International Committee for Future Accelerators

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BEAM DYNAMICS
NEWSLETTER

No. 16

edited by
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Contents

1: Forewords

1.1 From the chairman of ICFA Beam Dynamics Panel

K. Hirata `hirata@kekvax.kek.jp` the chairman

This time, I would like to consider the beam dynamics from the high energy physics (HEP) point of view. Since ICFA is a committee for HEP, this seems to be quite appropriate. There seems to be increasing criticism on HEP from outside (other disciplines of physics, scientific communities other than physics, some parts of government, and tax-payers) on the balance between ”huge” investment on HEP and its outcome. This might be one of the reasons of the cancellation of SSC.

From HEP point of view, the essentially important is to have the most advanced (in energy or luminosity) accelerator. In fact, the history of HEP consists of the competition and collaboration between physicists, laboratories, and nations in constructing new and powerful machines. An enormous amount of efforts has been made to develop accelerators. As by-products, many non-HEP accelerator were born, high intensity nuclear physics accelerators, synchrotron light sources, medical and industrial accelerators and so on. These accelerators can be regarded as the most practically useful outcome of HEP activity. It can be counted as a pay-back to the society for the huge investment to HEP.

Roughly speaking, the main developments of accelerators have been achieved in several big laboratories for HEP. It is natural because these laboratories have money and people. It seems, however, now that the flow of knowledge is becoming two-ways. This has started long time ago and became more and more important gradually. It means that the high energy accelerator community is becoming a part of more general accelerator community, where everybody helps others.

There is a serious dilemma for HEP. As the consequence of the competition and the demands in the HEP society, the major HEP laboratories are more or less obliged to **concentrate** on the present and near future projects. That is, accelerator physicists there should concentrate on the improvement within the present scheme. This is the way to make the best use of the present accelerator physicists and the way to produce more powerful accelerators within limited time and man power. This tends to lead to larger accelerators. Clearly, there is the upper limit in the size and the cost. The cancellation of SSC might imply that we are actually not far from the limit.

One way might be that the big laboratories stop the construction and R&D of near future accelerators for the moment and concentrate on the development of new, small but powerful, and realistic acceleration schemes. It seems, however, almost impossible. This is the dilemma of big HEP laboratories.

The only possible way for HEP community to go beyond the present situation might be that it encourages the world-wide collaboration between big laboratories, small laboratories and universities on the development of the accelerator physics which is free from any particular projects and not restricted to direct applications. This kind of activity is not fast and must be promoted more vigorously. Such “purely academic” research will eventually benefit the HEP as well as wide variety of research projects related to all kinds of accelerators.

I believe the above is one of the reasons why ICFA supports the present activities of the beam dynamics panel which is trying to integrate all the beam dynamics activities, “immediately useful” or not, into a world-wide community where everyone is helping others and enjoying physics at the same time.

2: Letters to the Editors

2.1 From Christoph Iselin, Eberhard Keil and Richard Talman

To: ICFA Beam Dynamics Newsletter, CLASSIC collaboration, and BNL Workshop on the Unified Accelerator Library

Call for a new accelerator description standard

Dear Members of the Accelerator Community,

Future colliders, such as the LHC, are or will be designed, constructed, commissioned and operated by international collaborations, often working remotely. This makes it essential for faithful lattice descriptions to be network-retrievable from a centrally-maintained, up-to-date source, for use by a variety of beam-dynamics programs.

It is now 14 years since the Snowmass Summer Study when Carey and Iselin [1] defined a standard input format (SIF) which successfully led to implementations in programs like MAD, SAD, TEAPOT and TRANSPORT. At the same time, Iselin, Keil and Niederer [2] introduced the concept of *common* database programs, which did not, however, lead to any effective standardization. Though there have been similarly intentioned efforts such as CLASSIC, the DOOM database to MAD implemented recently by Grote, and the SMF lattice description by Malitsky *et. al.* at BNL-Cornell, there has been no commonality.

It is therefore time to try again to define an accelerator description standard (ADS?) with the following objectives:

1. It should serve from the early phases of conceptual *design*, through the engineering design and *analysis*, to the *operation* of the accelerator.
2. It should generalize (but not replace) SIF in ways that experience has dictated appropriate.
3. Containing only element and lattice description and no beam dynamics, it is to be usable without prejudice by any physical method.
4. It should respect modern computer science standards, especially concerning database management and accessibility over networks.

To improve prospects for its broad adoption as a standard, ADS should mimic SIF where possible (retaining basic accelerator objects and their attributes for example), deviating only in essential ways, some of which are:

Flexibility Examples are: freedom (but not encouragement) to introduce additional elements or additional attributes to existing elements in a standard (for other purposes ignorable) way, support for shared lines (such as two rings), provision for definition of “families” of elements, and inclusion of algorithmic-specific data that is ignorable by default.

Full-instantiation Every ring element has its own parameters and may have its own name (laboratory-wide, for example).

Multiple-realization, in forms optimized for efficient computation (independent of particular computer language), ease of modification, network transmission, database management, and human editing. (Existing programs show that such flexibility is feasible.)

Minimal Completeness. All elements that can influence single particle motion (in their idealized operation) and only those elements are contained.

Extensions of the standard such as aperture sizes and shapes, and hardware limits on element strengths.

Other features that have been suggested include: *Ideal-actual* distinction between design lattice and lattice with deviations (be they intentional or unintentional, constant or time dependent), *error bars* for element parameters, and *nested line* preservation from an underlying SIF design.

Therefore we seek a small committee of representative and knowledgeable experts to volunteer to draft such a standard for later consideration by a broader community.

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3: Activity Reports

3.1 Measurement of third-order Hamilton coefficients at COSY

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Lie Algebraic tools provide a powerful method for describing and computing non-linear effects by making use of the equations of motions from the Hamiltonian that describes the particle motion through an electric and magnetic field. Let H be the Hamiltonian of a dynamical time-independent system. M is, in general, a non-linear functional operator that describes the transfer map of a particle. It is possible to write it in a matrix form when its Hamiltonian is known. The Lie operator is defined in terms of Poisson brackets. The transformation can be written as a product of Lie transformations [1]

$$M = \exp(-t : K :)L \tag{3.1}$$

where L is the linear transfer matrix through the beam line and K is a polynomial that describes the cumulative effect of all non-linear elements. We truncate the power series of Eq. 3.1 at third-order and only calculate up to third-order (sextupole aberrations). The Hamiltonian K consists of 20 independent third-order monomials in the four variables x, x', z, z' (in these variables x and $p_x = p_0 x'$ are canonically conjugate).

3.1.1 Method

The following method is utilized to determine the coefficients of the Hamiltonian that represent the sextupole effects in the beam line to first-order [2]. The method is based on the low-frequency sinusoidal excitation of the orbit corrector magnets (steerers) and detecting the response signals at mixed harmonics of the exciting signals at the beam position monitors (BPM's). Two horizontal and two vertical steerer dipoles are each excited at 4 different frequencies which are far off the tune (around 100 Hz) and with small amplitudes to ensure linear behavior ($\approx$ 1 mrad). The response of the beam is observed at different BPM's (horizontal and vertical about 1-2 mm). When the beam is excited with four different correctors (frequencies: f_1, f_2, f_3 and f_4), respectively 16 additional frequencies plus a DC-offset are observed. The corresponding frequencies are: 0, $2f_1$, $f_1 + f_2$, $f_1 - f_2$, $f_1 + f_3$, $f_1 - f_3$, $f_1 + f_4$, $f_1 - f_4$, $2f_2$, $f_2 + f_3$, $f_2 - f_3$, $f_2 + f_4$, $f_2 - f_4$, $2f_3$, $f_3 + f_4$, $f_3 - f_4$ and $2f_4$. These frequencies can be observed at individual BPM's. The Hamilton coefficients can be calculated with numerical codes and the beam response can be predicted. Numerical calculations have been carried out to simulate the expected results. It is also possible to calculate the individual Hamilton coefficients when the amplitude of the 16 response signals are known at four different BPM's (two horizontal and two vertical). The beam response is measured and the method and the results are presented in the next subsections.

3.1.2 Setup

The bunch in the COSY accelerator is excited with four wobbling steerer magnets (two horizontal and two vertical ones). All four steerers have a different frequency (f_1=56 Hz, f_2=107 Hz, f_3=131

Hz and f_4=140 Hz). The beam response is measured at different horizontal and vertical BPM's. Not only the excitation frequencies are present in the response but also the cosine-like sum and difference frequencies (mixing frequencies) are observed when sextupole magnets were turned on.

Theoretical calculations show that the amplitude belonging to the mixing frequencies depends on the kick size of the steerer. Furthermore, the amplitude belonging to the mixing frequencies depends on the amplitude of the sextupole strength. The amplitude of the measured peak increases quadratically when the kick of the steerer magnets is increased linearly. The amplitude of the measured peak increases linearly as function of the sextupole (non-linear) excitation. To verify these results measurements are done and compared to calculations.

3.1.3 Results

At the accelerator COSY the wobbling method was used to measure the third-order Hamilton coefficients.

The spectra are measured and the peaks belonging to the non-linear frequencies are observed. When we investigate the TRANSPORT mapping of a sextupole [3], we see that only terms of x^2, xx', x'^2, z^2, zz' and z'^2 are excited in the horizontal plane. In the vertical plane only the terms xz, xz', $x'z$ and $x'z'$ are excited. In the horizontal spectra we expect to detect signals of $f_3 - f_4$, $f_1 - f_2$, $2f_1$, $f_1 + f_2$, $2f_2$, $2f_3$, $f_3 + f_4$ and $2f_4$. In the vertical plane the other frequencies should be measured (beside the excitation frequencies). Measurements at several BPM's show that this is the case. It is possible to detect the non-linear frequencies as is shown in figure 3.1. In this plot the artifacts and noise are removed. The excitation frequencies and the peaks of the non-linear frequencies are visible.

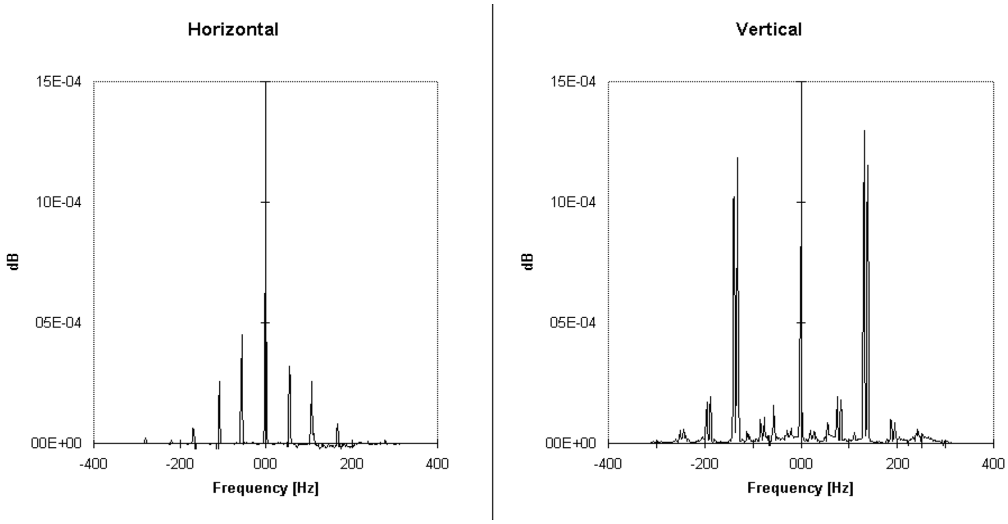

Figure 3.1: *Measured horizontal and vertical frequency spectrum. The difference between a measurement with and without sextupole excitation (sextupole MXL13) is plotted.*

For a quantitative evaluation of the amplitude of a non-linear peak the sextupole strength is varied or the steerer amplitude is varied. The corresponding measurements were carried out and the result was as follows. Firstly, the expected linear increase of the amplitude of the non-linear peaks as function of the sextupole strength is observed in measurements. Secondly, the quadratically increase of the amplitude of the non-linear peaks is measured when the kick of the steerer magnets is increased linearly [5].

The calculations show that it is possible to estimate the amplitude of the mixing frequencies. The measurements were repeated with other BPM's and using other sextupoles. Comparison with numerical results obtained from calculations with the numerical code COSY INFINITY [4] show that the results are roughly in agreement with the measured results [5]. However, the measurements are not accurate due to the large errors. This indicates that further development of the method presented here is useful.

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3.2 Beam Dynamics Activities of DSAT Group at the University of Maryland

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Recent beam dynamics work in the University of Maryland Dynamical Systems and Accelerator Theory (DSAT) Group has focused on the following topics: halo formation in 3-D ion bunches, fast particle tracking with Cremona maps, and computation of exact transfer maps from magnetic field data.

A list of all of the recent publications from the DSAT group, which is jointly directed by Profs. A. Dragt and R.L. Gluckstern, can be found on the WWW at `http://dsatpc3.umd.edu/`.

3.2.1 Halo formation in 3-D ion bunches

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The need for high current in a variety of new accelerator applications has focused a great deal of attention on understanding the phenomenon of halo formation in ion beams, which can cause excessive radioactivation of the accelerator. Starting in about 1991, a variety of two-dimensional (2-D) simulation studies have led to the conclusion that halos are formed when a beam is mismatched to a focusing channel, exciting some sort of collective oscillation(s) of the beam which are in parametric resonance with the non-linear oscillation of individual ions.

