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BEAM DYNAMICS NEWSLETTER

No. 13

edited by
K. Hirata, J. Jowett and S.Y. Lee

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1: Forewords

1.1 From the chairman of ICFA Beam Dynamics Panel

K. Hirata (hirata@kekvax.kek.jp) the chairman

1.1.1 Congratulations!

Another panel related to accelerators was created in ICFA after long lonely period for our panel.

In the last ICFA meeting held in January at SLAC, the new panel was approved on “Advanced and Novel Accelerators” whose chairman is C. Pellgrini. He was one of the most active members of the beam dynamics panel and is now organizing his new panel. He will officially quit the Beam Dynamics Panel soon.

Before, there were panels for ”Acceleration Technology” and ”Superconductivity and Cryogenics”. The former played an essential role for the world-wide collaboration on the linear colliders but became less active and less influential gradually. It was terminated in 1995. The latter was active in setting superconducting wire standards and completed its mission in 1995. After their termination, the beam dynamics panel was the only ICFA panel related to the accelerators.

The new panel is no doubt quite important for the future of accelerator society. The beam dynamics panel will support it as much as possible. Two panels should and will collaborate closely. The 13-th Advanced ICFA beam Dynamics Panel, which will be held in Kyoto Japan in July 1997, will essentially be the first workshop for the new panel.

1.1.2 News from Beam Dynamics Panel

Our panel has had some changes since the previous newsletter was published. Patrick Colestock (FERMILAB) has retired from the panel and Weiren Chou (FERMILAB) succeeded his job including the distributer of the newsletter. According to the creation of the panel for Advanced and Novel Accelerators, the working group ”New Acceleration Scheme” was terminated. (This new panel will be formed on the basis of this working group). On the other hand, we have created a new working group in our panel on ”High-Brightness Hadron Beams”. Its mission is to promote beam dynamics studies for high intensity, high brightness hadron beams and to foster applications of such beams in high energy physics and other fields such as nuclear physics, industry, etc. by inter-laboratory and international collaborations.

Thus, at present, there are three working groups in the Beam Dynamics panel:

- Future Light Source (Leader is J. L. Laclare)
- Tau-Charm Factory (Leader is A. Perelstein)
- High-Brightness Hadron Beams (Leader is W. Chou)

We will have three Advanced ICFA Beam Dynamics Workshops:

- “2nd Generation Plasma Accelerators” (Kyoto Japan, 14 to 18 July, 1997)
- “Beam Dynamics Issues (Frascati Italy, 20 to 26 October 1997) in e^+e^- Factories”.
- “Quantum Aspects in Beam Physics”. (Monterey California, May 1998)

In addition to this series of workshops, we have established another class of workshops, ICFA Beam Dynamics Mini-Workshops. The workshops in this category are of the same importance as the Advanced ICFA Beam Dynamics Workshops but can be organized more easily. It is meant that this type of workshop is more working-oriented and less formal. The proceedings are not obligatory. Now, the “High-Brightness Hadron Beams” working group is planning to have two mini-workshops:

- “rf cavities and coalescing/debunching-rebunching”. (BNL, 7-9 May 1997)
- “emittance budget and diagnostics”. (CERN, 5-7 November 1997)

1.2 The ICFA Beam Dynamics Newsletter No. 13

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This year, I am fortunate to have the opportunity to spend my sabbatical leave at Fermilab participating many interesting high energy beam physics projects. Currently, the TEVATRON at Fermilab is the highest energy machine at 1.8 TeV center of mass energy. In March 1995, D0 and CDF groups at the Fermilab jointly announced the the discovery of the Top Quark. The Tevatron luminosity is currently about $\mathcal{L} = 2 \times 10^{31}$ cm^{-2}s^{-1}. The completion of the Main Injector in 1999 will increase the TEVATRON luminosity by a factor of 4. The addition of the Recycler [1] will increase the luminosity by another factor of two. The TEV33 project with a 10^{33} cm^{-2}s^{-1} luminosity can be achieved by combining the increase in the number of bunches and the electron cooling capability in the Recycler.

Along with the collider physics at the Tevatron, the fixed target programs using the 120 GeV protons of the Main Injector will be an important Kaon factory for future high energy physics experiments. Other research ideas such as the Very Large Hadron Collider, the Muon-Muon Collider, Plasma Wake-Field Acceleration, TESLA, etc. are also actively pursued at Fermilab. These activities indicate that high energy accelerators remain to be essential tools for high energy physics research.

Looking around, the B-factory at the SLAC and the KEK will be commissioned in 1998, the RHIC at BNL will be completed in 1999, the LHC at CERN, the SPring-8 at RIKEN, the Cooler Injector Synchrotron at IUCF,[2] and the CSRs at Lanzhou are in the construction phase. The Radioactive Ion Beams Facility, and a Quasi-Isochronous Storage Ring (SUBARU) at RIKEN have recently been approved for construction. Similarly, the Japanese Hadron Project (JHP) at KEK/INS is likely to be approved in the near future. The APT project at LANL is funded for R&D. The R&D for the National Spallation Neutron Source at the Oak Ridge National Laboratory is actively pursued in various laboratories. The Light Ion Spin Synchrotron (LISS) at IUCF, and the Hydrotest Facility Projects at LANL, etc., are also in the R&D phase. Research activities are interestingly intense. These projects require close collaboration between beam physicists and engineers in many laboratories and universities.

Similarly, the Linear Collider programs at all major laboratories are progressing extremely well toward the goal of a Next Linear Collider, where, in this issue, W. Schnell provides a review of the

[1] The Recycler is an 8 GeV storage ring with permanent magnets in the Main Injector Tunnel. In its initial phase, the Recycler will have stochastic cooling. High energy electron cooling is an R&D project for the Recycler.

[2] The Cooler Injector Project includes a 3 MeV RFQ, a 4 MeV DTL, and a synchrotron that can accelerate protons from 7 MeV to 210 MeV. The commissioning of the synchrotron is late 1997.

current status of the Linear Collider design, G. Guignard and J. Hagel draw our attention to a visual simulation program for the Linear Collider beam dynamics, and J. Urakawa reports the status of ATF damping ring. Many interesting beam physics experiments will be carried out at the ATF ring in coming years. Toward the goal of a possible Tau-Charm factory, L. Teng provides an activity report, based on the Beijing Tau-Charm factory design, for the Tau-Charm working group. S. Krishnagopal provides a first light of the INDUS1 commissioning. S. Peggs reports a successful commissioning of a RHIC Sextant. U. Bechstedt *et al.* reports the status of the COSY at Jülich. Reports from CERN are always refreshing and informative. In general, Laboratory activity and workshop reports provide useful information to our community.

On the education of future accelerator scientists and engineers, S. Krishnagopal reported a very successful first Physics of Beams school in India. This is a wonderful news. There are CERN Accelerator School, KEK Accelerator School, and US Particle Accelerator School. It is important to extend accelerator physics education to other area in the world. On the related issues, I would like to draw your attention to a new development that the Indiana University (IU) and the United States Particle Accelerator School (USPAS) have jointly announced to sponsor a Master of Science Program for accelerator physics and technology. Students who enroll the IU/USPAS program for a total of 30 credit hours with a Master thesis can earn a Master of Science degree from the Indiana University. Such a degree program can provide students with option to choose one of many subfields in accelerator physics. The curriculum will be designed to meet the demand of students in various subfields. If you have questions, please feel free to contact the USPAS Office (uspas@fnal.gov; Phone 630-840-3896).

USPAS Office, Fermilab, MS125, P.O. Box 500, Batavia, IL 60510-0500, USA.

2: *Letters to the Editors*

2.1 Letter to the Editors by C. Zhang

Dear Editor,

Invited by Prof. S. Kurokawa, I was able to join the KEK as a visiting professor under Monbusho program over the past year, working at TRISTAN (for its last period of operation as a light source and machine studies), KEKB (when it was just switching into the component installation phase) as well as the proposed Beijing Tau/charm Factory, in cooperation with colleagues of both KEK and IHEP. The collaboration was enjoyable and fruitful, and there were many exciting experiences during the year, that I would share with you.

My visiting KEK was arranged not long after the SSC project had been canceled. However, the development of high energy physics and accelerators was not set back, especially in Japan. In KEK, a B-factory, called KEKB, was under construction, and would have been commissioned by the end of 1998, with about the same schedule of the SLAC B-factory project, the PEP-II. As the next step, the Japanese Hadron Project, the JHP, was almost approved, and would take its construction period from 1998 to 2003. In the meantime, early construction of the linear collider in Japan was recommended by the Japanese high energy physics community. There were interesting discussions during my stay in KEK about the reorganization of KEK in order to serve the wider research requirements from the high energy and nuclear physics to synchrotron radiation and material science. It was finally decided that KEK would have the new meaning of “high energy accelerator based research organization”, which contained two research institutes and two laboratories. Indeed, with its 300 million US Dollar annual budget, KEK may carry on its research program in such an aggressive way.

One day, I met Tom Taylor of CERN at the campus during his short visit to KEK and other labs in Japan. When asked him about his impression on his visit, “KEK is too poor”, he said, “to compare with some other labs I just visited.” It is true that high energy physics is not the only field that Japanese government funds. I had a chance to participate the 10-th Japanese (domestic) Symposium on Accelerator Science and Technology held in Hitachnaka, and visited SPring-8 Laboratory, Tokyo University, Osaka University and Kyoto University and some other institutions. I was very much impressed by the variety of accelerators in Japan, by the SPring-8 as a synchrotron light source, by the HIMAC as a heavy ion medical accelerator, by the OMEGA (Options Making Extra Gains of Actinides and fission products) project, by RIKEN radioactive ion beam factory, by the RCNP ring cyclotron, by the electron cooling ring TRAN II and many other projects.

Another thing which impressed me was the close relationship between research institutes and companies. The companies not only participate in the R&D of projects and take care the mass production of the accelerator components, but also contract to operate the machines. In KEK, the staffs from Hitachi company took the shifts for TRISTAN operation, while in the control room of the Osaka University Ring Cyclotron, I saw the operators with the uniform of Sumitomo company. Once the SPring-8 is completed, the administration of the laboratory will be switched to a private organization. One might worry about the effectiveness of the unique way of the management, however, it works well in Japan and indeed saves the limited manpower of the research institutions.

KEK is located in the north part of the Tsukuba Scientific City. It was established in order to cope with the over-crowded conditions in Tokyo through a systematic relocation of research and educational institutes to Tsukuba, as well as creating a center for high-level research education. About 30 years have passed since the decision was made. Now, 46 national institutions and nearly 200 private laboratories have been moved in or set up in the Tsukuba Scientific City, covering agriculture, industry, medicine, construction, environment, space science, and other basic and applied research fields. Taking advantage of the annual open house week, I had a chance to take looks in about 30 research institutions among them. It is those laboratories that make the rapid and steady development of the Japanese economy possible. I have realized that for China's modernization one needs science and technology serve as an "accelerator". This would also be true for other developing countries.

In the aspects of culture, as a Chinese, I did not feel particular inconvenience in Japan. It was troublesome when I was trying to communicate with non-scientific staffs, but we could write anyway. The story would be different for Western visitors. Eberhard Keil of CERN was my opposite door neighbor during his one month visiting KEK last year. I was invited to his apartment for dinner, and was then asked how to use the microwave oven and the washing machine. For few weeks, he could not use the apparatus only because all the buttons in them were labeled in Japanese and no English manuals were available.

Now, more and more foreigners go to Japan from East and West for cooperative research and other purposes. Having realized the importance of internationalization, the authority of the Tsukuba scientific city made efforts to improve the situation. We were able to participate in the Tsukuba International Festival organized by the city office, where we demonstrated Chinese cooking as a part of our culture and joined the Tsukuba Mountain Gama Festival where we foreigners tried to carry "Mikoshi" on our shoulders. It is in Japan, where the traditional culture is well preserved in combination with the modern science and technology.

Sincerely yours,

C. Zhang

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2.2 Letter to the editors by Yiton Yan

Dear S.Y.,

I appreciate very much that the ICFA newsletters have been providing a platform for beam dynamics discussions. These newsletters have conveyed valuable information in a concise and easy-to-digest format. I wish to take advantage of this popular Newsletter to discuss a new formula for the Truncated Power Series Algebra (TPSA) in hope of reaching some more potential allies. This new formula may lead to ultimate design of the TPSA in terms of speed and flexibility.

Let me begin with a brief review of the past computational designs of the TPSA. TPSA is the algebra for multi-variable Truncated Power Series (Tps). It is particularly useful in application to beamline design and nonlinear dynamics analysis. The algebra involves some fundamental operations such as addition, subtraction, multiplication, division, inverse, sine, cosine, square root, power, exp, log, derivative, integral, etc. of Tps's. Derived operations can be Poisson bracket, various formats of Lie generators (from a system of Tps's that form a map) in Cartesian or Action-Angle coordinates. The coefficients of a Tps can be Tps's (making a TpsTps class), too, such that the canonical coordinate variables form a class of Tps of which each coefficients is another class of Tps of certain parameter variables whose optimal values are to be determined after parameterized mapping analysis. All these can be programmed with an object oriented computer language, such as C++, for easy interface.

There were, fundamentally, three kinds of data structures used in programming the TPSA in beam physics community, the hybrid procedure of Cosy Infinity (M. Berz, Part. Accel. No. 24, 109, 1989), the One-Step-Index-Pointer procedure of Zlib (Y.T. Yan, SSCL-300, 1990), and the Link-List procedure of MXYZPTLK (L. Michelotti, FN-535, 1990). The recent elegant TPSA "look-back table" description of Prof. A.J. Dragt is fundamentally similar to Zlib "One-Step Index Pointer". In the following, description will be based on the One-Step-Index-Pointer scheme.

Through appropriate labeling and indexing, a Tps can be represented by a one-dimensional array of real (double) numbers one-to-one corresponding to the coefficients of the Tps. For allowing order grading, low order coefficients would be indexed first, followed by the next high-order and then the next high-order coefficients until the preset (or derived) maximum order is reached. In a mathematical formula, an n-variable, Ω-order Tps can be written as

$$T(n,\Omega) = H(n,0) + H(n,1) + H(n,2) + ... + H(n,\Omega),$$

where $H(n,i), i = 0,1,...,\Omega$, is the homogeneous polynomial of order i and $H(n,0)$ contains only the constant term. Clearly this formula allows for order grading (adding or truncating high-order terms does not affect the low order structure) but not for variable grading. Of course, in the above formula, one can let n be the fixed order and Ω be the maximum number of variables, then it allows for variable grading, but not for order grading.

The key to fast speed TPSA is to have One-Step Index Pointers prepared only once for repeated use such that for any coefficient involved in a given calculation, it can be identified with a minimum index path. For example, let A and B be two Tps's (may be with different orders), such that
Tps C = A * B (multiplication).
The task is to obtain all of the coefficients of C to a specified order derived from the orders of A and B and the preset cap order. To obtain $C[j]$ (jth-term of C), the "backward" scheme would go over a loop i from $ipBegin[j][beginOrder]$ to $ipEnd[j][endOrder]$ to sum over exactly the number of contributing multiplication terms given by $A[aOSIP[i]]*B[bOSIP[i]]$, where $aOSIP$ and $bOSIP$ are One-Step Index Pointers (OSIP's) stored for repeated use to achieve fast multiplication.

So much for the review, I shall briefly describe my new scheme now. As discussed above, a one-dimensional array representing the Tps can only allow for either order grading or variable grading but not both. My new scheme achieves both order and variable grading, which would ease the flexible use of the TPSA dramatically. The nice thing about this new scheme is that it builds on the top of the above one-dimensional scheme such that the One-Step Index Pointers can still be used to achieve fast speed. The master formula is as follows (Y.T. Yan, SLAC-PUB-7435):

$$T(n,\Omega) = T(0,\Omega-1) + x_1 T(1,\Omega-1) + x_2 T(2,\Omega-1) + .. + x_n T(n,\Omega-1),$$

where $T(0,\Omega-1)$ is just the constant term and $x_1, x_2, ...x_n$ label the n variables respectively. This formula means that a Tps of n variables and order Ω can be represented by a constant term and n Tps's of order $\Omega-1$ with 1, 2, ..., and n variables respectively such that adding (or truncating) the high-number-of-variable Tps's does not affect the structure of the low-number-of-variable Tps's (variable grading) while simultaneously each $(\Omega-1)$-order Tps's can have order grading as has been discussed above. Note that to achieve Tps operations up to a maximum order, Ω, One-Step Index Pointers may not need to be prepared up to the maximum order, Ω. For example, the multiplication

One-Step Index Pointers only need to be prepared up to the order of $\Omega - 2$. A detailed description of this new scheme, allowing both order and variable grading while still using One-Step Index Pointers, is given in SLAC-PUB-7435.

Sincerely yours,

Yiton T. Yan (`yan@slac.stanford.edu`)
SLAC, Stanford University, CA

2.3 Letter to the Editors by G. Guignard and J. Hagel

21th Feb. 1997

by **Guignard and J. Hagel** *

CERN, Geneva, Switzerland, and
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Dear S.Y. Lee,

We would like to draw the attention of the readers to an interesting tracking facility that we developed for linear colliders, and which has the capability of giving an animated graphic output. This allows a direct visualization of either the transverse motion or the phase space oscillation, of a train of bunches or of any individual bunch, as if the observer was actually following the beam going downstream the linac. Such a colored 'movie' is very didactic and helps a lot to understand the different mechanisms of single-bunch and multibunch instabilities and their suppression.

In linacs with strong wake fields,the stability of a train of bunches must be investigated in detail, using numerical simulations. For single-bunch effects, the short range wake fields provoke a bunch-tail instability, which is taken care of by the so-called BNS damping which consists of properly varying the focusing force along the bunch. In multibunch mode, the long range wakefields generate an instability called beam break-up and a transverse beam modulation is carried along the linac from accelerating section to accelerating section, through the beam. In both cases, a beam blow-up occurs which manifests itself as an amplitude growth from the head to the tail of each individual bunch as well as of the whole train. This growth decreases the luminosity.

Animated graphics associated to a tracking program make it possible to see and analyze these phenomena, their dependence on the linac- and beam-parameters, and the means available to compensate for the instability. For the long-range wake-field effects can however not be corrected, in contrast with short-range effects, such an analysis is very useful in order to establish for different models of accelerating structures (damped or damped-detuned) the field levels that are needed to avoid significant emittance growth and the sensitivity to variations of some parameters. To compute the blow-up and give the possibility to visualize the motion of the bunches through the different elements of the linac, every bunch is divided into slices populated according to a gaussian distribution and all the slice-to-slice interactions are described.

In the following, we give a brief description of the main features of the tool developed for the purpose mentioned above. An input file containing the vertical displacement of every slice in the train of bunches as function of the distance is used. The bunches are shown at successive defocusing quadrupoles, and plotting and erasing about 20 such pictures per second on the computer screen produce the feeling of a continuous motion of five bunches at once. To display the behavior of a train with more than 5 bunches it is possible to scan through it by using left and right arrow keys of the keyboard. In addition to the actual vertical positions of all slices, two rms beam dimensions in the vertical direction are also represented via rectangular boxes, the width of which is proportional to the length of each slice. The longitudinal charge density distribution is marked by different colors (red for the high density cores, yellow for the lower density parts next to the core and blue for the head and tail regions of the bunches).

Basically the animation can be run in the following modes:

- Showing the train of bunches (up to 5 at once) in real space meaning vertical displacement of slices vs. distance s.
- Showing the motion in real space of one of these bunches on full screen (”zoom in real space”).
- Showing the train of bunches (up to 5 at once) in the phase space $[y;\, dy/ds]$ vs. distance s.
- Showing the motion in phase space of one of these bunches on full screen (”zoom in phase space”)

For all these four modes, it is possible to show the complete motion of the bunches or to subtract the unperturbed vertical betatron motion in order to put in evidence the only distortions due to short- and long-range wakefield effects.

During the animation, it is possible to change the vertical scale in order to enable a more detailed view of the bunch motion. In addition, the apparent speed of the motion can be changed in a wide range (from a few pictures per minute to about 20-25 pictures per second) and the animation can be stopped in order to see any intermediate status of the multibunch system. It turned out that the number of images per unit-time is limited by the possibilities of the computer monitors rather than by the speed of the CPU on which the animation runs. It is also possible to alternate the four described modes of presentation during a run as well as during the halt status of the program. Such a pause allows to transform the image frozen on the screen into a TOPDRAWER graphics file for subsequent printing. Hereafter, as an illustration of what can be seen on the animated graphics, we propose four examples of such frozen images. The first two deal with the phase space; The upper plot of Fig. 2.1 shows how the tail of the bunch oscillates with small amplitudes (1.875 μm at maximum) around the head in the presence of BNS damping, while the lower plot shows an unstable bunch 20 which reaches large amplitudes (480 μm at maximum). The two pictures in Fig. 2.2 give the vertical oscillations in the normal space [z;y] for the first and the last five bunches of a train partly unstable, because of the long-range wakefields.

