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Formal Report (Summary)

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Beam Stability and Nonlinear Dynamics Symposium

(December 3 - 5, 1996)

Summary Report

BY

Zohreh Parsa

Institute for Theoretical Physics,
University of California,
Santa Barbara

&

Brookhaven National Laboratory,
Upton, NY 11973-5000

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SYMPOSIUM SUMMARY REPORT

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Zohreh Parsa

ITP / Brookhaven National Laboratory

901A, Upton, New York 11973-5000

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Symposium Summary Report

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A "Beam Stability and Nonlinear Dynamics" Symposium was held October 3 - 5, 1996 at the Institute for Theoretical Physics (ITP) in Santa Barbara. This was one of the 3 symposia hosted by the ITP and supported by its sponsor, the National Science Foundation, as part of our "New Ideas for Particle Accelerators" program. The symposia was organized and chaired by Dr. Zohreh Parsa of ITP/ Brookhaven National Laboratory. [A 4 member program advisory committee was selected Three who participated included: Z. Parsa, G. Guignard, J. Irwin].

The purpose of this symposium was to deal with some of the fundamental theoretical problems of accelerator physics by bringing together leaders from accelerator physics communities, mathematics, and other fields of physics. The focus was on nonlinear dynamics and beam stability. The symposium began with some defining talks on relevant mathematical topics such as single-particle Hamiltonian dynamics, chaos, and new ideas in symplectic integrators. The physics topics included single-particle and many-particle dynamics. These topics concern circular accelerators in which particles circulate for a very large number of turns as well as linear accelerators where space charge and wakefields induced in accelerating cavities play a strong role.

A major question is to determine the best model for numerical simulations in order to accurately reproduce behavior of beams in real accelerators and to predict long-term or long distance stability. Comparison with experiment is recognized as an important tool in improving models.

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Straight-forward tracking using linear elements and thin-lens multipoles to preserve symplecticity is the basic tool for studying single-particle dynamics and stability in large circular accelerators such as the Large Hadron Collider (LHC), which was recently approved for construction at CERN. Ideas have been aimed at improving the computation time and/ or in improving analysis of the results. Symplectification of Taylor maps was an important topic that was presented since truncation of expansion maps leads to maps that are not symplectic. The concept of jolt factorization makes it possible to obtain a symplectic truncated expansion. But if the nonlinearity is too large, as is usually the case near the onset of unstable motion, map predictions fail. This raises the difficult question of the applicability of a complete-turn map to a large accelerator. The expansion of such maps is laborious for phase-space dimensions larger than four. Another related development is the use of Taylor's models with additional functions which bound the initial function from above and below. Application of this concept to maps led to the development of an arithmetic, which applies to both the polynomial and the remainders, termed Remainder Differential Algebra. This should provide information on the accuracy of the map description. Symplecticity is ensured if we use the Hamiltonian formalism and action-angle variables. In this approach, the map over one turn or a fraction of turn can be computed by solving algebraic equations related to canonical transformations which are in implicit form. This is done for the non-periodic solutions of the generating function equation by using Newton iterations and approximation in Fourier series and B-spline functions.

Interesting results of numerous trackings and analyses (including those developed during our ITP workshop) were presented for the LHC. Different methods for estimating the dynamic aperture were tested, first using the Henon map. Early indicators such as the Lyapunov criterion, frequency map analysis, and variation of tunes have been used with tracking over an increasing number of turns. A new conjecture combining the result of the KAM theorem with the Nkhoroshev estimate predicts that the dynamic aperture depends on the inverse logarithm of the number of turns. There is remarkable agreement between the predictions of the early indicators and the result of the conjecture extrapolated to a very large number of revolutions. This gives an increased confidence in the numerical predictions, to within 10 or 20% of the actual value as supported by measurements on existing accelerators.

Particular examples of stability analysis were presented, such as a Hamiltonian system with a quartic potential and the three-body problem in celestial mechanics. Linearization around a periodic solution in the first case and around a Lagrangian fixed point in the second, provides a monodromic matrix which give information on the stability. For the three-body problem, developments to second order allows us to solve the equation of motion near resonance. Also presented was the idea to apply to accelerator dynamics the wavelet analysis of Hamiltonian systems.