Most of the simulations studies start with rms matched beams which are *not* stationary solutions of the Vlasov equation. As a result, the initial beam undergoes some sort of redistribution in phase space, masking the possible development of halos. Our effort has been devoted to populating a stationary distribution in phase space, in the hope that the halo development mechanism can be studied without being obscured by the "relaxation" of the beam in phase space. We have particularly studied initial distributions which are stationary by virtue of being a function only of the Hamiltonian.

It is clear that a realistic treatment of halo formation must take into account 3-D beam bunches and 6-D phase-space distributions. We have constructed, analytically and numerically, a new class of self-consistent 6-D phase-space stationary distributions [1]. The beam is then mismatched longitudinally and/or transversely, and we explore the formation of longitudinal and transverse halos in 3-D spheroidal (axisymmetric) beam bunches. Our main conclusion is that the longitudinal halo is of great importance because it develops earlier than the transverse halo for elongated bunches with comparable longitudinal and transverse mismatches, and because it occurs even for mismatches of order 10%. In addition, the control of the longitudinal halo could be challenging if the phase width of a beam bunch in the RF bucket cannot be made sufficiently small. Of particular importance is the result that, due to the coupling between longitudinal and transverse motion, a longitudinal or transverse halo is observed for a mismatch less than 10% if the mismatch in the other plane is large. We also found that the effect of coupling is especially important in short beam bunches (bunch length / bunch width < 3).

Now that the parameters which lead to halo formation in 3-D beam bunches for the 6-D self-consistent phase space distribution have been established, we explore distributions which are *not* self-consistent, to determine the extent to which the relatively rapid redistribution in the 6-D phase space influences the formation of halos.

3.2.2 Particle Tracking with Cremona Maps

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For circular machines that store particles for long periods of times, one must perform long-term tracking studies to determine orbit stability. For proton machines in which synchrotron-radiation effects on orbits are negligible, one must use a symplectic tracking code.

We have developed the tracking code CTRACK based on the concept of a Cremona map. Such maps constitute a special class of symplectic maps: their distinguishing feature is that they are also polynomial maps. This means that one can evaluate Cremona maps very rapidly.

Consider a map, expressed in the form of a truncated Taylor series, which approximates a multi-element symplectic map (*e.g.* a map describing motion through a collection of beam-line elements). It can be shown that, by adding some judiciously chosen higher-order terms to the truncated Taylor series, one can convert this map to a corresponding Cremona map. Since truncating a Taylor series generally violates the symplectic condition, this conversion process constitutes a form of symplectification. In prior work our group has developed means for performing this Cremona symplectification in an optimal manner—optimal in the sense that the terms added to the Taylor series are as small as possible [2].

In current work we are using CTRACK to study the dynamic aperture of the LHC [3]. Because the proposed lattice possesses a relatively small non-linearity, we have found that Cremona tracking with a one-turn map accurately predicts the same dynamic aperture as does element-by-element tracking—and it does so in much less time. At present CTRACK runs about four times faster than the element-by-element code SIXTRACK when applied to a simplified model of the LHC, but we expect to improve this to about a factor of ten. Also, by using one-turn maps, we can now model the LHC much more accurately—say by treating all elements as thick with a complete set of errors and including realistic magnet fringe fields—at no cost to the tracking speed. Future work (jointly with CERN) will include beam-beam studies in which the beam-beam interactions will be treated in some detail, and transit around the ring between beam-beam interactions will be described by a Cremona map.

3.2.3 Computation of exact transfer maps from magnetic field data

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Consider a beamline element such as a short or moderate length dipole, a quadrupole, or a higher-order multipole. Suppose one component (for example, the radial component) of the magnetic field is known on the surface of some imaginary cylinder coaxial to and contained within the magnet aperture. This information, which can be obtained either by direct measurement or by computation with the aid of some 3D electromagnetic code, can be used to compute the exact transfer map for the beamline element. Alternatively, one can compute the transfer map starting from short spinning coil data. A transfer map computed in this way takes into account all effects of real beamline elements including fringe-field and multipole-error effects [4]. Such transfer maps can then be used to compute accurately the aberration behavior of real single-pass systems such as microscopes, telescopes, spectrometers, and final-focus systems for linear colliders. They can also be used to compute without idealizations orbit stability and the dynamic aperture for circulating systems such as storage rings. The method we use automatically takes into account the smoothing properties of the Laplace Green function. Consequently, it is robust against both measurement and electromagnetic code errors. We have implemented our method in the code MARYLIE and are currently using it to study fringe-field and multipole-error effects in the Fermilab Recycler permanent magnets and in the high-gradient quadrupoles for the low-beta insertions in the LHC.

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3.3 Beam Dynamics Activities for CLIC at CERN

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Considerable effort has been invested in establishing a general set of scaling laws for the rational design of e^+e^- linear colliders. It has been shown that as long as the beam and linac parameters are chosen to fulfill the “BNS damping condition, and that optimum structure parameters are selected to maximize the RF efficiency, then operation with a higher acceleration gradient using high frequency structures results in (i) the same or better RF efficiency, (ii) the same or better luminosity to power ratio for equivalent background conditions, and (iii) the same beam quality preservation for equivalent beam correction techniques, as the lower frequency designs. As a consequence of this analysis the CLIC parameters have been updated. For the 0.5 and 1 TeV machines the charge and the bunch length have both been decreased (to 4×10^9 and $50\mu\mathrm{m}$ respectively) to reduce transverse wakefield effects. A revised CLIC parameter list compiled in October 1997 has luminosities of $6.1 \times 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ and $14.1 \times 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ for the 0.5 and 1 TeV machines with 60 bunches per pulse and an overall wall plug power of 92 MW and 161 MW respectively. This assumes final, vertical normalized emittances of 0.1 mm-mrad which simulations have shown to be feasible with simple correction schemes and a vertical emittance at injection equal to half this value. Since high frequencies permit the accelerating structures to be operated at high accelerating gradients (100 to 150 MV/m at the CLIC 30 GHz) which reduce the length of the linacs and therefore the cost, multiple TeV machines also become possible. Parameters for machines up to 5 TeV have been investigated and found to be feasible.

Beam dynamics studies for the main linac focused on single and multibunch emittance preservation using in some cases newly written computer programs. These studies have been guided by the results obtained from the work on the general scaling laws and have tried in particular to obtain a significant reduction of the single bunch wakefield, and to make multibunch effects in comparison very small in spite of the increase of the number of bunches per pulse. It was found that with 4x109 particles per bunch and an rms bunch length of $50\mu\mathrm{m}$ the BNS stability criterion could be obtained by introducing approximately 1% correlated energy spread across the bunch by running off the crest of the RF wave. The r.m.s. energy spread at the end of the linac in this case was adjusted to be 0.25% about. Micro-wave quadrupole structures for beam stabilization are therefore no longer necessary. A new design of the two-stage bunch compressor has been made to achieve the high compression rate needed (60) and a new lattice, scaled in sectors, was recalculated to match the new parameters. Simulations of multibunch emittance growth have been made using different accelerating structure wakefields models. For a bunch separation of 20 RF periods, it was found that the wakefield had to be reduced by a factor of between 65 to100 at the level of the second bunch and thereafter with an initial exponential decay of at least an order of magnitude over the first few meters. More emphasis has been placed on the use of simple correction schemes to achieve the specified machine performance in preference to the previously developed more sophisticated global trajectory corrections. A new trajectory correction scheme has been studied. It involves the measurement of the off-sets of the beam position monitors using the beam with quadrupoles over successive sections of 12 quadrupoles switched off and the beam in the last quadrupole centered. Storing these off-sets and applying a simple one-to-one correction produced a simulated vertical emittance growth less than 100 % for the 1 TeV machine (since the emittance ratio is of the order of 15 to 20, the horizontal blow-up is not critical). This value was further reduced to about 20-40 % by introducing emittance bumps by displacing two structures and minimizing the measured emittances at five positions along the linac. With the wakefield roll-off described above, the contribution to the emittance of multibunch beam break-up is kept below 10 %, as well as the ground motion effects when periodic trajectory corrections are assumed. Hence, the total, relative vertical growth simulated with $50\mu\mathrm{m}$ r.m.s. random quadrupole misalignments and $10\mu\mathrm{m}$ r.m.s. position monitor as well as cavity misalignments is well below the value of 100 % that would give the 0.1 mm-mrad quoted above and therefore provides a margin for effects not yet included. Simulations for the 5 TeV center-of-mass machine showed that the single bunch dilution can be kept under control, that multibunch dilution remains small, but that jitter as well as slow drifts of the components require frequent re-steering of the trajectory or the use of a slow feedback loop.

Work recently started on a new multi-drive-beam scheme which makes use of many of the developments of the past several years. It incorporates in particular the frequency multiplication and power distribution systems that were developed for the so-called ring scheme, where two rings of precisely defined circumferences are used to interleave four successive bunch trains over four turns in order to reduce the distance between bunches by the same factor four after their passage in each ring. The distribution system sends the drive beam towards the accelerating main beam allowing different time slices of the drive beam to be used to power separate sections of the main linac. The bunches however are generated by a conventional normal conducting fully-loaded 625 MHz accelerating system. The scheme requires the generation of a 5 A $100\mu\mathrm{s}$ beam of about 1.5 GeV energy. It has been shown that this beam can be generated with an efficiency of about 97 %. So far the technology to accelerate this beam seems very straightforward. The klystrons necessary are not presently available, but experts believe that they are relatively straightforward to build. The modulators are similar to ones that have already been built. The beam can be stabilized transversely during acceleration and the full beam loading provides a constant energy beam with some relatively minor beam loading compensation. After acceleration the beam is frequency multiplied ($\times 16$) and pulse compressed by the "ring" system. The final drive beam for one 625m long section of the 1 TeV machine has 1360 bunches with 11.7 nC per bunch and an energy of about 1.1 GeV. A first look at this system has shown no show-stoppers. This scheme seems to scale very nicely to either lower or higher energy with little change, and could also be used for other frequencies.

The challenge of the multi-drive-beam scheme is to keep transverse stability while the beam is being decelerated. As a consequence, an important parallel and necessary activity to confirm the validity of the above-mentioned drive beam studies has been the beam dynamics simulations of the behavior of the bunched beam in their associated power generating drive linacs. The full analysis including beam dynamics in the presence of collective effects and resistive structures is far too complicated to be treated by a single simulation program. In some cases new simulation programs have been written for this purpose. Some of the issues that have been examined individually include: the effects of electromagnetic field inhomogeneity on single particle dynamics; the choice of optimum transport lattices; beam disruption due to resistive-wall and synchronous wakefields; and the management of low-level losses in terms of beam control and structural heating. This information has then been fed back into the overall design study. Significant design changes have resulted from these studies. They include: the development of RF transfer structures with greater field homogeneity; an overall reduction of the disruptive effect of transverse wakefields by moving towards stronger focusing lattices and the use of RF transfer structures which incorporate microwave absorber to give some passive damping of these wakes. These changes have been optimized for the drive beam scheme under study and these considerations effectively dictate the requirements for a suitable design. Much more work in this direction is needed to improve the robustness of the RF power linac (decelerating the beam), in particular on transfer structure design and steering techniques.

The second CLIC test facility (CTF2) is now the first operating 30 GHz two beam accelerator, equipped with 3 meter length of drive and main linac components. It has been commissioned with beam and can now be used for a series of checks and beam dynamics measurements. In particular, the need to achieve very short bunches for producing 30 GHz power by going through a magnetic chicane suggested the possibility to address one of the challenging questions of large interest in this field. It concerns the generic problem of emittance growth in bends due to non-inertial space-charge effects and coherent synchrotron radiation in the presence of the reflective boundary of conducting pipe walls. Therefore, a series of transverse beam emittance measurements as a function of the magnetic bunch compressor setting was performed. These experiments showed for the first time clear evidence for emittance growth induced by coherent synchrotron radiation effects of short intense bunches transiting an achromatic bend, in this case the bunch compressor, although a quantitative interpretation remains difficult.

3.4 Development of a 7 MV folded tandem ion accelerator in India

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3.4.1 Introduction

Although there have been several Van-de-Graaff accelerators built throughout the world, only few attempts have been made to convert them into higher energy, heavy ion tandem accelerator facilities. The Nuclear Physics Division at the Bhabha Atomic Research Center, Mumbai has taken up a project to design and build a Folded Tandem Ion Accelerator (FOTIA). This involves conversion of the existing single stage Model CN 5.5 MV Van-de-Graaff accelerator into FOTIA with a terminal Voltage of 7 MV, for accelerating ions upto mass 50. Such a facility capable of providing a variety of particle beams, with high energy resolution and good quality, will enable research both in basic and applied fields.

In the design (see Figure 3.2), two NEC high gradient, compressed geometry accelerating tubes are positioned in a column structure of the same diameter as the earlier accelerator, retaining the high voltage terminal and the insulating gas tank of the Van-de-Graaff accelerator. With the use of $\mathrm{SF_6}$, instead of the earlier used $\mathrm{N_2 + CO_2}$ mixture as insulating gas, it is expected that the terminal will go upto 7 MV. The belt charging system is being replaced by a pellet charging system which gives a better voltage stability.