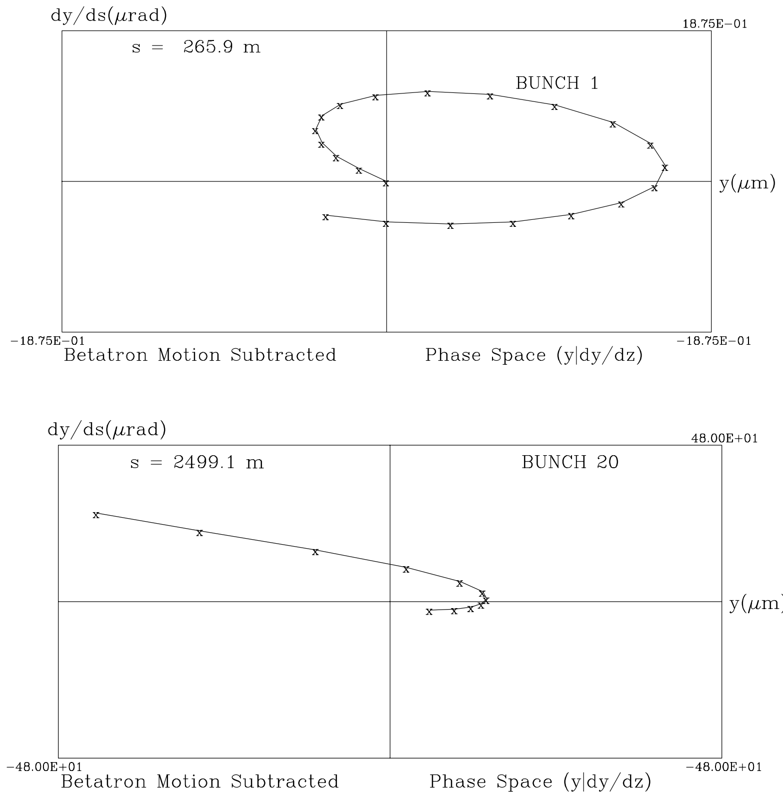

Figure 2.1: Phase space plots of bunch 1 (BNS damping) and bunch 20 (unstable) of a train of 20 bunches.

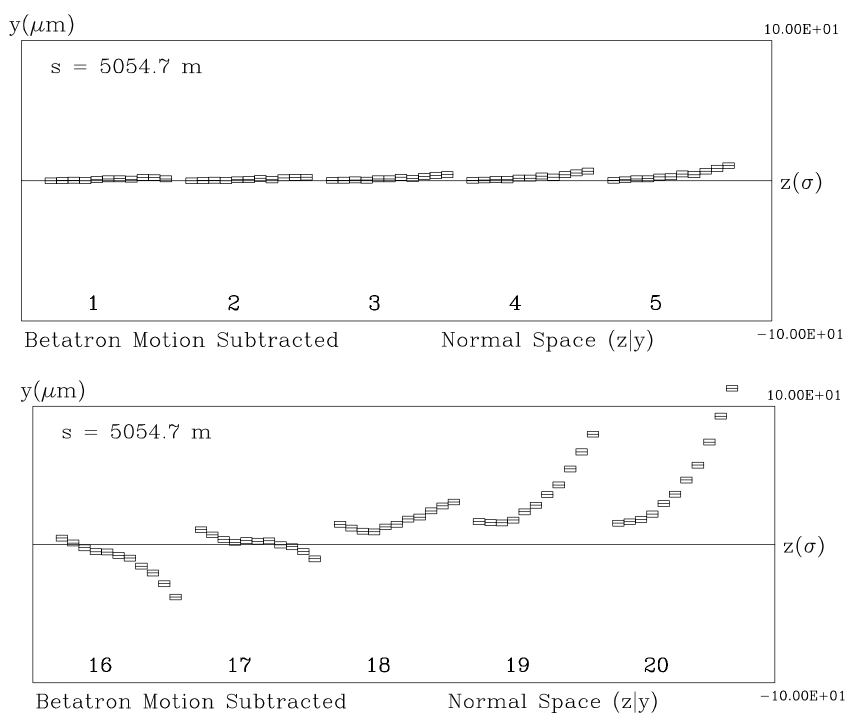

Figure 2.2: Normal space plots of the first and last five bunches of a train of 20 bunches.

3: Reviews of Beam Dynamics Problems

3.1 Linear Colliders

W. Schnell CERN, CH-1211 Geneva 23

3.1.1 Introduction

In the past, lepton colliders and hadron colliders have been complementary. At higher energies most of the relative merits will remain in spite of the gradual deterioration of energy resolution and background by initial state radiation in e^+e^- colliders. A general consensus has emerged, therefore, that the Large Hadron Collider (LHC) of 14 TeV should be supplemented by a lepton collider in the TeV range. Since circular e^+e^- colliders much above LEP energy are made impossible by synchrotron radiation loss, such a collider has to be linear. It consists basically of an injector complex (including positron production and damping rings for small emittance), the two main linacs accelerating electrons and positrons against each other, the final focus system providing the smallest possible cross-section of the colliding beams and the detector complex.

There is general agreement that 0.5 TeV in the center of mass is a good choice of initial energy, but at least 1 TeV should be reached later and 1.5 to 2 TeV (or higher) are desirable goals for ultimate upgrading. Also, the possibility of γ-γ collisions is a desirable option.

The main problem, apart from cost, is the generation of adequate luminosity. Since this should increase with the square of beam energy it should reach about $10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ at 1 TeV — more than an order of magnitude above the present record for circular e^+e^- colliders and several orders above the unique linear collider existing and model for all further developments, the SLC at SLAC.

3.1.2 Studies in Progress

In an early phase of linear collider studies the main emphasis was put on the highest possible accelerating gradient, possibly to be obtained by entirely new methods of acceleration such as employing plasmas and lasers. The problem of generating a very high clean luminosity at acceptable power input soon became dominant, however. As a result, all linear colliders proposed at present are based on essentially classical RF structures with more or less advanced methods of RF power generation. Six such proposals are listed in Table 1, all for an initial center of mass energy of 2×250 GeV and in the order of increasing RF frequency - from 1.3 to 30 GHz - the choice of frequency dominating the technology.

The accelerating gradient remains a prime parameter, however, as the total length of the facility will have a strong impact on its cost and general acceptance. This can be appreciated by considering the second line of the table. taking into account that the gradients listed refer to active length of acceleration. The physical lengths will become 30 % longer, plus several kilometers for the final focus system. Already at 500 GeV the total length of several proposed installations approaches or exceeds the LEP circumference of 30 km. At 2 TeV an active gradient of 100 MeV/m would be required to stay within that limit.

The TESLA proposal (DESY, Hamburg) is based on superconducting cavities, all others employ normal- conducting (copper) traveling-wave structures. The SBLC linacs (also DESY) are closest to conventional linacs with which they share the standard “S-band” frequency and the klystron type of power source, 150 MW pulse power per klystron having been in fact demonstrated. The JLC (KEK, Japan). NLC (SLAC) and VLEPP (Protvino, Novosibirsk) proposals are similar in principle but at higher frequency. Since here the achievable peak power per klystron output will probably be below 100 MW (at least initially) RF pulse compression is employed. For CLIC (CERN) the RF power is derived from high intensity drive beams of a few GeV initial energy, running parallel to the main linacs. Additional schemes under study, for which detailed parameters are not yet available, are a 30 GHz/5 TeV version at SLAC and a Two-Beam Accelerator (TBA) at LBNL/LLNL which differs from CLIC in employing different sources of microwave power.

Table 1: Main parameters of TLC designs in a first stage at 500 GeV c.m

	TESLA	SBLC	JLCC	JLCX	NLC	VLEPP	CLIC
Technology	S.C.	KLYSTRONS					TBA
Beam parameters at I.P.							
Center of mass energy $2eU$[TeV]	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Accelerating field (loaded) [MV/m]	25	17	31.9	58	29.4	91	100
Luminosity $L[10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}]$	6.0	5.0	6.6	5.2	5.5	9.3	6.7
Beamstrahlung mom. spread δ_B[%]	2.9	3.1	3.9	3.5	3.2	13.3	3.5
Linac repetition rate f_r[Hz]	5	50	100	150	180	300	700
Number particles/bunch $N_e[10^{10}]$	3.63	1.1	1.0	0.63	0.75	20	0.8
Number bunches/pulse N_b	1130	333	72	85	90	1	20
Bunch spacing Δ_b[ns]	708	6	2.8	1.4	1.4	-	1.0
Transverse emittances $\gamma\epsilon_x$	1400	500	330	330	400	2000	487
$\gamma\epsilon_y$ $[10^{-8}]$ rad-m	25	25	4.5	4.8	9	7.5	10
RMS beam width σ_x [nm]	845	335	318	260	294	2000	315
σ_y [nm]	19	15	4.3	3.0	6.3	4	4.2
Bunch length σ_z [μm]	700	300	200	90	125	750	160
Enhancement factor H_D	2.3	1.8	1.82	1.4	1.4	2.0	1.24
Beam power per beam P_b[MW]	16.5	7.25	3.2	3.2	4.8	2.4	4.49
Main Linac							
RF frequency of main linac [GHz]	1.3	3	5.7	11.4	11.4	14	30
Total two linacs length [km]	32	36	18.8	10.4	17.6	7	7.5
Length of sections [m]	1.04	6	1.8	1.31	1.8	1.0	0.32
Klystron peak power P_k[MW]	8	150	50.3	135	50	150	159000
Klystron pulse length [μs]	1315	2.8	2.44	0.5	1.2	0.5	0.041
RF pulse compression ratio	-	-	5	2	3.6	3.2	-
Number of klystrons N_k	604	2517	4184	3320	4528	140	10
AC to RF efficiency η_{RF}^{AC}[%]	35	37	22.6	30	28	39	35
AC to beam efficiency η_b^{AC} [%]	19	10.7	4.2	5.6	7.9	8.4	9.4
AC power for RF gen. P_{AC}[MW]	88	136	153	114	121	57	96

No consensus about the best solution has yet emerged. This reflects the difficulties and risks of advanced research and development into new territory. There is, however, not only full mutual understanding of the reasons for exploring different approaches but also intense cooperation. This is carried out in the frame of an international collaboration for research and development on TeV linear colliders (TLC) in which 24 laboratories join their efforts. A Technical Review Committee (TRC) has the mandate to “examine accelerator designs and technologies suitable for a collider that will initially have a center of mass energy of 500 GeV and luminosity in excess of $10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ and be built so that it can be expanded in energy and luminosity to reach 1 TeV center of mass energy with luminosity of $10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$." International workshops are regularly organized to monitor the progress of studies and form a forum for exchange of information and opinion.

3.1.3 Luminosity

Very generally, the luminosity is given by

$$L = \frac{N_e^2 N_b f_r}{4\pi\sigma_x\sigma_y} = \frac{N_e}{4\pi\sigma_x\sigma_y}\frac{P_b}{eU} \tag{3.1}$$

where f_r is the linac repetition rate, N_e, N_b are the numbers of particles per bunch and of bunches per linac pulse respectively, $\sigma_x\sigma_y$ is the beam size at collision, P_b the average power carried away (through the detector and into a beam dump!) by each beam and $2eU$ the center of mass energy. The beam size $\sigma_x\sigma_y$ includes a moderate compression by mutual space charge focusing. This "pinch- effect" has to be limited, however, as it generates synchrotron radiation ("beamstrahlung") with concomitant energy spread δ_B, a smeared out luminosity spectrum and severe background, all of which are detrimental to the physics experiments.

The beam power P_b controls the total input power to the facility — in the 100 MW range for all projects — via the overall conversion efficiency η_b^{AC} from mains input to beam. Therefore, the obvious course would seem to be making N_e — rather than N_b — as large as possible. This, however, tends to make the beamstrahlung effects intolerable, a general criterion being the energy spread δ_B for which a few percent is considered the maximum acceptable limit. In fact, the only known way of discriminating between luminosity per bunch crossing and electromagnetic interaction is to make the beams very flat $\sigma_y >> \sigma_x$ — and coupling as well as excessively small beam height puts a limit on this aspect ratio. Since the beam height squared, σ_y^2, is the product of emittance ϵ_y and the final focus parameter β_y, the latter has to be made small by a carefully designed final focus system, the necessary chromaticity correction being achieved by a combination of weak dipoles and sextupoles. However, the "hourglass" beam envelope appearing when β becomes comparable to the bunch length σ_z sets a limit to this and leads to an optimum choice of β.

As a result of all this it turns out that the ratio $\eta_b^{AC}/\epsilon^{1/2}$ remains the only free parameter available to maximize the obvious performance figure of luminosity per megawatt of mains power. The overall efficiency is, obviously, the product of the conversion efficiencies η_{RF}^{AC} and η_b^{AC}, from mains to RF power and from RF to beam power respectively. Concern about both efficiencies is a matter of technology — of RF power sources and accelerating structures respectively — and intimately related to the spectrum of different approaches shown in the table. A universal contribution to good power extraction, η_b^{RF}, is the choice of a large number N_b of bunches per RF pulse and this multibunching has now been adopted, albeit to a different degree, by all but one design, in spite of the serious difficulties it entails. This, then, leaves the generation of beams with the smallest possible emittance and, in particular, the conservation of vertical emittance throughout the linac, as the main objective of beam dynamics studies and designs.

3.1.4 Emittance Preservation

As can be seen from the table. the design values for vertical normalized emittance, $\gamma\epsilon_y$, are very small, in the range of $10^{-7}\ \mathrm{rad\,m}$ or less. Such values can be obtained in damping rings and this will be studied in an Accelerator Test Facility (ATF) at KEK, which began operation in January. The preservation of such an emittance through many kilometers of linac structure is a qualitatively new problem. Optimum strategies for orbit correction are being studied and sub-micron beam position monitors, micro-movers and micron prealignment systems form a major part of hardware developments for all projects.

Beam induced transverse wakefields in the accelerating structures tend to contribute seriously to the growth of transverse emittance, especially at the higher frequencies since these wakes increase with the cube of inverse aperture. In principle, at least, the reaction of a bunch to its own transverse wake can be reduced by making the bunch short (only a starting rate of rise of field is induced by a delta-function charge), and by "BNS damping" (focusing the tail of the bunch stronger than the head, thus counteracting the opposite effect of the wake). Since neither of these remedies is applicable to the long range wakes of preceding bunches all multibunch designs except TESLA require wake reduction at the source.

Damped-detuned or strongly damped accelerating structures are employed. In the first case, individual dipole resonances of the cells forming a traveling wave structure are distributed within a finite spread while maintaining their accelerating modes in synchronous tune. Decoherence of the individual contributions leads to a rapid drop of the net dipole wake behind an inducing bunch. Recoherence within the bunch train is counteracted by relatively weak damping. Much stronger selective damping of transverse modes is required if this alone is employed but might lead to mechanically simpler solutions.

The wakefields of actual structures have been measured in the ASSET facility at SLAC. Also at SLAC, and in the frame of an international collaboration, final beam sizes down to $70\,\mathrm{nm}$ RMS have been observed in a Final Focus Test Beam experiment.

3.1.5 Technologies

The TESLA approach is based on low frequency superconducting cavities. The main advantage is the high RF-to-beam efficiency, permitting an exceptionally high beam power. Moreover, the luminosity is distributed over a very large number of widely spaced bunches with obvious benefits for the detector. The main potential problem is the accelerating gradient. The design value of 25 MeV/m is not easy to achieve operationally and at acceptable cost per unit length while making the accelerator quite long at 500 GeV already. For 1 TeV a higher gradient is envisaged. A 500 MeV test accelerator is under construction.

The SBLC system is closest to a classical 3 GHz electron linac powered by pulsed klystrons. New requirements are wakefield suppression, micro-alignment for emittance preservation and massive cost reductions to cope with the overall length of such an installation. A 400 MeV test accelerator is being constructed.

The JLC, NLC, VLEPP approaches are very similar but the higher frequency permits higher accelerating fields (higher onset of dark current due to field emission, lower stored energy, higher shunt impedance) at the price of increased difficulties with wakefield suppression in damped and detuned structures and with the development of suitable klystrons of which a very large number will be required. SLAC is commissioning an 11 GHz, 500 MeV test accelerator. KEK, while following the same line of development, are making a vital contribution to the community by building a test injector complex (ATF); a 1.5 GeV damping ring of advanced design has in fact begun to operate.

The CLIC approach at still higher frequency aims primarily at energies well above 500 GeV. At 30 GHz and the associated short pulse length the design gradient of nearly 100 MeV/m is, in fact, not limited by field emission or breakdown. Here, the multitude of klystron power sources is to be replaced by drive beams of a few GeV initial energy, receiving their energy from superconducting linacs. In the LBNL/LLNL approach (TBA) this is to be replaced by a larger number of lower-energy drive beams driven, in turn by induction accelerators. A Test Facility (CTF) for studying drive beam generation for CLIC is in operation at CERN and has recently been upgraded. The addition of complete accelerating modules will turn it into a 200 MeV test accelerator.

References

[1] J.P. Delahaye "Design Issues of TeV Linear Colliders" and references therein, Proc. Fifth European Particle Accelerator Conference EPAC96, p. 37.

3.2 The Challenge of Tau-Charm Factories

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3.2.1 What is a "Factory" Machine?

Each family of mesons or some other particles (τ lepton and Z^0, $W^\pm$ bosons etc.) could be considered a candidate for a "factory" machine which produces the particles in copious quantities for doing high precision experiments. The particles are to be produced in clean leptonic interactions just above the threshold so that experiments can be carried out with low background and without contamination from the higher mass particles. For the production interaction one generally takes advantage of the zero quantum number quark/antiquark-pair states which have large resonant production cross-sections in zero quantum number e^+/e^- collisions.

Two old machines which in actuality do not satisfy the strict definition of a "factory" machine accelerate high intensity proton beams to energies far above the thresholds to strike fixed targets to produce copious amounts of mesons at regular cross-sections. These are:

- The pion factories now in operation at LLNL (LAMPF) and at INR (Moscow Meson Factory). Both are proton linacs.
- The kaon factories proposed by LLNL and by TRIUMF (KAON), and the earlier INR project of Moscow Kaon Factory. All are rapid cycling proton synchrotrons.

Full fledged "factories," all e^+/e^- colliders, are:

- The ϕ-factory ("strangeness" factory) in construction at INFN. The ϕ-mesons have a mass of 1.02 GeV and are states of "strange" quark-pairs.
- The "charm" factory producing ψ mesons which are states of "charm" quark-pairs.
- The B-factory ("bottom" factory) in construction at SLAC and at KEK. These factories produce Υ mesons with a mass of 10.58 GeV which are states of "bottom" quark-pairs.

One could also consider CESR as a first-generation B-factory and, LEP as a first-generation Z-factory. Presumably some day one will also want the "top" factory to produce large amounts of top-mesons.

[1] Yu. I. Alexahin, P. F. Beloshitsky, J. Le Duff, S. Kamada, L. Palumbo, V. V. Parkhomchuk, E. A. Perelstein, D. V. Pestrikov, L. Teng, D. Wang, Y. Z. Wu, C. Zhang, A. A. Zholents

Of the three factories listed above the “charm” factory is visualized to be the most versatile. To cover all ψ-meson states the c.m. energy of the factory should be adjustable from 3 GeV to 4.5 GeV, and if one extends the upper limit to 6 GeV one can even cover the production of all charm-baryon pairs. In addition, the production of tau-lepton pairs at a threshold energy of 3.6 GeV also falls in the range of 3-6 GeV, hence the name “Tau-Charm Factory” (TCF).

3.2.2 Comparison of the Three Factories

It is interesting to compare the performance parameters specified for the three factory machines.

Factory (example)	T/C (BTCF)	Φ (DAΦNE)	B (KEKB)
Beam energy (GeV)	1.55-3.0	0.51	3.5/8.0
Luminosity ($10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$)	1	0.5	10
Vertical β (cm)	1	4.5	1
Beam current per ring (A)	0.57	5.2	2.6/1.1
Bunch no. per ring	86	120	5000
Bunch spacing (m)	3.78	0.81	0.59
Beam-beam parameter	0.04	0.04	0.05

We see from this table that of these three factory machines the beam parameters of the TCF such as the beam current, the bunch spacing and the beam-beam parameter are the least demanding. However, the Tau-Charm Factory was envisioned ab initio as a versatile multipurpose machine, a feature which introduces challenges of its own. The performance specified in the table is that of the “High Luminosity” operating mode at 2 GeV. Two other modes of operation are desired and have been incorporated in the design as successive phases of modification.

For studying CP and T violations it is desirable to have collisions of beams which are longitudinally polarized. Available process and technology such as the Sokolov-Ternov effect, the Siberian snake and the spin rotator make the “Polarization” operation attainable.

For the production of the J/ψ and the $\psi(2S)$ mesons having very narrow energy widths ($\sim$ 100 keV), one needs to “monochromatize” the collision energy. The natural energy spread of the beams is more than ten times this width. Thus, the beams must be broadly dispersed in opposite senses to keep the collision energy uniform. This is the “Monochromator” mode.

During the past year a most extensive design study effort was expended by IHEP (Beijing) and resulted in the publication of a comprehensive “Feasibility Study Report on Beijing Tau-Charm Factory” [1]. Some parameters of this design were already cited in the Table above.

3.2.3 The “High Luminosity” Operating Mode

For high luminosity a two-ring collider design is preferred to ease the use of multibunch beams. Many different variances of the ring configuration and the beam-crossing geometry are possible. In the BTCF, the rings are racetrack shaped, each composed of two 180 degree arcs $\sim$ 26 m in radius, joined by two long straight sections each $\sim$ 111 m long. The two rings are vertically disposed. The beams are first brought together vertically at the midpoint of a straight section, then arranged to cross horizontally with a 5 mrad angle where the optics is adjusted to give vertical β = 1 cm and dispersion= 0. The lattice design including non-linear considerations such as sextupoles, chromaticity and dynamic aperture is rather complex but conceptually straightforward. A minor challenge is to obtain the requisite high beam current of $\sim$ 0.6 A necessary to reach $10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ luminosity. As usual, the concerns are:

All single beam, both single bunch and multibunch, instabilities must be avoided by properly minimizing all beam coupling impedances. The more "exotic" instabilities arising from interactions between the beam and the background ions or electrons should also be suppressed.

