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THE DOE INDUSTRIAL ENERGY CONSERVATION PROGRAM

MASTER

RESEARCH AND DEVELOPMENT IN SENSOR TECHNOLOGY

APRIL 1987

U. S. Department of Energy
Assistant Secretary, Conservation
and Renewable Energy
Office of Industrial Programs

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OFFICE OF INDUSTRIAL PROGRAMS

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OVERVIEW

The recent decline of the U.S. competitive advantage in the world market has been attributed partly to the relatively slow rate of U.S. technological innovation. In calling for the recapturing of our competitive edge, policy-makers and industrialists have agreed that increased emphasis on innovation is needed through concerted research and development efforts in the public and private sectors. The call for increased emphasis on innovation coincides with the objectives of the U.S. Department of Energy, Office of Industrial Programs (IP), which since its inception has been conducting energy conservation research and development activities. These activities have been directed toward achieving the objectives of improving energy use efficiency and providing for fuel flexibility within U.S. industry.

To date, the Office of Industrial Programs has supported over two hundred research and development projects covering a wide spectrum of industrial applications. Research and development activities have been initiated to address both generic conservation technologies and energy intensive processes unique to specific industries. Many of these efforts have resulted in the successful resolution of critical technical barriers faced by industry in developing advanced energy conserving processes and technologies.

Sensor technology is an important component of modern day process technologies. It lends itself to further research and development with the potential for increased energy efficiency and productivity. Sensors are used by industry in practically every aspect of the production process. The utilization of automatic control systems and the anticipation of increased future applications of computers in production processes have highlighted the importance of research in this area. Recognizing this need, IP has funded a series of targeted projects to develop process-specific sensors as well as sensors for generic applications.

This brochure describes, in summary form, the Office of Industrial Programs' research and development (R&D) efforts in the advancement of sensor technology. It was prepared with the intention of providing interested parties with an introductory orientation to Federal energy conservation activities in industrial sensor technology R&D. The brochure is comprised of the following sections.

Sensor Technology. Provides a summary of sensor technology applications in present process practices and future sensor technology development direction.

Potential Energy Savings. Identifies the potential for energy conservation through the implementation of advanced sensors in industry.

Office of Industrial Programs' R&D Efforts in Sensor Technology Development. Describes the sensor R&D projects that have been funded by the Office of Industrial Programs.

R&D Data Base. Presents names of the contractor institution, the principal investigator, and the location of each IP-assisted sensor related R&D effort.

SENSOR TECHNOLOGY

Sensor is a generic term referring to a device that is capable of detecting and providing information on process parameters. A sensor measures either a specific parameter or a number of parameters such as displacement and dimension, force and torque, pressure, temperature, flow and motion. A sensor consists of a number of working elements, active or passive. In an industrial setting, a typical sensor monitors the desired physical parameters relevant to the control of a process and provides a corresponding output signal to be evaluated by human operators and/or transmitted to a process control device. The control device uses this transmitted/conditioned signal to modify the desired system parameters that characterize the process. Exhibit 1 represents the utilization of sensors in an industrial production process setting.

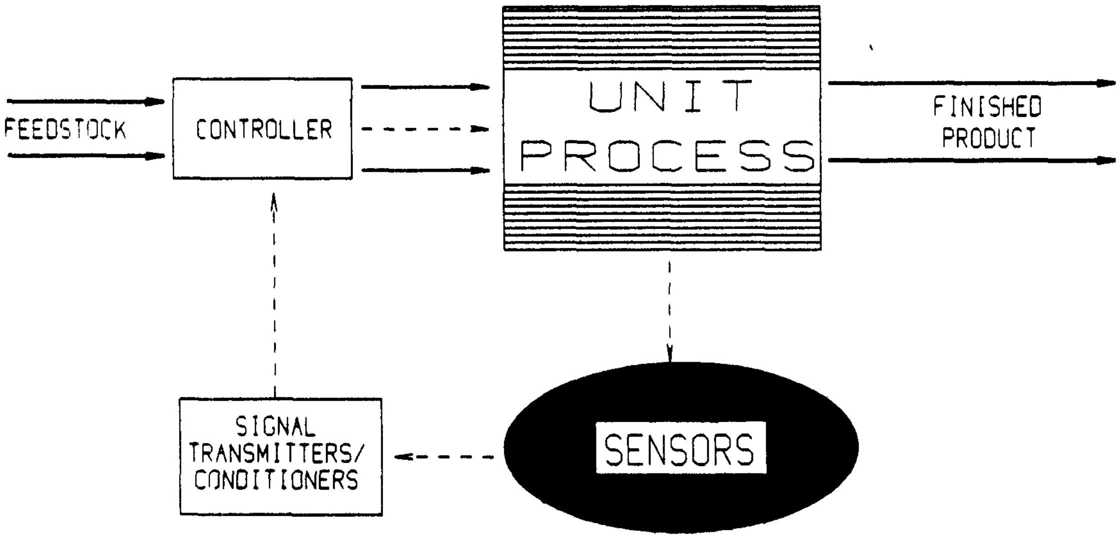


EXHIBIT 1. SENSOR'S FUNCTION IN AN INDUSTRIAL PROCESS SETTING

The present repertoire of industrial sensors features a variety of sensing devices. These devices can be categorized in a number of ways. One method of categorizing sensors is on the basis of parameter identification. Under this method (see Exhibit 2) sensors can be categorized as: displacement and dimension; force and torque; pressure; temperature; flow; motion; quantitative analysis and synthetic senses such as smell, vision and touch. Other popular methods of categorizing sensors include: principle of operation (mechanical, fluidic, optical, electrical) and process application (high-temperature, electromagnetic interference, remote location, and others). The following paragraphs describe sensors based on the parameter identification scheme.

Displacement and Dimension: Sensors in this category are developed for the purpose of measuring displacement and dimension, including liquid level and solid flow detection. New advances in this area include smart sensors, fiber optics, ultrasonics, vision and laser sensors.

Force and Torque: Force and torque are perhaps the easiest parameters to measure in a process. Sensor applications for this category center around machining and adaptive control, particularly for tool wear and unattended operation.

Pressure: The development of solid-state (silicon) technology has revolutionized this type of sensor development. Two types of solid-state pressure sensing devices presently exist: piezoresistive and capacitive. Development of these sensors is expected to further the present role of the pressure sensor as a detector by incorporating other functions such as self-diagnostics or analog/digital conversion.

Temperature: Sensors in this category account for over half of all sensors used by industry. Most temperature sensors are based on one of four physical phenomena: thermal expansion, electrical EMF generation, electrical resistance change, and radiation effects. The fluidic capillary pyrometer (FCP) is a new method of temperature sensing technology. FCP is capable of continuous temperature measurement in high-temperature environments.

Flow: Flow measuring devices are generally divided in two types: mass flow and volumetric flow. Volumetric flow is not accurate for many industrial applications, owing to problems with admixture ratio and super-compressibility of non-Newtonian media. For this reason, a variety of advanced methods and devices has recently been developed for mass flow sensing which includes: linear differential pressure, coriolis/gyroscope, thermal, vortex shedding, and acoustic.

Motion: Sensing devices in this category mainly measure two parameters: vibration and shock. Vibrometers and accelerometers are two examples of motion sensors. The application of microprocessor control to motion-sensing systems, in particular, accelerometers, is the most often cited new standard of development.

Synthetic Senses: A variety of synthetic senses is currently used by industry. These sensors are categorized on the basis of smell, vision, and touch. The vision sensors are the main sensors used by the automotive industry, specifically in their robotic production lines.

Sensors for Quantitative Analysis: This category includes all those sensors that cannot easily be classified under other categories. Quantitative analysis, at least here, includes not only species identification but the determination of the magnitude and extent of physical effects and characteristics, e.g., conductance and magnetic strength.