In FOTIA, negative ions extracted from a SNICS II source will be pre-accelerated upto 150 keV before being injected into the low energy accelerating tube through a combination of a 70° magnet and a 20°-electrostatic deflector. An electrostatic quadrupole triplet and an einzel lens will focus and match the beam parameters to the acceptance of the low energy accelerating tube. In the terminal the ion beams are focused to a spot of 3-4 mm diameter on the carbon foil, where electrons of the negative ions are stripped and positive ions with high charge states are produced, which are subsequently bent by a 180° magnet into the high energy tube. The high energy beams will be focused using a magnetic quadrupole triplet before being analyzed by a 90° analyzing magnet. Beam Profile Monitors(BPM) and Faraday cups are provided to help in adjusting and focusing the ion beams and measurement of the intensity.

3.4.2 Beam Dynamics

The beam dynamics of the FOTIA has been studied in detail using ion optics codes. The beam emittance is basically limited by the acceptance of the low energy accelerating tube, to around 5.3 π mm-mrad $[MeV]^{1/2}$ for an ion injection energy ranging between 75 and 150 keV. Therefore all the beam optics calculations have been restricted to a maximum ion source emittance of this value. An einzel lens has been introduced at the entrance of the low energy accelerating tube, in order to match the ion beam emittance to the acceptance of the tube. It is seen that with the einzel lens in operation, it will be possible to have good transmission through the accelerator even at the terminal voltage of about 1 MV.

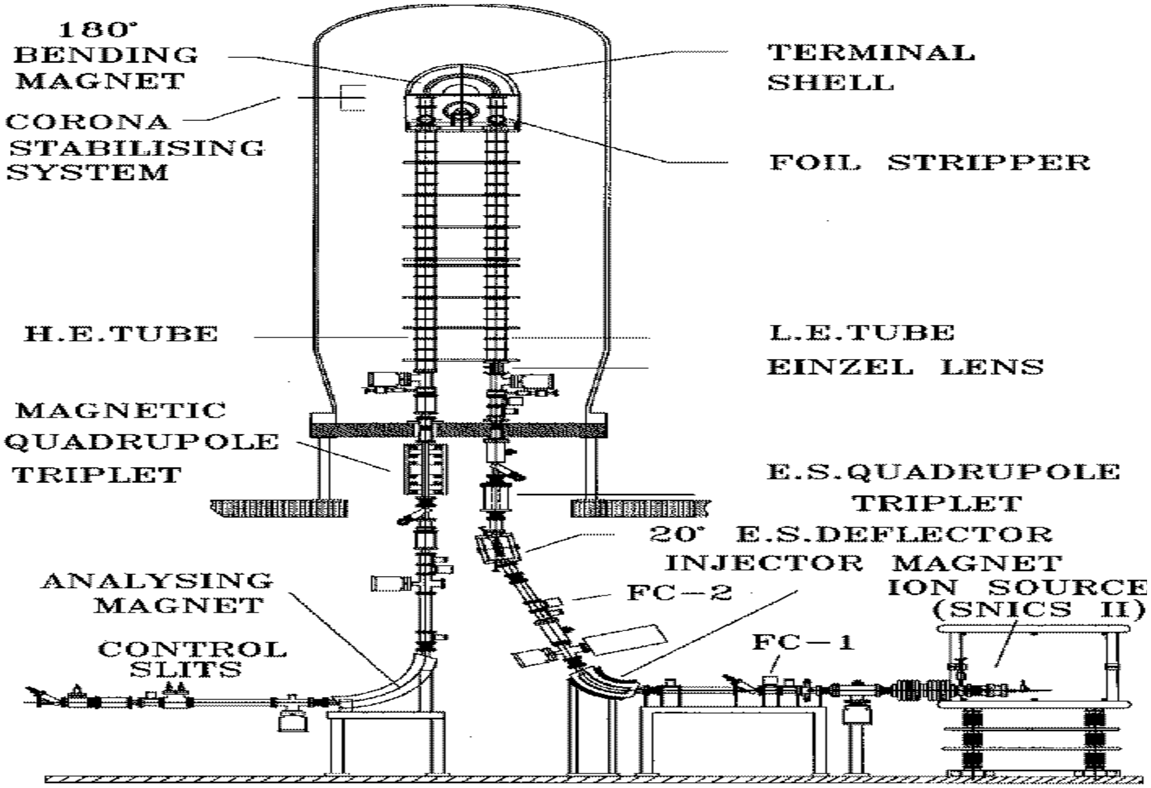

Figure 3.2: Folded Tandem Ion Accelerator

3.4.3 High Voltage System

The electrostatic design of the FOTIA has been carried out using the existing terminal shell and pressure vessel. Maximum field gradients are calculated to be 230 kV/cm at the top of the dome and 156 kV/cm on the coaxial surface of the terminal. These values are comfortably below the breakdown voltage for SF_6 insulating gas at 90 psi that will be used in FOTIA. Each of the two high gradient, compressed geometry NEC accelerating tubes consists of 33 gaps in one module, and each column post consists of 18 gaps. In the beginning corona needles will be used for voltage grading in the column section and accelerating tubes. The column section consists of seven 1 MV modules, each separated by a casting plate(fabricated in-house). The pellet chain has been designed to deliver a maximum required current of 150 μA, and is being developed indigenously.

3.4.4 Summary and present status

The FOTIA project will achieve, in a very cost effective way, a low energy, heavy ion accelerator (with beams of energy upto about 77 MeV), by utilizing a large part of the existing structure such as the pressure tank, gas storage tank, equipotential rings, high voltage dome and the accelerator and beam rooms. The salient feature of this accelerator is that one can get ions from very low energy, 2 MeV (H^+ at 1 MV terminal voltage) to 77 MeV ($^{40}\mathrm{Ca}^{10+}$ at 7 MV terminal voltage). An important gain from this project would be to widen the scope of research to fields such as material science, accelerator mass spectrometry, beam foil spectroscopy, etc.

At present most of the individual components have been fabricated. Work on the installation of the low energy beam line, gas handling system and the high voltage column section is in progress. Recently, injection system was made operational and several beams extracted from the ion source were analyzed using the 70° magnet. Beam currents of several micro-amperes ($\mathrm{H}^-(4.5\mu A), \mathrm{Li}^-(0.5\mu A),\ \mathrm{C}^-(5\mu A), \mathrm{O}^-(24\mu A), \mathrm{Si}^-(13\mu A), \mathrm{Cl}^-(11\mu A)$) were measured on the Faraday cup located after the 70° magnet. In these measurements the cathode voltage was fixed at 2 kV. The controlling and monitoring of the various parameters of the ion source, located at the high voltage, was done using a fibre-optic data telemetry system developed for the FOTIA.

3.5 Beam Dynamics Experiments at the Advanced Light Source

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Following are examples of some of the beam dynamics experiments that have been done over the past year in addition to our efforts to maintain and improve the storage ring. The ALS group consists of John Byrd, Winni Decking, Alan Jackson (leader), Charles Kim, Dexter Massoletti, Hiroshi Nishimura, Greg Portmann and David Robin.

3.5.1 Fast beam–ion instability

Several years ago, a new form of beam–ion instability was predicted in which a coherent oscillation of the beam could grow over a single turn in a storage ring or a single pass in a linac[1, 2]. Because the growth rate of this instability is predicted to be very fast, the effect could be very important for the next generation of storage rings and linacs. Predictions for the ALS indicated that the effect was not serious at nominal vacuum pressure of about 0.25 nTorr. However, in an effort to verify the existence of the instability, which had not yet been observed experimentally, we performed a dedicated experiment to study it. To enhance the effect, we added He gas to the vacuum and characterized the instability under a variety of beam currents and fill patterns. Most of the fill patterns included a large gap to avoid conventional multiturn ion trapping. We succeeded in observing the effect and also examined means for passively curing the instability via chromaticity or gaps in the fill patterns.[3]

3.5.2 Bunch-bunch diffusion in electron storage rings

Synchrotron oscillations in a storage ring occur within the potential formed by the radiofrequency (RF) voltage. Oscillations of electrons within the RF bucket formed by the potential well are stable. Electrons outside of the RF bucket slowly lose energy and eventually are lost. However, the process of radiation damping, which acts as a frictional damping to the synchrotron oscillations, provides a mechanism by which electrons outside the RF bucket have a small probability of being recaptured into a subsequent RF bucket. This is shown by a plot of the phase including radiation damping shown below. Each RF bucket has a narrow attractor which extends over previous buckets in the ring. Electrons landing on the attractor damp into that bucket. The diffusion process is important for a subset of synchrotron radiation users who desire a pure single bunch fill in the ring.

In the ALS, large–angle intrabeam (Touschek) scattering provides the mechanism for electrons to jump from a given bucket to the next. We've observed the diffusion process by carefully measuring the relative intensity of charge in buckets following a large bunch over the course of 20-100 minutes. This was done as a function of RF bucket height and showed good agreement with a theory developed by G. Stupakov of SLAC. [4]

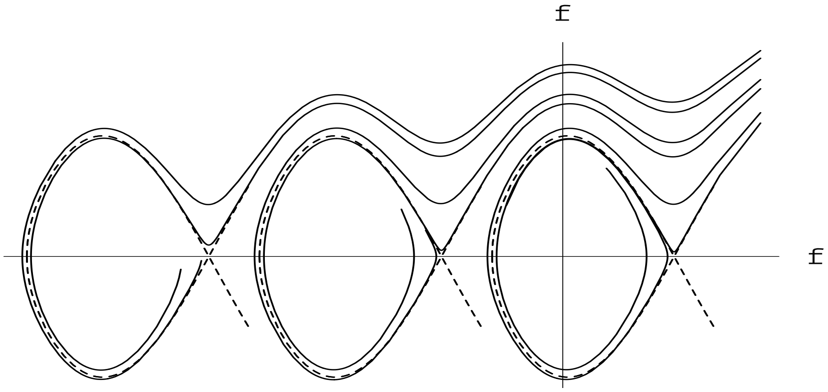

Figure 3.3: Trapping into buckets. The ordinate and coordinate are ϕ and $\dot{\phi}$.

3.5.3 Phase modulation of synchrotron oscillations

In an effort to understand some anomalous results in the study of longitudinal beam transfer functions, we were led into the fascinating field of nonlinear longitudinal beam dynamics. By driving synchrotron oscillations sufficiently hard via phase modulation, longitudinal phase space can be significantly distorted, even so far as to split an electron bunch into two separate bunches within the same RF bucket. [5]

We studied this phenomenon using a dual–scan streak camera in synchroscan mode.[6] This allowed us to observe the time evolution of the longitudinal distribution of a single bunch as the modulation frequency swept through the synchrotron frequency. Shown in Figure 3.4 is an example of the longitudinal distribution for 3 modulation frequencies. The vertical axis is time with respect to a synchronous bunch (i.e. a bunch not executing synchrotron oscillations) where positive displacement indicates early arrival. The horizontal axis represents the relatively slow sweep time of the streak camera. For these images, the horizontal time scale is about 530 turns. The darker area in the image represents higher intensity. The sinusoidal pattern of the distribution is due to the phase modulations (the nominal RMS bunch length is 15–20 psec.) At this level of excitation, the bunch has oscillation amplitude of about 100–300 psec peak–peak. At the bifurcation frequency, the bunch appears to split into two separate beamlets, oscillating with different amplitudes and out of phase by 180 degrees. The charge in the second beamlet increases while the first decreases. Above the bifurcation frequency, the original beamlet disappears and only the second remains. The time at which the second beamlet appears depends on the modulation sweep rate and the bunch current. We observe similar effects for downward sweeps of the modulation frequency, also with dependencies on the sweep rate and bunch current.

One interesting effect is that, at a fixed modulation frequency, the diffusion due to Touschek scattering between the islands seen in Figure 3.4b can be observed in real time over the course of several minutes. Although this subject is of some academic interest, we have yet to come up with an application. Please contact us with any ideas.

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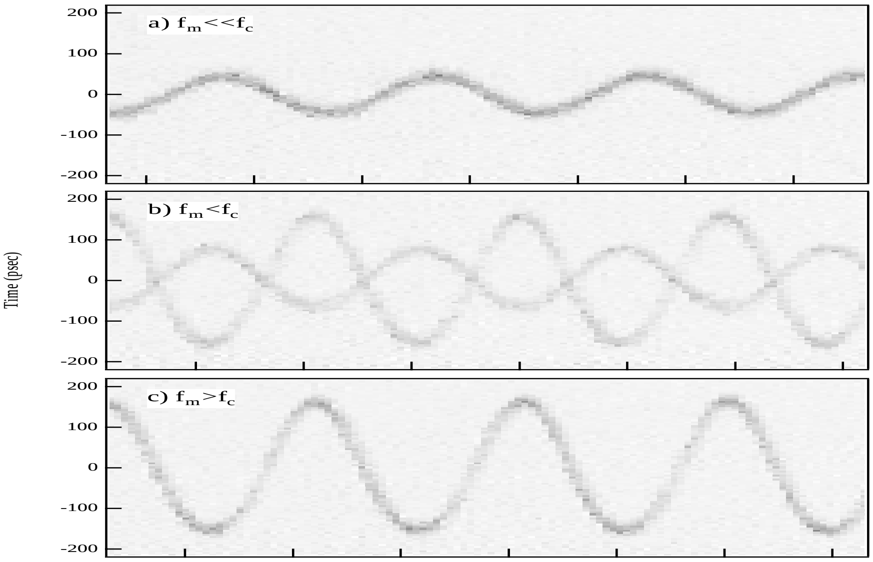

Figure 3.4: Images of the longitudinal profile (in psec) vs.time using the streak camera in dual scan mode: a) f_m well below bifurcation frequency; b) f_m just below bifurcation frequency; c) f_m above bifurcation frequency.