All beam-beam effects must be kept within the traditionally accepted limits.

Both the single beam and the beam-beam effects have long been extensively studied by analysis, by simulation and by experimentation, and recipes have been written to test whether a given effect is acceptable. These recipes were strictly followed in all the designs.

3.2.4 The "Monochromator" Operating Mode

The demand of monochromatization is most severe for the J/ψ state which has an energy of 3.1 GeV and an energy width of only 8.6$\times 10^{-5}$ GeV. To reduce the spread of the collision energy below that of the beam energy the two beams are arranged to collide head-on and are widely energy dispersed vertically in opposite senses. Thus a higher energy e^- always collides with a lower energy e^+ to keep the collision energy uniform. The spread of the collision energy is determined by the vertical beam betatron height compared to the dispersion height. The vertical dispersion, the emittances and the β functions must all be adjusted to yield the necessary collision-energy uniformity. It is expected and has been demonstrated that with proper arrangements a reasonably large region exist in the parameter space in which all the desired goals are achieved and that given adequate space in the beam crossing straight section and in the beam pipe through the detector these parameter values can indeed be obtained with reasonable strengths and arrangements of beam manipulating elements.

A major challenge for this mode is to determine the maximum allowable beam-beam parameter when the dispersion is large. One can expect that the large dispersion will accentuate synchro-betatron resonances which may lead to early vertical beam blow-ups. Computer simulations seem to confirm the expectation and give an upper limit of 0.015 instead of the empirical zero-dispersion value of 0.05. Further confirmation of this value is essential. If this limit is taken seriously the maximum achievable luminosity is only $\sim 10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$. The gain from the smaller collision energy spread should be appraised in relation to the reduced luminosity.

Efforts must be made to reduce the horizontal emittance in order to preserve the high luminosity with a reasonable Touschek lifetime [2].

3.2.5 The "Polarization" Operating Mode

For polarized electron beam alone one can use a SLAC type polarized electron gun which can produce transverse polarization greater than 80$\%$. The beam can then be accelerated to the injection energy of the collider in a linac without loss of polarization. For both positron and electron beams one can obtain transverse polarization by the Sokolov/Ternov effect [3]. A high energy electron or positron beam in a storage ring is spontaneously polarized by the emission of the spin-flipping magnetic dipole radiation. This effect has been observed in many e^+/e^- storage rings and was shown to agree well with analysis. To obtain reasonably short polarization time one needs a high field superconducting ring. A ring with 4T bending field will give a 2 GeV beam a polarization time of $\sim$ 30 sec. This "polarizing ring" could be used to polarize both positron and electron beams in sequence. This arrangement was first proposed by A. Zholents [4].

The transverse-polarized beams are then transported by spin-transparent transport lines and injected into the collider. Spin rotators are needed on both sides of a beam-crossing point to rotate the elsewhere transverse polarization to longitudinal at the crossing. The section of lattice in between the rotators must be tuned for spin transparency and the vertical orbit distortion must be corrected everywhere to a minimum to reduce stochastic depolarization [5]. Polarimeters and spin-flippers are needed to measure and to invert the polarization. The effectiveness of all these components have been studied extensively and demonstrated empirically at different accelerator laboratories.

The major challenge for this mode is to obtain the longitudinal polarization in the interaction region for a variety of beam energy.

3.2.6 General Remarks

From the above discussions it should be obvious that the TCF as conceived is a very versatile facility with a broad area of interesting physics applications. The greatest challenge is to make the initial design compatible with the future operating modes so that the modifications and additions are minimized going from one mode to the next.

A large amount of beam dynamics computations remains to be done in connection with the detailed design to ensure that the design performances can indeed be met. Luckily, a great deal is now known of the beam dynamics in colliders from analysis and simulation, and from actual beam experimentation. The least explored beam dynamics problem which needs further investigation is that of the beam-beam effect, especially that with large dispersion.

Another major challenge of the TCF project is the particle detector design. The portion of the design which interacts with that of the collider is the space allowance in the central beam pipe of the detector to accommodate necessary beam bending and focusing magnets and for masks of synchrotron radiation and stray particles. As always, the greatest challenge is the engineering and the manufacturing of the components. One can be confident of the performance of the collider only if the specifications of the hardware are met.

Since the TCF was first proposed [6] in 1987 eight workshops [7] have been held in various parts of the world to investigate the physics opportunities, the collider design and the detector design. However, the efforts to seek funding for construction have not yet been totally successful. The most hopeful at the moment is the effort at the IHEP (Beijing). A “Feasibility Study Report” was published in 1996 and was reviewed by an international panel of physicists. The reference design given in the report was enthusiastically endorsed by the Review Panel. The project should now proceed to the next phase of the Conceptual Design and the R&D for construction.

As an official endorsement by the ICFA-Beam Dynamics Panel of the special importance and urgency of the TCF for the high energy accelerator society, a working group [8] was created in May 1995 with E. A. Perelstein as leader and C. Zhang as deputy to promote studies of related beam dynamics problems and investigations of optimized machine designs, and to encourage the construction of at least one TCF in the world. The working group has met twice, in Beijing (February 1996) and in Barcelona (June 1996).

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References

[1] "Feasibility Study Report on Beijing Tau-Charm Factory," IHEP-BTCF, Report-03 (Oct. 1996)

[2] For example, Y.Alexahin, "A Scheme of Monochromatic Tau-Charm Factory with Finite Crossing Angle," Proc. 2-nd Workshop on JINR TCF, Dubna, p.178 (1993)

[3] A.A. Sokolov and I.M. Ternov, Dokl. Akad. Nauk. SSSR, 153, 1052 (1963), and "On Polarization and Spin Effects in the Theory of Synchrotron Radiation," Sov. Phys. Dokl. 8, 1203 (1964)

[4] A.A. Zholents, "Polarized J/ψ Mesons at a Tau-Charm Factory with a Monochromator Scheme," CERN SL/92-27 (AP) (1992)

[5] D.P. Barber et al, "The First Achievement of Longitudinal Spin Polarization in a High Energy Electron Storage Ring," Physics Letters B, 343, p.436-443 (1995)

[6] J. Kirkby, "A Tau Charm Factory at CERN," CERN-EP/87-210 (1987)

[7] The early history of the TCF was described in Ref. [8].

[8] E.A. Perelstein, "Tau-Charm Factory Working Group," ICFA-Beam Dynamics Newsletter, No.9, p.6 (Dec. 1995)

3.3 Quantum Mechanics of Accelerator Optics

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As pointed out by Chen [1], in the recent issue of the *Beam Dynamics Newsletter*, primary effects in much of accelerator physics are essentially classical since the de Broglie wavelength of the high energy beam particle is much too small compared to the typical apertures of cavities and other components in accelerators. In particular, about accelerator optics there has never been any doubt in the assumption that it can be treated very accurately using classical mechanics; even spin can be added to the set of classical coordinates and momenta to get a theory based on the framework of an extended classical phase-space (see, *e.g.*, [2, 3]). However, since any physical system is quantum mechanical at the basic level, it should be instructive to do the exercise of studying the relativistic quantum mechanics of charged-particle beam optics so as to understand precisely how $\hbar$ disappears from the formalism of the quantum theory of accelerator optics leading effectively to a very accurate classical theory. There may be surprises: particularly, due to the interesting phenomena related to quantum chaos (see, *e.g.*, [4]), such as the so-called quantum supression of classical chaos, which may have relevance to the problem of long time stability of particle motion in storage rings (see [5] for a recent review of classical dynamical systems theory in the context of beam dynamics of storage rings).

An exercise to develop a formalism of relativistic quantum theory of charged-particle beam optics at the simplest level – at the level of single-particle dynamics, treating the electromagnetic field as classical and disregarding the radiation aspects – has been in progress for the past some years for both the spin-$\frac{1}{2}$ case ([6]-[13]) and the spinless case ([10], [13]-[15]). While talking about the quantum theory of accelerator optics we should also mention that quantum mechanical implications for low energy polarized (anti)proton beams in a spin-splitter device, using the transverse Stern-Gerlach (SG) kicks, have been analyzed on the basis of the nonrelativistic Schrödinger equation [16, 17]. Here, we shall review some essential aspects of relativistic quantum mechanics of accelerator optics based on our experience, with particular reference to the case of the Dirac particle ([6]-[13]).

To introduce our formalism briefly, let us consider a monoenergetic, quasiparaxial, Dirac-particle beam being transported through an accelerator optical element with a straight axis, along the z-direction, and comprising a static magnetic field. Let the beam be moving in the $+z$-direction. To understand the optics of the system the best way would be to cast the corresponding time-independent Dirac equation, with Pauli's anomalous magnetic moment term, into a form

$$i\hbar\frac{\partial}{\partial z}\psi^{(A)} = \mathcal{H}^{(A)}\psi^{(A)}\,, \tag{3.2}$$

where $\psi^{(A)}(x, y; z)$ models the four-component spinor wavefunction of the beam particle in the (x, y)-plane at z in a suitable 'accelerator optical' representation. Then, it should be straightforward to study the z-evolution of averages of the relevant observables, in the (x, y)-plane, using the standard mathematical techniques of quantum mechanics. Identifying the quantum averages with classical values, *à la* Ehrenfest, one gets the quantum-corrected classical picture of the system behavior. To get such a formalism we proceed in our work ([6]-[13]) as follows.

The relevant time-independent Dirac equation, with the Pauli term, is,

$$\begin{aligned}
H^{(D)}\psi^{(D)} &= E\psi^{(D)}\,, \\
H^{(D)} &= mc^2\beta + \hat{\mathcal{E}} + \hat{\mathcal{O}} = \begin{pmatrix} mc^2 + \hat{\mathcal{E}}_{11} & \hat{\mathcal{O}}_{12} \\ \hat{\mathcal{O}}_{21} & -mc^2 + \hat{\mathcal{E}}_{22} \end{pmatrix} \\
&= \begin{pmatrix} mc^2 - \mu_a \boldsymbol{\sigma}\cdot\boldsymbol{B} & c\,\boldsymbol{\sigma}\cdot\hat{\boldsymbol{\pi}} \\ c\,\boldsymbol{\sigma}\cdot\hat{\boldsymbol{\pi}} & -mc^2 + \mu_a\boldsymbol{\sigma}\cdot\boldsymbol{B} \end{pmatrix}\,,
\end{aligned} \tag{3.3}$$

where $\hat{\boldsymbol{\pi}} = \hat{\boldsymbol{p}} - e\boldsymbol{A} = -i\hbar\boldsymbol{\nabla} - e\boldsymbol{A}$ and the other notations are as usual. Let us now rearrange (3.3) as

$$i\hbar\frac{\partial}{\partial z}\psi^{(D)} = \mathcal{H}^{(D)}\psi^{(D)}\,, \tag{3.4}$$

and define

$$\psi' = \frac{1}{\sqrt{2}}\begin{pmatrix} I & \frac{cp}{E-mc^2}\,\sigma_z \\ \frac{mc^2-E}{cp}\,\sigma_z & I \end{pmatrix}\psi^{(D)}\,, \tag{3.5}$$

where p is the magnitude of the design momentum of the beam. Then, it is found that the z-evolution equation for ψ' has the form

$$\begin{aligned}
i\hbar\frac{\partial}{\partial z}\psi' &= \mathcal{H}'\psi'\,, \\
\mathcal{H}' &= -p\beta + \hat{\mathcal{E}}' + \hat{\mathcal{O}}' = \begin{pmatrix} -p + \hat{\mathcal{E}}'_{11} & \hat{\mathcal{O}}'_{12} \\ \hat{\mathcal{O}}'_{21} & p + \hat{\mathcal{E}}'_{22} \end{pmatrix}\,.
\end{aligned} \tag{3.6}$$

The explicit expressions for $\mathcal{E}'$ and $\mathcal{O}'$ are not essential for our discussion here (see [11] for details). Up to this point there has been no approximation.

To proceed further, we note a striking similarity between (3.3) and (3.6). In the nonrelativistic, positive energy, case the upper pair of components of $\psi^{(D)}$ are large compared to its lower pair of components. The odd $(\hat{\mathcal{O}})$ part of $\left(H^{(D)} - mc^2\beta\right)$, anticommuting with β, couples the large and small components of $\psi^{(D)}$ while the even $(\hat{\mathcal{E}})$ part, commuting with β, does not couple them. Using this fact, the well known Foldy-Wouthuysen formalism of the Dirac theory (see, *e.g.*, [18]) employs a series of transformations on (3.3) to reach a representation in which the Hamiltonian is a sum of the nonrelativistic part and a series of relativistic correction terms; $1/mc^2$ serves as the expansion parameter and the nonrelativistic part corresponds to an approximation of order up to $1/mc^2$ while terms of order higher than $1/mc^2$ constitute the relativistic correction part. Solving (3.6) in the field-free case we find ψ' to have large upper pair of components compared to the lower pair of components when the positive energy particle belongs to a paraxial beam moving in the $+z$-direction (*i.e.*, $|\boldsymbol{p}_\perp| \ll p \approx p_z > 0$). Thus, in (3.6) the odd operator $\hat{\mathcal{O}}'$, anticommuting with β, couples the large and small components of ψ' while the even operator $\hat{\mathcal{E}}'$ does not make such a coupling. This suggests that a Foldy-Wouthuysen-like technique can be used to transform (3.6) into a representation in which the corresponding beam optical Hamiltonian is a series in the expansion parameter $1/p$. It should be noted that in this scheme there is no restriction on the value of p: it can vary from the extremely nonrelativistic to the ultrarelativistic. The only restriction is the quasiparaxility condition: $|\boldsymbol{p}_\perp| < p \approx p_z > 0\,.$

Application of a Foldy-Wouthuysen-like technique to (3.6) involves a series of transformations on it and after the required number of transformations, depending on the desired order of accuracy, say, up to order $(1/p)^n$, equation (3.6) is transformed into a form in which the residual odd part can be neglected and hence the upper and lower pairs of the spinor wavefunction are effectively decoupled. In this representation the large upper pair of components of the wavefunction correspond to the beam moving forward along the $+z$-direction and the small lower pair of components correspond to the backward moving (quantum mechanical reflection) component of the beam. Thus, for the beam component moving forward along the $+z$-direction, in which we are interested, the effective z-evolution equation can be written as

$$i\hbar\frac{\partial}{\partial z}\tilde{\psi} \approx \tilde{\mathcal{H}}\tilde{\psi}\,, \tag{3.7}$$

with $\tilde{\psi}$ as a two-component spinor wavefunction.

In accelerator physics spin is defined with reference to the instantaneous rest frame of the particle. Taking this into account entails a further transformation on (3.7) to get the desired 'accelerator optical' representation. If we stop at the first order (*i.e.*, $(1/p)$-order) approximation in the Foldy-Wouthuysen-like technique and define

$$\psi^{(A)} = \exp\left\{i\left(\hat{\pi}_y\sigma_x - \hat{\pi}_x\sigma_y\right)/2p\right\}\tilde{\psi}\,, \tag{3.8}$$

then, we get

$$\begin{aligned} i\hbar\frac{\partial}{\partial z}\psi^{(A)} &\approx \mathcal{H}^{(A)}\psi^{(A)}\,, \\ \mathcal{H}^{(A)} &= -p - eA_z + \frac{1}{2p}\left(\hat{\pi}_x^2 + \hat{\pi}_y^2\right) + \frac{\gamma m}{p}\underline{\boldsymbol{\Omega}}\cdot\boldsymbol{S}\,, \end{aligned} \tag{3.9}$$

where

$$\begin{aligned} \underline{\boldsymbol{\Omega}} &= -\frac{e}{\gamma m}\left\{\boldsymbol{B} + a\left(\boldsymbol{B}_{\parallel} + \gamma\boldsymbol{B}_\perp\right)\right\}\,, \\ \boldsymbol{S} &= \hbar\boldsymbol{\sigma}/2\,, \quad \gamma = E/mc^2\,, \quad a = (g-2)/2\,, \end{aligned} \tag{3.10}$$

and $\boldsymbol{B}_{||}$ and $\boldsymbol{B}_{\perp}$ are the components of $\boldsymbol{B}$ along the z-axis and in the (x, y)-plane, respectively (see [11] for more details). Now, we can recognize $\mathcal{H}^{(A)}$ as the quantum mechanical, accelerator optical, version of the semiclassical Derbenev-Kondratenko Hamiltonian [2, 3, 19] in the $(1/p)$-order approximation. Note that $\underline{\boldsymbol{\Omega}}$ in $\mathcal{H}^{(A)}$ is the same as the well known Thomas-Bargmann-Michel-Telegdi (TBMT) spin Hamiltonian except for $\boldsymbol{B}_{||}$ and $\boldsymbol{B}_{\perp}$ being defined with respect to the $+z$-direction, the predominant direction of motion of the beam particle, instead of the direction of the instantaneous velocity of the particle, and corrections to this will emerge from the higher order terms in $\mathcal{H}^{(A)}$ that will appear when going beyond the first order calculation.

Our work ([6]-[15]) is only at a very preliminary stage: there are lot of things to do, like, extension of the formalism to accelerator elements with curved optic axis (see [8] for some initial work in this direction), building the global one-turn quantum map from the local single-element maps (the LEGO block approach of [20] should be helpful to do this), integrating this formalism for analyzing the optical characteristics of elements comprising static fields with the regular techniques of analyzing the behavior of beam dynamics in time-dependent elements, going beyond the level of single-particle dynamics, taking into account the quantum nature of electromagnetic fields, inclusion of radiation in the treatment (both at the semiclassical as well as quantum electrodynamical levels), etc.!

Now, let us close this brief review of our experience, so far, with quantum mechanics of accelerator optics, by mentioning some salient aspects of our study and the associated problems:

- Since the probability of location of the particle in an (x, y)-plane is not necessarily a conserved quantity along the z-axis the accelerator optical Hamiltonian $\mathcal{H}^{(A)}$ is not hermitian, in general, and does contain small nonhermitian terms proportional to the de Broglie wavelength of the particle and its higher powers. The contribution of these nonhermitian terms to the dissipation of the beam needs, perhaps, a careful study; note that the exact $\mathcal{H}^{(D)}$ in (3.4), the starting point of our formalism, is nonhermitian.
- Let us ignore the small nonhermitian terms in $\mathcal{H}^{(A)}$ and call its hermitian part $H^{(A)}$, up to any desired order of approximation. Then, we can write

$$i\hbar\frac{\partial}{\partial z}\psi^{(A)} = H^{(A)}\psi^{(A)}\,, \tag{3.11}$$

  in the Schrödinger picture. With hermitian $H^{(A)}$, the two-component wavefunction $\psi^{(A)}$ has unitary z-evolution and a normalization in the (x, y)-plane,

$$\int\!\!\int dxdy\,\psi^{(A)\dagger}\psi^{(A)} = 1\,, \tag{3.12}$$

  is conserved along the z-axis. Thus, for any observable X of the beam, represented by a hermitian operator $\hat{X}_S^{(A)}(z)$ in the accelerator optical representation and Schrödinger picture, the average value at the (x, y)-plane at z is given by

$$\begin{aligned} \langle X\rangle(z) &= \left\langle\psi^{(A)}(z)\right|\hat{X}_S^{(A)}(z)\left|\psi^{(A)}(z)\right\rangle \\ &= \int\!\!\int dxdy\,\psi^{(A)\dagger}(z)\hat{X}_S^{(A)}(z)\psi^{(A)}(z)\,. \end{aligned} \tag{3.13}$$

  These quantum averages are the ones corresponding to the classical values of these observables. It is found that in the above accelerator optical representation the Schrödinger picture operator representatives of the mean transverse position (following Newton-Wigner), mean transverse momentum, and spin (with respect to the rest frame of the particle) are the canonical operators $\boldsymbol{r}_\perp$, $\hat{\boldsymbol{p}}_\perp$ and $\hbar\boldsymbol{\sigma}/2$.

- The Heisenberg picture operator $\hat{X}_H^{(A)}(z)$ will evolve according to the transfer map

$$\hat{X}_H^{(A)}\left(z_0\right) \quad \longrightarrow \quad \hat{X}_H^{(A)}(z) = U^{(A)\dagger}\left(z, z_0\right) \hat{X}_S^{(A)}(z) U^{(A)}\left(z, z_0\right) , \tag{3.14}$$

for any $z > z_0$, where the unitary operator $U^{(A)}\left(z, z_0\right)$ is such that

$$\begin{aligned} \left|\psi^{(A)}(z)\right\rangle &= U^{(A)}\left(z, z_0\right)\left|\psi^{(A)}\left(z_0\right)\right\rangle , \quad U^{(A)}\left(z_0, z_0\right) = I , \\ i\hbar\frac{\partial}{\partial z}U^{(A)}\left(z, z_0\right) &= H^{(A)}U^{(A)}\left(z, z_0\right) . \end{aligned} \tag{3.15}$$

In the classical limit, when

$$\hbar \longrightarrow 0 , \quad \frac{1}{i\hbar}\left[\hat{X}_1, \hat{X}_2\right] \longrightarrow \text{Poisson Bracket } \left\{X_1, X_2\right\} , \tag{3.16}$$

equations (3.14) and (3.15) lead to the classical theory expressed in the Lie operator formalism ([20]-[22]). However, it is interesting to note that, besides the nonhermitian terms vanishing in the limit $\hbar \longrightarrow 0$, as already mentioned above, $\mathcal{H}^{(A)}$ contains also small hermitian terms which are also proportional to powers of the de Broglie wavelength and hence vanishing when $\hbar \longrightarrow 0$. Such terms are really of nonclassical origin in the sense that they cannot be derived by a formal quantization of the classical beam optical Hamiltonian. Such small additional terms may also be relevant for the study of beams in storage rings as quantum dynamical systems, particularly with reference to questions related to chaotic diffusion.

