based communication can start.

2. The calling PC introduces itself by username and password.

3. The server verifies them and changes transfer mode to SLIP (Serial Line Internet Protocol) packet mode when both parameters are correct. In the other case the connection is refused.

4. The server assigns a IP address to the PC from a pool of reserved IP addresses and starts routing IP packets designated for this address.

5. After line mode switching an arbitrary internet applications can start sending and receiveing IP packets. Assigning of an IP address is provided by standard protocol BOOTP (Boot Protocol).

Exception Handling. If the telephone or modem connection fails for any reason, the client will try to re-establish it by calling another phone number operated by the server. If it succeeds, the server will assign the IP address used last time to the client, and will only change routing information to the new line. Then the user application on PC will continue after re-establishing connection without any loose of information.

Implementation. Software solution of described dial-up service consists of a SLIP packet driver, dial manager and TCP/IP application on a client side, and an Ethernet driver, one or more instances of SLIP driver, and Proxy-ARP router on the server side.

The SLIP packet driver is used by both client and server. Some new features have been added. The first one is a new program interface used to deliver modem status events to the application. Both server and client need it for timely reaction on modem events, which could not take effect properly with a standard SLIP packet driver. The second enhancement allows to run TCP/IP clients, which can operate only on top of an Ethernet packet driver. The SLIP driver emulates ARP (Address Resolution Protocol) used in IP to Ethernet address translating and from the point of view of TCP/IP application the SLIP driver looks like an Ethernet driver.

In a PC client, an TCP/IP application is connected to a standard packet interface of the SLIP driver. Dial manager, which keeps modem connection on, resides also as the TCP/IP application on top of the SLIP driver, but it is linked to the new modem control interface.

In dial-up IP server, an Proxy-ARP Router runs on top of the Ethernet driver, and one or more instances of the SLIP driver. During the start phase the router initializes all connected modems and having read the list of authorized users it awaits for establishing the modem connection. When such one appears, the server expects a correct user authentication. If user is permitted to use the dial-up service, the server will assign an IP addresss to it, will set the appropriated routing information and will switch the line to packet mode.

Conclusion. Two-modem configuration of the dial-up server is just now in the field-test operation. Performance of two-modem model is adequate, testing of four or more modem version is prepared and will be realized when additional phone lines and modems will be available.

This research has been conducted at the Department of Computer Science as part of the research project "Distributed Systems and Computer Networks: Development of Technology and Support of Education" and has been supported by the grant No. 102/93/0906 of the Czech Grant Agency.

STEPWISE DEVELOPMENT USING VDM

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Key words: formal specification, VDM, stepwise refinement, CASE

There are two known stepwise refinement methods - functional decomposition and data refinement. Present CASE systems usually support only functional decomposition. The data model is developed separately and usually there is not a tool for corresponding parallel data refinement. All functions are assumed to utilise common data types specified by the data model

A common CASE technique for functional decomposition are Data Flow Diagrams (DFD). A DFD hierarchy is not a real specification - it reflects syntactic aspects only. Upper level functions are not specified completely - input and output data flows merely indicate signatures of these functions. Only the leaves of the DFD hierarchy define the semantics of the lowest level functions by so called minispecifications.

It means that the designer cannot divide his job into succeeding steps, which can be verified with respect to each other. In the process of stepwise refinement, every step (including the first one) constitutes a complete specification of the problem. Later steps are refinements of the previous ones, they use more complicated data types, the details of which are hidden on upper levels. Whenever such an abstraction is described formally, the verification between refinement steps is made possible.

An analogy to this process in the realm of CASE systems seems to be versions development. Each version is a complete specification, but the later one is more detailed. If the DFD technique is to be used for description of a specified abstract data type (ADT), the *data flows have to express argument types only. Data stores summarise the state of a system.* Functions need not be connected directly on the DFD - but through data stores only. Function dependency has to be described by a lower level DFD or by a minispecification.

In this way, an abstract data type can be expressed by a constrained DFD. Each primitive process of a DFD describes the signature of a function. The meaning of a function can be defined by a well-formed formula over used data type signatures or by a precondition-postcondition pair. In such a case primitive processes have no side effects. Side effects are indicated on the DFD by flows connected to data stores. Input data flows can have the meaning of insertions or updates of data, output flows symbolise select or delete operations. The real meaning is not exactly expressed by a DFD but by a minispecification.

Let us imagine an example of Time-table Creation Support System (TCSS). In the early stage of the analysis the user needs to print the time-table ordered by groups. It seems to be clear that TCSS has to hold the data about time-tables, e.g. in a data store TIME-TABLE. This store can contain a set of time-table items. Each time-table item is represented by the 5-tupple:

<room, day, hour, course, group> , i.e.

TimeTable = Room ⊙ Day ⊙ Hour ⊙ Course ⊙ Group

State = TimeTable

TCSS has to support a function PrintG (version 1), the signature of which can be given by a DFD. The results of PrintG are time-tables ordered by groups. An appropriate model can be a mapping:

GroupTable = Group → Day × Hour → Course × Room

This mapping can be extracted from a general time-table by a function TtoG specified bellow or alternatively TtoG can be expressed with the help of the inverse mapping GtoT:

TtoG : TimeTable → GroupTable

TtoG(t) ⇔ [<group,day,hour>→<course,room> | <room,day,hour,course,group>∈ t]

GtoT : GroupTable → TimeTable

GtoT(g) ⇔ <room,day,hour,course,group> | g(group,day,hour) = <course,room>

The function PrintG then can be rigorously specified by the following formula, where GroupOK is a time-table correctness check (not defined hereafter):

PrintG : State → [GroupTable]

[GroupTable] = GroupTable ∪ { ⊥ }

POST-PrintG(st,gtb) ⇔ if GroupOK(st) then (gtb = TtoG(st)) else gtb = ⊥

On the more detailed level of TCSS analysis it was discovered that time-tables (reported by PrintG) have to be distributed to departments. Therefore, TCSS has to support a new version of the PrintG function, now called PrintG' (version 1.1). The result of PrintG' are time-tables sorted by streams and completed by text explanations associated to streams. A stream is a set of groups, that belong to the same department. An appropriate model of a stream, an explanation, and a stream table can be as follows:

Stream = StreamID → (Group)-set

Explanation = StreamID → Text

StreamTable = (GroupTable × Text)-set

The state of TCSS has to be enhanced by data stores for streams and explanations:

State' = TimeTable × Stream × Explanation

The new version of PrintG' specification can be specified by the following formula:

PrintS : State' × StreamID → GroupTable

PRE-PrintS(<ttb,str,exp>,sid) ⇔ GroupOK(ttb)

POST-PrintS(<ttb,str,exp>,sid,gtb) ⇔ gtb = TtoG({ttb | ttb.5∈str(sid)})

PrintG' : State' → StreamTable

PrintG'(<ttb,str,exp>) ⇔ { <PrintS(<ttb,str,exp>,sid),exp(sid)> | sid ∈ dom str }

One advantage that formal specification yields is a possibility to verify the correctness of versions with respect to each other, i.e.

∀ x ∈ State', y ∈ StreamTable . POST-PrintG'(x,y) ⇒ POST-PrintG(α(x),β(y)) .

where α and β are suitable conversions.

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This research has been conducted at the Department of computers of Faculty of Engineering of CTU Prague as part of the research project "Laboratory for CASE Systems Education and Development" and has been supported by GACR grant No. 102/94/0922.

DESIGN OF INFORMATION SUBSYSTEM FOR THE VUT BRNO

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Key words: design of an information subsystem, scientific research activity database

The design proposes to create a modern information system (IS) that will be integrated into the global university information system. As a result of the system implementation the automated processing of scientific research activities as well as related activities in the education and management fields should be achieved. There is no such system presently in operation at the TU of Brno. Two main objectives of the project have been specified based on the project analysis. The first objective is to design a global information system that will facilitate quick and user-friendly processing of a mixture of scientific research, arts and education related data. The second objective is to implement part of the designed system using the present computer network resources at the TU Brno.

The design of *an automated information system database of scientific research and arts related activities* (AIS DSRA) is based on an open UNIX operating system platform. This open multi-user operating system with an integrated security system giving access rights to individual users will enable:

- preventing data duplication within the university IS
- facilitating compatibility with the planned university economic information system (EKONFIS that is to substitute the present system of processing human resources, wages and accounting) and/or convertibility to/from other university IS subsystems and partly with systems outside the university (e.g. outputs for the Ministry of Education).
- data entry at the place of their origin (minimizing the transfer of paper documents)
- to maintain system security and respect the confidential nature of entered data.

During the design of the essential (substantial) model and the user implementation model of AIS DSRA the Yourdon structured method (YSM) proved to be the most appropriate. Based on an analysis the following specifications have been determined that the system will have to meet:

A) *to collect the employee personal data directly from EKONFIS and to complement it with the following items*, so far not stored in the employee database:

  - contact address (including telephone, fax and E-mail)
  - specialization, orientation
  - individual scientific research projects.

B) Based on activity types the system should *contain the following modules:*

VVU1. *Research, science, arts and technology development projects*
VVU2. *Publishing, free art, catalogue representations*
VVU3. *Conference activities, conference and art workshops attendance*
VVU4. *Patent rights and inventions*
VVU5. *Home and international relations*
VVU6. *Other activities*
VVU7. *Education and personal development*
VVU8. *Scientific and teacher degree awards*
VVU9. *Information, coordination, management and strategic activities.*

The *VVU subsystem* has been selected for the implementation of part of AIS DSRA in the TU Brno computer network. The subsystem will be created using a 4GL Progress language with a relational database management system. The planned university economic information system that the designed system will cooperate with should operate in the same environment.

Formally, the design uses graphic representation rather than word description. The graphic representation of the global information system design (in compliance with YSM) is clearly arranged and easy to read. Data flow diagrams (DFD diagrams or function models) have been used for the global design of AIS DSRA and detailed design of VVU1. DFD charts are accompanied by explanatory notes and lists of items from the most important files. The draft version containing the two proposals was submitted to the vice-deans for science, research and arts of the individual faculties for comments. There have been no serious objections or comments.

At present the designed VVU1 is to be implemented. A database for recording the TU employee project activities (e.g. VVU1) will be created. During 1995 the data will be collected and enter the database stage by stage and program applications related to the project module will be designed. The work is planned to be completed in a number of stages. The users will be acquainted with the results of the individual stages for comments to feed back into the system development. The final stage will include the preparation of detailed data based on the experience with the VVU1 module to be used in the development of the other AIS DSRA modules.

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This research has been carried out at the Center for Computing and Information Services as part of the research project "Automated processing of TU employee scientific research activity database" and has been supported by TU grant No. I-991/C29/94.

PERSONAL COMPUTER USE FOR THE REGISTRATION OF FINANCIAL MEANS

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Key words: balance sheet, financial cost, self-control

The Head of the Department of Forming, Casting and Welding at the Faculty of Mechanical Engineering CTU in Prague decided in 1993 to simplify the administration processes of the department. The areas in which it is possible to accelerate the compilation and evaluation of information by the use of computers were investigated. The need for economy, which under present conditions is of paramount importance to management, informed this investigation.

The software for simple registration in dealing with non-investment cost was created in the frame of the research work No 2103 "The possibility of management the administration work by means of computer technique". The head of Department must have knowledge of given data to take a decision on the adequate use of non-investment cost according to realization of own ideas.

The creation of software was based on two principal facts:

- different sources of money are at disposal (state budget, part of a profit from its own economical activities, loan from central budget of faculty),
- organization scheme of the Department which has several professional groups with limited autonomy in management.

Before giving the brief results of the investigation it should be emphasized that the input conditions and output demands are given by the concrete requirements of our Department. The following requirements of the system of registration were decide upon:

- registration of income sum with indication of the source
- registration of expenditure sum in total and according to individual groups
- registration of expenditure from given source for each group
- balance sheet for each group must be available according to individual sources and totals
- a balance sheet for the department must be available

The requirements from the point of view of running the software were:

- separation between the entry of input data and record of the results
- possibility of printing all parts of the registration
- simple entry to information and assurance of self-control of the input data validity

During the solution twenty service programs were created, the total service program, spreadsheet and the main executive program with twenty sheets.

Two sheets are anticipated for *the entry of input data, separately for receipt and expenditure*. The transfer to other sheets is based on the principle of flags. The same principle is used for self-control which enables the operator to check the correctness of entry.

Sheets 3 to 5 serve for receipt and expenditure registration and their actuality.

The survey of the expenditures of all groups (including the director's and reservation funds) is performed in sheet 6.

The survey of expenditures of individual groups (without the reservation fund) according to different sources is performed in sheets 7 to 12.

Sheets 13 to 19 contain the balance analysis for all groups according to different sources.

The last sheet contains the Department's balance analysis according to all groups. Self-control procedure is included which displays a warning message if the operator make a mistake.

The software was prepared on PC 386 DX/40 using the program WinText 602 (module WinTab 602) running under Windows 3.1 CZ. The system in the standard version is able to register 200 records. Occupied memory in this initial state is 918 kB. The number of records could be enlarged to the full possibility of the Tab-module (32.000 records).

The program was verified by inputting the non-investment means data of our Department for the current year. The necessary time for introducing and evaluating one record was cut down by about 80editor T602 was used.

The program encourages the operator who is now able to run this user friendly program with a basic knowledge of PC. The program does not support an operator's natural habit of registering data as late as more data are to be recorded. That is one of its main advantages – the continuous updating of data. An other advantage is the input and the evaluation areas separation.

The created system is universal. It could be applied anywhere with a two level system of organization, i.e. Faculty – Departments or University – Faculties.

This research has been conducted at the Department of Forming, Casting & Welding as part of the Department's research project No. 2103 "The Possibility of Contemplation the Administration Work by Means of Computer Technique" and has not been supported.

USING FORMAL METHODS IN THE CONTROL OF INDEPENDENT ANIMATED OBJECTS

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Key words: computer animation, object-oriented graphics, animation, modelling

Computer animation is one of the fastest developing areas in the computer science and in industry as a part of its simulation methods. Using animated sequences, a user can more easily imagine the processes of the objects of his interest. One of the most complicated real world objects for animation is the human body [4], [5]. When modelling any object of the real world, we must solve two main classes of problems:

1. to create and describe a suitable model and to control it;
2. to draw the animated model on the screen by fast method of computer graphics.

We have dedicated this paper to the first problem. In our project, we tried to implement algorithms (in object oriented language) for modelling the human body using formal methods to describe the structure of the model and to control its behavior.

The structure of the model (the model of the human body we have called "figure") is designed as an oriented ternary tree. The position in 3D space of each node of the tree is determined relative to its predecessor. Fig. 1 shows a simple model with 15 nodes and corresponding ternary tree. To describe the structure of the model we have made a simple language *FDL* (Figure Description Language) which allows us to create more or less detailed models. The *FDL* is generated by the grammar G described in [1], [2] and [3].

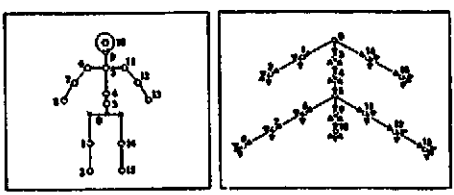

Fig. 1: The figure model and corresponding ternary tree

During animation, the model is controlled by messages containing instructions. Every message is addressed directly to a node by the identifier of the figure and the identifier of the node. To receive messages, the figure needs an interface between itself and other objects. The interface is realized by an object of class *Queue Manager* which also plays the role of the root node in the model's structure. Every *Queue Manager* represents one figure, and these objects are formed into a linked structure. This structure is processed by an object of

class *Scheduler*, which, in cycles, reads commands from a script and sends them as messages to the *Queue Managers*.

Every message contains information about the value of the global time counter, the time stamp giving the time that the message should be processed, the figure identifier, the node identifier and the type of instructions with parameters (see [2], [3]). Receiving a message, *Queue Manager* stores it in an instruction queue and compares the global time counter with the stamp message at the head of the queue. If the global counter is less than or equal to the stamp, the stamp message is fetched and distributed to the model's structure. Identifying itself as receiver of the message, the node only partially performs the required operation, and the rest of the calculation is inserted into the instruction queue as the last instruction in set of instructions with the same time stamp. It allows us to control every model and its parts independently of other objects (a pseudo-parallel effect).