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3.6 Beam Physics activity at Indiana University and IUCF

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3.6.1 The Cooler Injector Synchrotron

Recently, IUCF has uccessfully commissioned the Cooler Injector Synchrotron (CIS). The construction project includes 3 MeV RFQ, 4 MeV DTL, and the low energy rapid cycling synchrotron from 7 MeV to 225 MeV. Polarized or unpolarized H^- ions can be strip-accumulated and accelerated in the CIS for injection into the Cooler. So far, we have successfully accelerated 2×10^{10} protons to 220 MeV. The fast kicker and the Lambertson septum are being installed for beam transfer into the Cooler.

With the arrival of the CIS, many interesting accelerator physics experiments are being planned. The space charge dominated beam experiments in CIS at 7 MeV will study halo formation, effect of beam distribution, and emittance growth [1]. High intensity long pulse (400 μs) from Linac will be compressed into a time structure of 50–100 ns in CIS. This resemble the Neutron Spallation Source compression scheme. Being able to measure emittance turn-by-turn, we should be able to address questions such as emittance blow-up due to space charge force. Experiments will begin in April, 1998. Our experimental collaboration include ORNL, BNL, Fermilab, and IU.

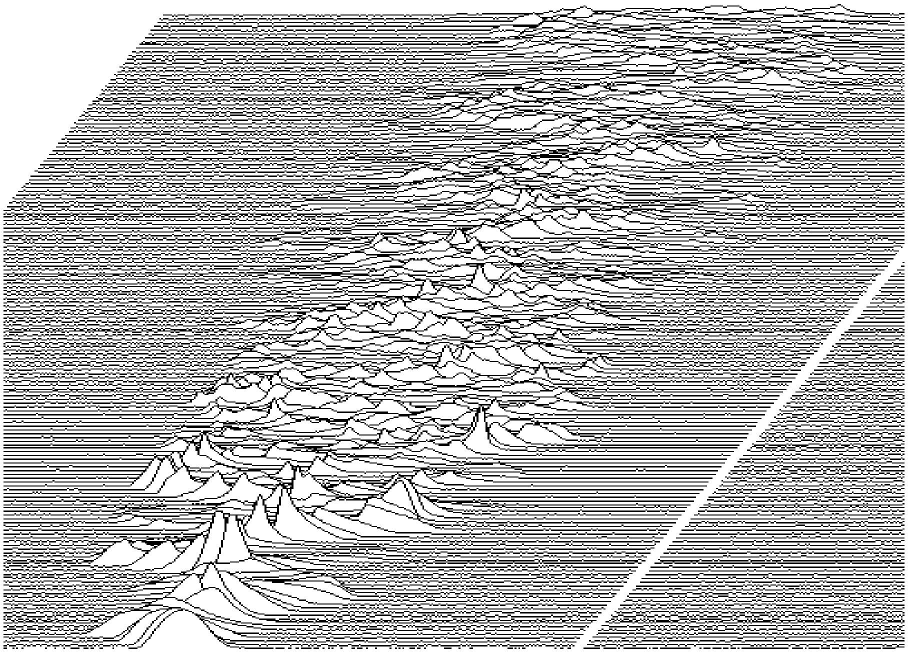

Figure 3.5: The mountain range plot of the evolution of the beam profile under the action of a modulational secondary rf system, where the rf voltage ratio is $r = 0.11$, the rf phase modulation frequency is $f_{\rm m} = 1400$ Hz, and the modulation amplitude is $A = 100^\circ$. The horizontal axis is the bunch length of a total of 512 channels with 1 ns resolution, the total number of profile traces were 1024 in about 25 ms.

3.6.2 Particle diffusion mechanism with rf noise

At IUCF, we have performed a series of emittance dilution experiments. Figure 3.5 shows an example of the mountain range plot when the cooler beam at $h_1 = 1$ is modulated by a secondary rf system at $h_2 = 9$. The data has been carefully analyzed. In particular, the square of the rms bunch length $\sigma^2(t)$ shows interesting dependence on time t. Working on diffusion modeling, the experimental data can un-ambiguously be identified as beam particles streaming along the separatrix of a dominant parametric resonance. Particles then diffuse into the chaotic sea at a slower rate. The result will be appear in the Physical Review Letters [2]. Detailed report of our studies will be reported shortly.

3.6.3 Bunch Beam Manipulation Using RF Dipole

Using an rf dipole, coherent betatron motion can be adiabatically excited without inducing emittance growth. The rf dipole field creates 1:1 resonance island in the phase space. Adiabatically transporting the beam bunch onto the resonance island the coherent beam motion can be sustained without emittance dilution. Fig. 3.6 shows mountain range plot of the measured transverse beam profile while the rf dipole is adiabatically turn on and off [3]. Employing coherent betatron motion in vertical plane, the intrinsic spin resonance can be overcome without using betatron tune jump. This has also been verified in a recent polarized beam experiment at the AGS. Results of this experiment will be published in Ref. [4].

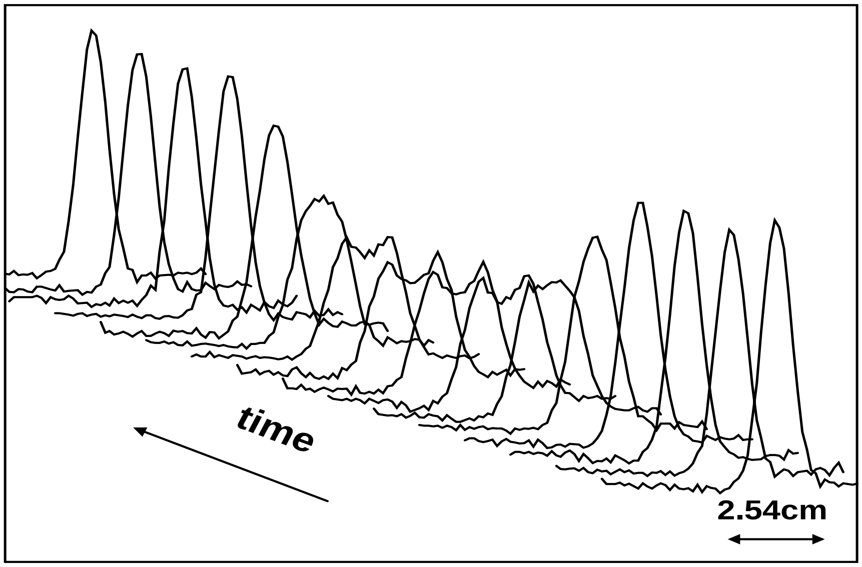

Figure 3.6: The mountain range plot of the evolution of the beam profile under the action of a modulational secondary rf system, where the rf voltage ratio is $r = 0.11$, the rf phase modulation frequency is $f_{\rm m} = 1400$ Hz, and the modulation amplitude is $A = 100°$. The horizontal axis is the bunch length of a total of 512 channels with 1 ns resolution, the total number of profile traces were 1024 in about 25 ms.

3.6.4 CE-74: Electron Beam Probe

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We will use a probe beam of electrons to observe the profile of the Cooler beam. Utilizing Wehnelt techniques from electron microscopy, we have electrostatically focused a 25 eV beam to a diameter of less than 0.5 mm (rms). This beam is channeled through a 100 gauss solenoid over a 50 cm interaction length and is collected on a position sensitive detector. The device is placed in the Cooler with the solenoid parallel to the beam axis. The line charge density of the Cooler beam will deflect the probe beam. Maps of this deflection, with the probe beam scanned transversely across the region, will yield the electric field profile of the DC Cooler beam. Particular attention will be directed at observing the electron cooling process.

Spatial resolution depends on the width of the probe beam. We have already made the probe beam thin enough to measure the position, central density, and width of the Cooler beam. An effort is underway to reduce the probe spot size by replacing the tungsten filament with a LaB_6 emitter, with aspirations of mapping the edges of the Cooler beam. The inclusion of time-dependence is also being considered.

3.6.5 Collective Instability

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My plans at Indiana are to continue work in studying collective effects, in particular Computational methods for single bunch longitudinal instabilities; Multibunch instabilities for non-symmetric bunch fillings; Instability computations for more complex lattices; How space charge works with the impedance formalism, including some experimental tests. Our group has also in principle taken on the task of making a preliminary design for the muon collider accelerating stage. As you can see, we have a very full program here at Indiana. We are planning on hiring some postdocs in the near future, and we are also always looking for more students.

References

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3.7 New Doctoral Theses in Beam Physics

3.7.1 Masanori Ikegami

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Supervisor: Akira Noda, noda@kyticr.kuicr.kyoto-u.ac.jp,
Nuclear Science Research Facility,
Institute for Chemical Research, Kyoto University,
Title: A Study on Halo Formation in Intense Axisymmetric Beams.
Date: November 25, 1997.

Abstract:

We study halo formation from cylindrical beams propagating in uniform and periodic focusing channels. Of particular interest here are the breathing-mode oscillations excited by an initial beam-size mismatch. Thus, we develop a one-dimensional space-charge code which is simple but powerful in self-consistently exploring the halo properties of breathing beams. Based on systematic simulation runs, we find that halo extent normalized with the initial root-mean-squared beam size is only weakly dependent on the tune depression and that the halo intensity appears to increase with the degree of mismatch. In a periodic focusing situation, the fundamental quantities such as halo extent, halo intensity, etc., exhibit the features analogous to those obtained for a uniform case unless the resonant instability driven by the periodicity of the external restoring force takes place. We also see that it is in principle possible to scrape halos by means of a multi-collimator system provided that the wake field generated by the collimators are negligible.

4: Workshop Reports

4.1 Workshop on Quantum Aspect of Beams

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The first week of the year is often a slow time in academia; however, over 100 physicists gathered in Monterey, California to attend the 15th ICFA Advanced Beam Dynamics Workshop, ”Quantum Aspects of Beam Physics”. In the midst of one of the rainiest wint ers in California history, the weather stayed clear through most of the week with a blue sky. The opening night recital at the historic San Carlos Cathedral, welcome by the Mayor of the City of Monterey, Dan Albert, and performed by the renounced Russian cellist Mikhail Gelfenbein and his wife, pianist Irina Sharogradsky, brought the conference participants to a high level of spirit right from the start. The mid-week field trip provided an excellent opportunity for international visitors to see the ocean and wildlife of the area. By the end of the week, history had been made; the term ”Quantum Beam Physics” was born.

The frontiers of beam research point to ever higher energy, increased brightness and lower emittance beams with ever increasing particle species. These demands in turn have triggered a rapidly increasing number of beam phenomena that involve quantum effects. Concurrently, the violent accelerations which are becoming available through novel accelerator research may, perhaps, help to investigate fundamental physics associated with general relativity. developments and the important role they may potentially play in the next century, this workshop attracted a broad spectrum of experts from beam physics, particle physics, laser science, astrophysics, condensed matter physics, nuclear and atomic physics. Participants came from 10 countries around the world as well as from the United States, representing a diversity of laboratories and universities.

The plenary session on the first morning was chaired by Vladimir Baier (Budker Institute). Following a welcoming address by Kohji Hirata (ICFA/KEK), Pisin Chen’s (SLAC) overview presentation set the tone of the conference. This was followed by a talk by Ron Ruth on ”Radiation Reaction and Fundamental Limit of Beam Emittance.” Claudio Pellegrini (UCLA) then presented ”Collective and Coherent States in Beam-Radiation Interaction.” One common theme from both talks is, what is the ultimate limit of the beam phase space. Rudolf Grimm (Max Planck, Heidelberg) reviewed ”Laser Cooling of Stored Ion Beams,” while Valery Telnov (Budker Institute) talked about ”Electron-Photon Interaction in High Energy Beam Production and Cooling.” It was apparent from these talks that the applications of lasers in beam physics, and thus phenomena involving laser-beam interaction, are rapidly increasing and all the more important.

While these topics may be more down to earth, the afternoon session, chaired by Kirk McDonald (Princeton U), was designed for more lofty subjects. Renounced astrophysicist Bill Unruh (U of British Columbia) reviewed the essence of ”Black Holes, Acceleration Radiation and Beams.” Toshi Tajima (U of Texas, Austin) then discussed ”Laboratory Production of Violent Acceleration,” on how the necessary violent acceleration for testing fundamental physics can be produced in laboratory settings. This is followed by McDonald’s survey on issues relevant to physics under strong fields. Other highlights include distinguished condensed matter physicist Tony Leggett’s (U of Illinois) explanation of ”Coherent Atomic Beams from Bose Condensate.” While production and handling of coherent Bose-Einstein condensate atomic beams may be outside of the traditional domain of high energy accelerator physics, it was a good opportunity to learn from a world expert on the BEC beams and to help shed some light on the possibility of condensation of other types of beam in the future.