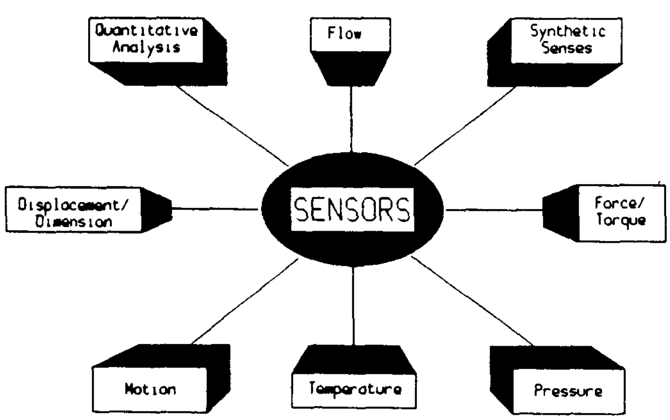


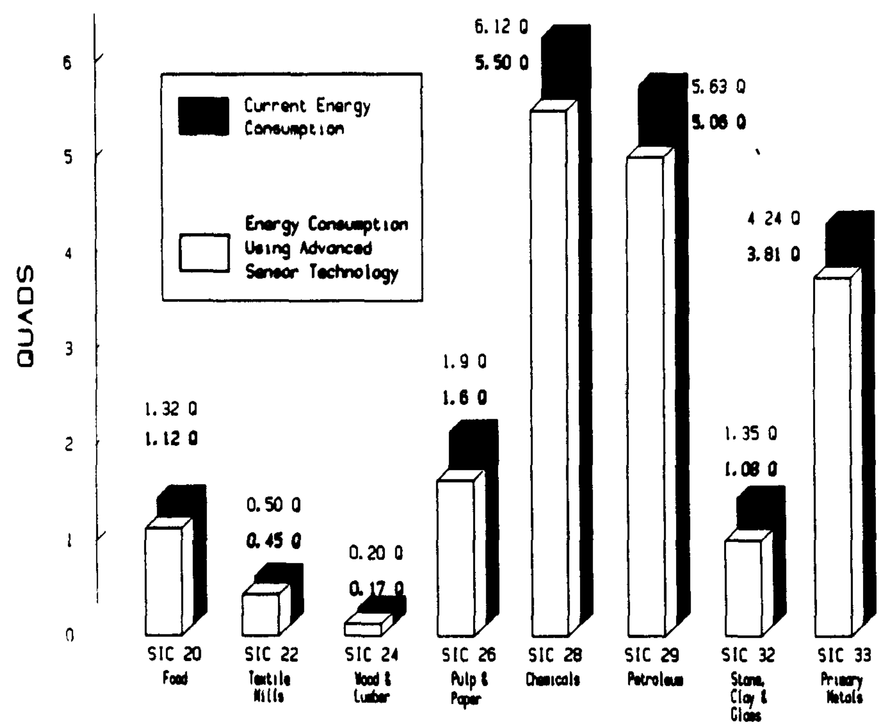
EXHIBIT 2. SENSOR TECHNOLOGY CATEGORIZED BY PROCESS PARAMETERS

The availability of advanced or second generation sensors will have a positive impact on the industrial sector. The new smart sensors should improve productivity by reducing time and money requirements of the operations. New fiber-optic sensors will provide flexibility, durability, and relative simplicity over existing systems, especially in severe or specialty environments. The improvements in high-temperature sensors are expected to result in large energy savings.

POTENTIAL ENERGY SAVINGS

The rapid development of control systems and computer technologies in the recent past has introduced a new challenge in industrial production process practices. The increasing uses of automatic control, backed by increasingly sophisticated computers, have become the cornerstone of modern industrial processes. As a result, significant energy and labor savings have been gained with increased production speed and efficiency. Despite these achievements, the maximum potential for energy savings and increased productivity has not yet been fully realized.

The potential energy savings associated with improved sensor technology for the most energy intensive industries are presented in Exhibit 3. Data provided in this Exhibit are drawn from several studies conducted to determine the potential impact of sensors on the different industries. They show that should appropriate sensors be developed, potential energy savings of 5 to 20 percent are achievable for the individual industries. Energy savings are achieved as a result of increased productivity, reduced energy requirements per unit of production, and reduced energy and material wastes. By the same token, the development of industrial sensors has the potential to reduce the overall industrial energy requirements by 10 percent, or about 2.5 quad, worth at least $10 billion at current fuel prices.



Source: Energetics, Inc.

EXHIBIT 3. ESTIMATED POTENTIAL ENERGY SAVINGS ASSOCIATED WITH IMPROVED SENSOR TECHNOLOGY

OFFICE OF INDUSTRIAL PROGRAMS' RESEARCH AND DEVELOPMENT EFFORTS IN SENSOR TECHNOLOGY

In support of advanced sensor technology development, the Office of Industrial Programs has sponsored a number of research and development efforts. To date, more than eighteen projects have been funded in this area addressing the needs of numerous industrial applications in various industries. A summary of each project is provided in this report along with each project's status as shown in Exhibit 4. This compilation focuses on technologies considered important in effecting significant energy savings. Many of these projects are expected to result in energy-saving technologies, while others are expected to produce important technical findings with potential for future national benefits.

Descriptions of these eighteen projects have been organized according to the industries to which the technology applies. A "Generic Technologies" category has been added to include those technologies which have applications in more than one process area or industry.

STEEL INDUSTRY

High-Temperature Sensor Sheath

Processing improvements in the basic oxygen furnace (BOF), such as continuous temperature measurements throughout BOF runs, would make shorter, more consistent, and more energy efficient steel production possible. However, continuous measurement of temperature (i.e., up to one hour of continuous service) in the basic oxygen furnace presents unusual challenges due to the aggressive nature of the slag and the high temperatures of both the slag and the steel. Similarly, continuous measurement of temperature during continuous casting of steel takes place in a slightly less rigorous environment--there is no highly oxidizing slag--but temperatures are still 3000°F in a rapidly flowing stream of molten metal. Fluidic temperature sensors have been demonstrated to provide accurate temperature measurement at these temperatures (3000°-3200°F). The problem with these sensors is that the fluidic device must be metal in order to provide a cavity for gas flow and maintain the critical dimensions of the gas orifice, and sheath materials used until recently had not been able to withstand the extreme chemical and thermal environments of these steelmaking processes.

The U.S. Army Materials and Mechanics Research Center (AMMRC), through funding by IP, undertook research in 1982 to develop and fabricate ceramic sheaths capable of protecting high temperature sensor devices under the extreme high temperature and chemical environments encountered in basic oxygen steel processing furnaces and continuous casters. This project included a literature survey and establishment of selection criteria, materials testing in both continuous casting and fluxed steel environments, fabrication of a prototype sheath; and analysis of material failure through microstructure, electron probe, and macroscopic physical properties. As a result, a promising new material was developed. To continue research in this area, a separate project is presently underway to evaluate the material in an actual Basic Oxygen Furnace Shop.

EXHIBIT 4
OFFICE OF INDUSTRIAL PROGRAMS RESEARCH AND DEVELOPMENT ACTIVITIES IN SENSOR RESEARCH AND DEVELOPMENT

Project Title	Contractor	Research Conducted: Basic/Lab	Research Conducted: Pilot Plant	Research Conducted: Field Test	Status*
Steel Industry					
High-Temperature Sensor Sheath	Army Mat. & Mech. Research Center	o	o	o	on-going
Non-Contact Direct Measurement of Thermal State of Solids	PNL	o			On-going
Rapid In-Process Analysis of Molten Metal	INEL/Los Alamos Lab	o			Completed
High-Temperature Remote Inspection System	Honeywell	o	o		Completed
Pulp and Paper Industry					
Lignin Sensor	JPL	o			On-going
Consistency Sensor	NBS	o	o	o	On-going
On-Machine Paper Sensor	Institute of Paper Chemistry	o			On-going
Polymeric Hygrometer Humidity Sensor	JPL	o	o	o	On-going
Lime Kiln Sensor	JPL	o			On-going
Agriculture Industry					
Advanced Soil Analyzer	Aguila Corp.	o	o	o	On-going
Aluminum Industry					
Alumina Sensors	PNL	o	o		On-going
Generic Technologies					
Steam Flow Meter	JPL	o			On-going
Spectroscopic Combustion Temperature Sensor	NBS	o	o	o	On-going
Heat Flow Dew-Point Hygrometer Humidity	Trans-Met Engineering, Inc.	o	o		On-going
Optical Humidity Sensor	Spectral Sciences, Inc.	o	o		On-going
Dew-Point Hygrometer Humidity	Honeywell	o	o		On-going
Optical Surface Motion Monitoring	Optra, Inc.	o			On-going
Spectral Flame Analyzer	TECO	o	o	o	On-going

*Completed designation indicates that no further IP funding is planned for the project.