The methods described above have been used in our project *VITALIATOR* implemented in C++. The next parts of the project are devoted to the problem of drawing methods. We would also like to include elements of dynamic control and deformations.

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This research has been conducted at the Department of Computer Science as a part of the research project "The Complex Educating System for Computer Graphics and CAD" and has been supported by CTU grant No. 12-31059.

GENERATING PLANTS USING NURBS

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Key words: Computer Graphics, NURBS, Modelling

An effort to find an algorithm for generating models of plants usable for computer graphics has continued since 1982. Because this problem has been unsolved until now we can see that it is very complex.

Existing methods work in two steps: during the first one a **topological description** is generated, while the second step generates a corresponding **geometrical model**.

The first phase creates a description of a neighbourhood of leaves, flowers, fruits and branches. Developed methods are mostly based on algorithms which work with probability assigned rules. The most known method, *L-systems*, is named by its author Aristid Lindenmayer [6] and was used for this reason, for the first time in [3] in 1981. Two new methods were introduced [4], [5]. These methods are much more intelligible and give more possibilities to control the shape of a plant. A product of the first step is a data structure which gives (after the application of the proper traversal algorithm) information about the structure of the plant. The second step uses this information to generate geometrical representation.

The geometrical description is in general a set of surfaces modelling the shape of the plant. This model must be suitable for rendering by the methods of computer graphics. This phase of generating the model is the hardest one, because the increasing level of credibility is reflected in the complexity of the model.

The lates research concerning this problem [1], [2], [3] and [4] uses for describing the plants mostly Bézier surfaces. We use NURBS which gives two basic advantages:

- an invariance to the perspective projection and
- a precise representation of conic sections and derived surfaces.

We pay for that with a higher complexity of all the algorithms: rendering, modelling and so on. The second advantage consequently gives unified data representations of "classical" surfaces like a sphere, a box and "free" surface like the utah teapot. Both advantages seem to be the reason for the intensive developement of NURBS theory and its application (*ACIS, PHIGS+, ALIAS, Iris Inventor*). This is the third reason why using of NURBS can be interesting for modelling the plants.

The key to the generation of a geometrical description of the plant is the joint between surfaces. For many technical reasons surfaces of degree three in computer graphics are used. The C^2 continuity is a very strong condition so for a nice subjective perception G^2 is acceptable. The G^2 condition guarantees the same orientation of tangent vectors in both direction u and v.

Branches generating an algorithm goes through the topological representation and collets points which belong together, and puts them in successive order into 3D space. These points determine a 3D polyline which is used as a sweep path for a polygon of eight point definition of a circle. The generated mesh is a control polygon of NURBS surface of a generalized cylinder of a branch. A branching node is a point of generated polyline, which

consists of one ingoing and at least two outgoing branches. To receive a smooth joining of two surfaces we use two last points of the ingoing branch as the two first points of the outgoing branch. Boolean operation exclusive or gives a final shape.

A leaf is generated as three surfaces: a stem and two patches. Both patches start from the stem and their orientation determines the local coordinate systemm. A joint into the tree structure is the same as for branching points except that the radius of the stem is constant. The patches are linear blending surfaces determined by their margin.

Fig. 1: A NURBS generated leaf.

The influence of global factors like wind, light and gravitation is also calculated. Each of them is represented as a vector where the size of the vector is an intensity. The amount of influence in each point of a branch is calculated from this vector, the distance of the point from the begining of the branch and the diameter of the branch. The same method is used for distorting the stem of the leaves. The distortion of the leaves surface is computed from the distance of stem. The global factors are applied solely for the control points of NURBS surfaces.

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This research has been conducted at the Department of Computer Science and has not been supported.

THE INFORMATION CAD CENTRE

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Key words: CAD, modeling, drawing, information

The designer needs for his work to know, what kind of support means CAD offers. The offer of publicity or advertisement is unobjective. It is connected with the interest of the firm. The information CAD Centre at the CTU, Department of Machine Elements and Mechanisms is independent of private firms and offers objective information.

The fundamental activities in CAD are conception, modeling, check and optimalization. The support means for conception are:

- net transmission of data, connection telnet, ftp, rlogin, faxmodem,
- acces to information services of Internet, Gopher, WWW etc.

The support means for modeling in graphics:

- management of drawings,
- quick viewing, use of slides,
- scanner drawing, editing raster formats,
- libraries of machine parts and components,
- type drawings, form numbers,
- drawing aids, the support of drawing,
- access to ungraphical environment, databases,
- work with schemes,
- design of pipe-lines and pipe network,
- design of frameworks and thin-walled structures,
- synthesis of mechanisms.

The support means for the computing check:

- calculation of the steel frameworks and thin-walled structures,
- calculation of the machine parts, transmissions, etc.,
- creation of discrete models of mechanical systems,
- finite elements method for space stress analysis.

The support means for the optimalization:

- analytical and numerical methods for finding extremes,
- linear and non-linear programming.

The building of information CAD centre began in 1994. We bought, with the support of FRVŠ, the computer Apple Macintosh Power PC 6100/60 MHz with 250 MB SCSI disc, 16 MB RAM, 14" Sony trinitron monitor and the further equipment Ethernet trasceivar, Internet fax, modem, voice US Robotics Dual Standard and software Apple system 7.5, Hermes BBS. A net connection was set up and internal environment is being prepared. The scheme of information database is being proposed according to the introduced view. The structure and access to the information is being solved. We have problems with the completion of hardware delivery. The installation of all parts of equipment was not realized untill now.

Our aim is to constitute an information CAD centre which has the program equipment for machine engineering and can support the education of our students.

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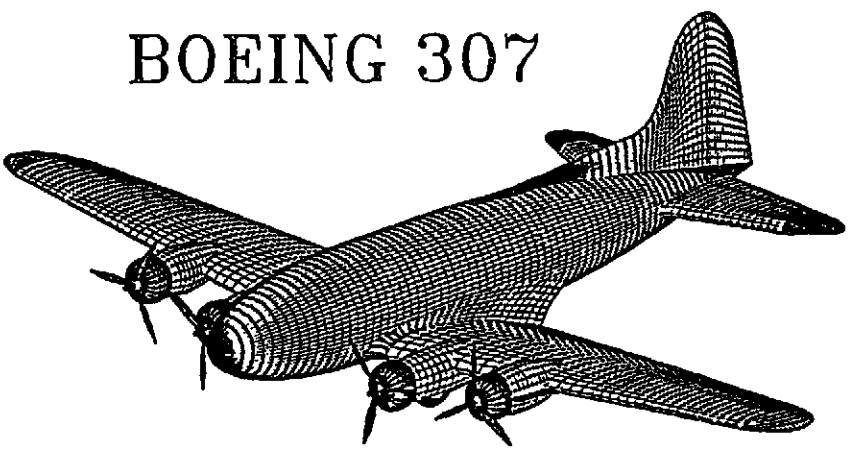
This research has been conducted at the Department of Machine Elements and Mechanisms as part of the research project "Building of Information CAD Centre" and has been supported by grant of FRVŠ No. 1182.



RESEARCH ON FORMALIZATION OF DESIGN PROCESS

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Key words: design process modelling, deduction, abduction, circumscription

The concept of design theory was first formulated in [1] as a General Design Theory. This theory developed into the metamodel theory [1], briefly described in [2], [3]. The basic idea of metamodel theory is based on two concepts:

- design as a mapping - the mapping of function space onto attribute space,
- metamodel as a finite set of attributes and knowledge in one step of the design process.

The idea of the design process formalization was developed and spread in a concept of *logical modelling of design process* [4]. By logical modelling of design process we can now understand a combination of three logical frameworks – *deduction, abduction and circumscription.*

Deductive framework can be formalized as follows:

$$S \cup K \vdash Ds,$$

where S, K and Ds are sets of formulae that denote required specification, knowledge used in design and design solutions, respectively. Solutions are derived from specification and knowledge that results from deduction. Deductive framework may be suitable above all for routine design.

In the second framework - abductive framework (as opposed to deductive approach specifications), we can derive specifications from design solutions and knowledge. We can formalize this logical framework as follows:

$$Ds \cup K \vdash S.$$

We can verify if our solutions meet given specifications. If the solution does not satisfy the specification or cannot evolve any more, the designer either tries an alternative solution or modifies the design knowledge and/or the specification.

During the design process much inconsistency can arise. But, inconsistency has not only negative effects in design but also positive ones. Most cases of inconsistency in design do not mean that knowledge consist of wrong information, but that knowledge is used in a wrong manner. Knowledge is used beyond the situations in which it is expected to be used. We assume that inconsistency comes such incompleteness of the knowledge description. Then, we have to find descriptions of knowledge which restrict wrong applicability of knowledge. One way to accomplish this process is through circumscription.

Circumscription is a technique of formalization of revisable reasoning that not only solves inconsistency but also helps reasoning to proceed futher by modifying knowledge. Circumscription is a type of logical reasoning and has been developed to deal with exceptions. Circumscription consists of minimizing selected formulas contained in a knowledge base which are exceptions of common valid formulas in a closed-world environment.

In our research we will use multi-worlds and closed-worlds assumptions of modal logic for design process modelling. We suppose that the design state can be modelled by one world of modal logic formalization. The modelling of the design process can be then interpreted as a proof of validity of modal logic formulae. The construction of a new world in modal logic has an equivalent in the search for the next design step in the design process.

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This research has been conducted at the Department of Computer Science as part of the research project and we hope it will be supported by CTU grant.

EXPERIMENTAL MULTIMEDIA SYSTEM – EMMS 2.0

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Key words: multimedia, authoring systems, multimedia database

A multimedia system is a system characterized by integrated processing, storage, presentation, creation, and manipulation of independent kinds of information under computer control. This multimedia information has an important attribute - time. We can define two types of multimedia information: time-dependent and time-independent media. Examples of time-dependent media are video, animation, and sound, and those of time-independent media are text and picture or drawing. The fundamental principle of multimedia systems is integration of the common effection of all these media.

There are several levels of multimedia systems [2]. They differ not only in possibilities but also in prices:

- **naive level** of multimedia system - a representative is WINDOWS 3.1 multimedia environment (PaintBrush, Media Player, Sound Recorder)
- **standard** multimedia system - a typical representative is software delivered with multimedia hardware - multimedia kits (authoring systems, Autorware Star, Actions!, Corel Show)
- **professional** multimedia system - special multimedia software and hardware for multimedia production with output on CD-ROM or video (ToolBook, Icon Autor, Autoware Professional, Adobe Premiere)
- **experimental** multimedia systems - these systems are constructed in common programming languages (Pascal, C), implemented on MPC (Multimedia PC) [3]. These systems give very professional results with minimal financial expense. Products of these multimedia systems can be used not only for student education but also for standard multimedia presentation production.

We presented the first version of our experimental multimedia system last year [1]. Now we have finished the EMMS Release 2.0. The system is implemented in Turbo Pascal 7.0, consistent with the object oriented paradigm. For time consuming operations, assembler routines were used. Our system has several parts:

- the authoring system, which can produce presentations with different multimedia elements; control structures can be , sequences, conditional structures and loops
- multimedia database with texts, pictures, sounds and simple animation
- user interaction possibilities; user can manage the run of multimedia presentation by text or by metaphors of buttons
- a part for presentation of multimedia applications

- other parts - fonts editor, setup, etc.

We have finished two main multimedia applications: an information kiosk for Jindřichův Hradec castle and a simple personal multimedia database. The second one is being presented at this CTU SEMINAR.

The difference between the first version of EMS [1] and system EMMS 2.0 is the following:

Software:

- uniform access to multimedia elements
- better user interface
- more than one picture element on the screen
- sound element presentation
- animation elements presentation

Hardware:

- additional graphic card support
- Sound Blaster sound card support
- usage of XMS storage for animation and picture storing

In the next version of EMMS we plan:

- to group several multimedia elements in one multimedia element
- to extend support of new graphical cards
- to add synthesized music, MIDI
- to extend support of data format for graphic and sound.

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This research has been conducted at the Department of Computer Science as part of the research project "Multimedia systems in University Education" and has been supported by CTU grant No. 11 - 31046

DEVELOPMENT OF FIXED POINT DSP SYSTEM AS AN APPLICATION DEVELOPMENT TOOL AND EDUCATIONAL AID

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Key words: Digital Signal Processing, DSP hardware, educational aid

A Fixed Point DSP System Board has been designed under Tempus JEP-1565 European Joint Program. The system has the following features:

- the board is based on ADSP-2101 DSP microcontroler from Analog devices; the microcontroler features a 62.5 ns instruction cycle, 8 k words of fast SRAM and DSP tailored architecture.
- the board includes own AD/DA conversion interface based on AD-1849 codec from Analog devices; the 16 bit AD/DA conversion interface features one stereo input and two stereo output channels with sampling rates up to 48 kHz; an option of the build in amplification for the microphone/loudspeaker system is available; all parameters of the conversion as sampling rate, input/output gain, kind of compression of digital data are software programmable.
- the system is built on the PC Add-On card and includes the interface to the 16bit ISA bus of PC/AT compatible computers; the interface allows the direct driving/monitoring of all signals of the ADSP-2101 and AD-1849, which enables the PC programs to drive the whole system.
- the comprehensive software supporting the system has been developed; this software includes the complete integrated development environment with all standard emulation tools, the C++ object library, and the set of the basic DSP applications for demonstration purposes.

Due to its emulation capabilities and easy handling, the system board is supposed to be a powerful development tool and also a very useful aid for education of basics of DSP.

There is another extra feature making the board exceptional beyond the others of its class: the hardware which provides the interface of the system to the ISA bus of PC has been implemented using Xilinx FPGA's and can be "programmed" by downloading the configuration data from the harddisk of the hosting PC. This feature enables the board to be compatible with a broad range of other devices. In addition, the architecture of the bus interface unit is designed to include all digital control signals of the system. The system

becomes the tool for the development of the DSP application: exclusively the application tailored hardware.

This research has been conducted at the Department of Electronics at KIHW Oostende, Belgium as part of the program TEMPUS: Education and Collaboration Programme in the Field of Microelectronics and has been supported by TEMPUS grant No. JEP-1565.

Section 6

FLUID MECHANICS

USE OF RADIALLY SWITCHED JET ATTACHMENT IN AN EXHAUST GAS FLOW CONTROL VALVE

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Key words: jet, jet attachment, Coanda effect, fluidic valve, engine exhaust

The Coanda effect of jet attachment to a wall is caused by entrainment: a submerged fluid jet entrains and carries away the surrounding fluid. If the space into which it issues is bounded by an adjacent wall, the removal of fluid between the jet and wall generates pressure difference across the jet which forces the jet towards the wall. The attached jet may follow the wall into a direction different from the original orientation of the nozzle. This interesting aerodynamic effect has been used in fluidic bistable no-moving part diverter valves. These are normally designed having planar geometry, with a slit-like nozzle directed between two attachment walls, each of them guiding the jet into a different outlet collector. There are two stable states: they differ in which one of the two outlets most fluid leaves. In usual fluidic valves, the switching between the two states is caused by the flow from control nozzles. If the active outlet (one into which most jet fluid flows) is gradually closed while the other one remains open, so-called load-switching may take place: the Coanda effect no more suffices to hold the jet at the particular attachment wall. The jet then switches to the other wall without the need for any any control flow. A load-switched valve based on this phenomenon was successfully developed in the usual planar geometry for automatic switching of the automobile engine exhaust gas flow out of a primary catalytic reactor as soon as an undesirably high catalyst temperature is reached, [1]. Operation without moving parts makes possible exceptional robustness and reliability of fluidic valves when compared with common electromagnetic valves. Also the price is much lower: the whole automatic by-pass control valve is manufactured in a single piece by casting without machining, being nothing more than just a cast exhaust pipe bifurcation. Unfortunately, the by-pass loop with the primary catalytic reactor and diverter valve tends to be very bulky and difficult to stow inside in the tight present-day engine compartment. A much more compact solution was later proposed according to Fig. 1: here the automatic control valve forms the entrance part of the catalytic reactor body, at the axis of which there is the by-pass pipe. The axisymmetric version of the valve, although it might be viewed upon simply as convolution of the planar arrangement, is much more difficult to develop. There is the obvious asymmetry of the two attachment walls: the inner one degenerates into just the small conical tip of the central body and cannot exert such attachment effect as the much larger outer wall. Previous experience also has shown that it is usually difficult to obtain uniform peripheral distribution of flow from a ring-shaped nozzle so that there is the risk of switching-action not taking place simultaneously at different circumferential locations. The problems were investigated on a full-scale aerodynamic model, Fig. 2. Rather tedious systematic investigations of individual geometric parameters was necessary, including the measurements of the diverter loading characteristics with different splitter shapes (again, as with the planar geometry, the concave, "cusped" shape of the splitter nose, generating a stabilising internal feedback, was found beneficial) and different splitter-to-nozzle distances.