- To appreciate the nature of quantum corrections to the classical picture we have to follow Ehrenfest. The form of the transfer map for the quantum average of any observable X, namely,

$$\begin{aligned} \langle X\rangle\left(z_0\right) \quad &= \quad \left\langle\psi^{(A)}\left(z_0\right)\right| \hat{X}_H^{(A)}\left(z_0\right)\left|\psi^{(A)}\left(z_0\right)\right\rangle \\ &\longrightarrow \quad \langle X\rangle(z) = \left\langle\psi^{(A)}\left(z_0\right)\right| \hat{X}_H^{(A)}(z)\left|\psi^{(A)}\left(z_0\right)\right\rangle , \end{aligned} \tag{3.17}$$

will differ from the form of the corresponding transfer map for the classical value of X by terms of the type

$$\left\langle f\left(X_1, X_2, \ldots,\right)\right\rangle - f\left(\left\langle X_1\right\rangle, \left\langle X_2\right\rangle, \ldots,\right) \neq 0 , \tag{3.18}$$

as is obvious; the differences are essentially due to the quantum uncertainties associated with $\psi^{(A)}$ at z_0. These quantum correction terms will modify the classical maps; e.g., a quadratic term X_1^2 in a classical map is really

$$\left\langle X_1^2\right\rangle = \left\langle X_1\right\rangle^2 + \left\langle\left(X_1 - \left\langle X_1\right\rangle\right)^2\right\rangle \tag{3.19}$$

in the map for the quantum mechanical average. Similarly, the terms X_1X_2 and X_1^3 in a classical map become in the quantum map

$$\begin{aligned} \left\langle X_1X_2\right\rangle &= \left\langle X_1\right\rangle\left\langle X_2\right\rangle + \left\langle\left(X_1 - \left\langle X_1\right\rangle\right)\left(X_2 - \left\langle X_2\right\rangle\right)\right\rangle , \\ \left\langle X_1^3\right\rangle &= \left\langle X_1\right\rangle^3 + 3\langle X_1\rangle\left\langle\left(X_1 - \left\langle X_1\right\rangle\right)^2\right\rangle + \left\langle\left(X_1 - \left\langle X_1\right\rangle\right)^3\right\rangle , \end{aligned} \tag{3.20}$$

respectively. It is thus clear that, essentially, quantum mechanics modifies the coefficients of the various linear and nonlinear terms in the classical map making them dependent on the quantum uncertainties associated with the wavefunction of the input beam; actually, even terms not present in the classical map will be generated in this way, with coefficients dependent on the quantum uncertainties, as a result of modifications of the other terms. In addition to this, there are also the contributions arising from the averages of the extra hermitian terms of nonclassical origin, already mentioned above, which are of course proportional to powers of the de Broglie wavelength. The results of these quantum modifications of the classical maps, depending on the quantum uncertainties, are to be analyzed carefully within the framework of classical dynamical systems theory itself; the influence of the modifications of the nonlinear terms on the stability of the beam, in particular. This effect is relevant in the case of polarization too, *i.e.*, when X corresponds to spin; for example, the transfer map for polarization $\boldsymbol{P} = \langle \boldsymbol{\sigma} \rangle$, due to the TMBT spin evolution, is not linear in its components, in principle, even in the lowest order approximation, since terms of the type, say, $\langle x\sigma_x \rangle - \langle x \rangle \langle \sigma_x \rangle$, $\langle x\sigma_z \rangle - \langle x \rangle \langle \sigma_z \rangle$, $\langle p_x\sigma_x \rangle - \langle p_x \rangle \langle \sigma_x \rangle$, $\ldots$, etc., do not vanish, in general.

- Finally, let us also note that accelerator physics may provide a testing ground for certain fundamental issues of relativistic quantum mechanics. For example, following the suggestion [23] that longitudinal SG kicks could be utilized more profitably, than transverse SG kicks, for operating a spin-splitter device to produce relativistic polarized (anti)proton beams, a closer examination of certain ambiguities in the generic form of the semiclassical relativistic SG force has revealed that the results of the corresponding quantum analysis would be sensitive also to the choice of the position operator for the Dirac particle (Newton-Wigner, Pryce, or ...?) (see [19] for a thorough analysis of the problem). It seems that only some suitable experiments can resolve the problems involved.

References

[1] P. Chen, *ICFA Beam Dynamics Newsletter* No. 12 (1996) 46.

[2] D. P. Barber, K. Heinemann and G. Ripken, *Z. Phys. C* **64** (1994) 117.

[3] D. P. Barber, K. Heinemann and G. Ripken, *Z. Phys. C* **64** (1994) 143.

[4] G. Casati, *Chaos* **6** (1996) 391.

[5] H. Mais, Some topics in beam dynamics of storage rings, DESY 96-119 (1996).

[6] R. Jagannathan, R. Simon, E. C. G. Sudarshan and N. Mukunda, *Phys. Lett. A* **134** (1989) 457.

[7] R. Jagannathan, Dirac equation and electron optics, in *Dirac and Feynman - Pioneers in Quantum Mechanics*, Eds. R. Dutt and A. K. Ray (Wiley Eastern, New Delhi, 1993) p.75.

[8] R. Jagannathan, *Phys. Rev. A* **42** (1990) 6674.

[9] S. A. Khan and R. Jagannathan, in *Proc. 3rd National Seminar on Physics and Technology of Particle Accelerators and their Applications* (Nov. 1993, Calcutta) Ed. S. N. Chintalapudi (IUC-DAEF, Calcutta) p.102.

[10] R. Jagannathan and S. A. Khan, in *Adv. Imaging and Electron Phys.* Vol. 97, P. W. Hawkes (Ed.), p.257 (Academic Press, San Diego, 1996).

[11] M. Conte, R. Jagannathan, S. A. Khan and M. Pusterla, *Part. Accel.* **56** (1996) 99.

[12] S. A. Khan, Transport of Dirac-particle beams through magnetic quadrupoles, `Preprint`: IMSc/96/33 (The Institute of Mathematical Sciences, Chennai, 1996).

[13] S. A. Khan, *Quantum Theory of Charged-Particle Beam Optics*, Ph.D. Thesis, University of Madras (submitted, January 1997).

[14] S. A. Khan and R. Jagannathan, Quantum mechanics of charged-particle beam optics: An operator approach, presented at the *JSPS-KEK Internat. Spring School on High Energy Ion Beams - Novel Beam Techniques and their Applications* (March 1994, Japan) `Preprint`: IMSc/94/11 (The Institute of Mathematical Sciences, Madras, 1994).

[15] S. A. Khan and R. Jagannathan, *Phys. Rev. E* **51** (1995) 2510.

[16] M. Conte and M. Pusterla, *Il Nuovo Cimento A* **103** 1087.

[17] M. Conte, Y. Onel, A. Penzo, A. Pisent, M. Pusterla and R. Rossmanith, The spin-splitter concept, `Internal Report`: INFN/TC-93/04 (INFN, Genova, 1993).

[18] J. D. Bjorken and S. D. Drell, *Relativistic Quantum Mechanics* (McGraw Hill, New York, 1964).

[19] K. Heinemann, On Stern-Gerlach forces allowed by special relativity and the special case of the classical spinning particle of Derbenev-Kondratenko, *e-print*: physics/9611001.

[20] E. Forest and K. Hirata, A Contemporary Guide to Beam Dynamics, KEK 92-12 (1992).

[21] A. J. Dragt and E. Forest, in *Adv. Electronics and Electron Phys.* Vol. 67, Ed. P. W. Hawkes (Academic Press, San Diego, 1986) p.65.

[22] A. J. Dragt, F. Neri, G. Rangarajan, D. R. Douglas, L. M. Healy and R. D. Ryne, *Ann. Rev. Nucl. Part. Sci.* **38** (1988) 455.

[23] M. Conte, A. Penzo and M. Pusterla, *Il Nuovo Cimento A* **108** (1995) 127.

4: Activity Reports

4.1 The RHIC Sextant Test

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4.1.1 Overview

The RHIC Sextant Test was a full systems and beam test which occurred from November 1996 through February 1997. Beam was successfully passed down a single sextant in its final configuration, including injection kickers, RF cavities, et cetera. The only items missing were the DX beam splitting magnets, and the Star experiment.

The BEAM test goals were to:

1. transport beam through one cryogenic sextant to a dump
2. "pre-commission" beam operations and establish nominal conditions
3. measure optical and dispersion functions
4. study injection - apertures, matching, emittances, stability ...
5. commission the Low Level RF controls
6. perform radiation fault studies

The major SYSTEM test goals were to:

1. verify cryogenic system performance when extrapolated to full ring
2. verify the quench protection system
3. test power supply ramping and storage
4. observe mechanical motion during thermal cycles
5. test the vacuum system performance

With only a few modest caveats, the Sextant Test was a great success. For more information and lots of pretty graphics, visit the Sextant Test home page,
`http://www.rhichome.bnl.gov/RHIC/Sextest`.

4.1.2 Diary

Gold beam was available from the AGS during the heavy ion run in December and January. It was used in parasitic (cycle stealing) mode.

The last magnet was delivered to the tunnel at the beginning of November 1996, and installation was complete by the last week of December. Four leaks in the insulating vacuum of the arc (8 cm) dipoles were found, and quickly repaired, after vacuum pump-down began. However, many leaks (about 20) were also found in the final focus quadrupole triplet assemblies. Most of these triplet leaks were in the large flex hose assemblies, and only opened up at high pressure (> 10 atmospheres). They were caused by damage to thin bellows from the ultrasonic tool used during super-insulation installation. Vacuum repairs were made and cryogenic cool-down began on January 20. The magnet string was cold $2\frac{1}{2}$ days later, and was powered to injection level (550 Amps) on January 24, when operating permission to run was granted.

Conditions from the 1995 AtR Test were rapidly restored, as beam was delivered 400 meters to the end of the straight part of the normal conducting AGS-to-RHIC (AtR) transfer line. Next, beam was maneuvered around a 90 degree bend, about 150 meters long, before encountering the Lambertson magnet. Beyond this lies the injection kickers, and the superconducting magnets of the sextant. A constant field vertical dipole corrector substituted for the kickers in the early part of the tests. After adjusting the strength of this vertical corrector, and the strength of the Lambertson magnet, gold ions immediately went all 400 meters to the dump at the end of the Sextant! This happened on January 26, after only 30 hours of available beam.

Beam tests continued until February 2, when the AGS gold run ended. Accelerator system tests without beam continued through the end of February. The sextant magnets were repeatedly ramped to high current. Various tests and measurements of the vacuum, cryogenic, and quench protection systems were performed. Finally, the magnets were taken through an additional complete thermal cycle, and re-tested.

4.1.3 Test results

Gold ions were immediately passed to the sextant beam dump once the Lambertson and the injection kicker were traversed - it was not necessary to adjust the main dipole current. This was an early indication that the Integral Transfer Function (ITF) of the arc dipoles had been accurately measured, and that the sextant quadrupoles had been well aligned. A later scan of the main dipole current showed that the best dipole current setting differed from the dead reckoned value by about 0.2%. Similarly, multiple measurements of the phase advance per FODO cell were made, with different QF and QD current settings. The values of the arc quadrupole ITF that were derived from these beam measurements were consistent with magnet test bench measurements, to within the 0.6% accuracy of the beam measurements.

The excitation level of the injection kicker was measured as 32 kV, very close to its design value. This is further confirmation that persistent high voltage breakdown problems appear to have been solved. The kicker rise time, measured with beam, was significantly less than the 95 nsec specification.

Various RHIC instrumentation systems have been fully commissioned, from hardware to high level application codes, in single pass injection line mode. These include beam position monitors, beam loss monitors, current transformers, and flag profile monitors. Prototype versions of multi-pass circulating mode systems have been tested, for beam position monitors and beam loss monitors. Further development of the reliability of the beam position monitor system will occur during the AGS g-2 run in spring and summer of 1997.

The prototype of an innovative ionization profile monitor, which collects electrons instead of positive ions, was also successfully tested. Electron collection is made practical by the simultaneous use of parallel electric and magnetic fields. The relatively fast electron drift times will allow the turn-by-turn measurement of transverse profiles of RHIC bunches. In an analogous activity in longitudinal phase space, tomographical algorithms were used to reconstruct the distribution of beam in an RF bucket, starting from a set of wall current monitor profiles recorded over half a synchrotron period. This application software was used to observe beam coalescence in the AGS. It will eventually be deployed in RHIC.

The sextant magnets were repeatedly ramped to 5,500 Amps, 10% beyond their nominal storage current, at a ramp rate that was also 10% higher than nominal. This was the first time that many of the magnets had seen full current, since only approximately 20% of the industrially built magnets were cold tested.

High power testing of some of the 200 MHz (storage) cavities was performed, under vacuum. These cavities have been recycled from their original use at the CERN SPS. Although one complete 28 MHz (acceleration) cavity has been assembled, it has not yet been high power tested. The digital low level RF system that controls the transfer of single bunches from the AGS into arbitrarily defined bunches in RHIC was also successfully commissioned.

4.1.4 Where does RHIC go from here?

Beam is scheduled to circulate in RHIC, for the first time, in January 1999. Production running for the experiments, with gold ions, is currently scheduled for fall 1999. Spin physics with polarized protons may start in 2000. Although RHIC still has 2 years to go before full operations begin, the major milestone of the Sextant Test shows that a lot has been achieved already.

All industrially produced magnets have been delivered, and the assembly of all integrated Corrector/Quad/Sextupole (CQS) packages will be finished in May 1997. Continued assembly of triplet magnets and the construction of DX magnets are the major items on the magnet front. Harmonic variations in the triplet (13 cm) quadrupoles, related to thermal cycling and quenching, will soon be revisited. Since the measured quench currents are typically about 30% above the operating current, most attention is being paid to the thermal cycling behavior. The first of the technically challenging DX beam splitting dipoles, with a field of 4.26 Tesla in a coil radius of 18 cm, is expected to finish construction in about October 1997.

All these magnets have to be installed, and connected to their neighbors. Two more sextants will be fully installed in 1997, and three more in 1998. In the meantime, we are deciding how best to use a series of short beam tests that will be held between now and the beginning of full commissioning. Beam would only passing through room temperature magnets to the AtR dump, in these tests.

4.2 Status report on the commissioning of INDUS1

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The Center for Advanced Technology, India, is in the process of commissioning INDUS1, the first of two synchrotron light sources. As reported in the ICFA Beam Dynamics Newsletter of December 1995, INDUS1 is a 450 MeV light source, producing usable radiation in the range of 3-10 nm. The injector system consists of a 20 MeV microtron and a 700 MeV booster synchrotron.

The microtron has been operational since September 1994, delivering an electron beam of 20 mA, in a pulse length of 1 μs, at a repetition rate of 1 Hz. Beam has been stored in the booster (at 450 MeV) since September 1995, up to a maximum of current of 9 mA. Attempts to store larger currents were unsuccessful for reasons not yet fully determined. With the extraction system in place the stored current dropped to 5 mA.

On 19 February 1997 first beam was extracted from the booster, and has presently has been transported 20 m downstream, to the injection point into INDUS1. During extraction the current in the booster is 3 mA (in 3 bunches), but the extracted current has not yet been measured. Efforts are presently underway to install the kicker system in INDUS1, so that injection can commence.

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4.3 Beam Dynamics in ATF Damping Ring

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4.3.1 Overview

The ATF(Accelerator Test Facility) has been designed to investigate the feasibility of the linear-collider operation scheme and to accumulate beam-control techniques for the linear collider. The ATF comprises three major parts: an S-band injector linac, a damping ring, and a beam diagnostic area. Each part directly contributes to the two essential factors for high-luminosity linear colliders. The multi-bunch scheme is a key technology used to boost the acceleration power-efficiency, and has been applied in most designs of future linear colliders. The ATF will generate, accelerate, and damp a train of 20 bunches with 2×10^{10} electrons/bunch and 2.8 ns spacing. The ATF will develop many basic technologies to handle the multi-bunch beam: gun, buncher, beam-loading compensation systems in linac, damped cavity, beam monitors (position, profile, bunch length) and so on. The purpose of the ATF is to develop accelerator technology that can stably supply to the main linear accelerator an extremely flat "multi-bunch beam" that can be squeezed down to a few nanometers at the collision point within the linear collider. Also, the construction is progressing to verify that this technology can supply a truly flat multi-bunch beam to the main accelerator. This technology development is not the only aim, but rather our belief is that it is essential to gather experience with the analysis and control of extremely small multi-bunch beams in order to most effectively design, construct, and operate linear colliders[1].

The main purpose of the damping ring is to achieve a horizontal 5 μm and a vertical 0.03 μm normalized emittance for the multi-bunch beam. The small emittance of the damping ring will be possible through a special design of a strong focusing lattice with a precise alignment of the components and beam orbit. The nonlinear behavior of the beam must be well understood in order to provide a sufficient dynamic aperture under such strong focusing. Since the beam intensity is so high, due to the multi-bunch scheme, unconventional designs are necessary for the acceleration cavity and the vacuum chamber in order to reduce the impedance and to maintain the small emittance. New ideas for the multi-bunch small-emittance beam will be also tested in the injection/extraction system, a beam-loading compensation, and beam diagnostics.

4.3.1.1 Damping Ring

The construction of the damping ring was started from November 1993. The beam commissioning was begun on this January(1997). The ring consists of 36 FOBO cells where most of vertical focusing is provided by the combined function bending magnet located at the center of each cell. The ring is designed so that the horizontal phase advance per cell can be varied from $100°$ to $160°$, varying the equilibrium horizontal normalized emittance from 6.6×10^{-6} radm to 4.3×10^{-6} radm . The ring is also designed in a racetrack form with two dispersion-free regions which contain the injection and extraction septa, the RF cavities, and 20.4 meters of damping wigglers which reduce the radiation damping rates by a factor of two.

Since the details of the ATF are given in the ATF design report[2], I briefly describe results of first beam commissioning for the damping ring. The beam dynamics including the instabilities in the damping ring is discussed in the following section.

The beam commissioning started from Jan. 21. We confirmed the first two turns in the damping ring on Jan. 27. A beam profile of first turn was measured by synchrotron radiation monitor and beam circulation observed on Jan. 30 by wall current monitor. The effect of the radiation damping was also observed on Feb.15 by measuring beam profile with $x - y$ strong coupling after arbitrary circulations. The results almost agreed with calculated values. We are investigating tunes, magnetic field errors, damping times, jitters of injected beam and so on. Many R&D's for beam instrumentation are under way. The 96 sets of BPM are measuring beam orbits of arbitrary turn and performance test of the active alignment system has been done. Laserwire system has also been developed to measure the profile of several micron sized beam. As a study machine, the ATF damping ring has several operation modes in the bunch structure. For example, the number of particles per bunch, the bunches per train and the trains per ring, and the train spacing can be flexibly chosen under a restriction of the total stored current($600mA$). Beam dynamics study and development for beam handling technique (beam based tuning, alignment and feedback) are continued to get ultimate beam for linear colliders.

4.3.2 Beam Dynamics

4.3.2.1 Alignment Tolerance (Coupling Sources)

The vertical emittance of the ATF damping ring is $\gamma\epsilon_y = 3 \times 10^{-8}$ ($\epsilon_y = 1 \times 10^{-11}$) in the design. The horizontal emittance is 100-times the vertical one, and less dependent on errors. The vertical emittance is generated by both the vertical dispersion and betatron coupling, both of which strongly correlate to the alignment errors. The vertical dispersion is produced by any vertical misalignment of the quadrupoles, rotation of the horizontal bends and the vertical correction dipoles. The skew quadrupole component arises from vertical offset of the sextupoles; rotated quadrupoles, also contribute to enlarge the vertical dispersion through coupling the horizontal dispersion to the vertical plane. On the other hand, these skew components couple the horizontal betatron motion to the vertical plane, which enhances the vertical emittance. Any misalignments of the BPM is also an indirect source of emittance; it offsets the orbit at the quadrupoles and sextupoles in the orbit correction. The sensitivities of the emittance to random misalignments have been studied by an analytical approach and by a combination with simulations for the ATF damping ring. We obtain the expected values of emittance according to Ref[3] as follows:

$$
\begin{aligned}
\frac{\gamma\epsilon_y}{3\times10^{-8}} &= \frac{1}{\sin^2\pi\nu_y} \\
&\times \left[1.16\cdot10^{-3}\left(\frac{\theta_q}{0.1\text{mrad}}\right)^2 + 0.78\left(\frac{y_s}{0.1\text{mm}}\right)^2 + 0.24\left(\frac{y_c}{0.1\text{mm}}\right)^2\right] \qquad (4.1)
\end{aligned}
$$

$$
\begin{aligned}
\frac{\gamma\epsilon_y}{3\times10^{-8}} &= \left(\frac{1}{\sin^2\pi\nu_+} + \frac{1}{\sin^2\pi\nu_-}\right)\left[5.7\cdot10^{-4}\left(\frac{\theta_q}{0.1\text{mrad}}\right)^2 + 0.15\left(\frac{y_s}{0.1\text{mm}}\right)^2\right] \\
&+ \left(\frac{1.93\cdot10^{-3}}{\sin^2\pi\nu_+} + \frac{2.83\cdot10^{-2}}{\sin^2\pi\nu_-}\right)\left(\frac{y_c}{0.1\text{mm}}\right)^2, \qquad (4.2)
\end{aligned}
$$

corresponding to the dispersion and betatron coupling, where $\nu_\pm = \nu_x - \nu_y$, θ_q, y_s, and y_c are the rms of the rotation angle for the quads, misalignment of the sextupoles, and residual orbit after correction, respectively. The terms of the residual orbit include a contribution from both misalignments of the quadrupoles and the BPM's. The emittance strongly depends on resonant denomina-

Table 4.1: Tolerances

	without bump-tuning				with bump-tuning			
	Δx (μm)	Δy (μm)	$\Delta\theta$ (mrad)	ΔK (10^{-3})	Δx (μm)	Δy (μm)	$\Delta\theta$ (mrad)	ΔK (10^{-3})
Quad	90	60	0.2	1.0	150	100	0.2	1.0
Sext	90	60	0.2	1.0	150	100	0.2	1.0
Bend	90	60	0.2	1.0	150	100	0.2	1.0
Corrector	—	—	0.2	1.0	—	—	0.2	1.0
BPM	100	100			100	100		

tors. We have chosen the tunes so as to minimize these values. The detailed operation points were decided based on the view point of the dynamic aperture, as described in a later subsection. The present tunes ($\nu_x = 15.145$, and $\nu_y = 8.715$) give rather large values for the sum resonance term, $1/\sin^2\pi\nu_+ = 5.52$, while $1/\sin^2\pi\nu_- = 1.05$ and $1/\sin^2\pi\nu_y = 1.64$. The above estimation tells us that the sextupole is a dominant source and that the dispersion and coupling make contributions in roughly equal magnitude. This suggests that the dispersion correction in the arc will not be effective. We have therefore adopted a correction scheme in which multiple orbit-bumps are made in the arc in such a way as to minimize the emittance while observing only the emittance. We call this correction "Bump-tuning". Although other correction schemes, such as tuning with skew quads, for example, would be used as a complement , they are not included in the simulation.