Non-Contact Direct Measurement of Thermal State of Solids

The addition of computer modeling and control to steelmaking processes offers great potential for productivity improvement and energy consumption reduction. However, the usability of this technology in the steel industry is considerably hampered by the lack of a suitable process-steel control sensor system. For example, in the thermochemical treatment of solid or solidifying steel masses, measurements of the temperature of the steel and the temperature distribution within the body of steel are needed. Currently, the temperature distribution is estimated based on surface temperatures. Since internal temperature distribution has a major impact on process parameters, a new sensor which would provide accurate, direct temperature measurement can lead to more efficient productivity and energy utilization.

This IP research project is co-funded by the American Iron and Steel Institute (AISI). In this effort, Battelle/Pacific Northwest Laboratories is investigating the use of non-contact ultrasonic techniques employing Electromagnetic Acoustic Transducers (EMATs) to measure the temperature inside solids or solidifying bodies. The first phase or the program which was completed in 1983 focused on the accumulation of relevant information on the proposed technique. The second ongoing phase includes the construction of a laboratory sensor and an evaluation of its performance on a hot steel sample as seen in Exhibit 5. A field evaluation of the sensor and the overall system is planned following the completion of laboratory evaluation.

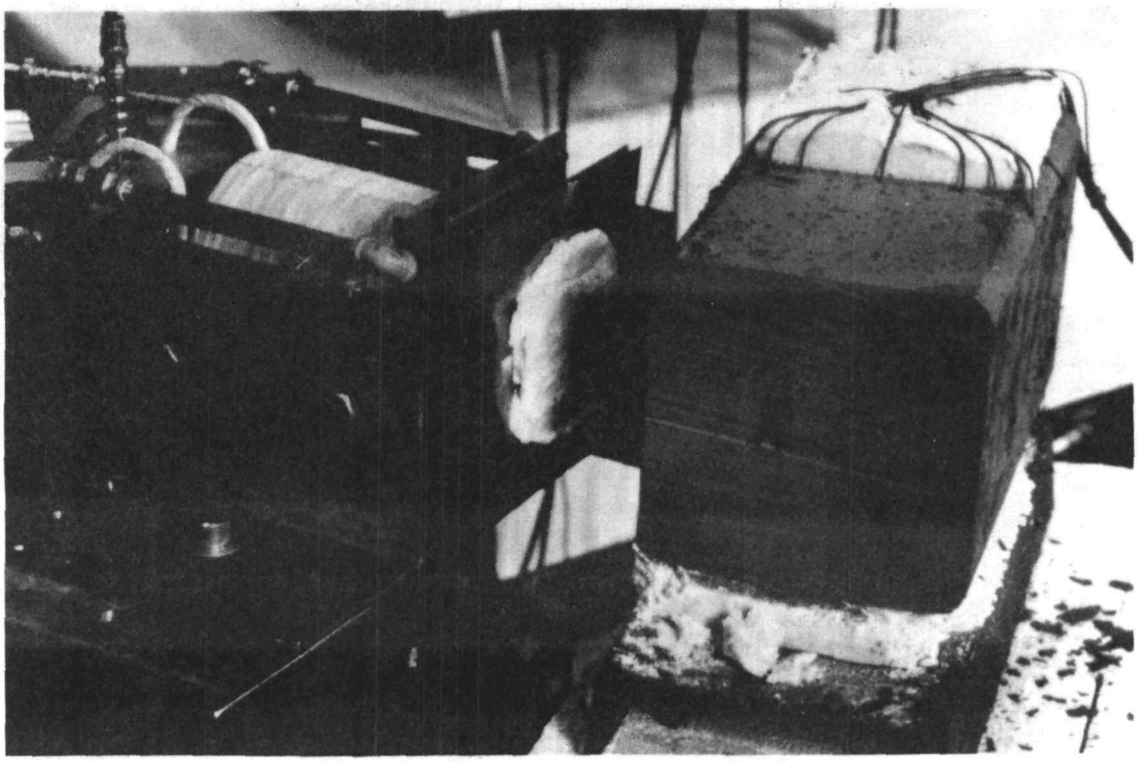


EXHIBIT 5. HOT BLOCK IN CONTACT WITH EMAT FOR ULTRASONIC MEASUREMENTS

Rapid In-Process Analysis of Molten Metal

Continuous, on-line, real-time monitoring of molten metal composition, either in the basic oxygen furnace or in the ladle, will improve the efficiency and reliability of steelmaking processes and reduce costs. The techniques typically used to obtain chemical analyses of molten steel are too slow to facilitate control of the steelmaking processes now being developed and used in the steel industry. Present methods of analyzing molten metal provide discontinuous analyses of solid samples taken from the molten bath, and instruments used to perform these analyses must be kept in air conditioned laboratory-type environments, with careful adherence to precise installation and use procedures. The nature of steel operations makes their use difficult, costly, and time consuming, since they must be remotely located. Of the total time for sampling and analysis, which varies from five to ten minutes, analysis and calculation time accounts for less than one minute; the balance is used for sample handling, chilling, transit, surface preparation, etc.

In 1983, IP awarded a contract to the Los Alamos National Laboratory to investigate novel and modern approaches to the problem of rapid, in-process analysis of molten steel. This project was co-funded with American Iron and Steel Institute (AISI). Two proposed schemes were studied. The first, Laser-Induced Breakdown Spectroscopy (LIBS) on molten metal surfaces, investigated the use of laser beams to project a high energy pulse onto a distant molten metal surface, as shown in Exhibit 6. By variations in repetition rate and energy characteristics, the beam causes the metal to instantaneously vaporize and emit radiation characteristic of the elements in the metal. These emissions are used to determine not only what materials are present, but also how much. The second scheme studied, LIBS on solid metal surfaces, examined the use of this technology to analyze solid steel ingots, billets, sheets and finished products for product quality and identification purposes. Considerable evaluation of laser vaporization disclosed a fundamental shortcoming in the analysis of elements having low atomic numbers. A concurrent program at the Idaho National Engineering Laboratory (INEL) investigated the production and testing of aerosols which could be transported pneumatically to a testing laboratory. An effective nozzle has recently been developed. The R&D effort is still continuing at Lee High University through AISI funding to further develop the concept of molten metal rapid analysis.

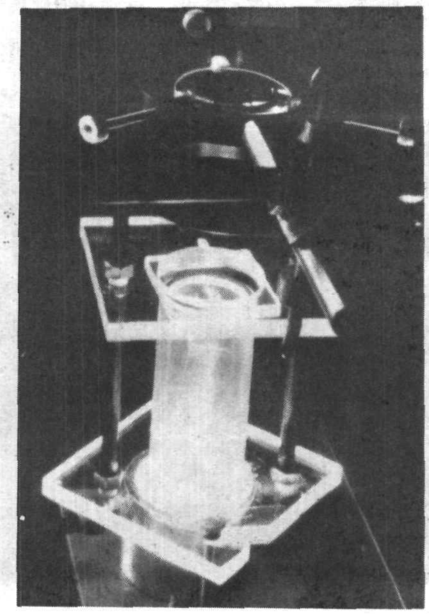


EXHIBIT 6. LASER USED TO ABLATE STEEL PARTICLES

High Temperature Remote Inspection System

In the production of high-surface-quality steel products, the surface defects are removed in an energy-intensive process commonly called conditioning. When steel slabs emerge from a slabbing mill or a continuous caster at temperatures ranging from 1500°F to 4000°F, they are usually shunted aside for cooling. Then the slabs are visually inspected and the surface imperfections removed with the use of manual scarfing equipment. From there, the slabs are reheated to a maximum temperature of about 2400°F in the reheat furnace prior to being processed through a plate or hot-strip mill.