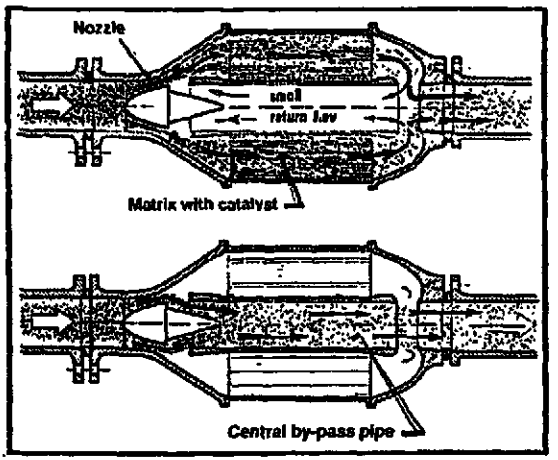

Fig. 1: The two stable states in the developed compact axisymmetric fluidic valve for passive control of an automobile catalytic reactor. Top: flow through the catalyst matrix after engine start. Bottom: flow switched to the by-pass pipe to avoid reaching dangerously high temperature (a secondary reactor further downstream then takes over the cleansing job).

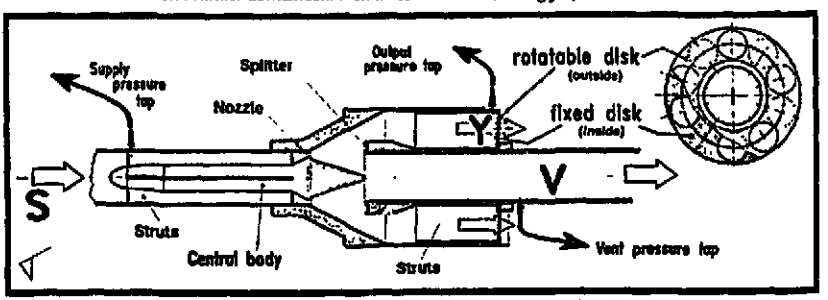

Fig. 2: Aerodynamic model of the radially switched axisymmetric Coanda-effect diverter which has recently underwent successful tests. The changes of aerodynamic resistance of the reactor matrix with temperature is simulated by adjusting the open area of holes in the two disks.

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This research has been conducted at the Department of Fluid Mechanics and Thermodynamics as part of the research project "New possibilities of automobile exhaust gas flow control for reduction of atmospheric emissions", supported by CTU grant No. 28179.

IMPACT FLOW OF COMPRESSIBLE FLUID ON A FLAT PLATE

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Key words: recovery factor, impact flow, compressible fluid

During the development of combined temperature and velocity probes based on shielded thermocouples, see [1] and [2], the problem of the value of the recovery factor

$$r = \frac{T_w - T_{pot}}{\frac{c_{pot}^2}{2c_p}}$$

(T_w ad is the adiabatic wall temperature, T_{pot} and c_{pot} are the temperature and velocity of the potential flow outside the boundary layer, c_p is the specific heat capacity at constant pressure) in the vicinity of the stagnation point in the compressible fluid flow was encountered.

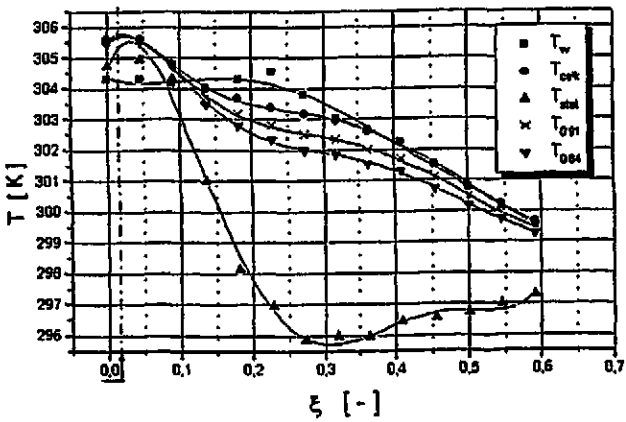

Fig. 1: Temperature distribution in axisymetric case

To gain some informatic... about this problem, an experimental investigation of the temperature and pressure distribution around the stagnation point of the flow caused by an air jet of the diameter 100 mm impinging on a perpendicular flat plate, i.e. in the axisymetric flow field was carried out. The distance between the nozzle exit and the stagnation point was l = 200 mm. The exit velocity was about 120 m/s (Ma = 0.37, Re = 840000), so

that some slight compressibility effects appeared. In the second series of experiments, an approximately plane flow field was created by means of two parallel covering plates situated between the nozzle exit and the plane of impact. During these experiments a new computer controlled data acquisition and evaluation system was developed as a part of a diploma thesis [3].

Some preliminary results of these two experiments can be seen in Fig. 1 (axisymetrical case) and Fig 2 (the approximately plane case). Curves I show the distribution of the static temperature t_{stat}, curves II the distribution of the measured total stream temperature t_{celk}. Curves III correspond to the theoretical adiabatic wall temperature distribution in the case of the turbulent flow parallel to a plane ($r = \sqrt[3]{Pr}$), curves IV in the laminar one ($r = \sqrt{Pr}$). Curves V represent the measured adiabatic wall temperature. An interesting phenomenon is the "peak" in the course of the curves V. In it's coordinate x/l the intensive sedimentation of particles carried by the jet on the impact plane was observed. In the incompressible fluid the increase of the convective heat transfer coefficient was measured.

More detailed investigation concerning phenomena in this region will be carried out.

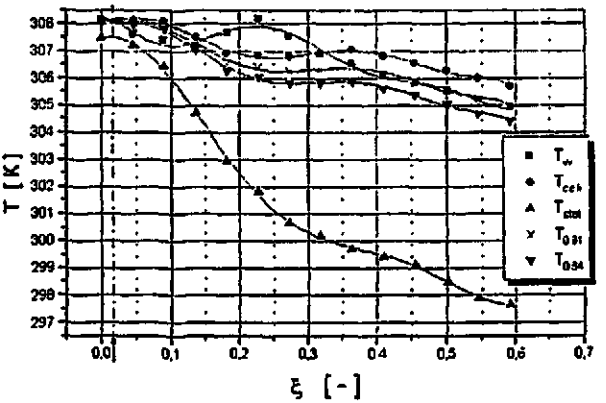

Fig. 2: Temperature distribution in the flow with side walls

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DATA REDUCTION METHOD FOR NON-HOMOGENEOUS GAS MIXTURE FLOWS

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Key words: data reduction method, gas mixture flows, blade cascades

This short paper deals with a contribution to the development of the data reduction method for gas dynamics tests and measurements. The homogeneous flow values are evaluated to represent the measured non-homogenous gas mixture flows. The method satisfies the conservation laws for mass (including mass balance of all injected gas components), momentum and energy.

Thermodynamic basic consideration supposes the flow to be a mixture of perfect gases. Consequently the gas constant R and specific heat capacities c_p, c_v are determined from the mass fraction of components. From them the isentropic exponent (ratio of specific heat capacities) is solved.

Using this thermodynamic basis and the dimensionless gas dynamic functions for the dynamic pressure, the static pressure, and the nondimensional mass flow rate the balance equations establish a system of equations for the values of the homogeneous flow. The original procedure [1] of the solution of the equation system have supposed one perfect gas flow and total temperature to be constant. The new treatment follows the original procedure and the guideline of non-constant total temperature proposed by Oldfield et al. [2] and considers non-constant mass fractions of gas components.

The analysis of the solution of the equation system formulates limitations for quadrates of ratio of the integral of momentum flux parallel to the measuring plane and the transformed integral of mass flux $I_C^2/\bar{I}_M^2$ and the ratio of the integral of momentum flux normal to the measuring plane and the transformed integral of mass flux $I_A^2/\bar{I}_M^2$. The limits, calculated for different isentropic exponents κ_2, are plotted in Fig.1. The transformation of the integral of mass flux I_M consists in the total temperature T_o correction and thermodynamic function K correction given by

$$\bar{I}_M = I_M \cdot \frac{K_1}{K_2} \cdot \sqrt{\frac{T_{o2}}{T_{o1}}} \tag{1}$$

where

$$K = \sqrt{\frac{\kappa}{R} \cdot \left(\frac{2}{\kappa+1}\right)^{\frac{\kappa+1}{\kappa-1}}} \tag{2}$$

index 1 denotes parameters of the homogeneous flow far upstream and index 2 denotes parameters of the homogeneous flow given by the data reduction method. Further analysis

opens discussion on two possible solutions by the data reduction method and determines their meanings on the basis of the oblique shock wave analogy.

The data reduction method was verified and applied in cascade flow investigations. It enabled to solve cases with injection of one or more other gases [3]. Measurements of a non-homogeneous flow behind the cascade, as shown in Fig 2, give distributions of static pressure p_{2y}, total pressure p_{o2y}, exit angle β_{2y}, total temperature T_{o2y}, and mass fractions of components ξ_{i2y} in measuring plane. The data reduction method solves the homogeneous data p_2, p_{o2}, β_2, T_{o2}, ξ_{i2}. It also enables to solve the kinetic energy loss coefficient, the entropy increase, and aerodynamic forces acting on the blades.

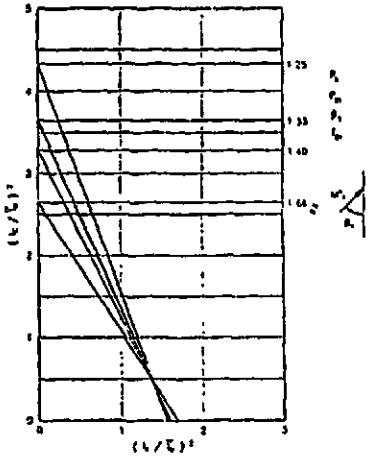

Fig. 1: The limits for data to be treated by the data reduction method

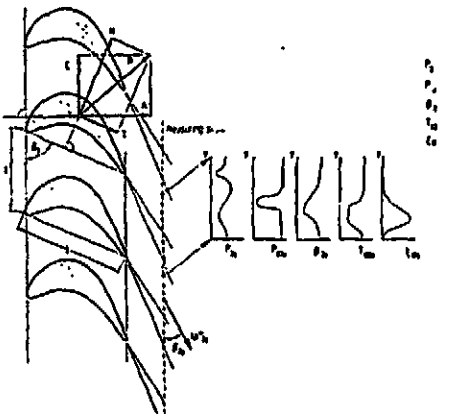

Fig. 2: The scheme of a blade cascade application of the data reduction method

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THE ANALYSIS OF MIXTURE FORMATION IN A DIESEL ENGINE

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Key words: injection, mixture preparation

The fuel spray penetration, fuel evaporation and mixture preparation, as well as the influence of in-cylinder air motion on mixture distribution, are frequent subjects of interest in a Diesel engine development.

For an approximate solution of the mentioned processes the two-dimensional computing model was derived. It has been done on the bases of the experimental and theoretical research of the atomization and velocity characteristics, the temperature and density fields and on the bases of the theoretical analysis of the droplet evaporization.

The first computing model issues from the presumption of the constant injection pressure. The aim of the presented work was to find a computing model of a real nonstationary injection. If all mass of injected fuel is divided into small consecutive injected amounts, the quasi-stationary solution can be performed.

Further the results of a computing solution for the supercharged railway engine of the bore of 230 mm are shown. At this engine an excessive carbonization of piston rings and a piston crown at certain running conditions were observed. Using the computing model it was found out an excessive amount of liquid fuel, pitching the combustion chamber wall at idling and at small power run. A part of liquid fuel slides along the combustion chamber wall towards the cylinder wall and causes the carbonization.

Another important phenomenon, which can be watched by the computing model is the quantity of fuel, entering the first stage of combustion, which is called the premixture combustion. This quantity influences the noise of combustion and the NOx formation considerably. The quasi-stationary solution for the mentioned engine at its full power gives results, which are plotted in Fig. 1. The hatched surface represents amount of fuel, entering the premixture combustion. It represents about 42% of all injected fuel at this case.

It is rather difficult to find correct position of a boundary between the premixture combustion and the consecutive diffusion combustion. Recently we started a work on the high pressure indication in combustion chambers with a heat release computation. We believe, that these experimental results help us to make the computational prediction more accurate.

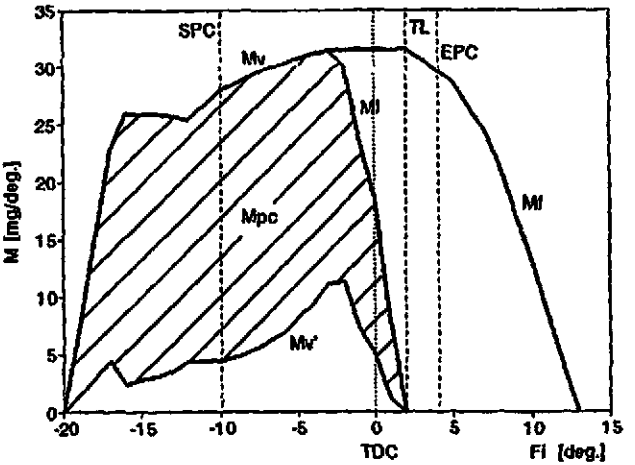

Fig. 1: A mixture formation in the combustion chamber of the supercharged railway engine of the bore of 230 mm (bmep = 136 MPa, n = 1000 rpm)

SPC	start of the premixture combustion
TL	time limit
EPC	end of the premixture combustion, start of the diffusion combustion
EPC-TL	chemical delay of a fuel ignition
Mf	rate of injection
Mv	vaporized fuell till time limit
Mv'	a part of vaporized fuel without an access of oxygen till time limit
Ml	nonvaporized fuel, injected till time limit
Mpc	mass of injected fuel, entering the premixture combustion

This research has been conducted at the Department of Automobiles ICE & Rail Vehicles as part of the research project "The calculated model of fuel motion and vaporization in combustion chambers of Diesel engines" and has been supported by CTU grant No. 08 28168 and GA CR grant No. 101/93/0237.

ORIGINAL SYSTEM FOR INTERNAL COMBUSTION ENGINE THERMODYNAMIC CYCLES DATA ACQUISITION AND ANALYSIS

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Key words: internal combustion engine, thermodynamic cycle, polytropic exponent, rate of heat release, high pressure indication, plug-in data acquisition board

The target of the research has been to develop comprehensive data acquisition and processing system for internal combustion engine inner thermodynamic processes analysis based on IBM PC AT compatible computer with plug-in data acquisition boards, which is suitable for research purposes of universities and other research establishments.

The author's endeavour has been to create a system, which is more suitable for research works on IC engines but development of which is less expensive than purchasing of a foreign system. Thanks to the fact that the system is original, it is possible to adapt it under special demands of research workplaces. The required facilities have been achieved using computer and measuring technology in combination with modern programming algorithms in a way that ensures necessary powerful performance. Using accessible comparisons it can be stated that the system is comparable with foreign ones offering more comprehensive informations about inner processes in combustion chamber.

The system has been completed with developed graphic user interface built on ergonomic principles and usual user's customs, which give it "user friendly" facilities.

The indication system is modular. At present there are used these modules:

Data acquisition module - it serves for data acquisition, classification and storage. Thanks to the used approach is data handling significantly faster than using original plug-in data acquisition board software.

Signal processing module - a module for high-pressure sensor's signal processing has been developed this year. It uses suitable digital filtering and Fourier transform algorithms and it is incorporated into the indication system. The included procedures can eliminate disturbing influences and "noise" during data acquisition and this way it can replace expensive signal processing devices. In addition, the module can be used for burning process noise analysis, mechanical parts stress analysis etc.