The analytical estimation mentioned above does not include a rotation of bends. Although the last term includes some mixture of quadrupole misalignments and BPM misalignments, it cannot separate them in a clear manner. We thus made a simulation by SAD which included these errors.

In the simulation we assumed random errors with a Gaussian distribution truncated by $\pm 4\sigma$, and corrected the orbit by the least-square method using corrector dipoles. In bump-tuning, the orbit bumps were created at five locations in the arc in order to minimize the emittance assumed to be measurable with 3% precision. The minimization typically converged within 20 iterations (20 emittance measurements). In the whole procedure, the maximum bump height was kept to be in the ± 1mm range and it did not degrade the physical aperture. We made 100 simulations and averaged these results in order to estimate the tolerance of errors. We did not take the intrabeam scattering effect into account. It has effects of about 25% to the horizontal emittance, and less than 25% to the vertical one[4].

Table 4.1 shows the tolerances of misalignments at the 95% confidence level both with and without the bump tuning. There would be another set of tolerances that gives an identical expected emittance. The tolerance given in table 4.1 seems to be feasible. Bump-tuning gives a looser tolerance by roughly a factor of two. It should be pointed out that the present bump-tuning has not been optimized: many free parameters remain to be adjusted. We checked the sensitivity of the emittance to the tolerance of specific errors. The emittance is insensitive to the rotation error. This is consistent with the analytical estimation. The BPM alignment has a stronger influence on the emittance. To achieve as small an emittance as possible is one of critical issues to obtain a high luminosity in the linear collider, as well as to achieve a high acceleration efficiency and a strong final focus.

About 300 magnets for ATF damping ring were roughly aligned within the accuracy of 200μm in January 1997. Since one combined bending magnet, two quads and two sextupoles were set on one

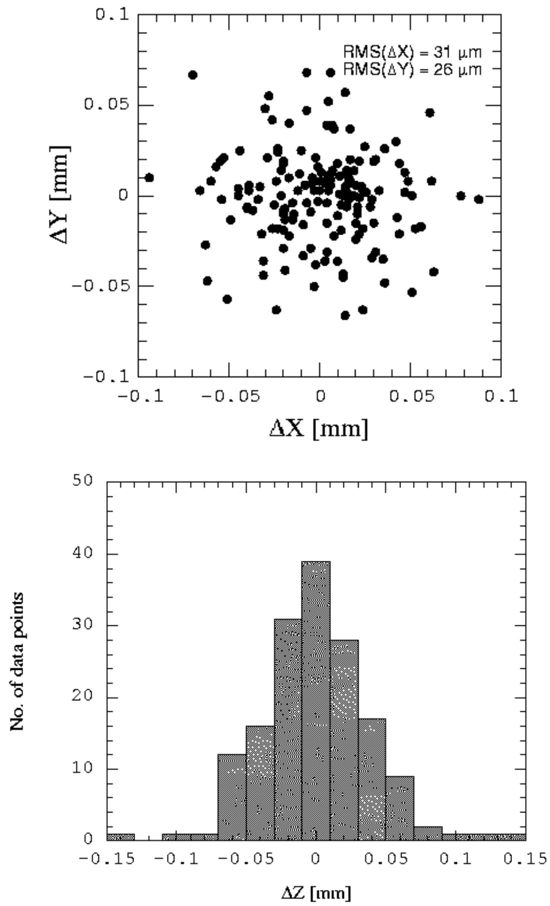

Figure 4.1: Scattered plot on transverse setting error and longitudinal setting error which were measured on magnets of the ATF 14 active girders using a 3D mobile tracking system

active girder within the accuracy of 31μm, we can align them precisely using beam based alignment and movers. The scattered plot on setting error of transverse position and longitudinal setting error are shown in Figure 4.1.

4.3.2.2 Dynamic Aperture

The ATF Damping Ring has a special characteristic so that the dynamic aperture can be smaller than the physical aperture. Since the tolerance of the beam intensity per train for the JLC is tight, less than 0.5% in r.m.s., a beam loss at the injection should be sufficiently smaller than this value. Otherwise, a small fluctuation in the incoming beam may cause a intolerable fluctuation in the intensity. The physical acceptance of the ring is limited by the injection/extraction septa horizontally and by the chambers of the wiggler magnets vertically, giving a normalized acceptance of $A_{xn} = 68$mm and $A_{yn} = 17$mm. The rf bucket height is 1.9%. All of these values are sufficiently bigger than the required acceptance. Once injected, the beam is lost due to its small fraction if the dynamic aperture is sufficiently large and the instabilities are well cured.

We estimated the dynamic aperture by particle-tracking simulations with SAD. The SAD code performs six-dimensional simplectic mapping with a nonlinear fringe field of all the magnets, non-linearity in drift and bending sections, and several types of machine errors, and orbit corrections.

The tracking was typically done for 1000 turns. Although tracking with synchrotron radiation was done also but the result did not change significantly.

The initial condition was chosen as $(J_x, J_y) = (A, A)$. The initial momentum offset was scanned within the range of ± 1.0%. The dynamic aperture is given in the unit of the equilibrium beam size (σ_{x0}) without intrabeam scattering. Note that the required acceptance for injection corresponds to $30\sigma_{x0}$. The errors are assumed to have a Gaussian distribution with the r.m.s. values, and have been truncated $\pm 4\sigma$. These errors correspond to the tolerance for a vertical emittance of less than 3×10^{-8} after correction, as described in the previous subsection. For each simulation, the closed orbit was corrected by a simple r.m.s. minimization at the BPMs. We also carried out simulations in which a "bump-tuning" was performed after the r.m.s. correction; however, no significant changes were observed in the performance of the dynamic aperture. The tunes were adjusted at $\nu_x = 15.145$ and $\nu_y = 8.715$.

In the case of the ATF Damping ring, the critical aperture appears in the transverse plane, mainly due to the sextupoles. The residual closed orbit after an orbit correction enhances the nonlinearity of the sextupoles and reduces the dynamic aperture by roughly 60%. The dynamic aperture does not strongly depend on the longitudinal amplitude: at least up to ± 1% of the initial momentum offset. We corrected the chromaticity by using simple two-family sextupoles. The multi-family scheme does not help, since it is usually used for enlarging the aperture in the longitudinal direction.

A non-interleaved sextupole scheme may improve dynamic aperture. We tested a non-interleaved sextupole scheme and found that the transverse aperture was greatly enlarged while the longitudinal aperture was reduced to ± 0.5%. The longitudinal aperture of the non-interleaved scheme generally depends on the number of families. Since only 4-families are possible in our case, due to the limited site, the non-interleaved scheme is not applicable to the ATF damping ring.

The dynamic aperture also depends on the operating tunes. A third-order structure-resonance ($3\nu_x = 46$) is observed in the case without errors, while in the case with errors, a structural sum-resonance ($\nu_x + \nu_y = 24$) is strongly excited. We also made several simulations using other seeds of random numbers and found a similar global structure. It is worth seeing the dependence of the dynamic aperture on the machine errors. Based on this simulation it is crucial to keep the transverse misalignment small. Further improvements will be made, for example, by using optional octupoles and skew quadrupoles.

4.3.2.3 Instabilities

A single-bunch instability, especially in the longitudinal plane, must be avoided in a damping ring. If the intensity exceeds some threshold, it can damage not only the longitudinal emittance, but also may cause so-called saw-tooth phenomena, which totally degrade the performance of the linear collider. Therefore, the impedance of the vacuum chamber and components should be carefully evaluated. First, a rough estimation of the threshold is given by the formula

$$|Z/n|_{\rm th} = \sqrt{\frac{\pi}{2}}\frac{\gamma Z_0}{r_e}\frac{\alpha_p \sigma_\delta^2 \sigma_z}{N}\ , \tag{4.3}$$

where Z_0 is the vacuum impedance and r_e is the classical electron radius. In the case of the ATF damping ring, Eq. 4.3 gives 0.24 Ω at $N = 1\times 10^{10}$. The impedance sources in the ring are listed in Table 4.2.

The impedance sources were estimated by TBCI and ABCI codes. Although the specific impedance ($|Z/n|$) reaches 0.33 Ω, $2/3$ of the total comes from the rf cavities, whose major contribution is capacitive. We thus expect that the actual threshold is higher than that given by Eq. 4.3.

Table 4.2: Impedance sources.

	$\lvert Z/n\rvert$/unit (mΩ)	Number of units	$\lvert Z/n\rvert$/ring (mΩ)
Rf cavities	40	5	200
Vacuum pump slots	6×10^{-4}	3600	2
Monitor electrodes	0.02	4×100	8
Bellows	0.4	80	32
Septum chamber	0.7	2	1
Rf quadrupoles	6.4	2	13
Tapered transitions	1.5	4	6
Clamp flanges	0.04	60	2
Gate valves	0.8	6	5
Photon masks	0.5	20	10
Kicker chambers	2.1	2	4
Rf absorbers			≈ 50
Total			331

Although the threshold of the instability is about $N = 3.5 \times 10^{10}$, even below the threshold the bunch length is longer than the expected one due to the potential-well distortion. We must therefore set the zero-intensity bunch length to be shorter than σ_{z0} by supplying a high accelerating voltage. This also changes the synchrotron tune so that it may affect the threshold. Actually, in this case that the threshold still stays at the same value ($N = 3.5 \times 10^{10}$). Around the threshold intensity, the unstable mode has a frequency of $2.7\omega_s$. The transverse strong head-tail instability has a higher threshold than does the longitudinal one in general. In the case of a high current and a large number of bunches in the ring, a cure for the coupled-bunch effect must be considered. The possible effects of the RF cavities are:

1. longitudinal coupled-bunch instabilities caused by the accelerating mode,
2. shift of the longitudinal bunch position due to beam loading, and
3. longitudinal and transverse coupled-bunch instabilities due to the higher order modes.

In addition, the wake field of the resistive wall of the vacuum chamber has an important effect on the transverse coupled-bunch motion.

Because of the high beam current and large circumference, the band width and detuning frequency of the cavities should be comparable with the revolution frequency. Then, the growth rate of the '-1' mode, excited by the tail of the impedance of the accelerating mode, can be higher than the radiation-damping rate under some conditions. This instability can be avoided by using a low RF frequency, high accelerating voltage with low-R/Q cavities. The design of our RF system will achieve this condition. Another solution is RF feedback for specific oscillation modes. The growth rate of the coupled-bunch motion has been analytically estimated to be less than 100 s^{-1} in the case of the highest current, which is less than the radiation-damping rate. The stability of bunches has been checked by tracking simulations of rigid bunches, including the wakefield of the accelerating mode.

Since the bunches are not uniformly distributed over the ring because of the gap between the trains, each bunch feels a different wakefield (beam loading) induced by the preceding bunches. The bunch energies are the same, so as to keep the revolution frequency unchanged. As a result, the head bunch in a train delays and tail bunch advances from the nominal positions. The shift in the positions would become comparable with the bunch length under some conditions. A high accelerating voltage with low R/Q can reduce this shift. In addition, an RF system for beam-loading compensation will be installed to test the minimization of the shift. This system has an idling cavity (no power is fed) having a resonance frequency of $f_{main} - N_t f_{rev} - D_f$, where f_{main} is the frequency of the main RF and N_t the number of trains, f_{rev} the revolution frequency and D_f the detuning frequency. The required peak voltage is about 50 kV. It is possible to install more than one cavity with frequency $f_{main} - nN_t f_{rev} - D_f, n = 1, 2, 3, \ldots$ to obtain more precise compensation. The behavior of bunches with this beam-loading compensation system has been studied by tracking simulations.

The longitudinal instabilities caused by the higher-order modes (HOM) can be suppressed by the damped cavity (cavity with low Q values of HOMs). In the case of the highest beam current, the threshold Q of HOMs estimated by a tracking simulation is

$(R/Q) \times Q \times f \sim 10^4$ for each monopole mode,

where f is the frequency of each mode in GHz and R/Q is in Ω. This value agrees with analytic calculations for uniformly distributed bunches having the same total current.

The transverse instabilities can be suppressed by a damped cavity and the bunch-to-bunch tune spread in each train. The requirements were estimated by a tracking simulation to be:

$(R/Q) \times Q \sim 10^6 (\Omega/\mathrm{m})$ for each dipole mode, and

$D_n \sim 1 \times 10^{-3}$,

where D_n is the peak-to-peak betatron tune difference in a train. These values also agree with the analytic result for uniformly distributed bunches having the same total current, assuming that the bunches in a train are decoupled because of different tunes. These requirements concerning the RF cavities can be satisfied and the tune spread can be obtained by an RF quadrupole. The tune difference is expected to suppress the transverse coupled-bunch instabilities due to the resistive wall wakefield too. In these estimation, bunches were assumed to be rigid point charge. Some single bunch effects, for example a head-tail effect with positive chromaticity, are expected to increase the damping rate of coherent oscillation and to relax the requirements. These effects will be tested in the ring.

The thresholds of the longitudinal and transverse coupled-bunch instabilities caused by a higher-order resonance with impedances $R_{||}$ and $R_{\perp}$ at the resonant frequency (f_r) are roughly estimated by the formulae

$$\begin{aligned} R_{||,\mathrm{th}} &= \frac{E\nu_z}{I\tau_z\alpha_p f_r e} \\ R_{\perp,\mathrm{th}} &= \frac{ET_0}{I\tau_\beta \beta e}, \end{aligned} \tag{4.4}$$

where β is the beta function at the cavities. Equation 4.4 assumes a uniform distribution of bunches; the worst case is when the coupled-mode hits the resonance exactly. In the case of the ATF damping ring, this threshold is

$$\begin{aligned} R_{||,\mathrm{th}} &= 1.4\left(\frac{1\ \mathrm{GHz}}{f_r}\right)\mathrm{k}\Omega \\ R_{\perp,\mathrm{th}} &= 16\mathrm{k}\Omega/\mathrm{m}, \end{aligned} \tag{4.5}$$

where we have used $\beta = 8$ m and $\tau_\beta = \tau_y = 9.2$ ms. The longitudinal threshold is satisfied by the damped cavity in the longitudinal direction. The transverse is cured by a damped cavity together with a bunch-to-bunch tune spread of $\Delta\nu_\beta \sim 10^{-3}$ introduced by an rf quadrupole. According to the tune-spread, the transverse threshold is effectively increased to be N_b-times bigger than Eq. 4.5.

The actual threshold with a real bunch/batch distribution including transient phenomena has been studied by multi-rigid-bunch simulations. The results show that conditions 4.4 and 4.5 are acceptable for the threshold.

The resistive wake of the vacuum chamber is another source of the coupled-bunch instability. The growth rate is estimated by

$$\begin{aligned} \nu &= \nu_0\left[1 - \frac{Ne^2\beta^2G^*(2\pi,\nu)}{\pi b^3\gamma m\sqrt{R}\omega_0^2\nu_0^2}\sqrt{\frac{c}{4\pi\sigma\beta}}\right] \\ G^*(2\pi,\nu) &= 2\sqrt{\pi}\sum_{n=1}^{\infty}\frac{\exp(i\nu 2\pi n)}{(2\pi n)^{1/2}}, \end{aligned} \tag{4.6}$$

where $\sigma = 3.5\times10^7\Omega^{-1}\mathrm{m}^{-1}$ is the conductivity of aluminum. The growth rate is 10 ms for $N = 1\times10^{10}$.

4.3.3 Prospects

The beam energy until now is about 1.0 GeV and the damping time is about $40msec$ because there are some troubles in the 1.54 GeV Linac. We are measuring magnetic field errors, alignment errors using beam based techniques. The energy will be gradually increased up to 1.54 GeV in this year. So, we concentrate on the development for the beam handling techniques to stabilize 1.0 GeV beam. Since there are many issues to investigate, for example, transient beam loading at high current beam injection, fast ion instability, beam loading effect due to train gap, nonlinear beam dynamics, intra-beam scattering, long beam tail due to beam-gas scattering, Touschek lifetime and so on., we will investigate each study item if hardware and software tools will be ready. If you want to see the status of the ATF, please open the following ATF WWW home page;
`http://www-acc.kek.jp/WWW-ACC-exp/JLC/ATF/ATF-home.html`.

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References

[1] Ed. by G. Loew and T. Weiland ”International Linear Collider Technical Review Committee Report” 1995

[2] Ed. by F. Hinode et. al. ”ATF Design and Study Report”, KEK Internal 95-4, June 1995

[3] T.O.Raubenheimer, Ph. D. Thesis, Stanford University, SLAC-Report-387 (1991)

[4] T.O.Raubenheimer et. al. Nucl. Instr. Meth. A335, 1 (1993)

4.4 The COoler SYnchrotron: COSY

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The cooler synchrotron COSY at the Institut für Kernphysik (IKP) in the Forschungszentrum Jülich is an accelerator and storage ring for protons. It has been designed to deliver high precision beams for medium energy physics (proton momentum range from 270 to 3500 MeV/c). To accomplish this goal two cooling systems are installed. The first one is an electron-cooling system that can be used up to a momentum of 645 MeV/c. The second one is a stochastic cooling system that covers the upper momentum range from 1500 to 3500 MeV/c.

The COSY accelerator is operated with three H^- ion sources, one of them for polarized protons, the other two for unpolarized protons. The H^- ions are preaccelerated in an isochronous cyclotron, and guided via a 100 m long injection beam line to the COSY-ring. Currents of approximately 10 μA are fed into the accelerator ring via stripping injection.

The COSY ring (184 m circumference) has a race-track design with 40 m long straight sections. Sixteen quadrupoles in each of these sections are grouped as four quadruplets and allow the ion optics to be tuned such that these sections act as telescopes with a 1:1 imaging giving either a π or a 2π phase advance. The arcs consist of six unit cells where each half-cell has a QD-bend-QF- bend structure. If these cells are identically operated, the ring has a superperiodicity of P=6. Two thirds of machine time are dedicated to experiments, and one third is available for machine development. Proton beams in a wide energy range (300 MeV - 2600 MeV) have been delivered to internal as well as external experiments.

Three internal target stations are currently in operation for experiments. Lambda induced fission of heavy nuclei is studied at TP1. At TP2 the energy dependence of the elastic pp-scattering is investigated (EDDA collaboration) and TP3 is used to study of near-treshold production of mesons with strangeness (COSY 11). In the near future a new zero degree spectrometer ANKE consisting of three bending magnets is being inserted into one of the straight sections of the ring. One of the experiments at COSY (EDDA) takes data during acceleration. To avoid transition energy crossing, the k-value of the quadrupole families in the arcs is continuously changed during acceleration to shift transition upwards. As a consequence, the superperiodicity is reduced. No change of beam properties at the TP2 target station has been detected. Tuning the optic at top energy to special requirements of other experiments is possible after debunching the beam. E.g. at the top energy after debunching the beam transition energy was shifted back to the injection value and only marginal beam losses were observed.

The circulating proton beam can be extracted by the conventional third order resonant extraction mechanism as well as with the method of stochastic extraction. Conventional extraction is made by creating a 11/3 integer resonant condition by sextupole excitation and sweeping the beam through the resonance in shifting the tune of the machine. The idea behind the ultra slow extraction is to move the beam across the resonance by a diffusion process. A flat narrow band noise will be used to shape the gaussian-like distributed beam into a rectangular distribution. To drive the beam to the resonance noise that permanently covers the extraction resonance will be moved across the beam distribution. The result is a random walk of the particles within the noise bandwidth. Particles that reach the resonance will be extracted. Spill times of more then 30 s were obtained. An extraction beam line guides the protons to three different external experiments, NEMP (low energy measurement site), TOF (time of flight facility) and BIG KARL (magnetic spectrometer with large solid angle).