A hot inspection system developed by Honeywell, Inc. in conjunction with USX allows further processing of hot steel without cooling it for inspection. The system is based on the principle of computer image-processing and pattern recognition techniques that have been developed over the past twenty years by the aerospace industry for airborne real time reconnaissance and tactical and navigational purposes. Exhibit 7 illustrates the general approach. Two linear scanning array cameras are positioned above the slab and move along the roll table. The primary camera scans the slab transversely at a rate commensurate with the rate of movement of the slab. This scan generates the "video" signal containing the image data; each scan is thus analogous to a line on a TV raster. A succession of scans then provides the image on which image recognition algorithms operate in the computer, allowing the computer to compare the slab it "sees" to the characteristics of a slab without surface defects. The results are then printed out on appropriate displays, containing slab identification, anomaly code, and position information. This IP sponsored project was completed in 1982. This inspection system is particularly applicable to a process governed by Statistical Process Control (SPC) techniques. It is presently not being commercially utilized within the steel industry.

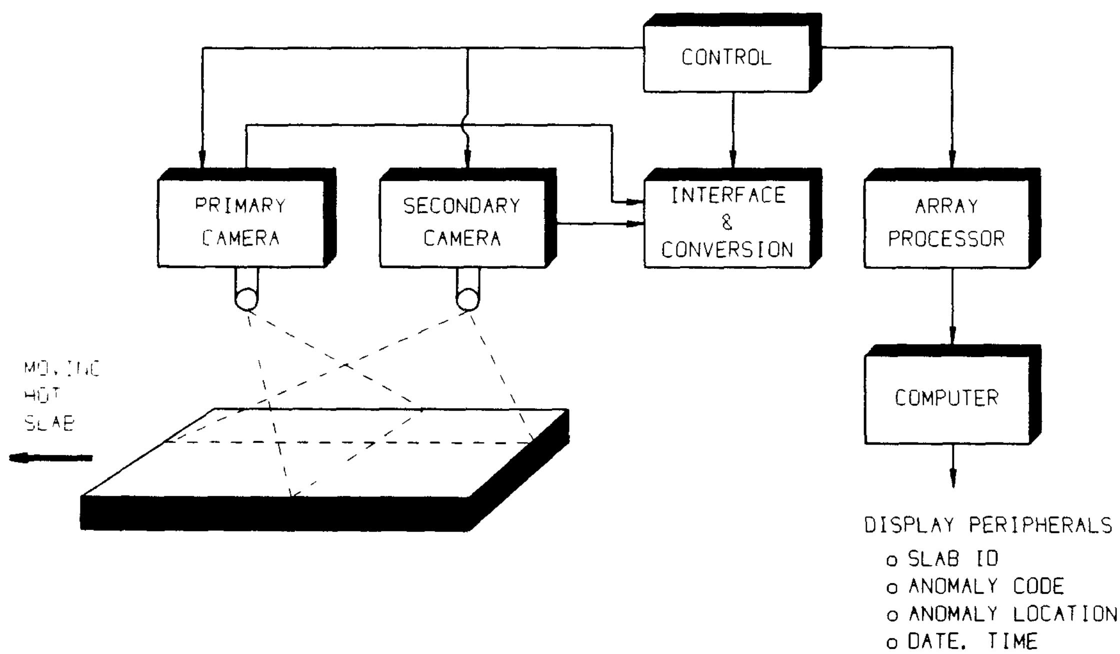


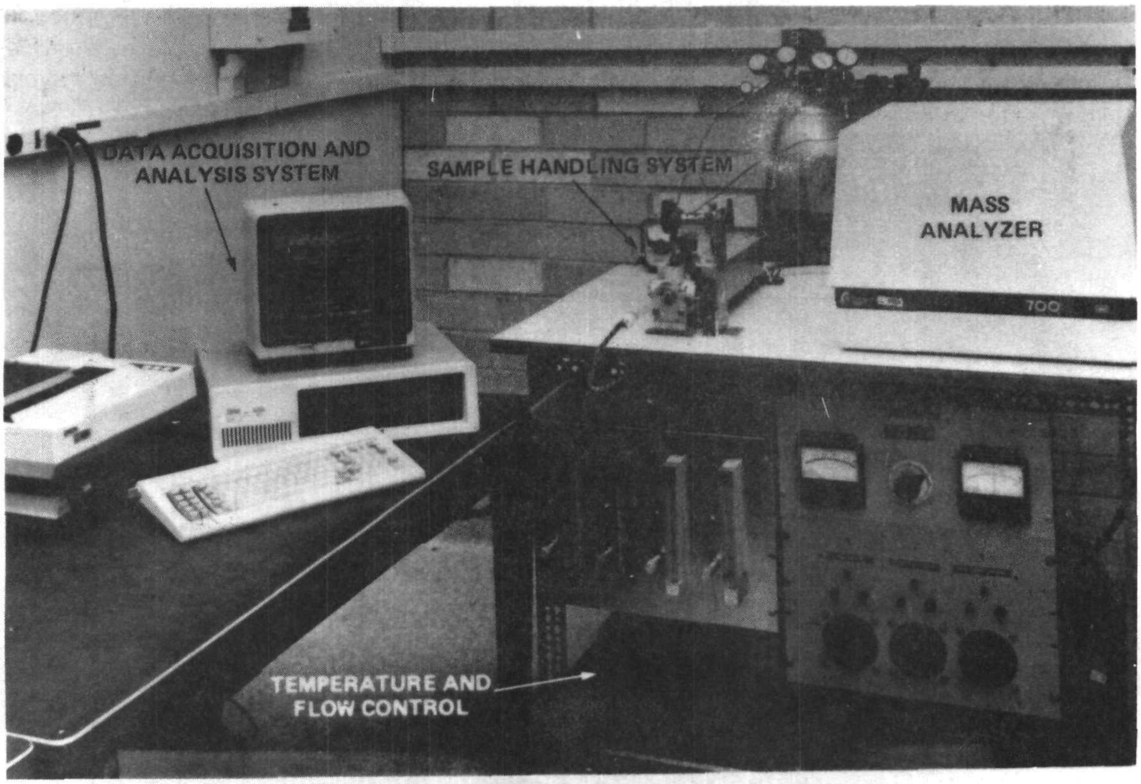
EXHIBIT 7. INSPECTION SYSTEM CONCEPT

PULP AND PAPER INDUSTRY

Lignin Sensor

One of the primary process parameters in the digestion, washing, and bleaching of wood in paper production is measuring the amount and type of lignin bound to the cellulose. Currently, the concentration of lignin, both in pulp and black liquor, is measured using off-line chemical titration tests. These tests are time consuming and subject to error.

For many years, the development of a sensor capable of measuring lignin concentration has mainly been deterred by the hostile nature of the process environment and the extreme complexity of lignin analysis. However, under a contract with IP, the Jet Propulsion Laboratory (JPL) is studying the feasibility of an advanced approach to measuring lignin concentration. The proposed sensor is a real-time, on-line lignin analyzer (see Exhibit 8). Using a state-of-the-art mass spectrometer and a probe sample preparation system, the new sensor measures the residual lignin content in digested wood pulp by ascertaining the ratio of differences between the pyrolysis spectra of cellulose and lignin. JPL is presently designing a prototype of the proposed system.