Initial conditions module - based on previous results, the system has been extended by module, which makes possible to determine equation of state thermodynamic quantities in moment of inlet valve closing down (eg. in a moment, when the closed thermodynamic system is considered). According to the analysis published in [2] the accuracy of determination of these initial conditions decides about the accuracy of the whole system. This module has been built in the way to determine these values using different methods depending on

the character of the measurement and required of the precision results. The main approach is to measure and analyze compress pressures and initial conditions are found out using non-linear optimization. The next supported method is initial condition determination using TDC, temperature and inlet manifold pressure sensors. For fast diagnostic measuring there has been chosen the method of individual cycle balance along with respecting given polytropic coefficient during compression and TDC correction using empiric formulas.

Statistic module - enables statistic data selection and processing. Its great advantage is powerful fast large data fields processing - thanks to used algorithms the results are almost on-line available. There are statistically processed selected characteristic quantities determined for each of measured cycle, for example pressure peak, maximum pressure rise, mean effective pressures etc. For each of these quantities the system gives in a graphic form a course of the important statistic functions (frequency distribution, cumulative distribution, cycle-to-cycle variability and correlation curves) together with numerical characteristics (spread, standard deviation, coefficient of variation, correlation coefficient etc.).

Thermodynamic module - a single zone thermodynamic cycle model modified by authors is used for thermodynamic evaluations. The model is enlarged by more accurate working medium parameters, which respects the kind of an engine (spark ignition, compress ignition engine), the kind of fuel (petrol, fuel oil, natural gas, propane-butane), air/fuel ratio, air humidity and residue contents. Working medium parameters (eg. specific heats, gas constants) are modelled by polynomial functions in dependence on temperature using multi-step iteration in order to achieve higher precision. Basic evaluated thermodynamic characteristics are mean effective pressures, net rate of heat release, ignition delay, burning process length (there is distinguished 0-5%, 5-95% and 95-100% level of energy conversion as a measure of combustion speed), courses of rate of heat release, temperature, polytropic exponent etc. Thermodynamic analysis results serve the purpose of evaluation wide-range engine performance conditions (engine duty, speed, air/fuel ratio, valve timing, ignition advance, kind of fuel etc.) and engine modification (combustion chamber shape, process of gas exchange, residue contents influence etc.) on combustion process.

The results of the project have been published in the country and also at international conferences, where have aroused favourable response of the specialists from universities and industry enterprises. The system is used for measuring and research works.

We don't consider the research work as to be isolated or closed. Further development is supposed to be in direction of extending included functions, number of evaluated quantities and improving user interface facilities. We intend to aim at non-steady state engine testing.

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This research has been conducted at the Department of Termodynamics and Nuclear Energetic in cooperation with the Department of Combustion Engine and Motor Vehicles as part of the research "System for Internal Combustion Engine Thermodynamic Cycles Data Acquisition and Analysis" and has been supported by TU grant No. 39/93-D.

EULERIAN MULTIZONE MODELS OF ENGINE THERMO-AERODYNAMICS

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Key words: *modelling, thermodynamics, fluid dynamics, reciprocating internal combustion engine, zone, vectorized formulation, ordinary differential equations, eulerian*

The development of thermo-aerodynamic models for internal combustion engines described in [1], [2] has resulted in three concepts of models, commonly used:

- zero- (or quasi-) dimensional models (Z-DM, Q-DM) for one or more parts of a computed domain - zones;
- single-dimensional models (1-D) of a 1-D unsteady flow;
- multidimensional, i.e. 2-D, "2.5-D", 3-D models (CFDM), solving the complete set of partial differential equations of fluid dynamics.

The future prospects of the CFDM are the best - [3]. Nevertheless, there are the problems of engine physics (especially turbulence understanding - [4]) and chemistry to be solved. The closures necessary for semi-empirical solutions even in the former group should be obtained by algorithms inverse to the solver used. The sensitivity to the grid coarseness can cause other obstacles.

This situation needs to bridge the gap between Z-DM and CFDM. Z- DM's have used up to now only zones of a limited number and shape. These models are, nevertheless, transparent and robust. They could be formulated in a modular way using a large set of ordinary differential equations so that the changes of submodels are easily feasible.

Two approaches commonly used differ in gas particles description: the Lagrangian approach describes an individual history of the same particles of gas, whereas the Eulerian one "bookkeeps" budgets of conserved mass properties at the frame of reference chosen arbitrarily. Both approaches have been generalized permitting description of diffusion fluxes over interfaces. Lagrangian approach is often used for multizone Q-DM's. However, it needs a nested zone concept which is rather ineffective for a large amount of zones - [2]. The necessary assumption of homogeneous state inside a zone is very artificial in the case of thin layer zones.

The aim of the work has been therefore to deduce an approach useable under the circumstances described, i.e. the goals are:

- flexibility in adopting new submodels;
- robustness, insensitivity to coarse grids, conservative system of equations;
- transparency, easy formulation of inverse or mixed algorithms for experimental results use and a combination with the existing successful models.

Especially, it includes the use of different models of combustion, real gas properties, a thin boundary layers description (heat exchange, flame quenching, knocking combustion etc.), spray propagation, evaporation and mixing, but also a flexible creation of a model with zones separated by ports that cause throttling of a flow and involve inertia effects (prechambers, piston ring crevices), i.e in general also a manifold modelling.

The way to this model can be based on the recently deduced Advanced Multizone Eulerian Model (AMEM) [5] which combines zones of an Eulerian type with the integral description of laws of conservation. Being based on Q-DM's and deduced by the refinement of them, the resulting system resembles by its integral approach to some CFDM's - [3]. Unlike these ones, the system of ordinary differential equations is deduced and a clear interface between numerical mathematics (initial conditions task) and physics features of problem is set.

The tools used are the explicit formulation of the system of ordinary differential equations (supplemented by algebraic ones) for a number of zones in a vector/matrix form, solved concerning all derivatives of the masses of species, momentum (i.e. velocity) components and enthalpy (i.e. temperature but often more convenient using the equation of state-pressure).

The most important achievements are:

- there is a possibility to solve the set of ordinary differential equations describing the laws of conservation for an arbitrary zone concerning all unknown derivatives; standard explicit or implicit solvers can be used then;
- all equations can be written in a vectorized form, using matrix products for some transformation goals (e.g. chemical reaction kinetics description);
- even the semi-empirical closures (turbulence models, flame front movement equations, boundary layer - "wall functions" - equations) can be written in this general form of equation set.

The vector and matrix formulation is useful for the brief notation, transparent and structured programming, easy changes of the zone representation. It has been used for a general code appropriate to the problem searched. More specialized codes can be then derived from it.

The real space structure of domain modelled is included in convective and diffusion terms of the right-hand side of equations. Having described the structure, these terms can be generated automatic. The system resembles then well-known multibody program packages used in solid body dynamics.

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This research has been conducted at the Department of Automobiles, ICE and Rail Vehicles as a part of the research project "Thermo-Aerodynamics of Internal Combustion Engines - the Base of Economy and Environment Protection" and has been supported by CTU grant No. 8085 and Czech Republic Agency grant No. 101/93/0237.

INTERNAL AERODYNAMICS OF PISTON INTERNAL COMBUSTION ENGINES

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Key words: flow pattern, swirl, tumble

Flow patterns inside the cylinder of the piston engine are very complex, particularly due to the high degree of turbulence. The turbulence intensity is essential concerning the transfer phenomena. A Laser - Doppler - Anemometry is suitable for velocity measurement of the turbulent flow, since it makes possible the velocity measurement in particular points within measured area using statistical evaluation of the acquired values without impact of the flow pattern.

We are trying to use various techniques in competition (such as classical steady-flow measurements, pneumometric probes and anemometry). Recently, suitable model configuration has been used for basic measurement on the aerodynamic steady-flow test bench. Such type of experiments makes possible the evaluation of the flow pattern taking place inside engine cylinder together with determination of integral values of flow patterns created during intake process:

- cylindrical swirl whose axis is parallel to the cylinder axis - SWIRL
- cylindrical swirl whose axis is perpendicular to the cylinder axis - TUMBLE

An unambiguously determined model with simple geometry is suitable to judge various methods of investigation of the properties of the flow pattern. The model with the symmetrically located intake valve has been designed and manufactured. The air supply into the chamber, placed around the valve stem, can be performed either through radial entries or (using tangential oriented holes) with significant tangential velocity vector.

In first stage development the anemometric measurement of flow pattern inside the cylinder has been compared with classical steady-flow testing.

The alternative with tangential entries causes a considerable pressure loss. The mass flow decreases by approx. 60 cylinder charge has been reached (absolute swirl speed of approx. 6000 rpm). The mean piston velocity derived from flow quantity is relatively low - vp = 3.8 m.s-1.

The anemometric measurement has been performed using an OEI Laser - Doppler - Anemometer arranged for a one-component two-beam back-scatter measurement equipped with 5 W Coherent Argon - Ion Laser (operating on 514.5 nm wavelength with 0.6 W power). An optics with 269 mm focus distance has been used. With regard to the appearance of the reversed flow the 10 MHz frequency shift has been exploited using Braggcells included in both beams (35 MHz in the first beam, 45 MHz in the second one). A tobacco smoke has been used for marking of the flowing air. The dispersed light has been received by a photomultiplier. The current output of the multiplier has been processed in the TSI 1980C count processor.

The above described arrangement makes possible the measurement of both axial and tangential velocity vectors. The same mass flow has been adjusted during the measurement with tangential entry and with radial entry as well. The flow pattern inside the cylinder has been examined in two levels at distance of 15 and 65 mm respectively from cylinder head at valve stroke of 6 mm.

In the Fig. 1 and Fig. 2 the examples of the measurement results with radial entry are shown. For 15 mm distance the high velocity has been observed at the intake together with a high level of fluctuancy. At 65 mm distance the fluctuancy magnitude is smoothed and a reverse flow originates. In this way, it has been confirmed that in the region of high velocity gradients the rather high turbulence level is reached.

The same unambiguously defined arrangement has been used for an introductional computation of flow patterns inside the engine cylinder using FLUENT software.

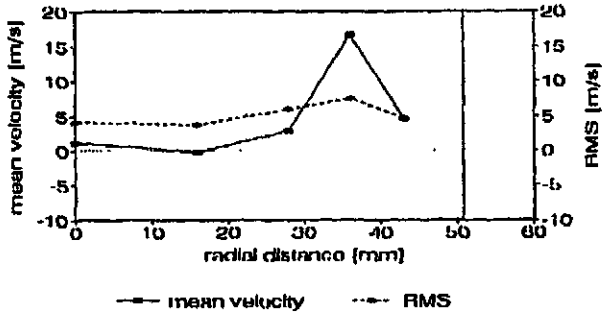

Fig. 1: Radial entry – axial velocities, 15 mm from the cylinder head

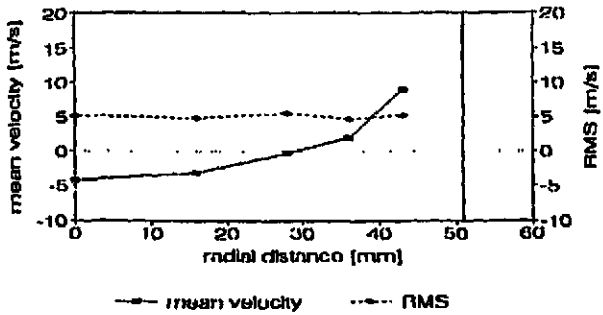

Fig. 2: Radial entry – axial velocities, 65 mm from the cylinder head

This research has been conducted at the Department of Automobiles, ECE & Rail vehicles as part of the research project "Internal aerodynamics of piston internal combustion engines" and has been supported by CTU (TU) grant No. 98 28165 and GA CR grant No. 101/98/0237.

FLOW FIELD IN THE INLET PART OF A STEAM TURBINE

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Key words: hydrodynamics, aerodynamics, flow field, optimum vall shape design

This paper deals with the solution of problems concerning the flow field in the inlet part of the low-pressure stage of a steam turbine in the Department of Mechanics and Materials Science.

As a first step we investigated the influence of the inlet case position to the first stage nozzle on the uniformity of mass flow on inlet to the first stage nozzle cascade. Research was performed on either the three dimensional potential flow model with the use of electrohydrodynamical analogy, or on the aerodynamical model. Experiments discovered the separation of flow in the bend of the confuser.

Secondly attention was paid to the optimization of bend shape. The method of axisymmetrical duct bend design founded on the modification of a hodographic synthesis of the two dimensional round flown contour was developed. At first optimum shapes, keeping ordered geometrical conditions were found. Experiments showed that flow without separation in the confuser is not possible without a change of the first stage cascade position.

In the next step the bend shape *without limiting geometrical conditions* with non-separated flow was found. The found shape caused a shift of position of the cascade and a lengthening of the turbine. A compromise was reached where the original cascade position is kept with the condition that the underpressure wall of inlet nozzle confuser exceeds the space of the cascade. The shape design was made by the method mentioned above.

The bend shape of duct designed was verified by the aerodynamical model. A measurement of the flow field in the confuser with hot wire anemometry method was made. A single hot-wire probe was inserted into a channel through the outlet section in the plane of symmetry of the model, at first without consideration of the effect of guide vanes. The velocity field was mapped in a dense grid with approximately 150 measuring points. The next measurement was carried out with the same aerodynamical model, however the effect of the exit area reduction by means of inserting guide vanes was approximately considered.

The results of both the analytical and experimental solution of the velocity field in the confusor bend are demonstrated in Fig. 1. In part a) the potential flow velocity profiles in five selected sections of the duct bend are plotted. The results of the experimental solution without the guide vanes effect in Fig. 1 b) show that the separation point is situated behind the point of the maximum potential flow velocity. The wake region is narrow and intervenes only in the region of the underpressure contour in the vicinity of the exit area. Velocity profiles, measured in the model with the substitutional guide vanes, are plotted in the identical sections in Fig. 1 c).

Conclusion: owing to the cross - section reduction from guide vanes (which also effects to some degree the upstream flow) the separation of flow was completely eliminated.

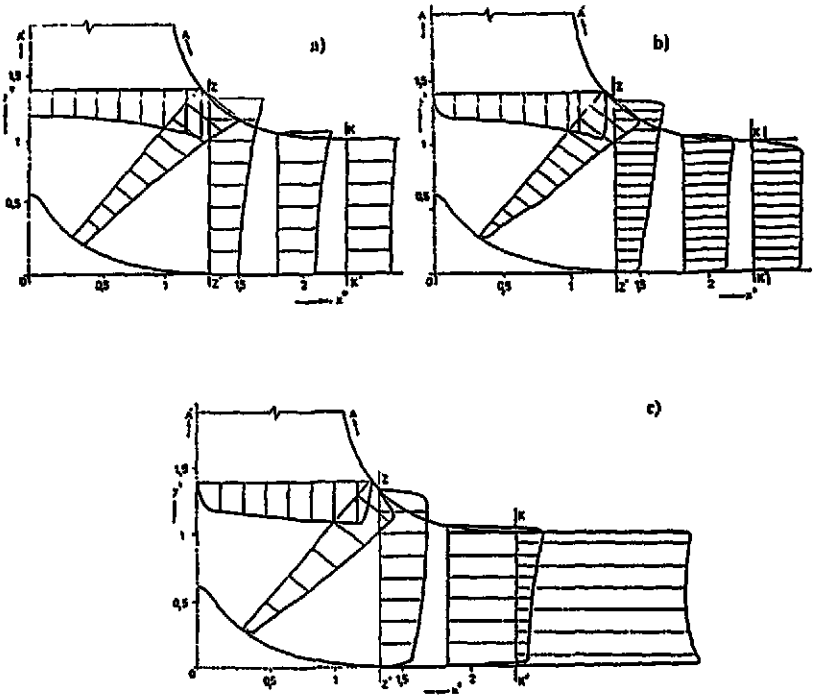

Fig. 1:

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This research has been conducted at the Department of Mechanics and Materials Science as part of the research project "A Complex Method of Round-Flown Wall Design" and has been supported by RS 305193 Škoda Turbiny Plzeň.