The electron cooling is applied to the beam at injection energy (45 MeV) and has been used for machine physics experiments. Commissioning of the stochastic cooling is in progress and first BTF measurements have been carried out to investigate the beam response.

A polarized beam can be produced and accelerated at COSY, but during acceleration, imperfection and intrinsic resonances may depolarize the beam. Imperfection resonances are caused by magnetic field errors and misalignments of the magnets. At these resonances spin flips are excited to conserve the polarization. For this purpose the correction dipoles as well as the solenoids of the electron cooler (partial snake) were successfully used. The number of intrinsic resonances depends on the superperodicity of the lattice and are excited by horizontal fields due to vertical focusing. The shifting of transition energy decreases the superperiodicity, thus leading to additional intrinsic resonances. At one of these additional resonances it was shown experimentally that the corresponding intrinsic spin harmonics can be suppressed by matching the optic. Nevertheless the standard method, a rapid change of the betatron tune, to conserve the polarization at intrinsic resonances can be applied, too. For this, a fast tune-jumping system has been inserted, and is under commissioning.

4.5 Progress Reports from CERN

4.5.1 LEP

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During 1996 the energy of LEP was raised, first to 80.5, then to 86 GeV per beam as further superconducting RF cavities were installed. Most of the operation period was spent running the well-tested optics with $(\mu_x, \mu_y) = (90^\circ, 60^\circ)$ in the arc cells. However because of the inexorable growth of emittance with energy, the horizontal dynamic aperture of this optics is expected to become insufficient. In addition, the luminosity is not beam-beam limited with the available bunch currents (limited mainly by the RF system in 1996) and the beam-beam limit clearly increases with energy. A beam-beam parameter of $\xi = 0.04$ was attained at 86 GeV with none of the usual signs of the limit.

Hence our continuing interest in low-emittance optics to attain higher luminosity and higher ultimate energy, both paramount considerations for the experimentalists. Two low emittance optics were tried out in 1996 and much was learned in the efforts to operate with the twin problems of a low-emittance optics (like a synchrotron light source …) and a low-β collider optics. In addition the radiation effects on single-particle dynamics are very strong at LEP2 energies and give rise to new dynamical effects such as radiative beta-synchrotron coupling (RBSC). This latter instability is only seen when radiation damping is properly modeled in tracking.

The machine was started with $(\mu_x, \mu_y) = (108^\circ, 60^\circ)$ but it quickly became evident that the horizontal dynamic aperture, determined by the large negative variation of the vertical tune with horizontal amplitude—the same effect as in the $(90^\circ, 60^\circ)$ optics—was a severe limit to the beam currents that could be brought into collision.

At the end of the year, a $(108^\circ, 90^\circ)$ optics was tried. Extensive tracking studies and pilot experiments had shown that it had a large dynamic aperture despite enhanced sensitivity to imperfections. At first, measurements of reduced lifetime and enhanced beam tails (see below) did not seem to bear this out. However measurements of the multi-turn evolution of kicked beams clearly showed the influence of a strong third-order resonance at the amplitude of the apparent dynamic aperture limit. This had been seen in tracking of imperfect machines but did not lead to instability. The resonance manifested itself as a loss of a few percent at a certain kick amplitude. Beyond this amplitude, the loss decreased before finally rising rapidly at an amplitude corresponding quite well to the predicted dynamic aperture. Later an explanation of the reduced lifetime in terms of enhanced diffusive transport by the resonance was proposed to account for the measured tails and lifetime, see the contribution on "Non-linear resonances" in the proceedings referenced below.

An important lesson from this experience is that dynamic aperture evaluations—even our rigorous 4-dimensional scans of many elaborately prepared and corrected, imperfect machines—are not enough to predict beam stability. A machine can have good dynamic aperture but poor beam lifetime. Semi-analytic estimates of the beam lifetime seem to be an essential complement.

Presently schemes to correct the resonance effects are being developed and will be tried out this year. It will also be of great interest to see how high we can go with the beam-beam parameter.

Studies of transverse beam polarization at energies above 50 GeV continue to be of interest in connection with the enormous effort made to calibrate the beam energy and take detailed account of the many phenomena that can affect it.

On the collective effects side, detailed calculations of impedance and loss factors continue and an impedance database has been implemented.

Detailed information on recent developments at LEP can be found in the Proceedings of the Seventh LEP Performance Workshop, held at Chamonix in January 1997, CERN SL/97-06 (DI), edited by J. Poole, available at
`http://www.cern.ch/CERN/Divisions/SL/publications/chamx97/contents.html`

4.5.2 Studies of non-Gaussian tails in LEP

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Non-Gaussian beam tails have been studied in LEP by using scraping collimators and loss-monitors close to the scraping collimators to measure the loss rate of particles. Strong scraping leading to short beam lifetimes is used to calibrate the loss monitors. The loss monitors are sufficiently linear and sensitive to measure beam tails corresponding to life times of several thousand hours down to minutes. Software has been developed such that tail scans can be done automatically: Collimators are moved slowly into the beam and the loss rates are recorded.

As presented in the EPAC 96 in Barcelona, significant non-Gaussian beam tails have been observed in LEP both in the horizontal and vertical plane. The results are compared to theoretical tracking studies. It was found that scattering processes like Bremsstrahlung on the residual gas, Compton scattering on "thermal" photons and beam-beam Bremsstrahlung produce non-Gaussian tails.

More recently, using additional collimators in regions with and without dispersion, the importance of the combined effect of energy loss in the scattering processes and dispersion to launch particles at large amplitudes could be demonstrated.

Comparing tail scans for small and large emittances and various optics has also become a very useful tool to study beam dynamics close to the dynamic aperture.

For further information see the contribution by I. Reichel in the Chamonix workshop proceedings referenced above.

4.5.3 LHC

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The version 5 of the LHC lattice is being assembled, incorporating the improvements described in the former newsletters, i.e. mainly the capability of making tune splits (the nominal is two units) and a more flexible and modular lattice.

Map analysis was used to compute resonance coefficients and attempt to relate them to the dynamic aperture results. A rather clear correlation appears between the latter and simultaneously two difference resonances driven by a_4 and b_4. The tune split of version 5 may thus have a positive impact on dynamic aperture.

The optimistic results obtained on the influence of long-range beam-beam effects at injection on the dynamic aperture were not confirmed by a more comprehensive 6D tracking. The separation of 7 sigmas appears to be not sufficient, with a dynamic aperture of 6.5 sigmas. The flexibility of the new version 5 will allow us to decrease the β-values so as to obtain a sufficient beam separation.

Version 9 of MAD (based on the Classic project) is progressing. Version 8 of MAD is also being reorganized around a small database common to the two versions. MAD algorithms will be implemented as independent modules interacting through the database.

Surface resistance measurements for the copper coated LHC beam screen are in progress. Preliminary results at 4 K and without magnetic field, for frequencies in the range 600–900 MHz, indicate a surface resistance above 2 mOhm, i.e., more than a factor two larger then previously estimated.

Coasting beam longitudinal echo signals have been observed at 120 GeV in the SPS even after 2 minutes from the last RF pulse, corresponding to diffusion coefficients as small as 10^{-13} s^{-1}. These results have been cross-calibrated by independent Schottky measurements of the energy spread induced by an additional RF noise. Bunched-beam longitudinal quadrupole echoes have also been recently observed.

An impedance database program (ZBASE) has been set-up and already successfully applied to estimate the LEP impedance budget: it helps keeping track of all the known impedance sources and of the input files used by different programs, such as ABCI or MAFIA, to compute HOM and loss factors for several bunch lengths. In the near future, a further interface is foreseen to existing beam dynamics codes for detailed calculations of multibunch transverse mode-coupling and microwave instability thresholds both in the LHC and SPS.

The existing LHC impedance budget has been used in conjunction with the program VLASOV for calculations of transverse instability thresholds and rise times including multibunch mode coupling: the transverse mode-coupling threshold is about a factor two higher than the nominal current, but the feedback bandwidth required to damp all multibunch dipole modes should be increased by a factor of two.

Landau damping of the rigid dipole oscillations with two-dimensional betatron tune spread has been investigated for Gaussian and quasi-parabolic transverse beam distributions. The results have been applied to specify the strength of the LHC octupole correctors required to stabilize dipole and higher order head-tail modes during the ramp and at collision energy. The two-dimensional analysis shows that the damping by octupoles is significantly more efficient than predicted by a one-dimensional approach.

4.5.4 Beam Dynamic Activities at CERN PSB and PS

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The main PSB and PS beam dynamic activities are presently devoted essentially to i) the preparation of the LHC beam (PSB and PS), ii) the consolidation of the high intensity ISOLDE beam (PSB) and iii) the improvement of slow extraction beam quality (PS).

For the LHC beam: the hardware modifications (mostly RF) necessary to produce the nominal LHC beam will be completed this year. For example the RF harmonic numbers in both machines will be changed in the PSB from the present $h = 5$ and 10 to $h = 1$ and 2 and from $h = 20$ to $h = 8$ and 16 in the PS. All the beams, of course, will be affected. Theoretical and experimental studies are in progress on the following main subjects.

In the PSB, for the LHC beam:

- A tracking code is being implemented to better understand the multiturn injection process in a space charge regime.
- Analyze injected beam momentum distribution with beam transfer function measurements.
- Study the beam stability with a dual Rf system with h=5+10 or h=1+2 systems and with gap-derived or beam derived 2nd harmonic phase.
- Study a controlled (h=1) bunch flattening with an h=10 cavity.
- Investigate integer stopband compensation.

In the PSB, for the ISOLDE beam (most of the previous studies will profit also to this beam):

- Investigate mwave instability in ring no. 4.
- Examine spurious transverse instabilities during the acceleration.
- Continue study of loss mechanisms and loss concentration.

In the PS, for the LHC beam:

- Study transverse matching conditions for the 4 PSB rings (possibly making use of a quadrupolar pick-up and /or a beam shape monitor, for example SEM grid, with a multiturn acquisition system).
- Investigate collective effects (space charge and head-tail instabilities) as well as coupled Landau damping at low energy.
- Examine closed orbit distortions at high energy.
- Study longitudinal collective effects (for example coupled bunch instabilities) versus HOM damping in the new 40 MHz cavities.
- Study collective effects during debunching- rebunching at 26 GeV/c.
- Analyze PS-SPS matching conditions.
- Prepare various beams for PS and SPS machine developments.

In the PS, for the Slow Extraction beam:

- Improve the low frequency duty factor with feed forward or feedback on extraction resonance.
- Test a 9 MHz bunched beam extraction.

Most of these machine studies will be performed in parallel with the scheduled physics program.

5: Workshop Reports

5.1 Round Beams and Related Concepts in Beam Dynamics

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The Mini-Workshop on "Round Beams and Related Topics in Beam Dynamics" was held from Dec. 5 to 6, 1996, at Fermilab. About twenty people from Cornell, Budker INP (Novosibirsk), Fermilab, University of Colorado (Boulder), ANL, and University of Michigan (Ann Arbor) attended. Plenary session presentations were as follow:

Dave Finley	Fermilab	Opening address
Slava Danilov	Novosibirsk	Round Colliding Beams for Increasing Luminosity
Richard Talman	Cornell	Mobius Modification of CESR
Yaroslav Derbenev	U.Mich.	Hollow Beams Concept
Vladimir Shiltsev	Fermilab	Tevatron Round Beams Simulations
Yuri Shatunov	Novosibirsk	Around Round Beams in Novosibirsk
Elizabeth Young	Cornell	Round Beam Results at CESR
Igor Nesterenko	Novosibirsk	Beam-Beam Effects Simulations for VEPP-2M with Flat and Round Beams
John Cary	U.Colorado	4D Simplectic Maps with Reduced Chaos
Slava Danilov	Novosibirsk	Integrable Optics Concept

As it was originally supposed, a lot of discussions arose during the presentations, so, each of nine talks took almost an hour, while the entire Workshop took one and a half days.

In his opening address, Dave Finley expressed an interest of proton machines community in "round beams" schemes which had being widely discussed for a long time as a way to increase beam-beam tune shift and, therefore, luminosity of colliders. Thorough evaluation of the "round beams" for the Tevatron upgrade has become a pressing problem since the experimental proof of principle at CESR.

5.1.1 "Round" Beams and Other Concepts: Theory, Simulations, Experiment

Slava Danilov made theoretical overview of the "round beams" (RB) concept. Three essential condition of the beams are:

1. equal horizontal and vertical emittances $\epsilon_x = \epsilon_y = \epsilon$;
2. equal beta-functions at interaction point (IP) $\beta^*_x = \beta^*_y = \beta$;
3. equal betatron tunes $\nu_x = \nu_y = \nu$.

Due to the symmetry, beam-beam tune shifts ξ are the same in both planes, that means valuable enhancement in luminosity of $e^+ - e^-$ colliders. Then, there is an additional integral of motion – angular momentum $\mathcal{M} = x \cdot y' - y \cdot x'$, and its conservation reduces 2D dynamics to one (radial) degree of freedom and, therefore, to a 1-dimensional set of resonances. All that improves beam stability and reduces particles diffusion under the impact of non-linear forces of the opposing beam. The most effective improvement needs the tune ν to be close to integer or half-integer. A general form of linear transformation matrices which conserve $\mathcal{M}$ is found to be a superposition of turns in betatron phase space (equal for both x and y) and in physical spaces.

Danilov also demonstrated several models with further elimination of stochasticity by maintenance of an additional integral of motion. The most remarkable case appears when the longitudinal bunch charge distribution $\rho(s)$ becomes inversely proportional to the beta-function at the IP: $\rho(2s) = Const/\beta(s) = Const/(\beta^* + s^2/\beta^*)$. Under such circumstances the impact of the counter round beam ceases to depend on time in normalized variables; that also helps to prevent diffusion.

The presentation of Richard Talman was devoted to modification of the CESR $e^+ - e^-$ collider for RB operation with use of Mobius optics. The Mobius accelerator can be obtained from a "normal" one by simple insertion of several skew quadrupoles which change polarization of betatron oscillations accordingly to $(x, x') \to (y, y')$ and $(y, y') \to (-x, -x')$. As in usual optics, certain matching of the Twiss parameters β and α is necessary. As the result of such a "twist", original ring tunes (ν_x, ν_y) yield Mobius tunes $\nu_{1,2} = (\nu_x + \nu_y)/2 \pm 1/4$ for "rotating" normal modes (note, that frequencies of signal spectra measured at either horizontal or vertical pick-ups are the same); and fluctuations of synchrotron radiation contribute equally to vertical and horizontal emittances $\epsilon_x^{Mobius} = \epsilon_y^{Mobius} = \frac{1}{2}\epsilon_x^{no-Mobius}$. An advantage of the obtained round beams is that higher ξ_{max} are possible, so, the CESR specific luminosity $\mathcal{L}/I_{tot} \propto \frac{\xi_{max}}{\beta_y^*}(1+R)/2$ can be increased about 2.5 times after the modification (present parameters set of ξ_{max}^y=0.04, β_y^*=1.8 cm, $R \approx$0 to be changed to ξ_{max}=0.1, β^*=3.6 cm, R=1). Another advantage is the possibility to control the ring chromaticity with substantially improved sextupole distribution, since in Mobius lattice each of them affects both planes.

Numerical simulations for CESR-Mobius were made in the "strong-strong" regime with a self-consistent transverse distribution which was found to be close to "near-Rayleigh" distribution

$$dN(r)/dr \propto r \exp -(r/\sigma)^p/2$$

where the parameter p is somewhat different from 2. Simulated luminosity, size blow-up and halo population have pointed to optimum tune points (twice-around tune)/2=0.77 or 0.27. The projected maximum luminosity of CESR with round beams is above $2{\cdot}10^{33}\ s^{-1}sm^{-2}$, that assumes installation of the Mobius section at North area (to be completed in spring 1997), more bunches per beam (from 9 to 15), and superconducting quads in South interaction region.

Vladimir Shiltsev presented simulations of beam-beam effects with RBs in the Tevatron $p\bar{p}$ collider. Hadron beam emittance formation is affected by space-charge and intrabeam scattering effects rather than by synchrotron radiation, and usually horizontal and vertical emittances of the beams coming from injectors are almost equal. Because of that, there were considered not only Mobius lattice with $\pi/2$ rotation, but also two other schemes of the RB preparation: one of them assumes two opposite twists back and forth around the ring $x \to y \to x$, another does not use any $x - y$ coupling elements at all (usual uncoupled lattice). Of course, different optics yield different resonant frequencies, e.g. 2-D resonances merge into 1-D ones when coupling increases from 0 to Mobius twist. Numerical comparison shows that all three round beam schemes provide larger luminosities and slower particle diffusion rates than a "non-round" collider where all three RB conditions are broken. All schemes were found to be rather stable to slight variation of emittance and tune ratio from 1 – at least over 10^5 turns of "weak-strong" tracking that corresponds to about 2 sec in Tevatron. A scan over tune ν (the only tune for RB) with different rms bunch length σ_z allows to conclude an existence of two optimums in the length corresponding to smaller maximum betatron amplitude achieved by any macroparticle – one occurs when σ_z is somewhat smaller than β^*, another $\sigma_z \approx \sqrt{2}\beta^*$ – in a good accordance with Danilov's prediction.

Nevertheless, studies of the effects of various imperfections and errors suggest that proton RB dynamics is not favorable to coupling. In particular, the RB scheme without any coupling has shown somewhat better performance in luminosity and stability under conditions of non-zero residual dispersion, finite beam-beam separation and crossing angle at the interaction point, as well as for betatron phase advance asymmetry between two IPs. However, no studies have been done to answer other important questions for the Tevatron, namely, what scheme is the most stable with respect to numerous parasitic crossings (where beams are not round), and residual coupling and substantial nonlinearities along the ring.

Yaroslav Derbenev outlined the general concept of RB as a way to integrability of particle motion. His theoretical analysis also proves the angular momentum conservation in circular optics and suggests to choose working point about sum resonance $\nu_x + \nu_y = integer$. Proposal of further increase of luminosity is based on idea of "hollow (in phase space) beams" which are characterized by large amplitude of betatron oscillations a ($x, y = a_{x,y} \cos \Psi_{x,y}$), spread of amplitudes Δa is small, and emittance remains the same as for round beams (in normalized variables $\epsilon \equiv \pi a_0^2 = 2\pi a \Delta a$). In the result, at the interaction point such beams can be "superfocused" and the luminosity enhancement is proportional to $\propto a/\Delta a$. Another advantage of the "hollow beams" is $\Delta a/a$ times reduction of tune shifts due to the parasitic crossings at the rest of collider ring. A method to obtain the "hollow beams" is proposed.

The hit of the Workshop was talk of Elizabeth Young on a just finished successful test of the "round beams" idea at CESR. Resonant coupling method was used in order to obtain the RB instead of Moibius or other strong-coupled techniques. Weak $x - y$ coupling due to existing skew quadrupoles around IP was enhanced by merging horizontal and vertical natural frequencies $\Delta\nu_x = \Delta\nu_y = 0.77$. Particle motion "sloshes" between x and y every 100 turns or so, and as the result, beams are approximately "round". Some technical difficulties were overcome with off-energy injection, and finally collisions took place with up to some 20 mA current in each beam (one bunch per beam, no crossing angle) that yielded in luminosity about $\sim 10^{31}\ s^{-1} cm^{-2}$ with $\beta_x^* = \beta_y^* = 30$ cm. No drastic degradation of the beam lifetime occurred during the experiment.

The maximum achieved split of σ and π mode frequencies was about 38.1 kHz that is almost 0.1$\times$(CESR revolution frequency). Based on Yokoya-Koiso theory of coherent beam-beam modes one gets that corresponding maximum beam-beam parameter is $\xi_{max} = 0.075$ – in a good agreement with the value calculated from measured beam sizes. Besides the tune shift measurements, there were carried out extensive studies of the RB blow-up in "weak-strong" and "strong-strong" regimes with different currents and tunes from 0.76 to 0.83.

Two speakers from Novosibirsk – Yuri Shatunov and Igor Nesterenko – shed light on status of "round beams" at Budker Institute of Nuclear Physics. Experimental plans are now focused on modification of existing VEPP-2M $e^+ - e^-$ collider (0.5-1.4 GeV c.m.) to RB operation with use of four 8.6 T superconducting solenoids. Resulting coupling depends on field directions in each of the four, and both Mobius and "back-and-forth" schemes can be realized. Installation of solenoids and the first test are scheduled to fall of 1997 with goal to overcome the achieved up-to-date ultimate beam-beam tune shift (vertical) of $\Delta\nu_y \approx 0.13$.

Extensive simulation of RB for VEPP-2M and for ϕ-Factory which is currently under construction in Novosibirsk show that maximum beam lifetime occurs when momentum compaction factor α is negative. It was also found that at high currents when the beam-beam tune shift exceeds 0.1, the field of chromaticity correction sextupoles leads to substantial degradation of the beam. Longitudinal component of the beam-beam kick leads to particle energy variation at IP

$$\Delta E = Ne^2\beta'(s)/(2\beta(s)) \approx Ne^2 \cdot s/\beta^{*2}$$

which can be comparable with cavity voltage (especially at low energy colliders). "Weak-strong" simulation code was tested with flat beams and rather good agreement with experimental results was observed.

5.1.2 Methods to Improve Dynamic Aperture

Two presentations were made regarding methods to control and reduce chaos, and to maximize dynamic aperture.