Among the other subjects treated were spin dynamics, nonlinear aberration correction including space charge aberrations, collective effects in the LHC, sawtooth instability, and Landau damping in the presence of strong nonlinearity. There were other presentations concerning plasma physics effects relevant to accelerators. And the peculiar effect of beam echos that has recently been observed for the first time in an existing accelerator with echo times as long as one to two minutes. Numerical tools for studying multibunch instability in linear accelerators with strong wakefields were presented, together with a statistical method of analysis of wakefield effects on emittance growth, based on beamline response coefficients.

The conference ended with a unique discussion session in which participants presented and clarified their views on outstanding problems and topics presented at the symposium. This international forum has provided new and valuable input for future developments in this field.

Summary of New Things in Nonlinear Beam dynamics:

- Recent development of the Remainder Differential Algebra for Taylor's maps.
- Suggestion of using wavelets for solving our nonlinear problems since they apply to Hamiltonian systems with perturbations.
- First or recent measurements on echos in accelerator beams, initially described for plasmas.

- New conjecture for very-long-time dynamic aperture and evidence of convergence of this estimate with early indicators.
- Statistical analysis of strong Wakefield effects on the emittance growth in high frequency linac.

INSTITUTE FOR THEORETICAL PHYSICS

UNIVERSITY OF CALIFORNIA
SANTA BARBARA, CALIFORNIA 93106-4030
http://www.itp.ucsb.edu

CONFERENCES/VISAS: (805) 893-3178
OFFICE FAX: (805) 893-2431
CREDIT CARD FAX: (805) 893-3486

ITP Conference on

Particle Beam Stability and Nonlinear Dynamics

December 3-5, 1996

Coordinator, Zohreh Parsa

SCHEDULE

Tuesday, December 3, 1996:

Time:	Speaker:	Title:
Convener:	**Z. Parsa**	
8:00 am	Registration	ITP Front Lobby
8:40	Welcome	J. Hartle, ITP Director
	Intro. & Welcome	Z. Parsa, BNL
9:00	J. Meiss, U Colorado	Single-Particle Hamiltonian Dynamics
9:45	Refreshment Break	ITP Center Patio
Convener:	**G. Guignard**	
10:15	J. Marsden, Cal Tech	Symplectic Geometry, Maps, Integrators
11:00	M. Berz, Michigan State	From Taylor Series to Taylor Models & Remainder Differential Algebra with Interval Arithmetic
11:45	A. Dragt, UM	Factorization of Taylor Maps
12:25 pm	Lunch Break	ITP Center Patio
Convener:	**J. Hagel**	
2:00	J. Irwin, SLAC	One-Turn Map Generators Aberration Sources, Consequences, and Corrective Actions
2:40	E. Todesco, INFN	Long-Term Orbit Stability Predictions (Lypunov estimates, Normal Forms)
3:25	Refreshment Break	ITP Center Patio
Convener:	**W. Lysenko**	
4:00	J. Laskar, BDL	Frequency Map Analysis - Theory & Experiments
4:45	R. Warnock, SLAC	The Effect of Resonances on Long-Term Stability & Symplectic Full Turn Maps
5:30	Wine & Cheese	ITP Center Patio
6:15	Conference Dinner	ITP Center Patio