EXPERIMENTAL EQUIPMENT FOR EHL TRACTION STUDY

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Key words: elastohydrodynamic lubrication, traction

In hydrodynamically lubricated contacts the relatively thick lubricating film (about $0,05.10^{-3}$ m) develops under relatively low hydrodynamical pressure (about 10^6 Pa). The lubricating film behaves as a Newtonian fluid so that the frictional force is proportional to viscosity and shear rate, and is independent of pressure. In elastohydrodynamically lubricated contacts between heavily loaded non-conforming surfaces the situation is rather different. The lubricating film is much thinner (about 1.10^{-6} m) and the pressure is very high (about 10^9 Pa) so that the changes in properties of the lubricant with pressure are all important and the elastic deformation of the friction surfaces must be taken into account.

The behaviour of the lubricating film in these contacts is characterized by the distribution of lubricating film thickness, pressure in lubricating film, surface stresses, temperature in lubricating film and temperature on the friction surfaces. Besides it is necessary to determine shear properties of lubricant during its passing through the contact (about 10^{-3} s) that are very important for the greatness of friction forces.

The objective of our research is experimental study of elastohydrodynamic lubricating films through experimental methods based on the detection of the electromagnetic radiation of various frequency (optical interferometry, infrared radiometry). The use of these methods requires realization of the experimental equipment so-called ball-plate machine with the transparent disc and the bearing ball or shaped roller as contact bodies. The construction of our experimental equipment (Fig.1) is based on analysis of more than 30 similar experimental rigs used in the world since the end of 60's. All these rigs were based on the conception designed by the team of professor Alastair Cameron from Department of Mechanical Engineering, Imperial College of Science and Technology London.

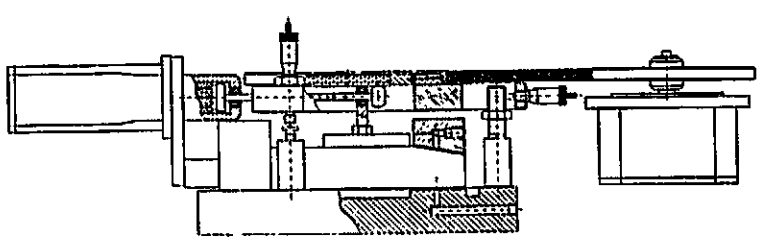

Fig. 1: Experimental equipment

The study of this problem has showed necessity of the determination of friction coefficients at the same time with other above mentioned parameters. This coefficient defined

as the ratio of the traction force generated in the contact to the normal force is of primary importance in understanding many lubricated mechanisms. This is directly related to the power and energy losses in real tribology systems (e.g. rolling bearings, gears and cams).

The one of ways to determine friction coefficients is to use the experimental method based on detection reaction forces on [illegible] friction surface. In most cases this surface is placed on hydrostatic or aerostatic bearings to minimalize passive rezistances. We decided to use the shaped roller (together with its drive) placed on the opposed-pad slideway hydrostatic bearing. This arrangement was chosen for its high stiffness and vibration resistance. For these reasons our hydraulic circuit (Fig.2) contains the capillary restrictor for each of eight pads. These capillary restrictors were designed with possibility of continuous changes of hydraulic resistance for easy changes in stiffnesses and loading capacity of the hydrostatic bearing. The inclinations of the upper hydrostatic bearing pads are 10° in order that the shaped roller can move only along one axis (in the direction of the contact velocity). The traction force is determine from the reaction force of hydrostatic bearing by the strain gauge coupled with the base of the experimental equipment.

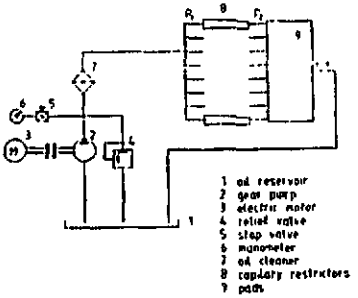

Fig. 2: Hydraulic circuit of hydrostatic bearing

The input measurements with this experimental equipment have proved its possibility to be used for studying of traction forces at the same time with measurements of the lubrication film thickness and shape. Our next work will be orientated towards the study of traction properties of various types of lubricants and their non-Newtonian behaviour under high contact pressures.

This research has been conducted at the Institute of Design as part of the research project "Experimental Modeling of Traction Forces in Elastohydrodynamic Contacts" and has been supported by TU grant No. A8/94.

AN EXPERIMENTAL INVESTIGATION OF PULSATILE FLOW IN CIRCULAR TUBES WITH SINGULARITIES

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Key words: pulsatile flow

The experimental investigation of pulsatile flow of a Newtonian fluid was performed by the Department of Fluid Mechanics and Thermodynamics and the Institute of Hydrodynamics, Academy of Sciences of the Czech Republic.

Models for experiments were manufactured by the Department of Fluid Mechanics and Thermodynamics and the measurements performed at the Institute of Hydrodynamics. For pressure losses measurement three models were used. Two models contain a singularity represented by an axisymetric sudden expansion and sudden contraction of the cross-section (Fig.1, detail A). Geometry of the models is different. The third model is a simple tube of a constant diameter.

The experimental equipment is installed at the Institute of Hydrodynamics. The flow channel diagram is shown in Fig. 1.

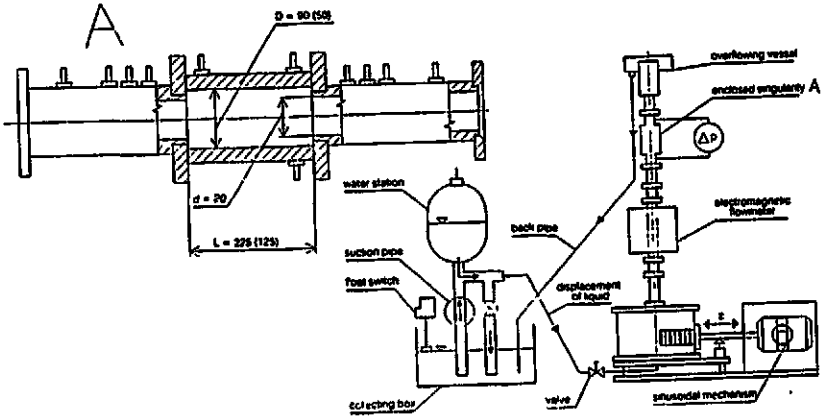

Fig. 1: The flow channel diagram

The model is located in a vertical position. The measured pulsatile flow is the result of a superposition of a stationary flow and periodic oscillations. A small water station supplies a steady flow. A piston with sinusoidal mechanism is the source of periodic oscillations. For these experiments models with a ratio D/L = 90/225 mm and D/L = 50/125 mm were used. *Pressure losses were measured in various distances by differential Validyne transducers.*

The flow is characterized by the flow ratio λ and the frequency parameter α. $\lambda = Q_{pm}/Q_s$ is the ratio between the maximum amplitude of the oscillatory component of the volume flow rate Q_{pm} and the corresponding stationary component Q_s. Frequency parameter $\alpha = d/2\sqrt{\omega/\nu}$, where ω is circular frequency and ν is kinematic viscosity.

The measurements were performed for two parameters (0.45 and 0.9) and for three stationary components of the flow. Q_s (3, 5 and 7 l/min). For example Fig. 2 shows the dependence of the mean dimensionless loss coefficient ζ on the frequency parameter α for Q_s = 7 l/min.

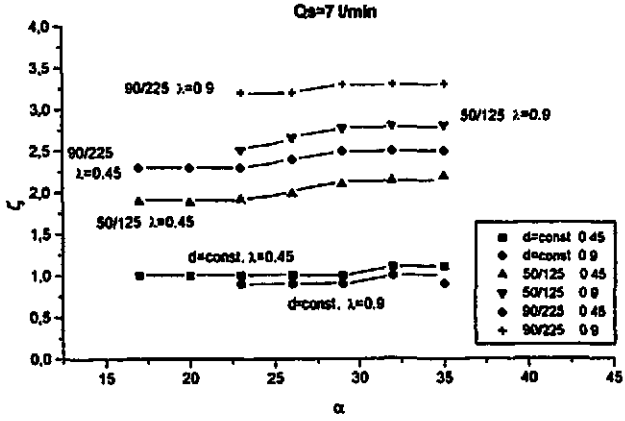

Fig. 2: Dependence of the loss coefficient ζ on the frequency parameter α

The above presented results can be applied both in industry and in biomechanics.

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AXIAL FORCE IN RADIAL TURBINE MACHINES

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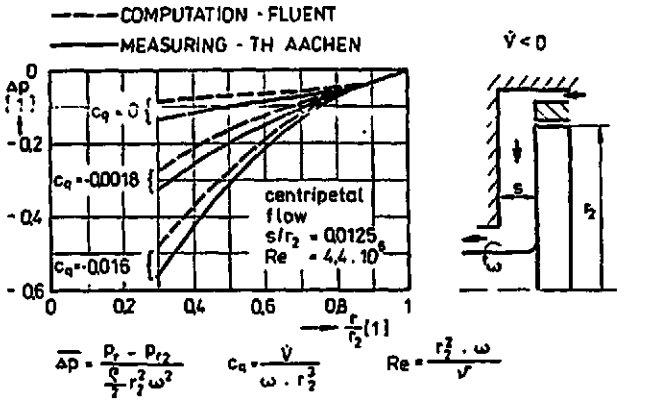
Key words: radial turbo-compressor, axial force, computation, Fluent, measurement

The Chair of Compressors, Refrigerating Systems and Hydraulic Machines of the Faculty of Mechanical Engineering, Czech Technical University, in cooperation with the Branch University Fachhochschule Giessen, Germany, studied the problem of axial forces acting on the impellers of radial turbocompressors. Knowing the magnitude of axial forces is an important design consideration for sizing of the rotor axial bearing, especially when designing high pressure multistage radial turbocompressors. The aim of joint efforts was to develop of a simpler mathematical model of the axial force, which would be applicable in a practical turbocompressor design procedure. The FH Giessen performs above all the necessary laboratory measurements and the Czech faculty of Mechanical Engineering performs at the same time the corresponding computations, using the Fluent software (a method of finite volumes). The verification of calculations performed in 1994 compared the results as obtained by means of the Fluent software with published measurement results (see e.g. /1/,/2/). Two specimens of the said results are presented in Fig.1 and 2. Fig.1 gives a comparison of measured and computed curves of the static pressure between the rotating disk and the static wall for various radial flow rates (the measurements took place at the Aachen TH, Germany). Fig.2 presents the graphs of the radial speed component distribution in the interstice and of the axial force value acting on the disk as a function of the flow rate through the interstice (the measurements were performed in the Compressor Works ČKD, Prague). The performed work confirms that the Fluent software will be applicable for the calculation of the flow fields for a wide range of radial interstice versions and will help to reduce the number of necessary measurements merely to a verification of selected cases designed with the use of the Fluent software. The computed and measured flow fields will then serve for the implementation of a simple mathematical model, which would be suitable for an industrial technical practice.



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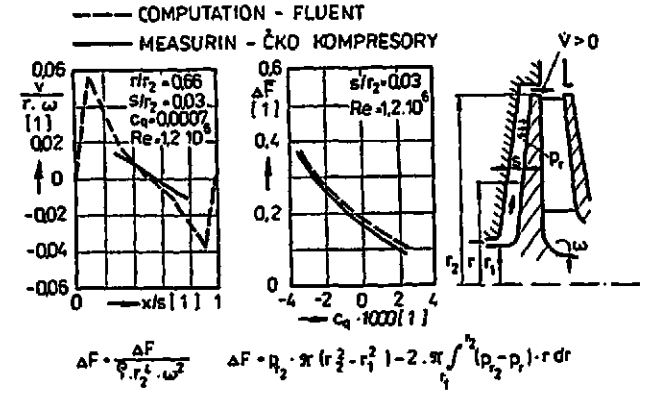

Fig. 2:

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This research has been conducted at the Department of Compressors, Refrig. and Hydr. Machines CTU Prag and has not been supported by grant.

MACRO-TRANSITION PHENOMENON IN AN AXIALLY AGITATED SYSTEM

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Key words: mixing, macro-transition, macro-instability

The paper deals with the study of turbulent macro-instabilities in the process of mixing in a cylindrical vessel provided with pitched blade impeller and four radial baffles. The macro-instability occurrence, i.e. the existence of eddy fields whose space and especially time scales considerably exceed those of current turbulent eddies, represents a well known reality in mixing systems. Rules of macro-instability occurrence were investigated in their dependence on physical parameters of the liquid mixed and on the regime of mixing. The observation was carried out partly in a visual way, partly by means of a mechanical device, developed specially for this purpose. All the liquids used in the experiment behaved as Newtonian. The aim of the experiments was also to confirm the hypothesis explaining the macro-instability existence as a phenomenon resulting from the transition from a single loop into a double or several loop flow patterns in the mixing system. This transition process has been termed as a macro-transition.

The experiment was performed in a cylindrical vessel of the diameter $T = 300$ mm filled with liquid to the height $H = T$ with the pitch blade impeller of the diameter $D = 100$ mm pumping liquid towards the vessel bottom and with four radial baffles of the width $B = 30$ mm. The impeller off-bottom clearance was set at three positions, $H_2 = 0.2\,T$, $0.35\,T$, and $0.5\,T$. Four different charges were used for the measurements. Water, saccharose solutions in water of mass concentrations of 27% and 46% and silicon-oil. The temperature of water and saccharose solutions was kept at $23 - 60$°C, the temperature of silicon oil was kept at the values ranging from $23 - 60$°C to $70 - 60$°C.

The dependence of frequency f of the macro-instability occurrence on the impeller speed N was obtained for each liquid tested and for three different impeller off-bottom clearances. Also, the dependence on liquid viscosity was obtained. In the region of $Re_M = 6.10^4 - 3.10^5$ (water, saccharose) which is evidently a turbulent one, the dependence of f on N is approximately of linear character. The analysis of the results showed that the effect of the impeller off-bottom clearance manifests itself only in different slope of the line approximating the dependence. In the region of $Re_M = 3.10^2 - 6.10^2$ (silicon-oil) which is supposed to be a transition region from turbulent to laminary flow, the frequency of macro-instability decreases with decreasing Re_M, and is practically zero for $Re_M = 500$. With further decrease of Re_M, the frequency of macro-instability increases again, reaching a local maximum for Re_M between 450 and 480. The second zero point is for $Re_M = 420$. The visual observation carried out by means of a "light knife" and video-camera record proved that the macro-transition phenomenon is closely connected with the macro-instability origin only for Re_M greater than 500. For Re_M smaller than about 500, the classical single-loop pattern

alternating with the double-loop one does not exist any more while macro-instabilities still appear.

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MIXING IN UNBAFFLED VESSELS

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Key words: mixing equipment, agitator, mixing time, turbine impeller

Our research on mixing in unbaffled vessels was subdivided in two parts. The first part was devoted to the power consumption measurements and the second part dealed with the homogenization of liquids in vessels without baffles.

In the first part the power consumption measurements with pitched blade turbines presented in [1] were completed by data for disc turbine. The experimental results were processed in two ways. In the first, the correlation recommended by Rushton et al [2] was used:

$$Po = Fr^a f(Re) \tag{1}$$

where

$$a = (1 - \log Re)/40$$

In the second, the standard approach was used and the experimental data were processed in the form of the relationship:

$$Po = f_1(Re) \tag{2}$$

(where $Po = P/\rho n^3 d^5$ - power number, $Re = nd^2\rho/\mu$ - Reynolds number, $Fr = dn^2/g$ - Froude number, d is agitator diameter, n agitator speed, P power input, g acceleration due to gravity, ρ liquid density, μ liquid viscosity).

Both correlations were compared and we can conclude, that the standard relation (2) is more suitable than the correlation represented by Eq. (1). The experimental results can be expressed by the following equations:

$$Po = 9,77\,Re^{-0,23} \tag{3}$$

for $300 < Re < 4.10^4$

$$Po = 0,72 \tag{4}$$

for $4,5.10^4 < Re < 5.10^5$

The second part of research programme was devoted to homogenization of liquids in unbaffled tanks. The three types of turbine agitators were used in experiments: pitched three-blade turbine, pitched six-blade turbine and six blade disc-turbine. The measurements were carried out in the flat bottomed vessels with inner diameter D in the range from 150 to 630 mm. The ratio of vessel to agitator diameter was varied in the range from 2,6 to 6. The conductometric method was used in mixing time measurements. The mixing time was

defined as that at which the fluctuations of concentration in the mixed liquid were less than 2% of the total concentration change.