John Cary presented results of finding symplectic maps with reduced chaos. It was shown that in the case of $1\frac{1}{2}$ degrees of freedom, such maps can be easier selected with use of Greene's residues. Algorithm is as follow: for a map $z' = T(z)$, one has to find fixed points $z_0 = T^q(z_0)$ (both stable and unstable), then for linearized motion about these points $\delta z' \equiv z' - z = M(\delta z)$ the Greene's residue must be calculated $R \equiv [2 - Tr(M)]/4$. Residue R greater than $1/4$ in magnitude implies chaos that should be avoided by variation of the parameters of the map $T(z)$. A test was made for real lattice of the Advanced Light Source, the dynamic aperture of which was more than doubled with properly chosen several additional moderate strength octupoles and decapoles in each of periodic cells.

In $2\frac{1}{2}$ degrees of freedom the stability of fixed points is governed by 2 parameters: $A \equiv Tr(M)$ and $B \equiv Tr(M)^2 - Tr(M^2)$. An application to the ALS predicts possible 3.5-fold increase of xy volume available for stable beam operation, although it again requires numerous nonlinear magnets.

The final talk made by Slava Danilov was devoted to another approach to the integrable systems. Based on analytical calculations, he finds general forms of the perturbation kicks $F(x)$ which lead to additional integrals of motion $I(x,p)$ in some specific form, e.g. $I(x,p)$ is quadratic in momentum p, cubic, etc. If really existing linear and sextupole force is close to Taylor expansion of one of the integrable systems, then making minor addition of higher order fields one can transform previously chaotic map to everywhere stable one.

One of "integrable" solution for the "round beams" near 1/4 resonance is $F(r) = a \cdot r/(b + r^2)$ where a and b are arbitrary constants – that is rather close to the kick due to beam beam interaction, and if there is a way to vary charge distribution in counter bunch so that its force is close to $F(r)$, then one can qualitatively improve particles stability.

There was also shown an example of 2D accelerator integrable accelerator map with drift and thin lenses with stationary magnetic fields which can be considered as a prototype of real "integrable" accelerator.

5.1.3 Discussion

Numerous discussions at the Workshop covered many issues of round and integrable beams: ways to obtain the RB, details of simulation codes used for RB studies, planning of experimental study of the crossing angle effect at CESR, etc. The last scheduled session was devoted to practical implementation of the "round beams" at Fermilab. It was pointed out by FNAL scientists that the Tevatron is probably not the best machine for a proof of principle test because of technical difficulties. Instead of that, 8-GeV antiproton recycler ring has enough space for necessary $x - y$ coupling insertions and RB interaction region optics and with two intensive p and $\bar{p}$ beams. Further evaluation of the idea is under way.

References

[1] F.M. Izrailev, G.M. Tumaikin, I.B. Vasserman. Preprint INP 79-74, Novosibirsk (1979). (Results on the round beam-beam effects simulations on the main coupling resonance are presented – *V.S.*)

[2] A.G. Ruggiero, "Integrability of the Two-Dimensional Beam-Beam Interaction in a Special Case", *Particle Accelerators*, v.12, p.45 (1982).

[3] *Proc. of the 3rd Advanced ICFA Beam Dynamics Workshop on Beam-Beam Effects in Circular Colliders*, I. Koop and G. Tumaikin, Eds., Novosibirsk (1989).

[4] S. Krishnagopal, R. Siemann, "Simulations of Round Beams", *Proc. of 1989 IEEE PAC, Chicago*, p.836 (1989).

[5] A.N. Filippov et. al, *Proc. 15th Int. Conf. High Energy Accelerators, Hamburg (Germany)*, p.1145 (1992).
V.V. Danilov, et. al,"The concept of round colliding beams", *Proc. EPAC'96, Barcelona* (1996).

[6] Ya. Derbenev, "Invariant Colliding Beams: A Concept for High Luminosity. 4. Hollow Beams: Dynamic Superfocusing", UM HE 93-27, University of Michigan, Ann Arbor (1993).

[7] R. Talman, "The Mobius Accelerator", *Phys.Rev.Lett.*, v.74, N.9, p.1590 (1995).

[8] E.M. McMillan, "Some Thoughts on Stability in Nonlinear Periodic Focusing Systems", Preprint UCRL-17795, Univ. of California, Lawrence Radiation Laboratory, Berkeley, California (1967).

[9] V.V. Danilov and E.A. Perevedentsev, "Analytical 1D method of increasing the dynamic aperture in storage rings", *Proc. EPAC'96, Barcelona* (1996);
V.V. Danilov and E.A. Perevedentsev, "Integrable Nonlinear Map of the Accelerator Lattice Type", CERN SL/Note 94-21(AP).

[10] C.C. Chow and J.R. Cary, "Integrable Nonlinear Accelerator Lattices", *Phys.Rev.Lett.*, **72**, p. 1196 (1994).

5.2 Report on the Workshop on Electron Effects in High-Current Proton Rings

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A Workshop entitled Electron Effects in High-Current Proton Rings was held from March 4 to 7, 1997, at Santa Fe, New Mexico. The workshop was sponsored by the National Spallation Neutron Source (NSNS) project, to be constructed at Oak Ridge National Laboratory. The NSNS design provides a 1-MW 1-GeV beam to a spallation target in short bursts of over 1×10^{14} protons. The short ($< 1\mu$s) pulse, required for neutron energy selection, is formed by accumulation of protons in a ring. This scheme is similar to the that of LANSCE source at Los Alamos which experiences peak intensity limitations in the Proton Storage Ring (PSR) from a fast lost of particles during accumulation, believed to be an electron-proton (e-p) instability. The workshop was held to aid NSNS and the PSR upgrade project in understanding and remediating this instability. While most of the 50 attendees were from the laboratories participating in the NSNS project (LANL, BNL, LBL, ANL, and ORNL) there was strong representation from other institutions, including FNAL, KEK, CERN, RAL, TRIUMF, JAERI, Univ. of Maryland, and SAIC.

The first day was devoted to plenary talks that included a review of e-p instability theory, an overview of PSR observations, observations at other laboratories, reviews of electron-production mechanisms, theoretical studies on the PSR instability, and design issues of the NSNS ring. For the second day, the workshop was organized into three working groups: a theory and computation group, a past-experiences and proposed-experiments group, and the NSNS-design-strategy group. Their charter was to summarize previous work in their respective areas and to originate a course for future progress. The results of the working groups and the workshop were summarized in a joint session in the morning of the third day.

The theory and computation group contrasted impedance and electrons as possible driving sources of the PSR instability observed and concluded that electrons are more likely to be the source. The group recommended more quantitative theoretical studies to gain better understanding in the area of frequency-density relation, rf effects, and the possibility of mode mixing. The working group also suggested that the instability in PSR could be due to either the "fast e-p" effect or to multi-turn electron trapping. To explain that the instability is always observed in the vertical plane, electron trapping in the dipoles could be the predominant cause or more Landau damping in the horizontal plane were invoked.

The past experiences and proposed experiments group recommended the following experimental studies in PSR: (1) more investigations on the beam-cavity interaction, (2) measure of the electron-signal spectrum and time dependence, (3) simultaneous observation of unstable-mode time dependence, (4) pursuit of beam transfer function studies, (5) use of the microwave-transmission technique to detect the possibility of electron trapping in quadrupoles, (6) studies on multipactoring including: revisiting the previous experiments and simulations performed in other laboratories, TiN coating one section of the beam pipe in PSR, implementing a solenoid in a local region to control multipactoring, (7) consider the possibility of instability active damping, and (8) consider a second gap in the beam to shorten the bunch length.

The NSNS design strategy group proposed a strategy that includes attaining a high vacuum, electron capture in the injection section, and possibly electron-clearing electrodes throughout the ring to keep the fraction of neutralization under 10^{-3}. A plan was suggested by the group to pursue theoretical studies on bunched-beam e-p instability, electron capture and clearing in quadrupoles, and comparison of NSNS and ESS tracking codes. The group also recommended experiments using electrodes in quadrupoles, using Kerr cells to study beam neutralization, and consideration of the two-step H^- injection scheme.

A summary talk articulated the general feeling that the PSR instability is a complex phenomenon and may involve more than one step. Multipactoring or an impedance-driven instability may lead to production of electrons and the onset of an e-p instability. The separate coasting-beam and bunched-beam instabilities observed may involve separate mechanisms.

5.3 Beam Dynamics & Optimization Workshops

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The report on the International Workshops on Beam Dynamics and Optimization (BDO) in St. Petersburg, Russia (1994, 1995, 1996).

5.3.1 Summary

The BDO Workshops were organized by Institute of Computational Mathematics and Control Processes and Faculty of Applied Mathematics - Control Processes of St.Petersburg State University and financially supported by Russian Fund of Fundamental Researches. The leading scientific institutes of Russia – D.V. Efremov Institute of Electrophysical Apparatus (St. Petersburg), Institute of High Energy Physics (Protvino), Russian Research Center I.V.Kurchatov Institute (Moscow), Joint Institute of Nuclear Research (Dubna) took part in organization of the BDO Workshops.

About 50 scientists from Russia, Ukraine, USA, France, Italy, Japan, Switzerland, Canada, Spain, Sweden took part in each workshop.

The goal of these meetings was to discuss problems of modeling and analysis of charged particle dynamics in accelerators, special software development, mathematical control theory and optimization, nonlinear beam dynamics: mathematical modeling and self-consistent distributions, mathematical methods of control theory in the problems of the beam and plasma dynamics optimization, mathematical modeling of the electro- and magnetic fields.

Series of the BDO Workshops is planned as a forum for novel ideas and should familiarize the participants with advanced concepts in the field of accelerators and mathematical control theory and help to establish interdisciplinary contacts.

The workshops proceeded in the Peter hall of the main building of St.Petersburg State University — one of the masterpieces of Russian art. A social program was provided for the participants as well as for the accompanying persons, including museums, theatres, river trips. Proceedings of the first two BDO- workshops were published, Proceedings of the third will appear in 1997.

To make interdisciplinary contacts closer only the plenary sessions were supported.

5.3.1.1 Sessions of The Third Workshop BDO-96

- Longitudinal Electromagnetic Field and Its Properties (V.I. Zubov, Russia)
- Boundary Integral Equations for Magnetostatic Problems (E. P. Zhidkov, Russia)
- Optimization Problems in High-Intensity Linac Design (R.A. Jameson, USA)
- Optimization of the High Current Deuteron RFQ Linac (Y.A. Budanov, V.A. Teplyakov, A.V. Zherebtsov, Russia)
- Mathematical Models of Beam Dynamics Control (D. A. Ovsyannikov, O. I. Drivotin, N. S. Edamenko , Russia)
- The Waves in Electric Conductivity Fluid (Yu. Z. Aleshkov, Russia)
- A Module Technique for Expert Systems for Beam Line Design (S. N. Andrianov, Russia)
- Losses of H^- Ions due to Electro-Magnetic Dissociation and Their Effect on the Selection Magnetic Structure of Isochronous Cyclotrons (N. K. Abrossimov, S. A. Artamonov, V. A. Eliseev, G. A. Riabov, Russia)
- Space Charge Dominated Beam (B. I. Bondarev, A. P. Durkin, Russia), (R.A. Jameson, USA)
- Beam Parameters Optimization for H^-, H^0, H^+ — Particles Produced After H^- — Ions Passage Through Gaseous Targets (Vedmanov G. D. , Lasarev Yu. G, Nikonov O.I. , Radchenko V.I., Khokhlov K.O., Russia)
- The Method of the Acceleration on Nearest RF-Field Harmonics (A.N. Dovbnya, Yu.D. Tur, Ukraine)
- Intense Electron Beam Transport Control by an Insulator Beam Guide (Shigeo Kawata, Shini-chi Nishiyama, Masataka Mori, Kenta Naito, Shigeru Kato and Musuhi Hakoda , Japan)
- RF Linac for PET–System (O.I. Drivotin, N.S. Edamenko, A.E. Loukianova, M.F. Vorogushin, D.A. Ovsyannikov, Yu.N. Gavrish, Yu.A. Svistunov , Russia)
- On Polyhedral Approximations of Trajectory Tubes (E.K. Kostousova, Russia)
- Equipartitioning Equations in the RFQ (Yu.A.Budanov, Russia)

- Mathematical Methods of Tokamak Plasma Shape Control (Belyakov V. A., Kavin A. A., Ovsyannikov D. A., Veremei E. I., Zhabko A. P., Russia)
- Electromagnetic Field Refraction on the Boundary Surface of the Solid Ferromagnetic Core and Air Interface at High Frequencies (Pulnikov A.A., Russia)
- Rigorous Bounds for Stability Times in Storage Rings (Martin Berz, USA)
- Magnetic Field Investigation for a Superconducting Magnet System of Toroidal Spectrometer (I. P. Yudin, V. V. Andreev, Russia)
- Electrical Field Mathematical Modeling of Ecological Accelerator for Band Beams Design (E.P. Zhidkov, R.V. Polyakova, I.P. Yudin, Russia)
- Formation of Emission Surface of Multi – Tip Field Cathodes (V. M. Zhukov, Russia)
- Approximation of Stochastic Distribution Functions at Whole (A.S. Khrissanoff, Russia)
- Mathematical Modeling and Calculation Trajectories for Electron Guns (E. M. Vinogradova, Russia)
- 3D Modeling of H-Resonator RF Fields (S.A. Minaev, Yu.A. Svistunov, S.A. Silaev, Russia)
- Development of Code SONIC for Secondary Radiation's Simulation (A.M. Fialkovski, Yu.N. Gavrish, A.G. Prosvirkin, A.V. Sidorov, Yu.A. Svistunov, Russia)
- Methods of Small Parameters Applied to Accelerator Problems (I.V. Amirkhanov, E.P. Zhidkov, I.E. Zhidkova, Russia)
- Stability Computing in Beam Control for The Systems With Post–Action (N. V. Zubov, Russia)
- Calculation of Closed Trajectory of Nonautonomus Hysteresis Control Systems (A.M. Kamachkin, V.V. Evstafyeva, Russia)
- Diagnosis and Analysis of Dielectric Units of Vacuum Electronics Devices (A.G. Karpov, D.V. Ryashentsev, Russia)
- New Methods of Energy Production (A. Zelinsky, USA)
- Generalized Formula for the Lorentz Force (Ya. G. Klyushin, Russia)

5.3.1.2 Poster Session

- A Solving Module for Hamiltonian Dynamical Systems (S. N. Andrianov, A. I. Dvoeglazov, Russia)
- Structure and RF Gun (M. Ayzatsky, V. Kushnir, V. Mitrochenko, D. Styopin , Ukraine)
- Automatization of Symbolic Motion Equations Creation for Multipole Magnet Systems (O. G. Chaklerov, Russia)
- The Bayesian Inference for the Extension of Superposition of Non-homogeneous Poisson Process (Kiheon Choi, Korea)
- Bayesian Inference for a Non-homogeneous Poisson Process (Kiheon Choi, O-Hun Kwon, Korea)
- Electron Linac to Obtain the High-Brightness Bunches Within Sub-picosecond Range (A.N. Dovbnya, V.V. Mitroshenko, Yu.D. Tur, Ukraine)
- Some Problems of Electrodynamics with Application to Charged Particle Beam (O.I.Drivotin, Russia)
- The Optimization of the Nonlinear Microprobe (A. Dymnikov, G. Martinez , Spain)
- Diffraction Mechanism of Rings Formation on Field Emission Image (N. V. Egorov, Russia)
- Improved Robust Variable Structure Systems Control Models for Uncertain Mechanical Objects (V.S. Gapanovich, I.V. Gapanovich, Russia)
- Experimental Determination of the External Beam Matrix on 1 GeV Synchrocyclotron (E.M. Ivanov, G.A.Riabov, Russia)
- A Prototype of an Expert System "Ion-Optical System" (V. V. Kashina, Russia)
- A Generation of Loading Curves in Parameter Spaces for Dynamical System (V. N. Kashin, Russia)
- On Numerical Solving of The Problem of Preassigned Motions Formation of Charged Particles in Magnetic Field (E. D. Kotina, Russia)
- On a Mean-Square MIMO Optimization Problem (B. A. Misenov, Russia)
- The Numerical Method for the Halactic Orbits Calculation of the Star Clusters (Igor V. Olemskoy , Russia)
- On Closed Loop System Matrix Spectrum Assigning Algorithm (A. D. Ovsyannikov, Russia)

- About One Approach to The Trajectories Bundles Dynamics Optimization Problem (D. A. Ovsyannikov, A. L. Kharchenko, Russia)
- Reduction Proceeding of Symbolic Expressions Structures (Yu. Yu. Ponomarev, Russia)
- A Method for Calculating System of Non-Linear Algebraic Equations (A. A. Pulnikov, Russia)
- On Beam Control in Multi-Resonator System (I.D.Rubtsova , Russia)
- Modeling of Electromagnetic Field MHD-Device with Liquid Metal Work Body (Ph.N. Sarapulov, O.Yu. Sidorov, V.N. Timofeev, Russia)
- Integral Sets of Dynamic Quasiperiodic Systems (S. A. Strekopytov , Russia)
- About The Auto–Oscillation Criteria in Beam Control (M. V. Strekopytova, Russia)
- Field Distribution for Field Emission ”Crater” Cathode (E. M. Vinogradova, Russia)
- On the Optimization of Multiregime Linear Accelerator for Electrons (L.V.Vladimirova, D.A.Ovsyannikov, Yu.A. Svistunov , Russia)
- Flat Field Emission Diode Characteristics Calculation with Space Charge in Control Magnetic Field (B. V. Yakovlev, Russia)
- ”SOLFAS” v.1.0 - A Program for Design of Beam–Lines With Solenoids (I. P. Yudin, Russia)
- About Regimes and Current Stability at Explosive Electron Emission (V.M. Zhukov, Russia)
- Stability Investigation in Beam Control (A. F. Zubova, Russia)
- A Method for Uniform Stability Computing in Beam Control (O. V. Zubova, Russia)
- On Response to Beam Related Errors (Yu. Zuev, V. Petrov, Russia)

5.3.2 Perspectives

In 1997 year (October 13–17) the Fourth International Workshop BDO-97 will be held in Dubna (near Moscow) on the base of the Joint Institute for Nuclear Research. The next (the Fifth Workshop BDO-98) is planned to be held in St.Petersburg again (on first week in July, as usual). The necessary information will be available by e-mail addresses of the JINR (for the Fourth Workshop) and of the St.Petersburg State University (for the next Workshop): The JINR Local Committee E-mail: mag@lcta50.jinr.dubna.su or special (for information) e-mail address which will be announced. The St.Petersburg Organizing Committee E-mail: nick@apmath.spb.su (special e-mail address for the Workshop BDO-98 will be announced later).

5.3.3 Organization

PROGRAM COMMITTEE
chairman - D.A. Ovsyannikov (Russia),
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5.4 Mathematical Aspects of Accelerator Physics

H. Mais (mais@mail.desy.de) DESY
S. Martin (s.martin@kfa-juelich.de) Forschungszentrum Juelich

Modern accelerators have not only become more and more sophisticated from a technical point of view but also from a theoretical point of view. Solving the rather intricate beam dynamics problems of these machines requires a good knowledge and a deep understanding of various mathematical tools and methods as for example from dynamical system theory, stochastic dynamics and partial differential equations - to name only a few. In order to discuss some of these mathematical topics and their applications to accelerator physics a workshop was held in the Physikzentrum (Physics Center) of the German Physical Society in Bad Honnef from Dec. 9 to Dec. 13, 1996. Accelerator and plasma physicists, theoretical and mathematical physicists met to give a view of their research fields and to discuss common techniques and concepts. In a series of review and tutorial talks the invited speakers covered

- the geometrical aspects of phase space in classical mechanics and the role of differential forms (H. Petry, University of Bonn)
- stochastic ordinary and partial differential equations and their analytical (perturbative) and numerical analysis (L. Vazquez, University of Madrid)
- basic concepts of the qualitative theory of dynamical systems such as fixed points, periodic orbits and chaos (H. Mais, DESY)
- diffusion due to modulation and due to explicit stochastic terms in Hamiltonian systems with applications to proton storage rings (A. Bazzani, G. Turchetti, University of Bologna)
- radiative effects in circular electron accelerators and their mathematical modeling (J. Jowett, CERN)
- spin dynamics in storage rings based on the Thomas-Bargmann- Michel-Telegdi (TBMT) equation with applications to HERA (G. Hoffstätter, TH Darmstadt)
- differential algebra techniques and their wide applicability not only in accelerator physics (M. Berz, University of Michigan, East Lansing)
- single bunch instabilities in storage rings (F. Ruggiero, CERN)
- multibunch instabilities in accelerators (J.S. Berg, CERN)
- basic mathematical methods and tools in plasma instabilities (H. Schamel, Univ. Bayreuth)

Besides these review talks there was plenty of time for spontaneous contributions from the participants. In these talks the speakers discussed theoretical topics such as coherent instabilities and solitons in particle accelerators, overlapping spin synchrotron sideband resonances, differential forms in plasma physics, wave packets and nonlinear evolution, geometrical characterization of dynamics, and Landau damping and decoherence of transverse dipole oscillations in colliding beams. Furthermore, there were experimental reports on measurements of third order Hamiltonian coefficients and on the first successful operation of the Darmstadt FEL.

Once more, the Physikzentrum of the German Physical Society has proven to be an ideal place for informal meetings of this kind. The relatively small number of participants (26), the living in the charming old building and the after-dinner discussions with beer and wine in the Bürgerstube not only facilitated the communication among the participants but also made the stay during this week very enjoyable.