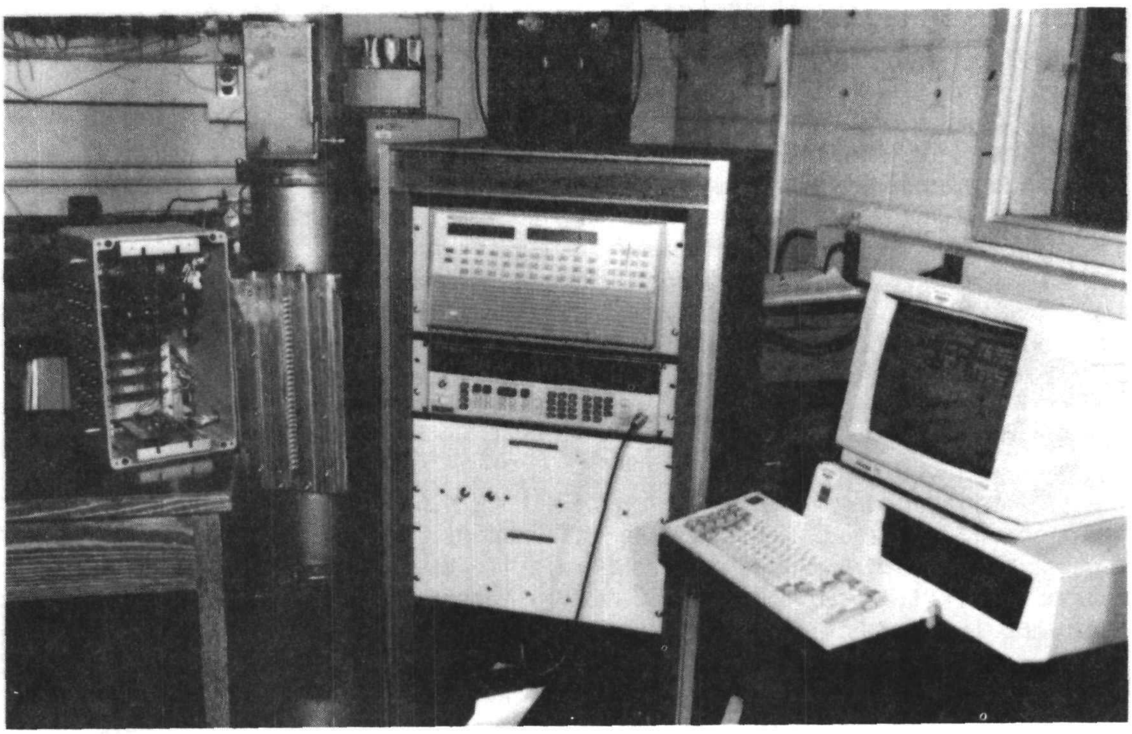
LIGNIN MASS SPECTROMETER SENSOR SYSTEM PROTOTYPE

EXHIBIT 8. LIGNIN MASS SPECTROMETER SENSOR SYSTEM PROTOTYPE

Consistency Sensor

Measurement of the consistency of pulp slurries is of vital concern to pulp and paper mills since its control directly affects the uniformity of the of the product produced. Although consistency is defined as the ratio of the mass of fibrous material in a slurry to the total mass of the slurry, consistency transmitters almost universally sense some property of the slurry other than the fiber/total mass ratio. There exists a number of consistency sensors currently used by the industry using either shear stress or optical transmission measurement. These sensors have been found to be rather inaccurate in high-consistency flows.

To develop a more accurate sensor for the high-consistency flow range, IP is currently sponsoring work at the National Bureau of Standards (NBS). In the new scheme of operation as shown in Exhibit 9, consistency is determined non-intrusively in real-time via an electromagnetic technique. Radio frequency energy is input to a pipe carrying the solids-liquid mixture or any mixture having two different dielectric constants. The piping acts as a waveguide; the input radio waves are propagated in a manner that is uniquely determined by medium's solids content (dielectric constant), temperature and electrical conductivity. Wavelength, frequency, attentuation, and temperature are measured and consistency computed. A prototype unit has been designed and constructed and is currently being mill tested.



CONSISTENCY SENSOR WITH DATA COLLECTION SYSTEM

EXHIBIT 9. CONSISTENCY SENSOR WITH DATA COLLECTION SYSTEM

On-Machine Paper Sensors

There are approximately 1400 paper machines currently operating in the United States. These machines produce a wide variety of paper and paperboard products that are classified in several different grades. Each paper and paperboard grade has distinctive mechanical properties, e.g., elastic stiffness, of its own. The automatic measurement of these properties, mainly the elastic stiffnesses, during the paper production would lead to great improvements in product quality, raw material utilization, and machine productivity. The Institute of Paper Chemistry (IPC) has recently developed an ultrasonic sensor capable of measuring elastic stiffnesses in the X- and Y-directions only. However, in order to fully automate the property measurements, a sensor capable of measuring elastic stiffness in the Z-direction is needed.

IP is currently involved in a joint R&D effort with IPC to develop the needed sensor and to integrate this sensor along with the already developed X- and Y-directions sensor in an automatic control system setting. In this effort, many types of transducers, e.g., ceramic acoustic transducers and polarized plastic films as the active piezoelectric elements are being investigated. The development of the automatic measurement system is projected to lead to a 10-12 percent decrease in energy consumption while increasing the paper machine productivity by 10-12 percent. The increase in machine efficiency comes from better product quality monitoring and improvements in the process control. This project is currently in the laboratory developmental stage.

Polymeric Hygrometer Sensor for Humidity

The control of humidity and moisture in pulp and paper mills can be valuable to energy conservation efforts, particularly during the paper drying process. However, the control system is always limited by the quality of the moisture/humidity sensor that measures the variable, i.e., air moisture content. Air is an important part of the paper drying process. Depending on what type of hood arrangement is used, from 7 to 20 pounds of air are utilized for each pound of water evaporated. Enough air must be used to avoid condensation anywhere within the hood to prevent drips, buildups, and corrosion. The air should be strategically supplied for economical operation. At present, the commercially available humidity sensors have been found to be inadequate for use due to their low survivability rate and accuracy. Current hygrometers either foul too often or damage too easily.

This IP sponsored research is directed at the development of an on-line humidity sensor and is conducted by the California Institute of Technology's Jet Propulsion Laboratory (JPL). The sensor concept being developed includes a tubular flow-through hygrometer comprised of a wire wound, polymer-coated metal cylinder, a power supply and electrometer, a microprocessor computing device and a digital data logger/read-out. The proposed hygrometer operates based upon the sulfonated fluorocarbon polymer's (DuPont's Nafion) changing electrical resistance, which varies as a function of water vapor pressure found in the environment. A prototype unit has been fabricated (see Exhibit 10), and preliminary laboratory and mill tests have been concluded. Further testing is planned.