The result of mixing time measurements showed that the product of agitator speed and mixing time $n.t_M$ is independent of Froude number and the following general equation can be recommended for their correlation:

$$nt_M = K\left(\frac{D}{d}\right)^b \tag{5}$$

The values of the constant K and exponent b in Eq. (5) can be found in Ref.[4].

The values of $n.t_M$ calculated from Eq. (5) for the ratio $D/d = 3,3$ were compared with the corresponding values reported in [3] for vessel with baffles. It was found that both values differ markedly only for pitched three-blade turbine, which exhibited about 20% higher mixing time in the tank without baffles than in the tank with baffles.

The energy needed for homogenization $E = Pt_m$ was used in comparing the agitators efficiency. For this purpose the following dimensionless criterion was suggested:

$$\frac{Et_M^3}{\rho D^5} = Po(nt_M)^3\left(\frac{D}{d}\right)^5 \tag{6}$$

The values of this criterion for the ratio $D/d = 3,3$ and fully turbulent region were compared [4] and it was found, that the agitators in unbaffled vessels need less energy for homogenization than the corresponding agitators in vessels with baffles.

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This research has been conducted at the Department of Chemical and Food Process Equipment Design, Technická 4, 166 07, Praha 6 and has been supported by CTU grant No. 08 28176.

TURBULENT FLOW OF LIQUID IN AGITATED SYSTEM WITH COUNTERCURRENT IMPELLERS

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Key words: agitated system, turbulent flow of liquid, countercurrent impellers

Mechanicaly agitated system with high height/diameter ratio and two countercurrent axial impellers under certain arrangement of impellers [1] (see Fig. 1) makes it possible to avoid a central vortex at the liquid surface as well as an insufficient mixing (blending) in liquid phase without installation of additional internals (e.g. baffles at the vessel wall) in agitated liquid. In this arrangement two impellers with six inclined plane blades of the same diameter d (see Fig. 2) rotate at the same level of revolution frequency n in the clockwise or counterclockwise direction respectively, both pumping the liquid downwards, towards the bottom of the mixing vessel.

The experiments in the above mentioned agitated system were carried out in a pilot plant system (see Fig.1) by means of the laser-Doppler anemometer (with back scatter mode) in water to determine the turbulent velocity field in an investigated system. Three components of the mean velocity (axial, radial and tangential) and (specific) kinetic energy of turbulence were calculated from the data mensured in a few radial cross-sections of the system at two levels of impellers revolution frequency.

For numerical simulation of turbulent flow in an agitated system with two countercurrent axial impellers, "k-ε" model of solution of the Reynolds equation of turbulent flow according to the standard software FLUENT (Version 4.2., Fluent Inc., 1993) has been used. Boundary conditions were considered at the mixing vessel, wall and bottom ("the wall function"), and the fixed option of all the components of the mean velocity, kinetic energy of turbulence and the rate of energy dissipation per unit volume in discharge flows from both the impellers following from the experimental data. The selection of model parameters follows from the previous studies on numerical simulation of the turbulent liquid flow in mechanically agitated systems [2], [3], [4].

It follows from the comparison of numerical simulation results with the experimental LDA data that calculated radial profiles of all three components of the mean velocity are in good agreement with the experimental results in all tested cross-sections of the mixing vessel; radial profiles of the (specific) kinetic energy of turbulence exhibit fairly good agreement, as well. Velocity field in the liquid mixed by two countercurrent axial impellers can be considered as two dimensional (axial and radial components prevail) for optimal geometric conditions described in Fig. 1 [1]. Then, except for the discharge flow between the upper and lower impellers, tangential components of the mean velocity can be neglected.

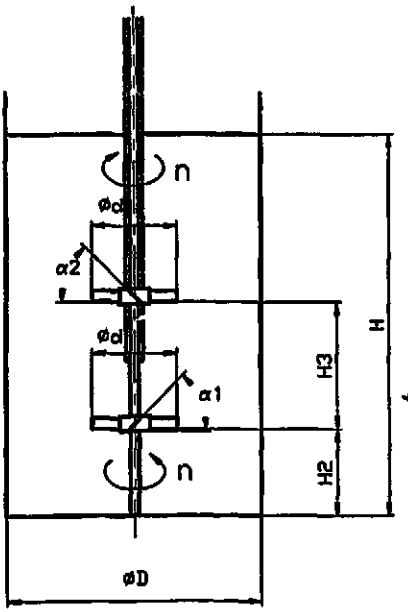

Fig. 1: Optimum arrangement of the pilot plant system with countercurrent impellers ($D = 0.292, d_1 = d_2 = D/3, H_2 = d, H_3 = 1.5d, \alpha_1 = 40°, \alpha_2 = 45°, H - H_2 - H_3 = 2d$).

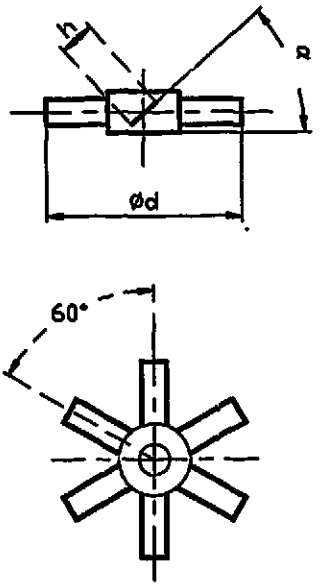

Fig. 2: Impeller with six inclined plane blades ($h = 0.2d$).

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FREE-CONVECTION OF RADIOACTIVE WATER IN MINING WELLS

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Key words: mine, free convection, waste water, FLUENT

The waste water from radioactive mines contains high concentration of ions such as Ca^{2+}, Fe, Cu, NH_4^+, SO_4^-, NO_3^- and NO_2^- and radioactive ions U and Ra. There is a possibility to deposit this waste water into the closed mines. The underground caverns and shafts are connected to a ground by vertical wells with an internal diameter of 5.1 m. The waste water will be pumped to a bottom part of the mine from about 1200 to 800 m below ground. On the top of this waste water the pure water will be deposited to prevent the ground water from contamination. However, the free-convection can developed in the vertical wells due to temperature gradient in the ground. This research is trying to answer the question whether the free-convection can cause the contamination of the ground water.

At the first stage of the research the theoretical approach was chosen. From physical point of view it is problem of hydrodynamic stability of a pure liquid in a vertical cylinder with a fixed linear temperature profile along the vertical wall. The increase of the temperature along the depth of 800 m is 15°C. The buoyancy-driven convection in a vertical cylinder is stable if the Rayleigh number is below 64 [1]. In our case the Rayleigh number was well above the stability limit $Ra = \beta g R' \Delta T' / (\nu a H) = 5,145.10^9$. Such a high value suggests that the flow will be turbulent.

We proceeded in a gradual steps. All calculation were performed with CFD code FLUENT for 2D axisymetric flows. First the laminar case of the transient flow at low Ra number equal to 10000 was investigated numerically in a short cylinder with height equal to radius. For this short cylinder the stability limit is $Ra = 2270$ as found by Yamaguchi et. all (1984). Above this limit 2270 up to $Ra = 25000$ the flow forms one axisymetric loop which is stable and the flow is laminar. For $Ra > 25000$ more than one flow pattern can exist and none of them is stable. The result of the transient laminar calculation for $Ra = 10000$ shows that just one stable loop is developed and fully confirms the results presented by Yamaguchi [2]. The heat flux from the bottom surface was 2 times higher compared to the heat flux in still liquid. The steady state was reached at dimensionless time of at/H^2 equal to 0,26. For the well with a diameter of 5.1 m and temperature conductivity $1,225.10^{-3} m^2 s^{-1}$ this time is about 6 hours. In our case the driving force is higher ($Ra = 5,141.10^9$) so the developed flow would be reached earlier.

The next step was to increate the Ra number above 25000 where no stable flow pattern can exist [2]. The results for $Ra = 5,145.10^9$ corresponding to the real situation and computed for laminar flow are shown on Fig.1.

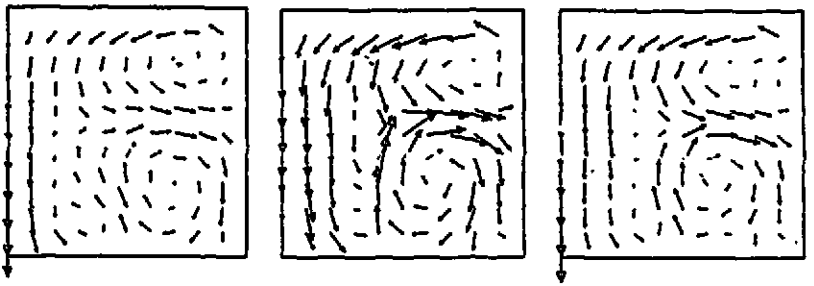

Fig. 1: Unstable numerical solution of free-convection in cylinder with $H = R$ at $Ra = 5,145 \cdot 10^9$ after 1000, 1300, 1460 iterations ($u_{max} = 0.01, 0.006, 0.008, m.s^{-1}$).

However, in all analysed cases (using the $k-\epsilon$, *RNG* $k-\epsilon$ turbulence models and transient analysis) the solutions were not probably correct, because during the course of iterations the relative residua oscilated around a stable value and did not decrease.

The major reason why all the solutions (except the small *Ra* cases) were not converging is probably due to a strong restriction to axisymetrical flows. It is known, that for cylinders with $H/R > 6$ the prevailing mode is nonsymetrical. The liquid flows up at one side of cylinder and down at the other.

Therefore the future step should be a fully 3D numerical simulation in a Cartesian grid. Cylindrical grid always prevent the flow to cross the axes.

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PROFILE EXTRUSION DIE DESIGN NUMERICAL SIMULATION

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Key words: extrusion, simulation, extrudate swell, profiles

In profile extrusion the main objective is to have the ability to control the shape of the profile, to achieve the required dimensions. The influence of an internal geometry of a die has to be considered. To obtain uniform discharge at the exit, the material has to have the same average velocity in all the parts of the die at the exit cross section [1]. This condition is the most important when designing profile dies.

We have to address also the problems of dimensional changes occurring after the die exit. The extrudate swell occurs whenever a polymer melt flows from a die. The drawdown and shrinkage can decrease or eliminate this effect. Some authors reported that the extrudate swell and drawdown are not generally isotropic. Many authors thoroughly investigated this extrudate swell phenomena [2]. Most of the studies conducted have involved flows through capillaries or flat geometries. However the swell in complicated geometries can be calculated only by fully three dimensional techniques. To better understand the die swell, one has to take into account the elasticity of a material as well as elongational properties.

To date the design of profile dies has been done mainly using experience. The powerful computers and new numerical methods started the trends of combining empirical approaches with numerical calculations for better die design.

Theory and results. The following assumptions are usually made when simulating the polymer processing problems. The polymer melt is treated as incompressible, with predominating viscous forces. The inertia, gravity and the surface tension are neglected. The flow is assumed to be steady and the validity of the 'No Slip' condition is desirable. Viscosity is shear dependent and the power-law, carreau or log-polynomial models can be used. In our study we have neglected the elasticity and elongational properties.

The governing equations are the mass, momentum and energy balance for incompressible flow.

$$\nabla . v = 0 \qquad \nabla . \tau - \nabla P = 0 \qquad Pe\, v . \nabla T = \nabla^2 T + Br\, \tau : \nabla v$$

The first problem we tried to solve was the 'flow balancing' inside a die based on several calculations of a velocity profile at two dimensional cuts parallel to the main flow direction. This method is based on know-how built up in the industry over the decades. The method can calculate the flow inside the die and can be used to design dies with a balanced mass flow rate. Also the pressure drop can be calculated.

To be able to study in detail the flow in a die, the influence of the extrudate swell and the drawdown on the final shape, we created powerful solver based on the fully three dimensional nonisothermal calculations. By this solver the velocity, pressure and temperature fields can

be obtained. Also the shape of the extrudate when drawn out from the die or for example the effects of temperature on the die swell can be calculated [3].

Conclusion. Comparison with published results and several experimental data suggested that the method of 'balancing' the flow inside the die using 2D cuts is reasonably accurate in predicting the flow behaviour. The calculated data differ from experimentally measured velocities approximately by 20 percent.

The 3D solver is at this moment capable to solve the whole profile die. Such calculations would be however uneconomical. The solver was routinely used to investigate the details in the extrusion die flow. The next challenge is to incorporate the elastic effects, elongational viscosity or perhaps the gravity and surface tension effects.

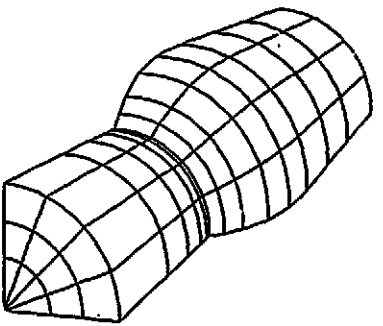

Fig. 1: Sketch of the 3D grid used for extrudate swell calculation.

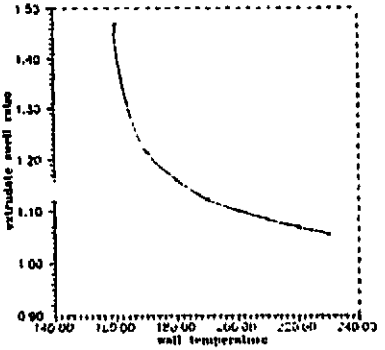

Fig. 2: Plot of the 3D calculation results - extrudate swell as a function of wall temperature.

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This research has been conducted at the Department of Plastics and Rubber Technology, Faculty of Technology Zlín, VUT Brno as part of the research project "Extrudate swell for complicated shapes".

DRAG REDUCTION AND HEAT TRANSFER REDUCTION OF MICELLAR SOLUTIONS

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Key words: drag reduction, surfactant, turbulent pipe flow

Different cationic surfactant solutions have been tested with the aim to find drag reducing solutions which would be suitable for use in recirculating district heating or cooling systems. These solutions should meet the following criteria: high drag reduction (DR) coefficient (compared to water) over a wide range of temperatures and velocities, no permanent mechanical degradation caused by high shear (centrifugal pumps etc.), and chemical and structural stability. A number of heat transfer reduction (HTR) tests on a plate fin heat exchanger were also carried out in order to find out if there is any correlation between drag and heat transfer reduction, and to minimize the heat transfer reduction effect in heat exchangers.

The first tested fluid was a solution of Ethoquad T-13 + sodium salicylate (NaSal). The initial concentration for drag reduction tests was 5 mM (2300 ppm) of Ethoquad T-13 + 12.5 mM (2000 ppm) of NaSal, and this was gradually reduced to 88%, 80%, 75%, 70%, 60% and 50% of the initial concentration. The drag reduction coefficient was measured on a recirculating testing loop with a cog-wheel pump and a testing tube of 25 mm diameter. The temperature of the liquid during the tests was maintained at constant values in a range from 10 °C to 110 °C, the velocity range corresponds to Re from 10,000 to 1,000,000 (Re based on the properties of water). The result of this study can be expressed with the following points: the maximum drag reduction of 72% was observed for concentrations higher than 1840 ppm + 1600 ppm of Ethoquad T-13 + NaSal and for temperatures lower than 70 °C. For less concentrated solutions the maximum DR gradually decreases, for 1150 ppm + 1000 ppm of Ethoquad T-13 + NaSal it was about 65% for temperatures lower than 30 °C. A critical wall shear stress exist, at which the solution loses its drag reducing ability. The critical wall shear stress ranges from 100 to 400 Pa and it is a function of both temperature and concentration of the solution. At concentrations higher than 1840 ppm + 1600 ppm of Ethoquad T-13 + NaSal the solution is saturated and the critical wall shear stress occurs between 60 °C and 70 °C. No permanent mechanical degradation caused by high shear in the pump was observed. The solution was stable and no structural or chemical changes were observed after several days of testing.

The heat transfer reduction tests were carried out on a plate fin heat exchanger (PFHE), design APV-CREPACO TR 15, consisting of 10 channels and configured for a counter-current operation. The initial concentration of the solution was the same as for the drag reduction tests (2300 ppm + 2000 ppm of Ethoquad T-13 + NaSal) and the other tested concentrations have been reduced to 80%, 70% and 60% of the initial concentration. Temperature of the solution across the PFHE ranged from about 20 °C to 70 °C.