Berkeley/LBNL), focused on beam-phenomena under strong fields. Kaoru Yokoya (KEK) reviewed ”Beamstrahlung and Other Nonlinear QED Effects in Linear Colliders.” Walter Greiner (U of Frankfurt) gave a thorough survey on ”Nonlinear QED Effects in Heavy Ion Collisions.” Yuri Kononets (U of Aarhus) then reported on the latest results of ”Crystal Channeling of High Energy Beams,” on behalf of Erik Uggerhoj (U. of Aarhus), who was unable to attend because of sickness. ¿From these talks it is clear that there are more and more beam phenomena occurring under extremely intense EM fields, some even stronger than the Schwinger critical field, $\sim 4.4 \times 10^{13}$ Gauss, which puts beam physics in the forefront of nonlinear quantum electrodynamics (QED).

Fluctuations in Beam Dynamics,” and by Swapan Chattopadhyay (LBNL) on ”Photon-Electron Interactions in Beam Production, Cooling and Monitoring” and ”Production and Handling of Condensate Beams.” Adrian Melissinos (U of Rochester) and Kirk McDonald co-chaired the working group on ”Beam Phenomena under Strong Fields” and ”Fundamental Physics under Violent Acceleration,” while Alex Dragt (U of Maryland) organized the sessions on ”Quantum Methodology in Beam Physics.”

In Working Group A, D. Barber (DESY) talked about ”Longitudinal Electron Spin Polarization at 27.5GeV in HERA”; J. Jowett (CERN) discussed ”Consequences of LEP2 Energy”; while Z. Huang and R. Ruth (SLAC) presented their newest studies on ”Effects of Focusing in Radiative Cooling”. K. J. Kim, the WG-A chair, then led a chain of discussions with his latest thoughts about ”Entropy & Emittance of Quantum Beams”, ”Microtip Guns for Compact X-Ray FELs”, and ”Quantum Effects for Self-Amplified Spontaneous Emission”. J. Wurtele (UC Berkeley) then talked about ”Beam Characterization with Spontaneous Emission from a Microwiggler”. An interesting presentation was given by F. Zimmermann (SLAC) on novel ”Quantum Chaos Features in Electromagnetic Cavities”. Finally, M. Zolotorev (LBNL) gave his typically insightful talk on ”Experiments for Quantum Beam Dynamics”.

In Working Group B, a talk on ”Grasers Based on Particle Accelerators”–accelerator production of gravity waves, was presented by E.Bessonov (Lebedev). A. Bogacz (CEBAF) discussed ”Stimulated Emission of Coherent Radiation from a Relativistic Hydrogen-Like Ion Beam”. J. Clendenin (SLAC) summarize his thoughts about ”High-Quantum Yield, Low-Emittance Electron Sources”. An exciting presentation was given by J. Hangst (Aarhus) with beautiful visual display of his experimental results on ”Laser Cooling Experiments in ASTRID”, and ”Ion Crystals”. Z. Huang and R. Ruth presented their newly invented concept of ”Laser Electron Storage Ring”. K. McDonald (Princeton) then talked about ”Temporary Acceleration of Electrons While in an Intense Electromagnetic Pulse”. J. Spenser (SLAC) presented an idea on ”A High-Brightness Source of Polarized Neutrons”, and reported on the ”Status of the Stanford Laser Acceleration Experiments (LEAP)”. T. Takahashi (Hiroshima) reported a Japanese experiment on ”Positron Production in Single Crystals by 1.2GeV Electrons”. John Byrd (LBNL) presented an idea of ”Parasitic Beams Generated by Touschek Effect”.

WG-C was perhaps the largest group in the workshop. Physical phenomena associated with ultra-intense EM fields attracted most attention, both theoretically and experimentally. R. Godbole (Indian Inst. Sci.) reviewed the status of ”Minijets Studies”, with its implication to linear collider beam-beam interaction in the background. Y. Jack Ng (U. North Carolina) proposed a theory of ”Magnetic Catalysis of Chiral Symmetry Breaking and the Pauli Problem”, i.e., why is the fine structure constant 1/137? G. Horton-Smith (SLAC) discussed ”Quantum Aspects, Experimental Results, and Beam Physics Implications of E144”. J. C. Wells (ORNL) presented an interesting

”Light-Fronts Approach to Electron-Positron Pair Production in Ultrarelativistic Heavy-Ion Collisions”. For applications to accelerators and colliders, V. G. Serbo (BINP) proposed ”A Polarized Laser Beam as an ”Anisotropic Crystal” for High-Energy Photons and Electrons”, and ”Coherent Bremsstrahlung at Colliders with Short Bunches and a New Possibility to Monitor Collisions of Beams”. One other main interest of the group, not unrelated to the ultra-intense fields, was novel effects induced by vacuum fluctuations. A. Larraza (Naval Postgraduate School) demonstrated ”Some Acoustic Analogs to Zero Point Field Effects”. P. Chen presented a talk on ”Testing Unruh Radiation with Ultra-Intense Lasers”. K. McDonald, co-chair of WG-C, digged deeper into ”Hawking-Unruh Radiation and Radiation of a Uniformly Accelerated Charge”. and on ”The Hawking-Unruh Temperature and Damping in a Linear Focusing Channel”. P. Chen and C. Pellegrini (UCLA) suggested ”Boiling the Vacuum with LCLS (Linear Compact Light Source) at SLAC”, while A. Melissinos, co-chair of WG-C, further discussed ”The Spontaneous Breakdown of the Vacuum”. While most these treatments took quantum theory for granted, it was good to hear from F. V. Hartemann and J. Van Meter (LLNL/UC Davis) who cross-checked ”Classical Theory of Ultrahigh-Intensity Relativistic Scattering of Electrons and Photons in Vacuum”, and ”On Radiation Reaction and the Consistency of Classical Electrodynamics with Quantum Electrodynamics”.

While WG-D may be a smaller group, it nevertheless collected a nice set of sophisticated mathematical minds. The focus of the group was the various applications of quantum formalism in beam physics, where the beam phenomena at stake may not necessarily involve Planck’s constant. But there are also efforts in developing a bona fide quantum theory of beam optics, where the leading order reproduces the well-known classical description, while the higher order terms would offer quantum corrections. R. Jaganathan (IMS, India) presented ”The Dirac Equation Approach to Spin-1/2 Particle Beam Optics”, while his former student, S. A. Khan (Padova) discussed the ”Quantum Theory of Magnetic Quadrupole Lenses for Spin-1/2 Particles”. The colleagues from Salerno, Italy, S. De Martino, S. De Siena, and F. Illuminati, presented ”A Stochastic Model for the Semiclassical Collective Dynamics of Charged Beams in Particle Accelerators”. M. Pusterla (Padova) investigated the ”Stern-Gerlach Force in Classical and Quantum Mechanics and its Application to Produce Polarized Beams”. J. B. Rosenzweig (UCLA) presented a quantum mechanics-inspired approach to the ”Analysis of the Evolution of Classical Distribution”. H. C. Rosu (Mexico) talked about ”q-Deforming the Synchrotron Shape Function”. P. Chen presented his new finding, together with J. Bjorken (SLAC), on a particular ”Supersymmetry in Beam Dynamics”.

In a joint session among Working Groups A, B, and D, further presentations were made by D. Barber on ”The Permissible Equilibrium Polarization Distribution in a Stored Proton Beam”. R. Fedele presented the ”Napoli School”’s approach on ”Quantum-Like Phase-Space Description of Beam Dynamics: Wigner-Like Picture and Particle Beam Tomography”. A. Dragt, WG-D Chair, gave an authoritative review on ”Lie Algebraic Methods for Ray and Wave Optics” and an interesting treatment on ”Aberrations & the Wigner Function”. D. Palmer (SLAC) reported on ”Emittance Compensated Spin Polarized RF Guns: Prospect & Directions”.

The parallel session discussions were intense, and gathered momentum throughout the week. For example, stimulated by Unruh’s plenary talk and related presentations, David Jackson generated a lively debate on the nature of Unruh radiation in one of the working groups. The warmth of the working group sessions can also be examplified by an unprecedented experimental demonstration (in a hotel!). Andres Larraza brought along his equipment and demonstrated the acoustic analogs of the well-known Cassimir effect. Jeffrey Hangst’s visual display was also another big attraction during the week.

Social programs contributed to the excellent style of this workshop. The very up-scaled Monterey Plaza Hotel, where the conference was held, is right on the famous Cannery Row and on the beach front facing the Pacific Ocean. Plus, the well-known Monterey Bay Aquarium was reserved exclusively for workshop participants mid-week for the banquet. A special lecture given by Steven Webster, Director of Education at the Aquarium, on ”Deep Ocean Exploration in the Monterey Bay”, attracted and inspired all who attended. During the banquet, there were short toasts made by the conference chairman followed by brief words by David Sutter (DOE-ER) and Lee Teng (Argonne). The combination of pioneering work and the developing need for refinement in this field led Teng to urge the audience to turn this very successful workshop into a series. His sentiments were warmly echoed by the participants.

Further information can be found at the workshop website:
`http://www.slac.stanford.edu/grp/ara/qabp/qabp.html`

4.2 Eighth RIKEN Winter Beam Physics School

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The Eighth RIKEN Winter School - Beam Physics in Accelerators - was held on March 3 - 6, 1998, in a beautiful ski resort area at Tsunan of Niigata Prefecture, Japan. The School, which was the first in this series for accelerators, was sponsored by RIKEN and organized by both RIKEN and the Japanese Beam Physics Club. The aim of the School was to teach graduate students as well as young researchers about beam physics. A total of fifty-six participants gathered from universities and research institutes all over Japan and enjoyed the School, thirteen of whom were lecturers. Many thanks are given to all the participants for their making this a very fruitful school. The following lectures were given:

- H. Tanaka (JASRI), ”Introductory Single Particle Dynamics” (2 hours)
- K. Hirata (KEK), ”Advanced Single Particle Dynamics” (2 hours)
- A. Ando (HIT), ”Lattice Design” (1 hour)
- H. Yoshida (NAO), ”Symplectic Integrator” (1 hour)
- H. Okamoto (Kyoto Univ.), ”Space Charge Effects” (2 hours)
- K. Nakajima (KEK), ”Laser Acceleration” (1 hour)
- O. Kamigaito (RIKEN), ”Beam Dynamics in RFQ Linacs” (1 hour)
- T. Suzuki (KEK), ”Impedance and Instability” (2 hours)
- T. Katayama (CNS), ”Beam Cooling” (2 hours)
- Y. Batygin (RIKEN), ”Beam-Beam Effects” (2 hours)
- A. Goto (RIKEN), ”Beam Dynamics in Cyclotrons” (2 hours)
- Y. Mori (KEK), ”Intrabeam Scattering” (1 hour)
- H. Kitamura (RIKEN), ”Synchrotron Light Source” (2 hours)

Eleven graduate students also gave a talk about their own field of study within the time frame of fifteen minutes. Members of Organizing Committee were: Y. Yano (RIKEN) A. Goto (RIKEN) T. Katayama (CNS) K. Hirata (KEK) H. Okamoto (Kyoto Univ.) and those of Local Organizing Committee were: A. Goto (RIKEN) N. Inabe (RIKEN) O. Kamigaito (RIKEN)

4.3 Report on Mini-Workshop on “Beam-Beam Compensation in the Tevatron

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A Mini-Workshop on Beam-Beam Compensation in the Tevatron was held at Fermilab on February 12-13, 1998. It was the second in a series of the FNAL Mini-Workshops devoted to advanced accelerator techniques to improve the Tevatron collider performance; the previous one was “Round Beams and Related Concepts in Beam Dynamics” (FNAL, December 1996) [1]. The purpose of the Mini-Workshop was to assay the current understanding of compensation of the beam-beam effects in Tevatron with use of low-energy, high-current electron beam, relevant accelerator technology, along with other novel techniques of the compensation and previous attempts. About 30 scientists representing seven institutions from four countries (FNAL, SLAC, BNL, Novosibirsk, CERN, and Dubna) were in attendance with 21 talks presented. The event gave firm ground for wider collaboration on experimental test of the compensation at the Tevatron collider. If there are any questions concerning the Workshop or its Proceedings [2] which are published with limited circulation, contact V.Shiltsev (shiltsev@fnal.gov), or visit our Web page `http://www-bd.fnal.gov/lug/tev33/ebeam_comp/ebeam_comp.html`

The cited proceedings for the Mini-Workshop are mostly copies of transparencies presented and compressed texts of already printed papers. The participants were very responsive and energetic in addressing the issues posed to them; nearly every concern was considered at some level and several points were resolved. Questions and answers were an essential part of the meeting and are placed in the Proceedings after each talk in a brief form.

There were no special working groups, and all talks were plenary, nevertheless, the informal format of the presentations and flexible schedule did allow enough time for discussions.

The meeting started with a welcoming address by John Marriner of the FNAL Beams Division, followed by talks which were divided in several groups according to the beam-beam compensation topics chosen by the organizer.