Wednesday, December 4, 1996

Time:	Speaker:	Title:
Convener:	**D. Robin**	
8:30 am	V. Balandin, DESY	Nonlinear Spin Dynamics
9:10	F. Schmidt, CERN	Dynamic Aperture - Simulation and Experiment
9:55	Refreshment Break	ITP Center Patio
Convener:	**J. Ellison**	
10:25	F. Ruggiero, CERN	Longitudinal Beam Echoes & Diffusion Rates
11:05	R. Siemann, SLAC	Sawtooth Instability & Over-Shoot Phenomena
11:45	H. Yoshida, NAO	Instability of Periodic Orbit and Non-Integrability of Hamiltonian System
12:25pm	Lunch Break	ITP Center Patio
Convener:	**J. Krommes**	
1:40	P. Zenkevitch, ITEP	Neutralized Beams: Landau Damping in Systems with Strong Nonlinearity
2:20	G. Guignard, CERN	Stability of Beams in a High Frequency Linac with Strong Wakefields
3:05	Refreshment Break	ITP Center Patio
Convener:	**E. Lessner**	
3:35	M. Zeitlin, IPME	Wavelet Analysis of Hamiltonian System and its Perturbations
4:20	S. Andrianov, St. Petersburg	Nonlinear Aberration Correction
4:55	S. Heifets, SLAC	Search of the Mechanism of the Saw-Tooth Instability
5:30	Reception	ITP Center Patio

Thursday, December 5, 1996

Time:	Speaker:	Title:
Convener:	**A. Chao**	
8:30	F. Ruggiero, CERN	Collective Effects in LHC
9:05	J. Hagel, Univ Maderia	Galaxy Dynamics: Resonance Analysis in Celestial Mechanics
9:50	Refreshment Break	ITP Center Patio
Convener:	**M. Berz**	
10:20	A. Pankin, INR	Nonlinear Structure Near Boundary of Marginal Stability
10:40	G. Stupakov	Nonlinear Dynamics of Single Bunch Instability in Accelerators
11:10	V. Zadorozhny, IC	The Dynamic 2-D Electron Beams of the Plasma Lense
11:30	TBA	Map Measurements
11:45	G. Guinard	Statistical Analysis of Emittance Growth
12:20 pm	Lunch Break	ITP Center Patio
Convener:	**R. Siemann**	
1:50	Round Table Discussions on Outstanding Issues in Beam Instabilities and Nonlinear Accelerator Dynamics	Z. Parsa, A. Dragt, G. Guignard, J. Laskar, J. Meiss, E. Todesco, & other speakers and participants
3:00	Z. Parsa, BNL	Summary and Closing Talk

Conference Ends

TBA = To be announced
* = late contributions
BNL = Brookhaven National Laboratory
FNAL = Fermi National Laboratory
LANL = Los Alamos National Laboratory
SLAC = Stanford Linear Accelerator Center
DOE = Department of Energy
NSF = National Science Foundation
UCLA = Univ. California Los Angeles
UCSB = Univ. California Santa Barbara

Dan Abell
Department of Physics
University of Maryland
College Park MD 20742-4111

off. ph.: (301) 405-????, 6028 msg
FAX number: (301) 314-9525
dabell@quark.umd.edu

Serge Andrianov
Dept. of Applied Mathematics &
Control Processes
St. Petersburg State University
Bibliotechnaja pl.2
St. Petersburg 198904
RUSSIA

FAX number: 7-812-428-7189
serge@asn.apmath.spb.su

V. Balandin
NSCL
Michigan State University
East Lansing MI 48824-1321

off. ph.: (517) 333-6431
FAX number: (517) 353-5967
balandin@nscl.msu.edu

Martin Berz
Physics and Astronomy
Michigan State University
East Lansing MI 48824

off. ph.: (517) 333-6313
FAX number: (517) 353-5967
berz@pilot.msu.edu

Nathan Brown
G. H. Gillespie Associates, Inc
10855 Sorrento Valley Rd, #201
San Diego CA 92121

off. ph.: (619) 677-0076
FAX number: (619) 677-0079
ghga@millennianet.com

Alexander Chao
SLAC, MS 26
Stanford University
P.O. Box 4349
Stanford CA 94309

off. ph.: (415) 926-2985
FAX number: (415) 926-4999
achao@slac.stanford.edu

David Cline
Department of Physics
University of California
405 Hilgard Avenue
Los Angeles CA 90024-1547

off. ph.: (310) 825-1673, 3440 msg
FAX number: (310) 206-1061
dcline@physics.ucla.edu

Alex Dragt
Dept. of Physics & Astronomy
University of Maryland
College Park MD 20742-4111

off. ph.: (301) 405-6053, 6028 msg
FAX number: (301) 314-9525
dragt@quark.umd.edu