The results of these tests can be summarized as follows:

The overall heat transfer reduction in the plate fin heat exchanger is about 25% to 28% for solutions of concentration higher than 1840 ppm + 1600 ppm of Ethoquad T-13 + NaSal (the saturated solutions), in the range of Re from 500 to 4000. For concentrations lower than 1840 ppm + 1600 ppm of Ethoquad T-13 + NaSal the HTR was gradually decreasing. This indirectly proves (because the temperature of the solution across the PFHE was up to 70 °C) a close correlation between HTR and DR in terms of the dependency on both temperature and concentration. No significant differences of pressure drop across the plate fin heat exchanger between solutions of various concentrations and water were observed.

More drag reduction tests were carried out with solutions of Arquad 16 (5 mM = 3195 ppm) + NaSal (5 mM = 800 ppm) + 3-OH-2-naphtoate (5 mM = 910 ppm). The combination of two counter-ions have been chosen in order to achieve high drag reduction over wide range of temperatures and velocities. A drag reduction of about 40% was observed for temperature 10 °C and low Re. For 20 °C the maximum DR occurred also in low Re. area, but reached more than 80%. For temperatures from 25 °C to 35 °C, the solution showed a high DR over a wide range of Re. An unusual peak (DR is higher than 90%) occurred at Re from 60,000 to 100,000. For temperatures from 40 °C up to 100 °C the DR curve had a common shape with a maximum DR around 72%. The diversity of behavior over the range of temperatures is probably caused by different "working conditions" of the two counter-ions present in the solution. In addition, the measurements at temperatures between 25 °C and 35 °C after a few days of rest did not show any "peaks" or other irregularities, the DR curves were similar to those for higher temperatures. To gain more understanding, tests of solution consisting of Arquad 16 (5 mM) + NaSal (5 mM) + 3-OH-2-naphtoate (2 mM) were carried out later. Results of this test did not show any irregular behavior, the drag reduction curves were of a common shape for all temperatures from 10 °C to 100 °C with a maximum DR about 72%. This proves, that the irregularities mentioned above were caused by presence of high concentration of 3-OH-2-naphtoate. However, the structures which caused the "peaks" at temperatures between 25 °C and 35 °C apparently were not stable and degraded with time. The peaks dissapeared after a couple of days of testing and a regular behavior was observed afterwards.

Heat transfer reduction measurements on the PFHE were carried out with a solution consisting of Arquad 16 (5 mM) + NaSal (12.5 mM). The results showed a reduction of about 25% for NRe from 1200 to 3500 (Re based on properties of water). No significant change in pressure loss was observed.

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MEASURING THE FRICTION LOSSES FOR FLOW OF HIGH CONCENTRATION HOMOGENEOUS SUSPENSION IN PIPES

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Key words: laminar flow, turbulent flow, friction losses, experimental measuring

Flow of high concentration suspensions is used in many industrial applications,e.g. for raw materials transportation (coal, iron ore), and/or for hydraulic disposal of various wastes such as fly ash, phosphate mud, etc. New technologies require the transport of high concentration suspensions in both laminar and turbulent flows.

Theoretical description of suspension flow possessing Non-Newtonian behaviour has to reflect their rheological behaviour as well as their pipe flow characteristics. Lazarus and Slatter (1988) observed flow behaviour of dense slurries using capillary viscometer. Havlik (1991), Chára et al. (1993) investigated the flow behaviour of fly ash. A particle size distribution, volumetric concentration of solids and the changes in rheological parameters were the most important.

In order to determine flow behaviour of dense slurries in pipes, it is necessary to measure the pressure losses dependence on flow rates both in laminar and turbulent flow regimes. Experimental measurements have been carried out on a test loop in the Institute of Hydrodynamics in Prague using fly ash and ash-gypsum suspensions. Particle size distribution varied with the mean particle in a range of $d_{50} = 0.025 - 0.032$ mm. Volumetric concentration for the experimental measurements in pipes of two different diameters, namely D = 0.0175 m and 0.0268 m, has shown the strong influence on the friction losses. The relative hydraulic gradient, i.e. the dimensionless ratio of the hydraulic grade line for suspension concerning water alone respectively,ir = im/iw, may vary within several orders of magnitudes. The experimental results with high concentration indicated Non-Newtonian behaviour. Preliminary results from the tube viscometer showed that the suspensions behaved as time independent viscoplastic fluids. The rheological parameters of power law two parameter model are shown in Table on the Fig. 1.

Further research will focus on determination of suitable rheological model using the capillary and/or rotational viscometers. A mathematical model describing the flow dependence on rheological parameters can be verified in the experimental loop using different pipe diameters. The results can be used for a design and optimisation of pipe hydrotransport of dense fly ash and ash-gypsum slurries.

Ash-gypsum suspension - Mělník - Riedersbach			
Weighted ratio ash / gypsum	Volumetric concentration cv	Non-Newtonian flow behaviour index n	Fluid consistency index K [Pa.s^n]
2 : 1	0,33	0,554	0,525
2 : 1	0,38	0,536	1,275
2 : 1	0,43	0,592	2,30
3 : 1	0,27	0,567	0,451
3 : 1	0,42	0,803	0,35
3 : 1	0,44	0,759	0,842
Ash-gypsum suspension - Nováky - Riedersbach			
Weighted ratio ash / gypsum	Volumetric concentration cv	Non-Newtonian flow behaviour index n	Fluid consistency index K [Pa.s^n]
2 : 1	0,42	0,52	1,832

Fig. 1: Table

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This research has been conducted at the Department of Hydraulics and Hydrology, Faculty of Civil Engineering as part of the research project "The Influence of Concentration and Selected Physical Parameters of Concentrated fine Suspensions on flow Regime" and has been supported by Grant Agency of Czech Rep. under Grant No. 103/93/0397

HYDRODYNAMIC AND THERMODYNAMIC STABILITY OF SHEAR LAYERS

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Key words: hydrodynamic stability, shear layer, thermodynamic stability

The theory of hydrodynamic stability has gained an important position in fluid dynamics research due to its fundamental aims to discover mechanisms of transition to turbulence and of turbulent motion itself. The nonlinear equations of fluid motion cause mathematical difficulties that were not solved satisfactorily up to this time. As no closed theory of hydrodynamic stability hitherto exists, some features of the instability behaviour of fluids can be due to stability theory accounted for having the nature of a law. An example is energy division into individual modes so that most of energy is carried by the lowest frequency modes, i.e. the origin of the subharmonic frequency.

The first stability theory applied an approximation of infinitesimally small perturbations. The approximation enabled to linearize the evolution equation of a perturbation. The parallel shear flow approximation enabled to reduce the number of primitive variables to one, which is the cross-stream coordinate. The general solution of the evolution equation of the perturbation is then in the form of travelling wave. The resulting equation of the perturbation is a linear ordinary differential equation. Its special form is called Orr-Sommerfeld equation which is the fourth order linear ordinary differential equation for the amplitud of cross-stream coordinate of the perturbation velocity $\hat{v}$:

$$\hat{v}'' - 2(\alpha^2+\beta^2)\hat{v}'' + (\alpha^2+\beta^2)^2\hat{v} = iRe\{(\alpha U' + \beta W' - \omega)[\hat{v}'' - (\alpha^2+\beta^2)\hat{v}] - (\alpha U'' + \beta W'')\hat{v}\}$$

If the viscous effects for high Reynolds numbers and free shear layers (remote from a wall) are neglected then the Rayleigh equation follows. The Rayleigh equation considers inviscid instability mechanisms. They are caused by a convective mechanism, which transfers momentum or kinetic energy in cross-stream direction - it means in direction where the gradient of transferred quantity is very high. The viscosity effect appears in two different directions. The first one is a damping effect on the convective instability. It means that for lower Reynolds numbers the viscosity stabilizes the shear layer. The second effect of viscosity is opposite, it causes so called viscous instability, especially in flows where viscous stresses are dominant. Tollmien-Schlichting waves in boundary layers serve as a typical example. For the purely viscous instability it is characteristic that it appears only in a certain interval of Reynolds numbers for each frequency or wave number of a disturbance. It disappears for increasing Reynolds number.

One of the most important results of stability theory are stability criteria. For the inviscid stability theory a theorem follows from the Rayleigh equation. From this theorem

the criterion of inviscid stability can be concluded: If the second derivative of the velocity profile does not equal zero inside the shear layer, the flow is stable. It is very well known that such a criterion is not valid for boundary layers where the viscous effects are not negligible. The stability criterion for boundary layers follows from the Orr-Sommerfeld equation. The equation is homogeneous and together with homogeneous boundary conditions forms an eigenvalue problem. The fundamental result of the Orr-Sommerfeld eigenvalue solution is so called neutral stability curve. It is a curve in the plane of Reynolds number - wave number or frequency for which the imaginary parts of both wave number and frequency are zero. Minimal Reynolds number on the neutral stability curve is called the critical Reynolds number. The stability criterion for flows in which both inviscid and viscous instability mechanisms play a certaine role is then formulated: If the Reynolds number of the flow is higher than the critical Reynolds number, then the flow is unstable.

The above mentioned criteria do not take other dissipative processes than viscous into account. From the thermodynamic point of view the dissipative processes are those which produce entropy. The sign of the time derivative of the mean square of entropy fluctuations determines the evolution of fluctuations and states the form of the thermodynamic stability condition [1]. It was deduced that the condition of local minimum of the total enthalpy for thermoviscoelastic fluids relates to dissipative processes in fluid flows through the condition of non increasing entropy fluctuations. The general form of this condition is

$$-\frac{\rho_0 T_0}{c_0}\overline{(\delta s)^2} = -\frac{\eta_l}{T}\frac{\partial T}{\partial v_l} + t_{dis,kl}\frac{\partial v_l}{\partial x_k} + v_l\frac{\partial t_{dis,kl}}{\partial x_k} \geq 0\,,\ (k,l \equiv x,y,z)\,.$$

This inequality forms the criterion for damping of fluctuations and is one of possible forms of the Braun-Le Châtelier principle. If the boundary layer approximation is applied, the inequality will have the form

$$\frac{c_p}{T\,Pr}\left(\frac{\partial T}{\partial y}\right)^2 + \frac{\partial^2}{\partial y^2}\left(\frac{v_x^2}{2}\right) \geq 0\,.$$

This inequality states a criterion for thermodynamic stability of the boundary layer. The stabilizing effect of the temperature gradient can be deduced from this criterion. This criterion was compared with Orr-Sommerfeld equation calculations for flows without temperature gradient (e.g. Pohlhausen, Blasius, Hagen-Poisseuille flows) as well as with experimental observation [2] of transition to turbulence delay due to temperature perturbation.

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This research has been conducted at the Department of Fluid Mechanics and Thermodynamics and at the Institut of Thermomechanics of the Academy of Sciences of the Czech Republic as a part of the research project "Hydrodynamic stability" and has been supported by grant MŠMT No. PV 353/1994/VŠAV.

SIMILARITY SOLUTION OF THE FILM COOLING

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Key words: convective heat/mass transfer, turbulence, protective fluid film, wall jet, similarity solution, one-equation turbulence model, temperature profiles

A possible way to prevent chemically corrosive, radioactive, high temperature or otherwise dangerous fluids, flowing past a wall, from coming into a direct contact with the wall surface is to blow tangentially along the surface a protective layer of another, harmless fluid. A typical example is the film cooling of turbine blades, combustion chamber or rocket nozzle walls, but there are other similar applications where the film protects against mass transport towards the wall. In spite of its importance, the common calculations of the problem are still based on very rough, nourealistic simplifications. The present much more realistic and yet relatively simple universal solution of the distribution of a passive scalar contaminant (such as admixture of some substance or temperature) near the protected surface is based on the experimentally [1, 2] discovered fact that in the outer layer, beyond the velocity maximum, located at the distance δ_m from the wall (Fig. 1), the profiles of time-mean temperature $\overline{T}$ as well as of time-mean streamwise velocity $\overline{w_1}$ exhibit mutual similarity (Fig. 2). Using the one-equation turbulence model, the problem is described by three thin-shear-layer transport equations: for specific momentum (= velocity), temperature, and kinetic energy of turbulent fluctuations: $\overline{w_1}[\mathcal{P}\nu_t] = 0$, $\overline{T}[\mathcal{P}\sigma_{Tt}] = 0$, $\epsilon_J[\mathcal{P}\nu_t] = \mathcal{P} - \epsilon$.

The overwhelming part of the total temperature drop across the protective layer takes place in the outer part of the wall jet, outside its velocity maximum and hence sufficiently away from the wall for a basic, high-Re turbulence model being applicable. Solution of the outer velocity profiles is then identical to the one as presented in [3], where it was also shown that no further improvement is obtained by more complex turbulence models than the one-equation one. The plausible assumption, due to Tollmien (1926), of a constant integral scale of turbulence across the layer, was used. By transformations into the similarity variables [3], the equations could be converted into the system of seven ordinary first-order equations:

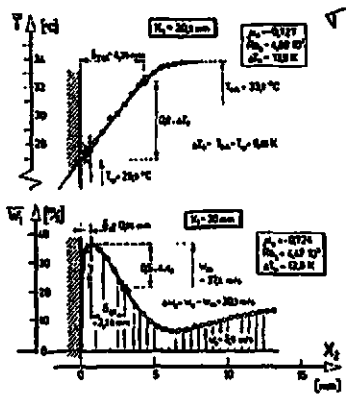

Fig. 1: An example of measured temperature and velocity profiles

$$f_C = u, \qquad u_C = g, \qquad \varepsilon_C = n, \qquad h_C = r, \qquad g_C = \frac{-1}{2\sqrt{\varepsilon}}\left[g(n\sqrt{\varepsilon} + f) + u^2\right]$$

$$n_C = \varepsilon\frac{\cdot}{k\varepsilon} - g^2 - u\sqrt{\varepsilon} - \frac{\cdot\cdot}{2\sqrt{\varepsilon}}\left(f + \frac{\cdot}{\sqrt{\varepsilon}}\right), \qquad r_C = -\frac{1}{2\sqrt{\varepsilon}}\left[Pr_t(uh + rf) + \frac{rn}{\sqrt{\varepsilon}}\right]$$

where the nonsubscripted derivatives are differentiations with respect to the similarity transverse co-ordinate

$$\eta = \frac{X_2}{\sqrt{k\varepsilon c_\mu}\,X1}$$

which is the same as in [3] - this holds also for the other similarity variables used, apart from the relative temperature difference, which is here introduced as

$$h = \frac{T - T_w}{T_{t,1} - T_w}$$

The equations were solved numerically and Fig. 3 presents a typical solution for constant turbulent Prandtl number. When comparison is made with Fig.2 (note, however, the different nondimensionalisation on the horizontal axes in the two diagrams), correspondence substantially better than with solutions used so far is apparent. Adjustment of variable $Pr_t = f(X_2)$ (is a well nown fact that turbulent Prandtl number is not constant across jet flows) can further improve the correspondence so that it is nearly perfect.

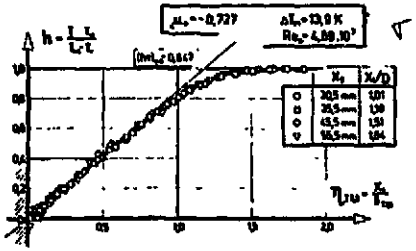

Fig. 2: The similarity character of experimental temperature profiles.

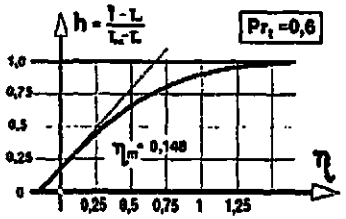

Fig. 3: Similarity solution of the temperature profile for a constant turbulent Prandtl number.

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ELECTRORHEOLOGICAL BEHAVIOUR OF MONOMER SUSPENSION

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Key words: Electrorheology, Monomer suspension, Epoxy resin, Acrylate resin, Celullose

Introduction. The electrorheological behaviour of suspension of different materials in nonconducting medium has been the object of many studies in the past. It has been demonstrated that a reversible increase in non-Newtonian viscosity upon the application of an electric field is due to a drastic change in suspension structure. This phenomenon caused by strong interactions of polarized particles is controlled predominantly by particle polarizability which depends on the inner structure of the particle. We have investigated the ER effect of two polymers to determine their fluid states upon several processing conditions and two types of electric field (DC and AC).