4.3.1 Proposals and Physics of Beam-Beam Compensation

The first day of the Workshop was devoted to the theory of the beam-beam compensation, and previous proposals and attempts. There were nine talks on:

V.Shiltsev	FNAL	Beam-Beam Compensation with Electron Beam in Tevatron
V.Danilov	INP/FNAL	Beam-Beam Tracking for Tevatron with ”Electron Compressor”
R.Siemann	SLAC	Beam-Beam Interaction with Four Colliding Beams
A.Zinchenko	Dubna	Compensation Proposals for SSC and LHC
H.Riege	CERN	What Could We Gain with Beam Neutralization in LHC?
G.Stupakov	SLAC	Plasma Suppression of Beam-Beam Interaction
M.Syphers	BNL	Issues of e-p Polarimetry in RHIC
F.Zimmerman	SLAC	Beam-Beam Effects in Linear Colliders
D.Whittum	SLAC	Beam-Beam Compensation in Linear Colliders

V.Shiltsev presented an idea of compensation of beam-beam effects in the Tevatron collider with use of 1-2 Amperes 10-keV electron beam [3, 4]. Modifications of the proposal are 1) the “electron lens” with modulated current which is supposed to provide different linear defocusing forces for different antiproton bunches (spaced by 132 ns in the Tevatron’33 upgrade project) and, therefore, equalize their betatron frequencies which are not naturally equal due to proton-antiproton interaction in numerous parasitic crossings along the ring; and 2) the “electron compressor”, essentially nonlinear but DC electron lens to compensate (in average) the effect of proton beam on $\bar{p}$ beam and, thus, to reduce the beam-beam footprint. The electron beam setup looks much like an electron cooler, besides electrons collide with antiprotons (proton beam is separated from the latter two). About 2-m long and 2-mm diameter electron beam to be installed in a place with large beta-function($\sim$100m), away from the main interaction points (IPs - B0 and D0). A strong longitudinal magnetic field of the order of 3 T plays a significant role in maintaining stability of both electron and antiproton beams. The R&D plans of the beam-beam compensation experiment in the Tevatron were also discussed.

Results of 3D beam-beam tracking with nonlinear “electron compressor” were reported by V.Danilov. One important conclusion was that the electron beam distribution has to be tuned to the form other than Gaussian in order to mimic bunch-length effects on beam-beam interaction previously studied by Krishnagopal and Siemann, Pestrikov, and Hirata.

An excellent historical overview of the four beam compensation $e^-e^-e^+e^+$ theory and the DCI(Orsay) experiment [5] was given by R.Siemann along with presentation of computer simulations of his and Podobedov [6], which explain coherent instabilities taking place in the system due to multi-turn memory in all the beams. Another extreme case (no memory at all) is the interaction at the IP of future e^-e^+ Linear Colliders(LCs). There the beams disruption over time of interaction will play a major role and corresponding beam-beam limits are orders of magnitudes higher than in circular colliders. F.Zimmerman and D.Whittum discussed these effects and possible gain of four-beam compensation in LCs [10].

A.Zinchenko and H.Riege reported similar beam-beam compensation proposals for the SSC and the LHC [7, 8]. G.Stupakov outlined a plasma neutralization idea of his and P.Chen [9], which looks very promising for muon colliders, while plasma causes strong deterioration of the beam lifetime in proton machines. M.Syphers overviewed a new polarimeter technique for RHIC using polarized electron beam, where coherent stability may be of similar importance to what is expected for the FNAL “electron lenses”.

4.3.2 Coherent and Incoherent Effects due to Electron Beam

There were seven talks devoted to stability issues:

V.Danilov	INP/FNAL	TMCI of Tevatron p-bar Beam Interacting with Electron Current
A.Burov	INP/FNAL	Impedance of Compensating Electron Beam
V.Shiltsev	FNAL	Simulations of Head-Tail Instability in Tevatron with ”Electron Compressor”
V.Shiltsev	FNAL	Requirements on Electron Beam for Beam-Beam Compensation in Tevatron
A.Zinchenko and V.Shiltsev	Dubna FNAL	Electron Beam Distortions due to Interaction with (Anti)Protons
A.Sery	INP/FNAL	Stability of Electron Beam with Ions

As mentioned above, the electron beam that interacts in the Fermilab beam-beam compensation project will go to a beam dump (collector) just after interaction with antiprotons; therefore, no long-term memory will occur in the two beam system, and the stability issues are somewhere in between the past (and somewhat discouraging) experience of the DCI and expectations for future Linear Colliders. Nevertheless, some effects may appear even in the single-pass system.

V.Danilov, A.Burov and V.Shiltsev pursued semi-analytical, theoretical [11] and numerical approaches to a “head-tail” instability caused by wide band impedance due to electron beam. The results were in good agreement to each other, and concluded in the requirement of some 3-5 T solenoid magnetic field. the $\bar{p}$ emittance growth consideration of V.Shiltsev concluded in technically challenging requirements on the electron current stability and the magnetic field uniformity. A.Zinchenko and V.Shiltsev reported results of their studies of the electron charge distribution distortions due to oncoming elliptic antiproton beam, which were found inversely proportional to the solenoid field and quite acceptable with 3 T field. Residual ions can be easily cleared from the electron beam to the stability safe level, as estimated by A.Sery [12].

4.3.3 Electron Beam Sources, Beams Diagnostics

The last group of presentations was as follow:

S.Nagaitsev	FNAL	Experience with Electron Guns for Medium Energy Electron Cooling and Possible e-Source for ”Electron Compressor”
I.Meshkov	Dubna	Generation of Intense Stationary Electron Beam with Controlled Parameters
P.Wesolowsky	DESY	Electron Cooling in PETRA
V.Shiltsev	FNAL	Particle Loss Diagnostics for PACMAN-Effect in TEV’33
A.Sery	INP/FNAL	Particle Losses due to Electron Beam

S.Nagaitsev, I.Meshkov and P.Wesolowsky presented an overview on powerful electron sources developed for the “electron cooling”. The beam-beam compensation does not require a very cold electron beam, it makes the task of an electron gun design easier. Nevertheless, the requirement of the electron current distribution tuning and/or fast current modulation will require novel approaches in the design. Vast experience and good understanding of the space-charge dominated thermionic electron sources was demonstrated (see also overviews in [13], and several technical solutions were proposed for the required electron gun.

V.Shiltsev discussed pbar beam diagnostics necessary for the beam-beam compensation test, including fast PIN-diode beam loss monitors to distinguish losses from different bunches in the Tevatron [14]. Finally, A.Sery had shown that back-scattered electrons with energies up to TeV produced in the "electron compressor" will not cause any radiation problem due to very small collision cross section.

Numerous discussions at the Workshop covered many other issues of the beam-beam compensation. In addition to reviewing the plausibility of the beam-beam compensation in the Tevatron, it was the goal of the Workshop to advance understanding of the general character of the challenges to be met and to make incremental progress on design issues. In this, the Workshop was very successful.

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4.4 Report of the 4th ICFA Beam Dynamics Mini-Workshop

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4.4.1 Introduction (R. Cappi)

In the framework of an informal collaboration between BNL, FNAL, KEK and CERN, the 4th ICFA Beam Dynamics Mini-Workshop was organized at CERN on 5-7 November 1997. The subject this time was: "Transverse emittance preservation and measurements", a key issue in particular for hadron collider injectors.

The aim of the workshop was to discuss beam dynamics, performance requirements and achievements as well as the various diagnostic methods and instruments, comparing the experience from various labs. Lists of problems in the various accelerators, diagnostic methods and instrumentation, exotic measurements, blow-up causes and cures were the main topics debated.

The workshop was discussed rather than presentation oriented. No formal proceedings will be published but a collection of copies of the transparencies will be distributed to the participants and to interested people. Summary reports will be published as CERN and/or FNAL internal reports and in forthcoming ICFA Beam Dynamics Newsletter. There will be two summaries, one concerning the discussions on Beam Performance (by W. Chou and L. Vos) and one concerning the discussions on Beam Instrumentation (by H. Koziol and K. Wittenburg). I take this opportunity to thank both teams and reporters for their very helpful contribution.

Of the 44 participants, 2/3 were from CERN and 1/3 from BNL, DESY, FNAL, KEK, RAL and TSL. No group splitting was adopted to facilitate exchange between instrumentation designers and users.

The Local Organizing Committee members are: G. Arduini, M. Chanel, R. Cappi (Chairman), N. Gaillard (Secretary), D. Manglunki (Scientific Secretary), M. Martini, U. Raich, J.P. Riunaud, F. Ruggiero, C. Ronan (Secretary), K. Schindl, H. Schonauer.

4.4.2 Summary on transverse emittance measurement and instruments (H. Koziol and K. Wittenburg)

4.4.2.1 Introduction

Preservation of emittance and, as a prerequisite, emittance measurements, take on a particular importance in the long chain of accelerators and storage rings of big hadron colliders. Not only has one to provide instruments capable of measuring transverse emittance with the necessary precision, one also has to make sure that the data stemming from instruments of quite different nature are treated such that the results can be validly compared, throughout the chain.

Although all instruments have the final goal of determining the emittance, what they primarily measure are such varied properties as projected density distribution, 2-dimensional density distribution, amplitude distribution, etc., and the methods vary greatly as well.

It was therefore most valuable to be able to compare, in the course of the Workshop, the experience made with the many different instruments used in so many different laboratories. It was also valuable to understand why experience with the same kind of instrument quite often differed from lab to lab: what the one scorned, the other praised. The differences of appreciation have essentially three causes:

1. What is good for one type of beam, may not be so for another (depending on the kind of particle, energy, intensity, time structure).
2. Most instruments work well only when certain precautions are taken (linearity, clearing field, magnetic focusing).
3. Last but not least, treatment of the raw data and interpretation of the results play a decisive role.

In a 2-dimensional table of labs and instruments, an appreciation matrix was shown in the verbal conclusions at the end of the Workshop. Although useful and instructive for that purpose, it will not be shown here, because its correctness in the details could only be easily disputed. Instead, we report in the following the advantages and disadvantages, quoted during the Workshop, for each of the discussed instruments.

4.4.2.2 The instruments

Scan with slits The modern variants, using either a single slit and a SEM- grid, or two slits and a single collector, are sophisticated descendants of the ancient ”pepper-pot”. With it, they share the destructiveness and limitation to low energies, at the output of ion-sources, or RFQs, or linacs of moderate energy. There they are the standard instruments to measure emittance, reliably and in phase space (not only a 1-dimensional projection).

Scintillator screens They are the ever-greens of diagnostics, used since nearly a century. The modern versions consist of doped alumina, and stand high intensity beams and large amounts of integrated charge. They are the simplest and most convincing device when one has to thread a beam through a transfer line, into an accelerator, and around and out of it. In their simplest form just a graticuled screen, observed with a TV-camera, they certainly deliver a wealth of information to the eye of an experienced observer, but only in a semi-quantitative way. Much can be done about that with modern means of rapid image treatment, but questions concerning linearity of screens at high beam densities remain.

Optical Transition Radiation OTR screens are a welcome and cheap substitute for scintillator screens. Although usable only for highly relativistic particles, they are absolutely linear in response and can be made so thin as to hardly disturb a beam in a transfer line, and even permit observation over many turns on a circulating beam. High time-resolution is easily achieved. As the scintillator screens they profit from modern means of rapid image treatment.

Semi-grids Also known as harps, they may consist of ribbons or wires. They are the most widely used means to measure density profiles of beams in transfer lines, and sets of three, properly spaced, allow determination of the emittance ellipse. What makes them popular is their simple and robust construction, the fact that there is little doubt about the measured distribution, and the high sensitivity, in particular at low energies and for ions. At higher energies they can be considered semi-transparent. Amongst the drawbacks are the limited spatial resolution (0.25 mm appears to be smallest wire-spacing achieved) and the rather high cost for mechanism and electronics.

Wire-scanners They are nearly non-destructive, in particular the fast ones, over a wide range of energies. Their spatial resolution can reach the micrometer range and with fast electronics, bunches can be observed individually. Their great sensitivity allows the study of halos.

At very low energies, multiple Coulomb scattering affects the beam and falsifies the measurement. Heating of the wire limits use of high intensities, but the problem of thermal emission can be avoided by looking a the secondary particles instead of measuring the secondary emission current. High mechanical precision is required. The measurement is not continuous. Of all the instruments used on circulating beams, the wire-scanners were certainly considered the most trustworthy one.

Residual gas profile monitor Quite non-destructive and delivering continuous information, they might be the ideal profile monitors for circulating beams. However, spatial resolution, whether one uses the electrons or the ions, is limited, as space charge perturbs the profiles of all but he weakest beams. That can be greatly improved upon by applying high extraction voltages and a focusing magnetic field in the same direction, but this is usually avoided, because it perturbs the closed orbit and may need to be compensated. Most users consider these monitors to be semi-quantitative, even after calibration against some other instrument.

Beamscope There seems to be only two instruments of that kind in use in the world. Driving the circulating beam into a stationary obstacle allows the most valuable direct measurement of amplitude distribution. Its advantage is that no fast-moving devices are needed. On the other hand, the deflection of the beam can introduce some uncertainties, e.g. through interaction with the accelerating RF. It is a destructive method, although one may limit the measurement to scraping off only a small fraction of the beam.

Synchrotron radiation What is a curse for acceleration is a boon for diagnostics. Limited to highly relativistic particles, it offers a completely non-destructive and continuous measurement of the 2-dimensional density distribution. Spatial resolution is usually limited to some 0.2 mm by diffraction and depth-of-field effects.

Schottky scans They are a paradigm of diagnostics free of charge (if one doesn’t count the time it takes to make a scan). The measurement is completely non-destructive, can be made continuously, and delivers a wealth of information. Mostly useful for coasting beams, with the necessary precautions also bunched beams are accessible. The sensitivity is unparalleled. Quantitative measurements, however, need calibration, the scans take time and the absolute precision is limited.