At this point it is a pleasure to thank the staff of the Physikzentrum for the friendly and efficient service, which allowed a smooth running of the meeting, especially the help of Dr. J. Debrus with various organizational problems and questions is gratefully acknowledged. The success of the workshop was largely due to the excellent and stimulating lectures given by all the speakers and thanks are due to all participants for making this a lively and exciting meeting. Last but not least this workshop would not have been possible without the generous financial support of the Forschungszentrum Jülich and DESY Hamburg.

5.5 Report on the School on the Physics of Beams in India

Srinivas Krishnagopal (skrishna@cat.ernet.in) CAT, India

A School on the Physics of Beams was held from 13-25 January 1997, at the Centre for Advanced Technology (CAT), Indore, the premier accelerator physics laboratory in the country. The School was sponsored by the Indian Department of Science and Technology. This was the first School of its kind in the country, following in the tradition of the Particle Accelerator schools held regularly in the United States, Europe and Japan. The School was organised by Srinivas Krishnagopal and A. S. Raja Rao of CAT.

There were a total of 53 registered students at the School, representing 15 universities and 5 national laboratories. The backgrounds of the students ranged from first-year Masters students to young professionals in the field. In spite of the varying backgrounds, the common thread amongst the students was that none of them had had a formal, pedagogical, exposure to the physics of beams. There were 12 lecturers at the School, including 3 from abroad: Alex Chao from SLAC, Alex Dragt from Maryland, and Swapan Chattopadhyay from LBNL. The course contents were divided into core topics and special topics. The former were short courses, typically of five hours, and included: (i) introduction to accelerators; (ii) introduction to storage rings; (iii) nonlinear dynamics in accelerators; (iv) introduction to coherent instabilities; (v) introduction to free-electron lasers; (v) introduction to ion sources. The latter were in the form of single seminars, designed to 'fill in the gaps' and give the students a perspective on the field. Topics included: (i) accelerators for high-energy physics; (ii) future accelerators for condensed-matter physics; (iii) beam-plasma interaction; (iv) synchrotron radiation sources; (iv) utilization of synchrotron radiation; (v) synchrotron radiation work at Daresbury; and others.

The response to the School surpassed expectations. The students found the course material interesting and well presented, and attendance didn't thin with the passage of time; the tea-breaks found the students clustered around the lecturers, refusing to let them get some well-deserved refreshments! Subsequent to the School three of the students have expressed their interest in doing their Masters projects on free-electron lasers, and it is to be hoped that their experience would induce them to continue their professional careers in the field. Given the success of this first School, it is proposed to make it a regular feature, with the aim of attracting and training students in the presently nascent but fast-growing field of the Physics of Beams in India.

6: Announcements of Forthcoming Beam Dynamics Events

6.1 WORKSHOP on Fixed Target Physics at the Main Injector

The Fermilab Main Injector is a 120 GeV proton synchrotron scheduled for completion in early 1999. The fixed target physics workshop will be held at Fermilab on May 1-4, 1997. The purpose of this workshop is to review and further develop the plans and prospects for the Main Injector fixed target program. Further information is available at
`http://www.fnal.gov/projects/numi/mist.html`.

6.2 Particle Accelerator Conference

The 1997 Particle Accelerator Conference - the 17th in this series - will be held 12-16 May 1997 at the Hotel Vancouver in downtown Vancouver, British Columbia, Canada, organized by TRIUMF in association with the University of Maryland. Detailed information is available at
`http://www.triumf.ca/pac97.html`.

6.3 Muon-Muon Collider Workshop

A Workshop on Muon Colliders (Workshop Chair: Jonathan Wurtele) will be held immediately following the PAC Meeting, on Orcas Island, Washington, one of the San Juan Islands on Puget Sound (a pleasant drive and ferry ride from Vancouver). The workshop will run from Saturday-Tuesday morning, May 17-20, 1997. The workshop will focus on a point design of a 2 TeV $\times$ 2 TeV muon collider complex, on a lower energy (0.3-0.5 TeV center-of-mass) machine, and on the critical issues on which these machines depend. The complex consists of a number of components which first produce pions, and as a result muons, then capture muons, cool the muons, accelerate the muons and, finally, collide the muons. All three aspects—production, cooling and final collision (ring and detector)—have technical feasibility questions in a few key areas which will be discussed, along with the required R&D, in the working groups.

Accommodations on Orcas Island limit attendance, and, due to the publication date of the newsletter, we cannot guarantee that space will be available. We will, however, make efforts to accommodate all those who wish to attend. If you are interested please contact Ms. Sam Vanecek, conference administrator, 510- 486-4182 (Tel.), 510-486-7981 (Fax), or Sam Vaneck (`sam_vanecek@lbl.gov`). The announcement for this workshop can be found at
`http://www.lbl.gov/Conferences/muon97/`

Much information on the muon collider can be found on the World Wide Web at:
`http://www.cap.bnl.gov/~cap/mumu/mu_home_page.html` and
`http://waldo.fnal.gov/MUMU/mumu.html`.

6.4 Beam Physics Symposium at the OCPA Annual Meeting

Four Chinese Physical Societies (Chinese Physics Society, Taiwan Physical Society, Hong-Kong Physical Society, and OCPA) will hold the next joint annual meeting in Taipei on Aug. 11-15, 1997. The beam physics symposium is organized by A. Chao (`achao@slac.stanford.edu`).

7: Announcements of the Beam Dynamics Panel

7.1 The 13th Advanced ICFA Beam Dynamics Workshop on the Second Generation Plasma Accelerators

Kyoto, 14-18 May, 1997
`http://www-acc-theory.kek.jp/ICFA/plasma.html`
A. Ogata (`picfa@kekvax.kek.jp`)

Scope

Recent theoretical and experimental results on acceleration of particle beams using plasmas and lasers have led to an expansion of the research in this field at many laboratories and universities, and in many countries. There is now a widespread and growing community in this area of research in Europe, Japan and the United States. Accelerating fields over 10GeV/m have been experimentally demonstrated in the laser/plasma systems. These results are also interesting because of the exciting progress in the technology of high peak power, multi-terawatt lasers, and the expectation that in the near future their cost will be reduced, while their average power, and their efficiency will increase.

A new set of experiments are now being designed to show that the beams accelerated by these laser/plasma systems can be of the intensity and phase-space density required for application to practical accelerators to be used industrial, medical, and academic purposes including high energy colliders. These experiments should produce their initial results in the next two to five years.

In view of the present strong, growing and successful activity in this field, and its promise for future developments in accelerators, now is a critical time to organize a workshop, which will be dedicated to the topic of beam quality in laser/plasma accelerators.

This workshop will be joined together by the First JAERI Workshop on Ultrashort-Pulse Ultrahigh-Power Lasers and Simulations for Laser-Plasma Interactions, as the Joint ICFA/JAERI-Kansai International Workshop '97. These two workshops are loosely coupled. All the participants are free to join either of the workshops. Interchange of discussions between two parties will be highly welcomed.

Organization

CHAIRS: C. Pellegrini (UCLA) and A. Ogata (KEK)
LOCAL ORGANIZING COMMITTEE:
T.Arisawa (JAERI) Y.Kimura (KEK) K.Mima (ILE, Osaka U.) K.Miya (U. Tokyo)
Y.Nishida (Utsunomiya U.) R.Sugihara (Nagoya U.) S.Tagawa (Osaka U.)
K.Hirata (KEK, secretary) K.Tani (JAERI, secretary) K.Nakajima (KEK, secretary) A.Ogata (KEK, secretary)
PROGRAM COMMITTEE:
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K.Hirata (KEK) C.Joshi (UCLA) T.Katsouleas (USC) Y.Kitagawa (ILE, Osaka U.)
K.Nakajima (KEK/JAERI) Y.Nishida (Utsunomiya U) A.Noda (ICR, Kyoto Univ.) A.Ogata (KEK)
C.Pellegrini (UCLA) A.Skrinsky (INP) R.Siemann (SLAC) P.Sprangle (NRL)
T.Tajima (U. Texas, Austin) S.Tazzari (LNF)

Invited Talks (tentative)

C. Clayton	UCLA	Second Generation Beatwave Experiments at UCLA
M. Downer	U.Texas, Austin	Laser Wakefield Acceleration Experiments
R. Assmann	SLAC	Proposal for a 1GeV Plasma-Wakefield Acceleration Experiment at SLAC
A. Skrinsky	INP	Plasma Wakefield Acceleration Projects at INP (to be confirmed)
H. Milchberg	U. Maryland	Recent Results from the University of Maryland Plasma Waveguide Experiments
F. Amiranoff	LULI	(to be confirmed)
Y. Nishida	Utsunomiya U.	Plasma Based Cross-Field Particle Acceleration with High Power Microwave
H. Dewa	JAERI	KEK-JAERI-U.Tokyo Experiments

Talks by G. Mourou, C. Barty and A. Antonetti will be given at the plenary session of the JAERI Workshop.

Working Groups

group		chairs
I	injection and dynamics of accelerated beams	K. Yokoya, J.Rosenzweig
II	dynamics of plasma-wave drivers (lasers in LWFA and beams in PWFA) and plasmas	T. Katsouleas, K.Nakajima
III	near-term and far-term applications of plasma accelerators	T.Tajima, S.Chattopadhyay

PROGRAM

July 14 (Mo)	
morning:	registration, plenary (opening, invited talks)
afternoon:	plenary (invited talks, WG organization)
evening:	reception
15(Tu)	
morning:	WG
afternoon:	WG
evening:	free
16(Wed)	
morning:	WG
afternoon:	plenary (invited talks, joint with JAERI workshop.)
evening:	Workshop banquet and the Gion Festival Eve
17(Th)	
morning:	free (Gion Festival ”Yamaboko Junko”)
afternoon:	WG
evening:	free
18(Fr)	
morning:	plenary (WG reports, closing)

7.2 The 14th Advanced ICFA Beam Dynamics Workshop on e^+e^- Factories

Oct. 20-25, 1997
L. Palumbo, Program committee chairman
Frascati National Laboratories, Italy

The ICFA advanced beam dynamics workshop on issuess for e^+e^- factories will take place at the Frascati National Laboratories (Italy) on Oct. 20-25, 1997. It is aimed at the accelerator physics community working on the development, commissioning or design of high luminosity electron positron colliders with particular regard to phi, B and tau-charm factories and to LEP and CESR colliders.

Primary goal of this workshop is to discuss beam dynamics issues related to high luminosity: Theoretical analysis and predictions, New developments, Technological limitations, Experimental observations. There will be 4 working groups on the following subjects:

- Interaction region design
- Single Particle Dynamics
- Beam-Beam Effects
- Impedance, Instabilities , Cures

The deadline of registration is March 31, 1997. The deadline for abstracts is Oct. 1, 1997. Detailed registration information is available at
`http://www.lnf.infn.it/conference/icfa97.html`.
e-mail available at ICFA97: (`icfa97@axlnf1.lnf.infn.it`).

7.3 New Working Group on High Brightness Hadron Beams in ICFA Beam Dynamics Panel

Weiren Chou (`chou@fnal.gov`) Fermilab, Batavia, IL 60510, USA

At its recent meeting of January 31, 1997, the ICFA approved the formation in the Beam Dynamics Panel of a new Working Group on High Intensity High Brightness Hadron Beams. The mission of this group is stated as follows:

> “To promote beam dynamics studies for high intensity, high brightness hadron beams and to foster applications of such beams in high energy physics and other fields such as nuclear physics, industry, etc. by inter-laboratory and international collaborations.”

The members are:

Baartman, Rick	TRIUMF	krab@triumf.ca
Chou, Weiren (Chair)	FNAL	chou@adcalc.fnal.gov
Colestock, Patrick	FNAL	colestock@adcalc.fnal.gov
Davidson, Ronald	PPPL	rdavidson@pppl.gov
Galayda, John	ANL	galayda@aps.anl.gov
Linnecar, Trevor	CERN	trevor.linnecar@cern.ch
Machida, Shinji	KEK/INS	machida@kekvax.kek.jp

Maidment, John	DESY	maidment@vxdesy.desy.de
Mori, Yoshiharu	KEK/INS	moriy@kekvax.kek.jp
Pestrikov, Dmitri	BINP	pestrikov@inp.nsk.su
Rees, Grahame	RAL	jvt45@isise.rl.ac.uk
Roser, Thomas	BNL	roser@bnl.gov
Wurtele, Jonathan	LBL	JSWurtele@lbl.gov
Zhang, Chuang	IHEP	zhangc@bepc3.ihep.ac.cn

The ICFA also approved two mini-workshops that will be sponsored by this group. One is scheduled May 7-9, 1997 at BNL. The topic is longitudinal dynamics and rf related subjects (longitudinal emittance, HOM, rf gymnastics, beam loading, barrier buckets and slip stacking, etc.). Tom Roser is the organizer. Details can be found in his announcement in this issue of Newsletter. Another will be November 5-7, 1997 at CERN. The topic is emittance conservation and measurement. The organizer is Roberto Cappi (roberto.cappi@cern.ch).

This group has a home page on the web, which is presently under construction. Its temporary address is `http://www-acc-theory.kek.jp/ICFA/proton.html`. The permanent address will be announced after the construction is completed. Any comments and suggestions of how to make the work of this group productive and effective would be greatly appreciated. We look forward to working together with all of you in the accelerator community for accomplishing our mission in the years to come.

7.4 ICFA Mini-Workshop on High Intensity High Brightness Hadron Accelerators

May 7 - 9, 1997, Berkener Hall Room B.
Brookhaven National Laboratory, Upton NY, USA

Four institutions–the PS Division at CERN, the PS Division at KEK, the AGS Department at BNL, and the Main Injector Department at Fermilab–have agreed on a collaboration to co-sponsor a mini-workshop series. The purpose of this series is to investigate the major technical issues associated with achieving high intensity, high brightness hadron beams. This type of beam is expected in such accelerators as the Proton Synchrotron in the LHC era at CERN, the AGS in the RHIC era at BNL, the 50-GeV synchrotron being designed at KEK, and the Main Injector being constructed at Fermilab. The Workshop will be problem-solving oriented rather than presentations oriented. In particular, there will not be any formal proceedings. Summary reports from working groups will be the main publication.

The 3rd Mini-Workshop on high intensity, high brightness hadron accelerators will be held at BNL, May 7-9, 1997 and will focus on longitudinal dynamics and rf related issues. It will start with a half day plenary session with representatives from CERN, FNAL, INS/KEK, BNL and possibly other laboratories presenting experimental results from and plans for existing machines. Working Group Discussion Items are listed as follows.

- Barrier cavity issues: generating sufficient gap voltage, rf feedback and other control issues, cavity design and driver considerations.
- Longitudinal emittance control: effect of mismatch, controlled emittance growth.

- Longitudinal instabilities: theory and simulation, convergence and accuracy issues, comparison of theory/simulation with experiment, effects of barrier cavities and higher harmonic cavities, machine impedance issues.
- Beam loading and rf system stability

Registration form is available at: `http://www-acc-theory.kek.jp/ICFA/proton.html`. For further information, please contact:

Organizing committee	Telephone	email
Thomas Roser, Chairman	(516) 344 7084	roser@bnl.gov
Michael Blaskiewicz, Scientific Sec.	(516) 344 7049	mmb@bnl.gov
Marion Heimerle, Secretary	(516) 344 5954	heimerle@bnl.gov

7.5 ICFA Beam Dynamics Newsletter

Editors in chief

Kohji Hirata (`hirata@kekvax.kek.jp`)
John Jowett (`John.Jowett@cern.ch`)
S.Y.Lee (`shylee@indiana.edu`)

7.5.1 Instructions to the authors

The ICFA Beam Dynamics Newsletter is intended as a channel for describing unsolved problems and highlighting important ongoing works, and not as substitute for journal articles and conference proceedings which usually describe completed work. It is published by the ICFA Beam Dynamics Panel, one of whose missions is to encourage international collaboration in beam dynamics.

It is published every April, August and December. The deadlines are 15 March, 15 July and 15 November, respectively.

The categories of articles in the newsletter are the following:

1. Announcements from the panel
2. Reports of Beam Dynamics Activity of a group
3. Reports of Beam Dynamics related workshops and meetings
4. Announcements of future Beam Dynamics related international workshops and meetings.

   Those who want to use newsletter to announce their workshops etc can do so. Articles should typically fit within half a page and include descriptions of the subject, date, place and details of the contact person.
5. Review of Beam Dynamics Problems

   This is a place to put forward unsolved problems and not to be used as the achievement report. Clear and short highlights on the problem is encouraged.
6. Letters to the editor

   It is a forum open to everyone. Anybody can show his/her opinion on the beam dynamics and related activities, by sending it to one of the editors. The editors keep the right to reject a contribution.
7. Editorial

All articles except for 6) are by invitation only. The editors request an article following a recommendation by panel members. Those who wish to submit an article are encouraged to contact a nearby panel member.

The manuscript should be sent to one of the editors as a LaTeX file or plain text. The former is encouraged and authors are asked to follow the example below.

Each article should have the title, author's name(s) and his/her/their e-mail address(es).

To avoid wrapping problem, please do not put comments (through e-mail.

7.5.1.1 An example of LaTeX format

The following can be used as a model for preparing contributions.

```
\documentclass{report}
\usepackage{graphics}

% PLEASE USE THESE DUMMY DEFINITIONS FOR DRAFTING AND
% DO NOT CHANGE THEM !!
% They will facilitate the conversion to hypertext for WWW.

% use this to give a link on WWW
\newcommand{\htmllink}[1]{\texttt{#1}}

% use this to give a person's name and email address
\newcommand{\email}[2]{#1 (\texttt{#2})}

% use this to give name, email and address at the top of a
% contribution
\newcommand{\contact}[3]{{\noindent%
                          \makebox{\textit{#1}}\hfill%
                                   \makebox{\texttt{#2}}\hfill%
                                   \makebox{{\small\raggedright#3}}\\%
                                 }
                         }%
                        }
% The following can be used for long comments
\newcommand{\comm}[1]{}

\begin{document}
\section{Beam Dynamics Activities at KEK}

\contact{K.~Hirata}{hirata@kekvax.kek.jp}{KEK\\
                     National Laboratory for High Energy Physics}

Recent developments at KEK include \ldots

\subsection{Further instructions}

You can refer to these instructions at
\htmllink{http://130.87.74.156/ICFA/instruction.html}.

Please prepare your contribution as plain text or straightforward
\LaTeX, following this example.  Remember that the final version
(fonts, layout, etc.) of the newsletter (whether on the World-Wide Web
or on paper) will look very different from your draft so it is
```

```
\emph{useless to include any visual formatting commands} (such as
vertical or horizontal spacing, centering, tabs, etc.).  Use only
structural markup as recommended in~\cite{Lamport}.

Above all, avoid \TeX\ ccommands that are not part of standard \LaTeX.
These include the likes of \verb|\def|, \verb|\centerline|,
\verb|\align|, \ldots.

These restrictions are necessary so that we can automate production
and conversion of the newsletter into HTML for the Web.

Please include the author's name, electronic mail and laboratory
addresses as above and keep the title of your section concise.

Please keep figures to a minimum.
The preferred graphics format is Encapsulated Postscript (EPS) files.

Remembering that this is a newsletter and not a journal or laboratory
report, please also avoid using too much mathematics and giving formal
statements of results.

\begin{figure}[htbp]
    \resizebox{\columnwidth}{!}
         {\includegraphics*[144bp,598bp][349bp,720bp]{dummy.eps}}
    \caption{Example of a figure.
             The optional arguments give the coordinates of the
             lower left and upper right corners of the part of the
             image which is to be included.
             The units bp are the same ``points'' used in Postscript.
             The image is resized to the width of the current column.
             See~\protect\cite{Lamport}, pp.129--131.
            }
    \label{fig:example}
\end{figure}

A short bibliography may be included.
\begin{thebibliography}{99}

\bibitem{Lamport}
      \LaTeX: A Document Preparation System, Second Edition
      Addison-Wesley, Reading, Massachusetts, 1994.

\end{thebibliography}
\end{document}
```

7.5.2 World-Wide Web

Recent issues of this newsletter are available through the World-Wide-Web via the addresses given below. This is now intended as the *primary method of communication.*

The home page of the ICFA Beam Dynamics Panel is at the address

`http://www-acc-theory.kek.jp/ICFA/icfa.html` which happens to be in Japan. For reasons of access speed, there are mirror sites for Europe and the USA at

```
http://wwwslap.cern.ch/icfa/
http://www.indiana.edu/~icfa/icfa.html
```

All three sites are essentially identical and provide access to the Newsletters, Future Workshops, and other information useful to accelerator physicists. There are links to information of local interest for each area.

7.5.3 Distribution

The ICFA Beam Dynamics Newsletters are distributed through the following distributors:

W. Chou	chou@adcon.fnal.gov	North and South Americas
Helmut Mais	MAIS@mail.DESY.DE	Europe* and Africa
Susumu Kamada	kamada@kekvax.kek.jp	Asia** and Pacific

(*) including former Soviet Union.
(**) For mainland China, Chuang Zhang (zhangc@bepc5.ihep.ac.cn) takes care of the distribution with Ms. Su Ping, Secretariat of PASC, P.O.Box 918, Beijing 100039, China.

It can be distributed on a personal basis. Those who want to receive it regularly can ask the distributor to do so. In order to reduce the distribution cost, however, please use WWW as much as possible.

7.5.4 ICFA Beam Dynamics Panel Members

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The views expressed in this newsletter do not necessarily coincide with those of the editors. The individual authors are responsible for their text.