Materials, Results and Discussion. All materials used in this study were from commercial sources and were used as received. An epoxy and an acrylate resins were used as dispersants. The epoxy resin employed was Epicote 828 supplied by Shell Chemical Co. and the acrylate resin was NK ester BPE-200.2 bis (4-Methacryloxydiethoxyphenyl)propane, supplied by Shin - Nakamura - Kagaku and cured with benzoyl peroxide at 80°C. The dispersed phase was crystaline cellulose C.C. containing 5% (w) of water, average diameter 15 μm (Avecil PH - M06) supplied by Asahikasei Co. The filler and resins were mixed mechanically before each measurements. Concentrations of filler were 30,40 and 50% (w).

Parallel plate type rheometer which was partially reconstructed was used for this study. Diameter of plates is 2,5 cm, and the gap between plates was fixed at 0,5 and 1,0 mm and temperatures were set at 22,66 and 88°C.

From the viscosity measurements without electric field, it was found that all the samples had constant viscosities over used shear rate. Fig. 1 shows the relationship between shear stress in DC electric field (EF) and shear stress without EF, for C.C.50/Epoxy sample at various temperatures. The shear stresses were defined as the values at the edge of disc plate. The broken line in the figure shows the relation of both shear stresses in the absence of ER effect and with. It was found that ER effect is small for lower temperatures and higher shear stresses. With increasing temperature and electric field strength and with decreasing shear rate the ER effect increases. This relation is valid for all C.C./Epoxy suspensions. The C.C./Arcylate suspensions show lower sensitivity to the shear see Fig. 2 and also there is shown more complicate relations among used parameters.

Fig. 3 shows an effectivity of AC electric field strength on the C.C.30/Epoxy sample vs shear rate. There should be mentioned that ER effect is reversible according to the applied frequency(50 Hz), and it shows Bingham behaviour. The effectivity of DC electric field at 66°C on both, C.C.40/Epoxy and C.C.40/Acrylate suspensions is shown in Fig. 4. Both

used suspensions show different sensivity to the electric field strength under relatively equal processing conditions.

Conclusion. It was found that C.C./Epoxy and C.C./Acrylate suspensions containing 5% of water show ER effects. These effects are various ways influenced by the composition of suspension, temperature, gap, shear rate and electric field strength.

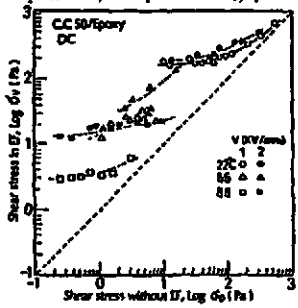

Fig. 1: Relationship between shear stress in DC electric field, σ_E and shear stress without electric field, σ_0 for C.C.50/Epoxy sample at various temperatures

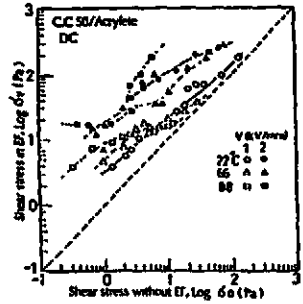

Fig. 2: Relationship between shear stress in DC electric field, σ_E and shear stress without electric field, σ_0 for C.C.50/Acrylate sample at various temperatures

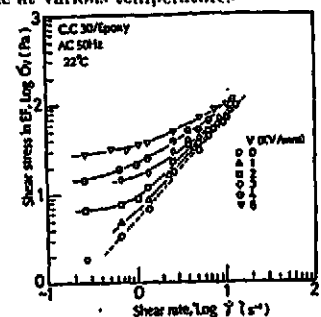

Fig. 3: Shear stress in 50Hz AC electric field of C.C.30/Epoxy sample as a function of shear rate, γ at 22°C in various electric field strength, V

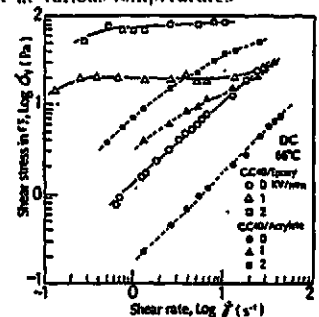

Fig. 4: Comparison of shear stress in DC electric field, σ_E of C.C.40/Epoxy and that of C.C.40/Acrylate at 66°C as a function of shear rate

This research has been conducted at the Department of Plastics and Rubber Technology as part of the research project "Behaviour of Polymer Suspensions in Electric Field" and has been supported by VUT grant No. D 103/93.

THE PROCESSING OF THE LDA MEASUREMENTS OF THE FLUID FLOW WITH THE NONSTATIONARY CONTENT OF THE MACROPARTICLES

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Key words: fluid flow, turbulence, macroparticles, velocity histogram, fluctuation energy

At the equipment of the Chemical Engineering Department at the Ohio State University, Columbus, OH, USA we got the LDA records, generated by the fluid flow with the macroparticles. The aim of the experiment was to answer the question whether and how the macroparticles influence the turbulence of the flow.

Measurements were carried out in the vertical column, in upgoing stream. The diameter of the column was 4" (101.4 mm), the length was 1040 mm. The index refraction match technique was used: the index of the refraction for the fluid – paracymene ($\varrho = 860\,kg/m^3$, $\mu = 1.023\,cP$) was the same as that for the macroparticles, beads – colorless transparent spheres of PMMA ($\varrho = 1130\,kg/m^3$). The experiment was arranged as the set of the individual runs: after the beads had set on the bottom of the column the pump was turned on and by opening the inlet valve of the column the run was started. The beads rose up, dispersed and escaped by the sequal with the fluid from the column to the bead collector, from where they were returned after finishing the run. It follows, the presence of beads in the measuring point was only transient. The fluid velocity was measured by means of the microparticles of china clay ($d = 5\,\mu m$), which are used as the tracers. The beads have two sizes: 1/8" and 3/16", the falldown velocities in the paracymen are 0.165 m/s and 0.209 m/s respectively.

There have been arranged runs with only microparticles, with only beads and with both kinds of the particles. If we consider the microparticles as the first factor and we assign their absence and presence to 0 and 1 resp. and do the same for the beads as the second factor, we get the runs 01, 02, 10, 11, 12, which may be further distinguished by the followed component of the velocity (axial or radial), the superficial velocity (set by the number of turns of the inlet valve) and the position of the point in the column. The nonstationary runs (x1, x2) have been terminated after 30 seconds, the run 10 lasted 100 seconds.

All runs (but 10) are transient, therefore our first task was to find the time regions, where the flow conditions are almost constant. Our second task was to eliminate the possible reflections on the beads as we only want to register the fluid velocity. The first problem was solved through dividing the whole runtime period to the subperiods (I to IV). We supposed to solve the second problem by means of the runs 0x - runs without the LDA particles. If

there were really no such particles, all the records would be caused by the reflections on the beads and it would be no problem to find their characteristics and to eliminate them from the runs 1x. The occurence of the records in the region IV, where no beads are present (and not only this) indicates, the previous idea is not accessible, the removing of the tracers is not perfect and in the region I to III the reflections as well as the velocity records are possible. We have tried to solve the problem by means of the double filtration: to find the characteristics of the tracer velocities from the region IV and by means of them to eliminate the records of tracer in the regions I to III. Then we suggested to repeat the procedure: to find the characteristics of the remaining records and to eliminate them from the runs 11, 12. We have had no problem to accomplish the first step, but we have not succeeded in repeating it: the only characteristic of the remaining data was the high value of the autocorrelation function for the smallest time shift 0.5 s; the mean velocity was significantly lower and the standard deviation higher than that in region IV, the shape of the distribution was not reproducible. We can only estimate the part of data in runs 1x caused by misreading, because of the same number of the beads in the runs 0x.

Each run x1, x2 was split into regions I to IV, in each of this regions the histogram number of record – velocity was evaluated. The results were extremly dispersed, when we used the original physical coordinates, we have achieved the concentration by the normalisation of velocity by the formel $(v - v_{IV})/s_{IV}$ where the values for the normalisation were taken from the region IV of the same run, where undisturbed flow occurs. All the presented results are expressed in this normalised velocities.

As the additive quantities, the total and fluctuation energies have been evaluated. The fluctuation energy has been calculated in two manners: in respect to the mean of the actual region (internal f. energy) and to the mean of the region IV (external f. energy). All these numbers are evaluated as the sum of the squared velocities or differencies of them, and are corresponding to the common measuring of turbulence intensity; we relate our numbers to the total processed runtime, our numbers are the rate of energy, dimension $m^2/s3$.

Fluctuation energy in respect to the local mean shows the turbulence intensity and its spread to the upper and lower velocity band, the external fluct. energy points out the shift of the mean velocity between the regions.

The comparing of the fluct. energies shows, that the registred flux of energy for beads only (runs 0x) is much less than that for runs with beads and particles (runs 1x). Moreover, in runs 02 only 50 to 60% records are due to missreading, caused by the reflection and present in the same amount in the records of the runs 12.

All calculations are presented in the tables. It can be seen that the local fluctuation energy for both bands – lower and upper – has the maximum in the region I to II, then decrease significantly. External fluctuation energy is almost constant for the upper band, independend of the presence of beads. We conclude that most of the changes caused by the beads are concentrated into the lower region of the velocities. If this is true, the ratio of the fluctuation energy for lower and upper bands shows the changes in the turbulence intensity: the value greater than 1 indicates the increased turbulence intensity and inversely.

This research has been conducted at the Department of the Chemical Engineering of the Mechanical Faculty of the Czech Technical University and at the same department of the Ohio State University as part of the research project "Research of Turbulence in the Flow with Macroparticles" and has been supported by grant No. 132 1014 of GA ČR.

AN ORIGINAL NUMERICAL MODEL OF SOLIDIFICATION, COOLING AND HEATING

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Key words: thermokinetics of solidification, Fourier's equation, numerical model, enthalpy, explicit difference method

The original and universal numerical model of solidification, cooling, and heating has been set up and checked that enables to analyse the one-up to three-dimensional steady or unsteady temperature field of the casting - mold - neighbourhood system and namely of the system as a whole or of its arbitrary parts during any industrial technological process whose individual processes can be solidification, cooling, heating, refrigerating, and others in any sequence or singly. The model makes possible to simulate traditional and also non-traditional technologies of casting in foundries, metallurgical plants, forging operations, heat treatment process, etc. but also for instance the process of heat wear of a tuyère or other partial problems apparently of lower importance. If solidification is not the matter, the metal part of the system need not be called the casting but a component, a billet, a block, a forging, and the like. Solidification (crystallization) and cooling tank to the most important technological processes. It is the case of generally up to the three-dimensional (spatial) transmission of heat but of a mass too. In the system of casting - mold - neighbourhood the all three kinds of heat transmission take place. In such a range the problem is exactly insoluble. It is not exactly soluble nor in the case when the mass transmission is not under consideration and from the three kinds of heat transmission in the system the conduction is considered the decisive one. Thus exactly soluble is neither the Fourier equation (the melt does not flow) nor the Fourier-Kirchhoff one (the flowing melt). The both are the partial differential equations of the 2nd order. The chance of their successful solution have only the nowadays outdated analogue and numerical methods. From them the differential explicit method has been chosen. It will allow the most elegant way of simulation of development of latent heats of the phase or structural transformations that in the both mentioned equations appear as a member of the so called heat flow from the internal source. For the proper simulation of latent heats development the thermodynamic function of enthalpy is introduced. It is not a common method and the authors of this contribution have used it in the Czech Republic as the first ones. In addition the algorithm of calculation is highly economical and realizable also on small computers.

The differential form of the equation for the explicit expression of the unknown temperature in time (k+1) in the Cartesian coordinates can be for illustration derived from thermal balance of the general nodal point that need not be rectangular nor regular. For volume elements of the casting or of those parts of the system in which it is necessary to simulate the latent heats development the equation is expressed in the form, where the difference of enthalpies is introduced, i.e. the decrease of general nodal point enthalpy of the casting in the time step. From the explicit expression of the unknown nodal point enthalpy in the

time (k+1)in casting the unknown temperature is obtained from the functional dependence temperature-enthalpy. This dependence needs to be determined for the given material of the melt. E.g. in the range of temperatures of liquidus and solidus the decrease of enthalpy equals to latent heat of the phase transformation. When calculating the temperatures or the enthalpies it is necessary to choose the time step in such a way that the condition of a solution stability is kept. This condition of stability has been determined in the framework of the solution for one-up to three-dimensional calculation. When setting up the ballance equations on the network borders it is necessary to pay regard to the boundary conditions. On the network borders in contact with neighbourhood (the area of a foundry, of a metallurgical plant, of a laboratory) mostly the boundary condition of the 3rd kind is taken into account. When setting up the ballance equations on the internal surface (on the interface of mold-casting or core-casting) the boundary conditions of the all four kinds may be applied. It depends on that in which way the heat transmission on the melt-mold interface is characterized. According to the worked up algorithm the calculation programme in FORTRAN was devised and it has been trimmed with the three-dimensional system of cubic casting-mold-neighbourhood.

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AN INFLUENCE OF THERMODYNAMICAL PROPERTIES AND BOUNDARY CONDITIONS ON A SOLIDIFICATION PROCESS

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Key words: thermal conductivity, specific heat capacity, density, boundary conditions, calculation accuracy

The analysis of the influence of the main thermophysical properties of casting and molding materials on calculation accuracy of temperature field in the casting mold neighbourhood system has been performed. On a steel sample casting of a cylindrical shape that was cast in a fireclay or cast iron cylindrical mold.As a comparing datum of accuracy the total time of solidification (crystallization) and mechanism of forming of the temperature field of a solidifying casting represented by isotherms in longitudinal axial section through the casting and the mold have been chosen.

For the cast material the influence of thermal conductivity, specific heat capacity, density in the melted or in the solid phase,in addition of latent heat of phase transformation, too, has been analysed. The influence of the same main parameters for metallic or non-metallic molding material has been analysed and their combination, the influence of thermal conductivity and heat storage introduced for characterization of a mold by foundry technologists have also been considered.

The influence of the individual parameters on the total solidification time has been analysed separately and shown graphically. The other parameters have been taken for that moment in their average real value. The influence of each parameter has been studied in a range from 50 to 150 % of its real value (to the axis of abscissas). The influence of the parameter on the total solidification time has been studied; its relative value towards the real solidification time (corresponding to the real average value of the property just analysed) is plotted on the axis of ordinates. The tangents slope to the curves means different value for different parameters and even for the same parameter the slope differs for the values of parameters to the left or to the right of their real value. In the case that the parameters of some materials entering into the solution are not sufficiently known and their values need to be estimated, the curve region of a lower slope is chosen and according to this the given property is either underestimated or overestimated towards the hypothetical real value in order to obtain more accurate results of calculation.

If a requirement to an accuracy of calculation of solidification thermokinetics controlled by the total solidification time (in a range of + 50 %) will be given in advance, then it is possible to estimate from the obtained graphs what error can burden the used thermophysical parameter.

From the boundary conditions the most important influence on the total solidification time and on the mechanism of forming of temperature field has the boundary condition

on the interface of casting - permanent mold, then follows the boundary condition on the casting surface, the negligible influence has the boundary condition on the permanent mold jacket and bottom.

Therefore it is suitable before [illegible] of solidification thermokinetics to perform the calculation analysis of influence of thermophysical properties of particular materials entering into the system (material of a casting, of chills, of a mold, of cores, of powdered materials for covering the risers, insulants, etc.) and further on the analysis of the boundary conditions and namely in both cases on a simplified geometrical form of particular system. Only then a qualified decision follows how accurate determination of parameters and boundary conditions will be necessary for following routine calculation of the proper operating system in order to achieve the required accuracy of the results of the temperature field solution. The required accuracy will be basically given by a type of a setting according to the fact whether the main object of the solution will be the proper casting (directional solidification, determination of internal non-homogeneities and removing of them, the character of primary crystallization, shortening of solidification time, etc.) or a mold or cores (increasing of permanent molds service life, use of different molding materials into different mold parts, heat load of molds, formation od scabs, a problem of condensing zone, etc.).

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