Quadrupole pick-up What it measures is not the dimensions of a beam, but rather the ellipticity of its cross-section and its variation in time. This makes it a potentially useful tool, completely non- destructive, to verify whether upon injection the beam was well betatron-matched to the ring lattice.

Deriving an information that can be quantitatively interpreted is quite an oar. A prerequisite is careful centering of the beam in the pick-up, otherwise the dipole oscillations will completely swamp the weak quadrupolar component.

4.4.3 General conclusions

It appeared very clearly that a perquisite for any emittance measurement is the precise definition of emittance that one uses. That there is a variety of different definitions is quite justified; they need to be tailored to the particular situation at hand. But whenever data are presented, they should be accompanied by the definition. That still leaves the question of how to convert results from one definition to another. Furthermore, the rms-value of a profile, or whatever else one quotes, can often depend critically on the exact method with which the raw data were treated. Here again, the method used ought to be indicated.

On-line calibration of each instrument and cross-calibration with others is important. One should not rest before reasonable agreement of results (without fudge-factors!) is obtained.

The overall conclusion is that no emittance measurement is yet proven to be precise to better than 10%. Certainly, a number of instruments are basically capable of measuring the beam size quiet precisely, but the details of data treatment play an important role for the final result. Furthermore, when calculating emittance from beam size, one relies on the knowledge of the beam optical parameters at the place of the instrument and these are often fraught with considerable uncertainties.

And a final comment: there is evidently not enough exchange of information and experience between the labs. Were it better, many wheels would be invented only once, and much bad experience would not be repeated. But that is what workshops like this one is for. We are looking forward to the next one.

4.5 Summary on transverse emittance preservation (W. Chou and L. Vos)

4.5.1 Introduction

In the design of a modern large hadron accelerator, the transverse emittance budget is an essential part. Without cooling, the emittance always grows from the first stages (*e.g.,* an ion source, a linac) to the last one (*e.g.,* a synchrotron or a collider). Careful plan is needed for how much blow up one would allow at each stage. There are two main reasons why the emittance preservation is important.

4.5.1.1 Effects on luminosity in a collider

The relation between the luminosity $\mathcal{L}$ and emittance ϵ is:

$$\mathcal{L} \propto \left(\frac{N_b}{\epsilon}\right) \cdot N_b \tag{4.1}$$

in which N_b is the number of particles per bunch. It is seen that before one reaches the beam-beam limit, the luminosity is proportional to $1/\epsilon$. In other words, in order to have high luminosity, the emittance has to be kept small. One illustrious example is the former SSC. The total beam current in that machine was limited by the cryogenic power (for absorbing the synchrotron radiation energy). The value of N_b was limited by the number of events per crossing. Therefore, to achieve the design luminosity, it was required to have an emittance as small as 1π mm-mrad (normalized), which was about a factor of 3-4 or more smaller than that in any existing collider.

If, however, the beam-beam limit is reached, the ratio N_b/ϵ becomes a constant. The emittance would then be an irrelevant parameter as far as the luminosity is concerned. This was actually the case for the Tevatron at Fermilab during its last collider run. Thus, the luminosity upgrade program calls for an increase of the beam intensity only (which leads to the construction of the Main Injector and Recycler) rather than for a brighter beam.

4.5.1.2 Effects on particle losses

In the injector chain of a collider and in a synchrotron, large emittance may lead to particle losses at injection, during acceleration and at extraction. For example,

- AGS Booster at BNL:
  It was shown at this workshop that after $\sim$10 ms during the acceleration, the emittance grows from 60π to 80π mm-mrad (95%). However, the extraction aperture is limited by the septum magnet at 60π. There are appreciable particle losses at extraction.
- Fermilab Booster:
  The bottleneck is again at the extraction region, where there is a "dog leg" structure (2 pairs of orbit deflectors) that limits the aperture and has become a radioactive hot spot. A new "dog leg" is being built for the purpose of providing a larger aperture.
- Fermilab Main Injector:
  This is a new synchrotron, which has a much larger transverse acceptance and momentum aperture than the Main Ring, which it will replace. But still, the aperture of the Lambertson magnets and quadrupoles in the extraction region is a potential concern. If the beam emittance is larger than 40π (95%), particle losses would be foreseen.

4.5.2 Emittance tables of existing and planned machines

At the workshop, a survey was conducted for the beam emittance at each stage in the accelerator chain at seven laboratories — Fermilab, CERN, KEK, DESY, BNL, RAL and TSL. The results are listed in seven tables that can be found in Ref. [1] as well as on the web (*http://www-bd.fnal.gov/icfa/database/database.html*). The followings are some observations of the survey results.

1. If there is no cooling and the synchrotron radiation damping is negligible (which is true in all these cases), the emittance should either keep a constant value or grow. The decrease at certain stages is believed to attribute to measurement errors.
2. It is interesting to see that these labs start with more or less the same emittance in the linac (about 0.5 μm) and end up with more or less the same emittance in the collider (about 4 μm), while there are large variations in the middle stages (transfer lines, Booster and Main Synchrotron). Part of the reason is probably the limited accuracy of the measurement in these stages.
3. It was pointed out in the workshop that the limited accuracy of the emittance measurements cannot be imputed entirely on the instruments alone. The flying wire, for example, is known to be very precise and yet the uncertainty on the measured emittance can be large. Therefore, a large part of the measurement error can be attributed to the fact that the knowledge of the lattice functions is often insufficient.

4.5.3 Sources of emittance blow-up

4.5.3.1 During beam transfer

General types of mismatch The following sources that can cause emittance blow-up during beam transfer have been observed in almost all machines and discussed in some detail at this workshop. The encouraging news is that these mechanisms are relatively simple and, therefore, are calculable. The discouraging news, however, is that the calculations and measurements can disagree with each other.

1. Missteering:
   M. Syphers gave the following expression for estimating the relative increase of emittance due

to missteering:

$$\frac{\Delta\epsilon}{\epsilon} = \frac{1}{2} \cdot \frac{\Delta x^2 + (\beta_0 \Delta x' + \alpha_0 \Delta x)^2}{\sigma_0^2} \tag{4.2}$$

in which Δx and $\Delta x'$ are the missteering of the position and angle, respectively, β_0 and α_0 are the Twiss parameters, and σ_0 is the rms beam size.

2. β-Mismatch:
   Syphers also estimated the effect due to β-mismatch:

$$\frac{\Delta\epsilon}{\epsilon} = \frac{1}{2} \mid det\ \Delta J \mid = \frac{1}{2} \cdot \frac{(\Delta\beta/\beta_0)^2 + (\Delta\alpha + \alpha_0 \cdot \Delta\beta/\beta_0)^2}{1 + (\Delta\beta/\beta_0)} \tag{4.3}$$

where ΔJ is the matrix of the error Twiss parameters:

$$\Delta J = \begin{pmatrix} \Delta\alpha & \Delta\beta \\ -\Delta\gamma & -\Delta\alpha \end{pmatrix} \tag{4.4}$$

3. Dispersion mismatch:
   The expression for the dispersion mismatch is:

$$\frac{\Delta\epsilon}{\epsilon} = \frac{1}{2} \cdot \frac{\Delta D^2 + (\beta_0 \Delta D' + \alpha_0 \Delta D)^2}{\sigma_0^2} \left(\frac{\sigma_p}{p}\right)^2 \tag{4.5}$$

where σ_p/p is the relative rms momentum spread of the beam.

A general comment is that, among the three sources, missteering seems to be the most critical one, especially at high energy when the beam size is small. For example, at the BNL for a beam of an emittance of 20π, a missteering of $\Delta x = 1$ mm would lead to 2.5% and 25% emittance growth in the AGS and RHIC, respectively. On the other hand, a β-mismatch of as big as 25% only results in 2.5% emittance increase (assuming $\Delta\alpha = 0$). The numerical example of the dispersion mismatch was given for the AGS: For $\Delta D = 2$ m and $\sigma_p/p = 10^{-3}$, the emittance growth would be 10%.

A. Jansson reported his work on the emittance blow-up measurements and comparison with the theoretical predictions using controlled missteering and β-mismatch in the CERN PS. The agreement was rather poor. In particular, when the missteering and mismatch were small, the measured emittance increase was significant. This demonstrated the difficulty of the experimental studies of these seemingly simple phenomena.

Special type of mismatch — Mismatch of the four Booster rings and PS at CERN In the CERN PS complex, there are four Booster rings. The match between the four rings and the PS presents a specific problem. K. Schindl reported a machine experiment in the PSB and PS using the LHC type beam, *i.e.*, 1.7×10^{11} protons per bunch with small emittance. When only one PSB ring was used, he showed the machines could be well matched so that there was virtually no emittance dilution from the injection to the PSB to the extraction from the PS. (Note: Both horizontal and vertical emittances vary at various stages but the average of the two remains a constant.) This was a respectable accomplishment. But the simultaneous match of the four PSB rings to the PS is a real challenge. Jansson estimated that there could be a 20% emittance blow-up from the PSB to PS if there are no proper corrections to be implemented or no better optics measurements to be taken.

4.5.3.2 Space charge and intrabeam scattering

Space charge effects The space charge is a principal source causing emittance growth when the beam energy is low. Although this has been known for decades, the status of the theoretical study of this phenomenon is not satisfactory. One knows how to calculate the incoherent space charge tune shift, but doesn't know how to estimate the emittance growth in an analytical way. The alternative is computer simulations. But this usually requires substantial computing resources (cpu power and run time). Several codes have been written. S. Machida reported his work using the code SIMPSON. It is a 3-D code. There is a 2-D module that can study the coherent modes due to the space charge. For a debunched beam, his results showed coherent dipole mode, which was previously studied by I. Hofmann, and also quadrupole, sextupole modes, *etc.* At this moment, except the dipole mode, his results are not easy to be checked by experiments because of the lack of appropriate pickup instrumentation. (Note: CERN PS is in the process to develop a quadrupole pickup.) However, this by no means suggests that one could overlook this study. On the contrary, these coherent modes play an important role in high intensity accelerators. The ISIS at RAL is an example. It operates at 50 Hz and delivers 2×10^{13} protons per pulse, *i.e.*, 1×10^{15} protons per second. The loss at extraction is remarkably low at 0.01%. G. Rees commented that this is mainly due to the good control of the closed orbit, which prevents the image current-induced coherent dipole mode from occurring.

Intrabeam scattering The intrabeam scattering is another source of emittance growth. One usually treats it separately from the space charge effect, even though both are closely related. In the study of the space charge effect, each particle is in an electromagnetic field, which represents the smoothed forces of all the other particles. The Coulomb collisions are neglected. In the analysis of the intrabeam scattering, on the other hand, each particle collides with another particle at a time. The forces of all other particles are neglected. Unlike the case of the space charge, there are two existing theories — Piwinski's [2] and Bjorken-Mtingwa's [3] — that tell how to estimate the emittance growth rate due to intrabeam scattering. At high energies and above transition, these theories give similar results and are in agreement with machine experiments. However, at low energies and especially when below the transition, the two theories could give quite different results. To make things more complicated, there is no conclusive machine measurements (to the authors' knowledge) below transition for checking the theories. The difference is not just quantitative. It is in some sense fundamental. This can be explained as follows. When $\gamma < \gamma_t$ (below transition) and $\beta' = D' = 0$ (ignoring variations of the β- and dispersion-function in the machine), Piwinski predicts the existence of an equilibrium distribution in the 6-D phase space, while Bjorken-Mtingwa says this will almost never happen. (It only happens when all the three eigenvalues of the matrix L in Ref. [3] are equal. But this condition will almost never be met in any machine.) It should be mentioned that this conceptual confusion is not merely of academic interest. It has consequences in the design of real machines. For example, Fermilab is building a Recycler to recycle and accumulate antiprotons. It will operate below transition and will use stochastic and/or electron cooling. The intrabeam scattering is considered to be one major source of emittance growth in this storage ring. A correct estimate of the growth rate is essential to the design of the cooling facility. The different estimates from the two theories make the design difficult. As part of the efforts to resolve this problem, a machine experiment is being carried out on the Accumulator Ring at Fermilab. The measured data will be analyzed and compared with the theories.

4.5.3.3 Other sources

The following sources can also cause emittance growth. But they were not carefully discussed at the workshop due to time limitation.

- Power supply noise (*e.g.,* which was identified as one of the major causes of the emittance blow-up in the Tevatron at Fermilab).
- RF noise.
- Rolled quadrupole (which was found in the Tevatron/FNAL and was the cause of large optical distortion and reduction of luminosity).
- Beam instabilities.
- Stacking (coalescing) and cogging.
- Beam-beam effect (*e.g.,* which was believed to cause emittance dilution in the HERA at DESY), *etc.*

4.5.4 Measures to control emittance blow-up

4.5.4.1 Better steering and better match

The followings were discussed at the workshop:

1. Better understanding of the optics:
   This is essential to the better steering and better match. It means better instrumentation and more careful measurement. B. Autin introduced the ABS project (Automated Beam Shaping and Steering) in the PS complex. It requires a dispersion-free section for the measurements, which, however, does not exist in the rings nor in the beam lines. He argued that this was crucial to a better understanding of the optics so it is worthwhile considering a modification of the present PS complex for creating zero-dispersion regions.
2. Installation of correctors.
3. Compensation of the end fields:
   M. Giovannozzi studied the non-linear end field of the PS magnets near the transfer line to the SPS. This field can change the optics of the beam line and lead to the mismatch between the beam line and SPS. The resulting emittance blow-up could be as big as 15-20% during the SPS injection. During the discussion, it was pointed out that special care was needed in analyzing the end fields, because they are 3-D. The field harmonics used in 2-D analysis (*i.e.,* the b_n's and a_n's) should be replaced by the pseudo-harmonics or by their integrated values (integration from the longitudinal component of the field $B_z = 0$ somewhere inside the magnet to $B_z = 0$ somewhere outside the magnet).