James Ellison
Department of Mathematics
University of New Mexico
Albuquerque NM 87131

FAX number: (505) 277-5505
ellison@math.unm.edu

Anna Fishchuk
Dept of Plasma Physics
Institute for Nuclear Research
pr. Nauki, 47
Kiev-022
UKRAINE

off. ph.: +380-44 266-4791
FAX number: +380-44-265-4463
fedun@astrophys.ups.kiev.ua

Vladimir Gorev
Plasma Processes Laboratory
Russian Research Center
Kurchatov Institute
Kurchatov Sq. 1
123182 Moscow
RUSSIA

off. ph.: (7)095 196-7658
FAX number: (7)095 943-0023
(none)

Gilbert Guignard
European Lab for Particle Physics
CERN
CH-1211 Genéve 23
SWITZERLAND

off. ph.: (41)22 767-5975
FAX number: (41)22 767-8333
Gilbert.Guignard@cern.ch

Johannes Hagel
Universidade da Madeira
Proigo do Município
P-9000 Funchal, Madeira
PORTUGAL

off. ph.: (351)91 231-312
FAX number: (351)91 231-312
hagel@dragoeiro.uma.pt

Katherine Harkay
ASD/401
Argonne National Laboratory
9700 South Cass Avenue
Argonne IL 60439

off. ph.: (630) 252-9758
FAX number: (630) 252-4732
harkay@aps.anl.gov

Samuel Heifets
SLAC, Bin 26
Stanford University
P.O. Box 4349
Stanford CA 94309

off. ph.: (415) 926-4600
FAX number: (415) 926-4999
heifets@slac.stanford.edu

John Irwin
SLAC, MS 26
Stanford University
P.O. Box 4349
Stanford CA 94309

off. ph.: (415) 926-2740
FAX number: (415) 926-4999
irwin@slac.stanford.edu

John Krommes
Plasma Physics Laboratory
Princeton University
P.O. Box 451
Princeton NJ 08543

off. ph.: (609) 243-2606
FAX number: (609) 243-2662
krommes@princeton.edu

Jacques Laskar
Astronomie et Systemes Dynamiques
Bureau des Longitudes
3 rue Mazarine
F-75006 Paris
FRANCE

off. ph.: (33)1 42 34 58 60
FAX number: (33)1 43 29 60 84
laskar@bdL.fr

Guy Laval
CPHT
Ecole Polytechnique
91128 Palaiseau, Cedex
FRANCE

off. ph.: (33)1 69 33 43 22
FAX number: (33)1 69 33 30 08
laval@orphee.polytechnique.fr

Eliane Lessner
Argonne National Laboratory
9700 South Cass Avenue
Argonne IL 60439

off. ph.: (630) 252-6466
FAX number: (630) 252-4732
esl@aps.anl.gov

Walter Lysenko
AOT-1, MS-H808
Los Alamos National Lab
Los Alamos NM 87545

off. ph.: (505) 667-7431
FAX number: (505) 665-2904
WPL@LANL.GOV

William (Bill) Marciano
Particle Theory Group
Brookhaven National Laboratory
20 Pennsylvania Avenue
Upton NY 11973

off. ph.: (516) 282-3151
FAX number: (516) 282-5568
marciano@bnLajc.bnL.gov

Jerrold (Jerry) Marsden
Control & Dynamical Systems
CALTECH 116-81
Pasadena CA 91125

off. ph.: (818) 395-4176
FAX number: (818) 796-8914
marsden@cds.caltech.edu

James Meiss
University of Colorado
Campus Box 526
Boulder CO 80309

off. ph.: (303) 492-3731
FAX number: (303) 492-4066
jdm@colorado.edu

Alexei Pankin
Department of Plasma Theory
Institute for Nuclear Research
pr. Nauki, 47
Kiev -22
UKRAINE

off. ph.: +380-44-227-4833
FAX number: +380-44-265-4463
alexei@uiccu.freenet.kiev.ua