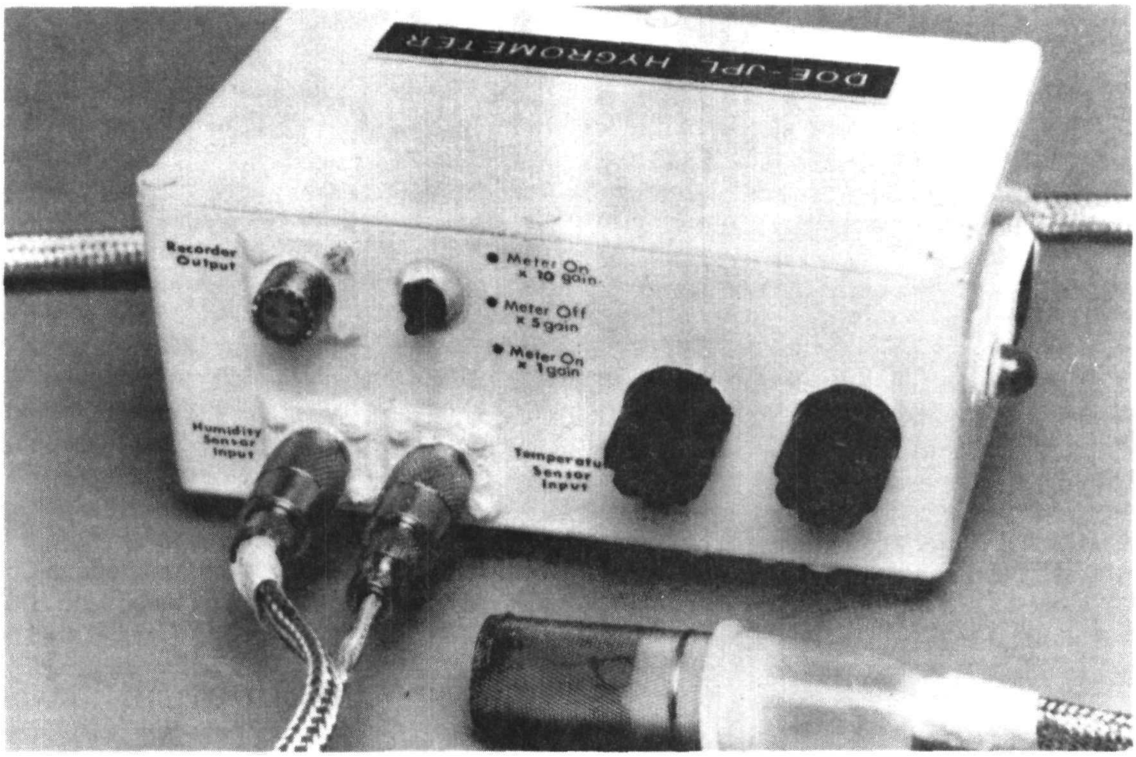


EXHIBIT 10. POLYMERIC HYGROMETER SENSOR PROTOTYPE

Lime Kiln Sensor

There exists a great need for developing temperature measurement sensors in a hostile environment. An example of such an application is that of a lime kiln in the paper industry. The needed sensor has to have the capability of accurately measuring temperatures varying from room temperature to 2000°F, as well as surviving the hostile chemical environment. Therefore, the commonly employed thermocouples and radiation pyrometers have been ruled out as a solution for lime kiln application.

A new sensor capable of meeting the demands mentioned above has been developed by Jet Propulsion Laboratory (JPL) under funding by IP. This sensor is known as the acoustic temperature profile measurement system (ATPMS). The ATPMS operates based on the fact that the speed of sound in a gas is a unique function of temperature. The speed of sound can be accurately measured by the measurement of a distance and the corresponding time of flight (TOF). A schematic of the ATPMS is shown in Exhibit 11. The region consists of a sensor tube of desired length, immersed in the gaseous environment whose temperature profile is desired. In the single ended TOF system shown a transmitter (a speaker) which doubles as a receiver (TR/RE) is fitted on to one end of the sensor tube. The other end of the sensor tube may be either open or closed. The sensor tube contains a gas of known composition. The sensor is arranged to have a required number of reflectors (R_1, R_2, etc.) which may take the form of diametrically placed rods or may be obstructions of any other type or holes on the periphery of the sensor tube. TR/RE is driven by a pulse generator through an amplifier. The TR/RE is also connected to either an oscilloscope or a digital waveform analyzer for time measurement. JPL is currently involved with the development of the laboratory scale model for further laboratory testing.

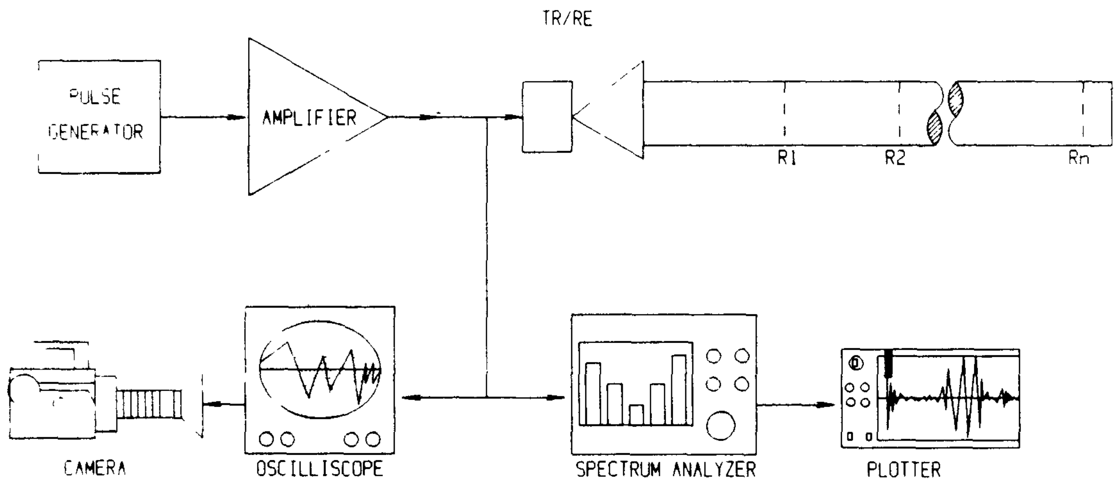


EXHIBIT 11 LIME KILN TEMPERATURE SENSOR SYSTEM

AGRICULTURE INDUSTRY

Advanced Soil Analyzer

Due to current market conditions, the agricultural community is seeking new approaches which would reduce its capital cost while maintaining its current production level. A potential area for reduction in capital cost and energy cost is the present distribution method of nitrogen fertilizer. Currently, fertilizer is applied after soil sampling followed by the conventional laboratory chemical analysis. The cost per sample precludes the use of this method as a means for reducing the total cost of fertilizer energy consumption through repeated sampling.

IP, in cooperation with Aguila Corporation, is developing a fertilizer sensor and control system, known as the "smart spreader" (see Exhibit 12). The experimental sensor measures the distribution of nitrogen in the soil and applies the needed supplement during actual field operation. The information obtained directly from the "smart spreader" will limit the waste of nitrogen fertilizer while maintaining yields. An additional positive benefit of the sensor and control system would be the limiting of nitrate migration into groundwater supplies. It has been determined that the contamination of groundwater in many parts of the country is partly attributable to the excessive use of agricultural fertilizer. The smart spreader technology is applicable to all environmental and geographical areas of the United States, as well as all types of fertilizer spreaders including granular, liquid solution, and ammonia. The continuous soil sampling method has been proven to work in a lab scale. A prototype sensor and control system is currently undergoing laboratory and field testing.

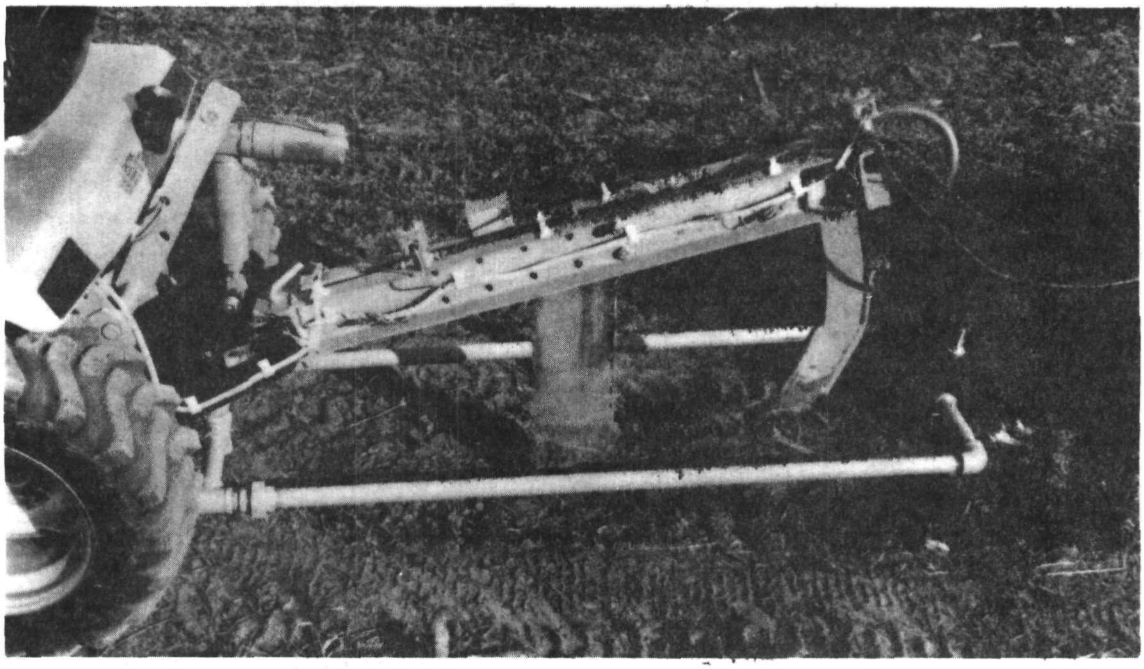


EXHIBIT 12. ADVANCED SOIL ANALYZER SYSTEM

ALUMINUM INDUSTRY

Alumina Sensor

Modification of the present aluminum production processes by replacing carbon anodes with inert materials and mating them with stable cathodes to reduce the anode to cathode distance setting could result in an estimated annual energy savings of more than 0.2 quad of electricity. However, the successful use of these materials is partly dependent upon the development of sensors that control bath composition. Presently identified inert materials require cell operation as close to alumina saturation as possible. Due to this requirement, currently available control systems can not adequately perform in the new cells.