Zohreh Parsa
Department of Physics
Brookhaven National Laboratory
P.O. Box 5000
Upton NY 11973-5000

off. ph.: (516) 344-2085
FAX number: (516) 344-3248
parsa@bnl.gov

Alain Piquemal
CEA/DRIF/DPTA
BP12
91680 Bruyers-le-Chatel
FRANCE

off. ph.: (33) 0169264466
FAX number: (33) 0169267024
piquemal@bruyeres.cea.fr

David Robin
Lawrence Berkeley Laboratory
University of California
Berkeley CA 94720

off. ph.: (510) 486-6028
FAX number: (510) 486-4960
robin@lbl.gov

Francesco Ruggiero
SI Division
CERN
CH-1211 Genéve 23
SWITZERLAND

off. ph.: +41 (22) 767 3726
FAX number: +41 (22) 783 0552
Francesco.Ruggiero@cern.ch

Raymond (Ray) Sawyer
Inst. for Theoretical Physics
University of California
Kohn Hall
Santa Barbara CA 93106-4030

off. ph.: (805) 893-3488, 4111 msg
FAX number: (805) 893-2431
sawyer@sarek.ucsb.edu

Frank Schmidt
Theory Division
CERN
CH-1211 Genéve 23
SWITZERLAND

off. ph.: (41)22 767-5245
FAX number: (41)22 783-0552
Frank.Schmidt@cern.ch (case-sense)

Robert Siemann
SLAC, MS-26
Stanford University
P.O. Box 4349
Stanford CA 94309

off. ph.: (415) 926-3892
FAX number: (415) 926-4999
siemann@slac.stanford.edu

Gennady Stupakov
SLAC
Stanford University
P.O. Box 4349
Stanford CA 94309

off. ph.: (415) 926-4320
FAX number: (415) 926-4999
stupakov@slac.stanford.edu

Andrei Terebilo
SLAC
Stanford University
P.O. Box 4349
Stanford CA 94309

off. ph.: (415) 926-3041
FAX number: (415) 926-4100
terebilo@ssrl.slac.stanford.edu

Ezio Todesco
INFN Sezione di Bologna
Via Irnerio 46
40126 Bologna
ITALY

off. ph.: (39) 51 351095, 351001 m
FAX number: (39) 51 244101
etodesco@bo.infn.it

Marco Venturini
Department of Physics
University of Maryland
College Park MD 20742-4111

off. ph.: (301) 405-????, 6028 msg
FAX number: (301) 314-9525
venturin@quark.umd.edu

Chunxi Wang
SLAC, MS 26
Stanford University
P.O. Box 4349
Stanford CA 94309

off. ph.: (415) 826-3847
wangcx@slac.stanford.edu

Robert Warnock
SLAC, MS 26
Stanford University
P.O. Box 4349
Stanford CA 94309

off. ph.: (415) 926-2870
FAX number: (415) 926-4999
warnock@slac.stanford.edu

Yiton Yan
SLAC
Stanford University
P.O. Box 4349
Stanford CA 94309

off. ph.: (415) 926-3315
FAX number: (415) 926-4999
yan@slac.stanford.edu

Haruo Yoshida
National Astronomical Observatory
of Japan
Mitaka
Tokyo 181
JAPAN

off. ph.: (81) 422 34-3614
FAX number: (81) 422 34-3793
yoshida@gauss.mtk.nao.ac.jp

V. Zadorozhny
Institute of Cybernetic
National Academy of Sciences
of Ukraine
252187 Kyiv, Teremkovska st. 53
UKRAINE

FAX number: 380-44-266-26-17
zv@daosu.carrier.kiev.ua

Michael Zeitlin
Institute of Problems of
Mechanical Engineering
Russian Academy of Sciences
V.O., Bolshoj pr., 61, Room 24
St. Petersburg 199178
RUSSIA

off. ph.: (7) 812 217-8636
FAX number: (7) 812 217-8614
zeitlin@math.ipme.ru

Pavel Zenkevitch
Institute for Theoretical
& Experimental Physics
B Cheremushkinskaya Ulitsa 25
RU-117 259 Moscow
RUSSIA

off. ph.: (7)095 123-0292
FAX number: (7)095 123-6584
zenkevich@vitep3.itep.ru