In an effort to develop process control sensors, IP has sponsored a research and development activity with Pacific Northwest Laboratories. The objective of this R&D is to use digital signal analyses and a liquid sensor to determine all conditions in real time. The system is expected to analyze and control alumina concentration and bath ratio. In addition, the liquidus sensor will have application to present industrial cells for improved control and higher current efficiency. Presently a prototype unit has been designed and is being constructed.

GENERIC

Steam Flow Meter

Orifice meters are widely used throughout U.S. industry to measure the steam flow parameters such as velocity and pressure. These flow meters are suspected of sub-standard accuracy performance and are not capable of giving simultaneous average gas temperature measurements. Since the energy efficiency of most industrial processes is heavily dependent on the accuracy of the flow parameters, the Jet Propulsion Laboratory has pursued the development of a new steam flowmeter with IP funding.

The new meter uses the long wavelength acoustic principle to measure the velocity of steam. The system is composed of a sound source and two microphones mounted on top of a pipe and connected to the electronic processor. Sound waves cogenerated by the energy of steam flow are used to measure the flow rate and temperature simultaneously. There are no limitations of temperature and pressure and there are no moving parts in the sensor system. An experimental unit has been built and is currently being tested in a laboratory environment.

Spectroscopic Combustion Temperature Sensor

In recent years, considerable work has gone into increasing the energy consumption efficiency of production processes in the pulp and paper industry. One area receiving close attention has been better combustion control systems. A control system's performance is closely analogous to the capabilities of the sensors that measure the process variables; therefore, these efforts have mostly been directed to developing more accurate sensors.

The Office of Industrial Programs is currently sponsoring research at the National Bureau of Standards (NBS) to investigate a combustion control sensor designed to measure temperature in the air/fuel reaction zone of a recovery boiler. Temperature is determined non-intrusively in real-time via ultraviolet emission spectroscopy performed through multiple fiber-optic probes. The intensities of two spectroscopic lines present in the reaction zone are measured. The ratio of these concurrently observed intensities uniquely identifies the combustion zone temperature and stoichiometry. A simplified flow diagram of the sensor is shown in Exhibit 13. A prototype of the system has been designed and built and is currently being tested at a mill-site.

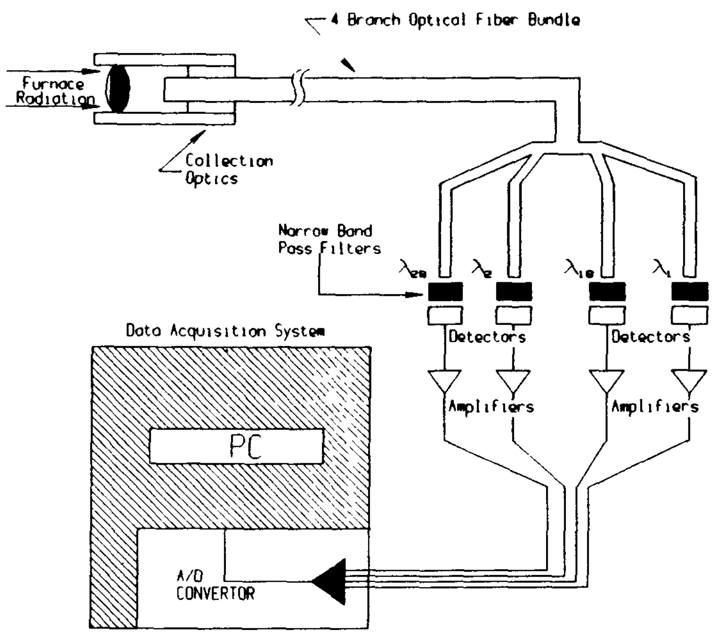


EXHIBIT 13. IN-SITU CONTROL SYSTEM'S FLOW DIAGRAM

Heat Flux Hygrometer for Humidity

In convective, hot air dryers, heat is lost through the exhaust gas, through the walls and by means of the product itself. The addition of new control systems, which accurately and continuously monitor the exhaust gas humidity and temperature for the purpose of maintaining the practical optimum exhaust gas conditions, have achieved significant energy savings in many industrial processes where they have been developed and implemented. However, the existing humidity sensors are inadequate for continuous use in many of the more common drying processes, since the high-temperatures and excess contaminant-filled environment encountered in these processes damage the measuring instruments and/or alter the absorption properties of hygroscopic salts and ceramics and cloud reflectivities, rendering the sensors unreliable and inaccurate. With funding from IP, Trans-Met Engineering, Inc., has developed a measuring instrument which senses the heat flux resulting from the release of the latent heat of condensation when the sensing surface is cooled to the dew-point temperature. The prototype sensor is insensitive to grease and grime contamination, insensitive to vibration and prolonged exposure to 500°F air, and does not require a dust filter or a sweep gas. The prototype has measured the dew-point to within $\pm$4.5% for both clean and contaminated theoretical conditions. This effort is continuing with a prototype unit design, construction and evaluation.

Optical Humidity Sensor

A hygrometer which has the capabilities of measuring high temperature and humidity as well as staying operational in a severely contaminating and/or particle-laden environment is currently unavailable commercially. The conventional hygrometers measure humidity by using the properties of a surface in contact with and directly influenced by the bulk medium containing the water vapor. The commercial availability of a reliable and accurate hygrometer for industrial drying chambers could significantly reduce the overall energy consumed by the industrial drying process.

Spectral Sciences, Inc., in a cost-sharing program with the Office of Industrial Programs, is developing an ultraviolet absorption hygrometer which uses the differential absorption property of light by water vapor. Since the ultraviolet radiation absorption is a property of water vapor in the bulk medium, the surfaces are kept away from coming in direct contact with the contaminating and/or particle-laden flow medium. A breadboard version of the proposed sensor was successfully designed, fabricated and tested. The on-going work involves the installation of the prototype in an industrial environment for verification of laboratory results and further experimentation.

Dew-Point Hygrometer

At the present time, grains are generally overdried to ensure safe storage without deterioration from insect manifestation or mold growth, but increasing the amount of grain damaged due to breakage in subsequent handling operations and consuming more energy than required.

Honeywell, in a cooperatively funded project with IP, is examining the potential of a dew point hygrometer which would provide a more accurate and stable sensor for measuring moisture in the exhaust gas of dryers. The sensor uses a capacitative condensate detector instead of a dew point transducer. The surface contains an array of interdigitated fingers. These fingers are interleaved and connected to form two electrodes but are protected with an insulated layer. As water condenses on the surface, the capacitance between adjacent fingers increases because of the high dielectric coefficient of water. This increase in capacitance serves as the output signal.

Eighteen pilot-scale prototype sensors were fabricated and performance tested. These units are presently installed in commercial dryers for further testing and evaluation in an industrial setting.

Optical Surface Motion Monitoring

Monitoring of surface motion, velocity, net displacement, unit length produced, and differential motions (e.g., across a web of material) are all essential in certain manufacturing processes. Specific examples would be cutting to length in a continuously cast steel process, thickness control in a paper making process (for example, at the slurry stage), and skew control to maintain thickness uniformity. Non-contact optical measurement of these parameters would have multiple advantages over current measurement systems. These advantages would be: capability of monitoring parameters in harsh industrial environments, higher flexibility in accommodation of measurement requirements, and real-time response for process control purposes.

OPTRA, Incorporated, is currently pursuing the development of a non-contact optical surface motion monitor for multiple industrial applications. A laboratory scale unit was designed and tested. The laboratory set-up used in the experiments is shown diagrammatically in Exhibit 14.

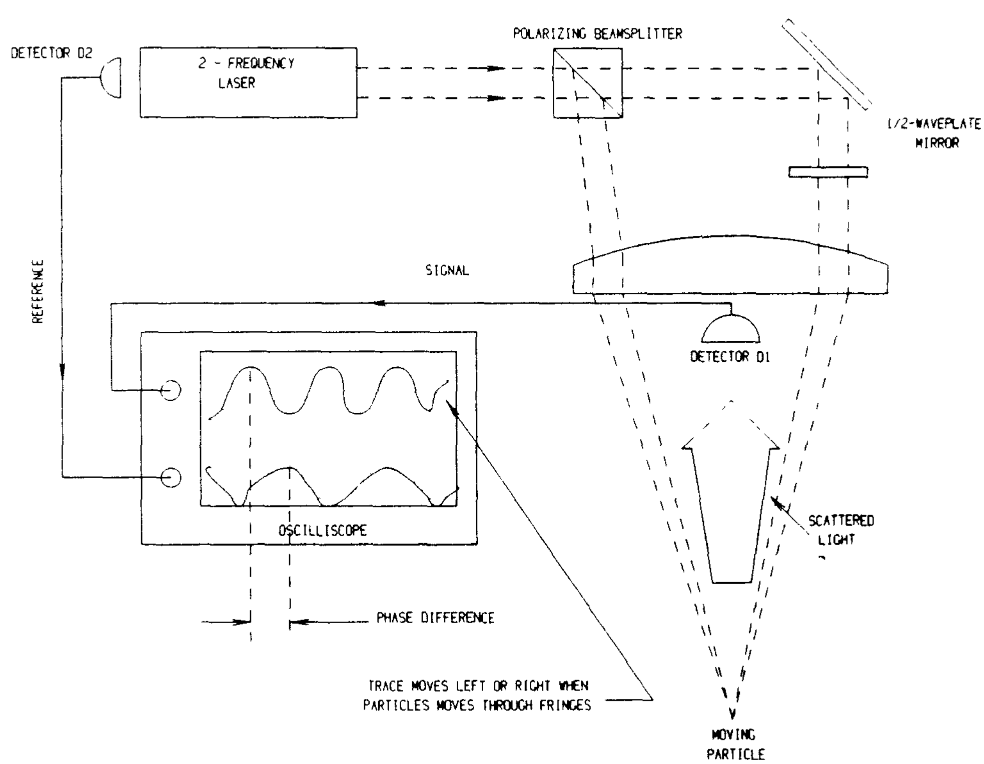


EXHIBIT 14. SCHEMATIC OF NON-CONTACT OPTICAL SURFACE MOTION MONITOR

The system works in reflection as well as transmission and works with only a minimal amount of light scatter from materials. The prototype's remote, passive optical laser probe has been found to be satisfactory for measuring surface motions in a variety of industries with sufficient precision and accuracy. The proposed monitor system is currently undergoing further laboratory experimentation.

Spectral Flame Analyzer

A potentially powerful technique for improving boiler efficiency is to fire the fuel with a level of excess air as low as possible, yet consistent with achieving complete combustion and stable operation. Firing with low excess air enables stack thermal losses to be kept to a minimum. In practice, the general procedure is to fire steam boilers with excess air levels significantly above stoichiometric, because practical limitations caused by maldistribution in fuel and air frequently require oxygen levels significantly above the stoichiometric value. High excess air levels result in a significant boiler efficiency penalty because of the higher stack thermal losses resulting from the extra airflow.

Thermal Electron Corp., with funding from the Office of Industrial Programs, is developing a Spectral Flame Analyzer (SFA) which utilizes the principles of flame emission spectroscopy. The intensity of the light emitted by the flame is measured repeatedly at multiple wavelengths. The primary wavelength is selected to coincide with a specific infrared emission of luminous, universal combustion species. The secondary intensity measurement is made at a nearby wavelength where these combustion species do not emit radiation. The two measured intensities are ratioed electronically to form the output signal. An SFA, therefore, utilizes high resolution wavelength selection and the rationing of emitted radiation at multiple closely spaced wavelengths to provide a unique capability. The SFA mounts on the front of a burner, and in some cases may utilize the viewing port normally used by the flame-proving device found on most industrial boilers. The SFA gathers light from the portion of the flame immediately in front of the burner. The optical system provides a limited field of view so that any one analyzer can see only one flame. Output is not affected by nearby flames. This sensor system can be used to control multiple burners since it can control individual fuel/ratio in a multi-burner combustion system. The SFA is currently undergoing further field testing.

RESEARCH AND DEVELOPMENT DATA BASE

Project Title	Contractor	Principal Contact	Address
Steel Industry			
High-Temperature Sensor Sheath	Army Materials & Mechanics Research Center	George G. Bryant	Army Materials and Mechanics Research Ctr. Watertown, MA 02172
Non-Direct Direct Measurement Thermal State of Solids	PNL	Don Boyd	Pacific Northwest Laboratories Battelle Boulevard P.O. Box 999 Richland, WA 99352
Rapid In-Process Analysis of Molten Metal	Los Alamos Lab	Larry Blair	U. of California Los Alamos National Lab P.O. Box 1663 Los Alamos, NM 87545
	INEL	Joe Alavarez	Idaho National Engineering Laboratory 550 Second Street Idaho Falls, ID 83401
High-Temperature Remote Inspection System	Honeywell	Don Waters	Honeywell 2600 Ridgeway Parkway Minneapolis, MN 55413
Pulp and Paper Industry			
Polymeric Hygrometer	JPL	D.D. Lawson	Jet Propulsion Laboratory California Inst. of Technology 4800 Oak Grove Drive Pasadena, CA 91109
Lignin Sensor	JPL	H. Boettger	Jet Propulsion Laboratory California Inst. of Technology 4800 Oak Grove Drive Pasadena, CA 91109
Consistency Sensor	NBS	A. Gaigalas	National Bureau of Standards Gaithersburg, MD 20899
On-Machine Paper Sensor	Institute of Paper Chemistry	Gary Baum	Institute of Paper Chemistry Appleton, WI 54913
Lime Kiln Sensor	JPL	S.P. Venkateshan	Jet Propulsion Laboratory California Inst. of Technology 4800 Oak Grove Drive Pasadena, CA 91109
Fertilizer Sensor	Aguila Corp.	John Colburn	Aguila Corporation 24 Park Street Pepperell, MA 01463
Alumina Sensor	PNL	Patrick Hart	Pacific Northwest Laboratories Battelle Boulevard PO Box 999

RESEARCH AND DEVELOPMENT DATA BASE

(Continued)

<u>Generic</u>			
Optical Surface Motion Monitoring	OPTRA, Inc.	Geert Wyntjes	OPTRA, Inc. West Peabody Office Park 83 Pine Street Peabody, MA 01960
Steam Flow Meter	JPL	S. Parthasarathy	Jet Propulsion Laboratory California Inst. of Technology 4800 Oak Grove Drive Pasadena, CA 91109
Spectroscopic Combustion Temperature Sensor	NBS	R. Charagundla	National Bureau of Standards Gaithersburg, MD 20899
Heat Flux Dew-Point Hygrometer	Trans-Met Engineering, Inc.	Dieter Rall	Trans-Met Engineering, Inc. 1640 S. St. Claire Ave. Anaheim, CA 92806
Moisture Sensor for Harsh Drying Environment	Spectral Sciences, Inc.	Michael Gersh	Spectral Sciences, Inc. 111 South Bedford Street Burlington, MA 01803
Dew Point Hygrometer	Honeywell	Robert E. Sulouff	Honeywell-Solid State Electronics Division Sensor Operations 12001 St. Highway 55 Plymouth, MN 55441
Spectral Flame Analyzer	TECO	William Cole	Thermal Electron Corp. R&O New Business Center 101 First Avenue P.O. Box 459 Waltham, MD 02254