4.5.4.2 Injection damper

This is important for minimizing the emittance blow-up at injection due to missteering. The damping time has to be shorter than the beam decoherence time. The bandwidth is determined by the batch spacing (not the bunch spacing). In other words, it does not need to be bunch-by-bunch, but should be able to damp the coherent motion of each individual batch.

W. Hofle reported that the injection damper in the SPS works fine for the normal short bunches (5 ns long). But the horizontal emittance blow-up of the long (25 ns) bunches can not be reduced by this damper. The cause is not clear.

4.5.4.3 Improving bunching factor

One effective way for reducing the space charge effect is by improving the bunching factor. There are two examples.

1. KEK PS:
   K. Shinto reported that, at the injection of the KEK PS, a longitudinal phase error of 90° was intentionally introduced for increasing the bunching factor. As a result, the beam intensity was increased by 25% while the transverse emittance remains about the same. The advantage of this method is that it does not need any additional hardware. The concern is, of course, the quality of the beam (*e.g.*, the filamentation).
2. CERN PSB:
   The second harmonic rf cavity has been used for years in the PSB for increasing the bunching factor. The voltage ratio of the fundamental and second harmonic rf cavities has been optimized by analytical method. But the experimentally observed improvement in bunching factor is somehow lower than the theoretical prediction. The reason is unknown. At present, the system consists of h = 5 and h = 10 cavities. But they will soon be replaced by h = 1 and h = 2 cavities in 1998.

4.5.4.4 Low noise feedback system

This is critical for control of emittance dilution due to external noises (*e.g.*, ground motion and power supply ripple) in a large collider, such as the LHC. There have been extensive studies on this subject both theoretically and experimentally. But it was not discussed at this workshop because the focus was on synchrotrons and beam transfer lines.

4.5.5 Conclusions

During the past years, significant progress has been made in understanding the beam transverse emittance blow-up and its preservation. However, one often finds him-/herself ignorant when he/she tries to explain what was observed in an existing machine or to predict what will happen in a machine under design. There are a number of such examples given in this report. Some of them are even fundamental. These are the challenges. But they are also the directions leading to new achievements. The workshop gladly acknowledged them and promised to work on them.

References

[1] W. Chou and L. Vos, FERMILAB-Conf-97/419 (1997).
[2] A. Piwinski, *Proc. 9th Int. Conf. on High Energy Accel.*, pp. 405-409, SLAC (1974).
[3] J.D. Bjorken and S.K. Mtingwa, *Particle Accelerators*, Vol. 13, pp. 115-143 (1983).

4.6 Report on Mini-Workshop on IP Physics for Linear Colliders

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A mini-workshop focused on physics issues associated with Interaction Point (IP) of linear colliders was held in January 12-16,1998 at Lawrence Berkeley National Laboratory. An interaction point of a linear collider is where intense beams of electrons, positrons, or photons collide. It is an interface between particle physics and collider technology. The collision processes occurred at the IP will on one hand directly affect the detectors and particle physics experimentation, and on the other hand put technical constraints on collider design as a whole. Therefore a crucial task to assess the potential of future linear colliders is to understand these processes and identify effective IP approaches and operation regimes where the deteriorating effects of these processes on collider performance can be minimized, taking into account other collider constraints and requirements. Recently there have been renewed interests in IP physics for linear colliders, driven by the need to re-optimize current designs to enhance performance and reduce cost, the need to reach higher energy, and the need to explore innovative IP schemes and drastically different parameter regimes that could potentially be reached with new acceleration methods. The mini-workshop is organized in response to these new developments in accelerator and high energy physics communities. More than thirty accelerator and particle physicists from Russia, Japan, Europe, India and US participated in either full or part of the workshop program. Following talks were presented and the list given here is in the order of presentation.

Welcome address and opening remarks (S. Chattopadhyay, LBNL). Motivation and program matters (M. Xie, LBNL). Historical review/primer on calculations of synchrotron radiation, classical and quantum (J. D. Jackson, UCB & LBNL). Beamstrahlung, coherent pair creation, and nonlinear QED effects in linear colliders (K. Yokoya, KEK). E-144 experiment – nonlinear QED in strong laser field (G. Horton-Smith, SLAC). Experiments on interaction of high energy (10-200 GeV) electron, positron and photon with crystal (A. Belkacem, LBNL). Synchrotron-Cerenkov radiation and pair production by photons in intense fields (T. Erber, Illinois Institute of Technology). The equivalent photon approximation for coherent processes in linear and ring colliders – coherent bremsstrahlung and effect of short bunch (V. Serbo, Novosibirsk State University). To foundations of classical electrodynamics (E. Bessonov, Lebedev Institute). Synchrotron radiation: the real story – including quantum effects and radiation reaction (T. Erber, Illinois Institute of Technology). Introduction to radiation theory in quasi-classical electrodynamics: Baier-Katkov method (V. Baier, BINP). Progress towards photon colliders, study of an interaction region for gamma-gamma, gamma-e interactions at TESLA/SBLC (V. Telnov, BINP). Measuring the two-photon decay width of intermediate-mass Higgs bosons at a photon-photon collider (T. Ohgaki, Hiroshima University). Some considerations on IP physics (P. Chen, SLAC). Polarization of high energy gamma quanta and electron traversing a laser beam (V. Serbo, Novosibirsk State University). Some thoughts on muon vs. linear collider (J. Wurtele, LBNL & UCB). Comparison of IP environment for hadron collider and e+e- linear collider (D. Cline, UCLA). Robust particle physics experiments doable in dirtier IP environment (H. Murayama, UCB & LBNL). Background studies for present and future e+e- machines (M. Ronan, LBNL). Calculation of mini-jet hadronic background for 5 TeV e+e- linear colliders (T. Ohgaki, Hiroshima University). e+e- pairs and bremsstrahlung luminosity monitor studies for TESLA (O. Napoly, CEA Saclay). CAIN: a Monte-Carlo code for full-blown IP simulations (K. Yokoya, KEK). Quantum suppression of beamstrahlung – scaling and simulations (M. Xie, LBNL). Laser cooling of electron beams, multigun low emittance injector for linear colliders (V. Telnov, BINP). Beam size measurements in a LC using an X-ray gradient undulator (E. Bessonov, Lebedev Institute). A possible final-focus system for a 2.5-TeV W-band linear collider F. Zimmerman, SLAC). Design of a final focus system for linear colliders in the multi-bunch regime (O. Napoly, CEA Saclay). A 3 to 5 TeV linear collider at 30 Ghz (T.Raubenheimer, SLAC). Summary and conclusions (M. Xie, LBNL).

In addition to the talks given above, seven themed discussion sessions were conducted.

- Discussion Session 1 (Leader: T. Erber). Main Theme: Experiments on strong field QED. Topics: The past, present, and more importantly future experiments on strong field QED; importance and feasibility to check on the full structure of strong field QED.
- Discussion Session 2 (Leader: V. Baier). Main Theme: Methodology for IP physics. Topics: QED methodology for IP physics; in particular, versatility, applications and limitations of quasi-classical method.
- Discussion Session 3 (Leader: K. Yokoya). Main Theme: Scaling laws for IP phenomena. Topics: QED phenomena in different regimes: classical regime, quantum regime in weak field and strong field; governing parameters; scaling laws for IP phenomena.
- Discussion Session 4 (Leader: P. Chen). Main Theme: Critical issues and loose ends in IP physics. Topics: Unresolved issues, uncertainties, limitations, prospects, new approaches, future directions of IP physics for linear colliders.
- Discussion Session 5 (Leader: V. Serbo). Main Theme: Photon, hadron, muon colliders vs. e+e- linear collider. Topics: Issues for photon colliders; interaction of electron, positron and photon with strong field in laser and in crystal; IP environment. Discussion Session 6 (Leader: H. Murayama). Main Theme: Interface between IP physics and particle physics. Topics: Robust particle physics experiments that can be done in dirtier IP environment, QED and QCD background issues, mini-jets, effects of background on experimentation, difference in IP environment between hadron collider and e+e- linear collider and its implications for particle physics experiments.
- Discussion Session 7 (Leader: M. Xie). Main Theme: General. Topics: Anything.

Thanks to the stimulating contributions from all participants, the workshop has successfully reached its original goal that is to provide a timely platform where the exciting development of the field especially during past ten years be reviewed and reexamined in the light of the recent developments, and new topics of IP physics important for future linear colliders be identified. Investigation on some of the critical issues identified during the workshop will be coordinated and carried out. For more information on workshop organization see announcement in previous issue of ICFA Beam Dynamics Newsletter `http://wwwslap.cern.ch/icfa/nldec97/`.

5: Announcements of Forthcoming Beam Dynamics Events

5.1 Workshop on Space Charge Physics

The workshop on space charge physics in high intensity hadron rings will be held at Pridwin Hotel, Shelter Island, Long Island in May 4–7, 1998. The workshop focuses on experimental, theoretical and simulation issues. Detailed information available at `http://scwatsi.bnl.gov/`

5.2 European Particle Accelerator Conference

The 1998 European Particle Accelerator Conference will be held at Stockholm, Sweden in June 22-26, 1998. Detailed information available at
`http://www.cern.ch/EPAC/stockholm/EPAC98/Welcome/General.html`

5.3 The 17th High Energy Accelerator Conference

The 17th International High Energy ACcelerator Conference will be held at DUBNA Russia in Sept. 7–12, 1998. Detailed information available at `http://www.jinr.ru/HEACC’98/`

5.4 The Joint US-CERN-JAPAN-RUSSIA Accelerator School

The Joint US-CERN-JAPAN-RUSSIA accelerator School on beam dynamics and measurements will be held at Montreux, Switzerland in May 11–20, 1998. Detailed information available at `http://www.cern.ch/Schools/CAS/`

5.5 US Particle Accelerator School

The US Particle Accelerator School (USPAS) will be held at Stanford University from June 16 – June 26, 1998. The courses scheduled are (1) Accelerator Fundamentals, (2) Accelerator Physics, (3)Microwave Measurement Laboratory and RF Systems for Accelerators, (4) Classical Theory of Radiation from Free Electrons, (5) Beam Experiments, (6) Magnetic Systems, (7) Classical Mechanics and Electromagnetism for Beam Physics, (8) Plasma Accelerators, Lenses and Light Sources, (9) Klystron Technology and Measurement Laboratory. Detailed information available at `http://www.indiana.edu/~uspas/programs/stanford.html`

5.6 Beam Physics School

An beam physics accelerator school sponsored by OCPA, Synchrotron Radiation Research Center, South East Asia Theoretical Physics Association, will be held at SRRC in Taiwan in Aug. 3-11, 1998. The official language is Chinese. Contact A. Chao (`achao@slac.stanford.edu`). Detailed information available at `http://www.bpl.nthu.edu.tw/OCPA98/`

5.7 INTERNATIONAL WORKSHOP on BEAM DYNAMICS & OPTIMIZATION

BDO98 `bdo98@apcp.apmath.spbu.ru` St.Petersburg, RUSSIA
St.Petersburg, Russia, June 29 - July 3, 1998

The objective of the Workshop is to bring together mathematicians, physicists and engineers to present and discuss recent developments in the area of mathematical control methods, modeling and optimization, theory and design of charged particle beams. This Workshop is the fifth event in a series which started in 1994. Working languages are Russian and English.

MAIN TOPICS includes (1) Nonlinear problems of beam dynamics: mathematical modeling, nonlinear aberrations, including space charge forces and the self-consistent distributions problem, long time beam evolution, dynamic aperture and halo problems; (2) Methods of control theory in the problems for the beam and plasma dynamics optimization; (3) Mathematical modeling of the electro- and magnetic fields; (4) Computing problems for beam physics, object-oriented modeling; (5) Software for the beam dynamics and optimization.

5.8 Particle Accelerator Conference

The 1999 Particle Accelerator Conference - the 17th in this series - will be held March 29 - April 2, 1999 at the New York Marriott Marquis organized by BNL. Detailed information available at `http://pac99.bnl.gov/`.

6: Announcements of the Beam Dynamics Panel

6.1 The 16th ICFA Advanced Beam Dynamics Workshop on Nonlinear and Collective Phenomena in Beam Physics

M. Cornacchia `cornacchia@slac.stanford.edu` SLAC
C. Pellegrini `claudio@vesta.physics.ucla.edu` UCLA
Arcidosso, Italy, September 1–5, 1998.

The Workshop will be sponsored by ICFA, the US Department of Energy, the National Institute for Nuclear Physics (INFN-Frascati, Italy), the National Institute for Alternative Energies (ENEA-Frascati, Italy), the National Laboratory for High Energy Physics, (KEK, Japan), the Lawrence Berkeley National Laboratory (LBNL, USA), the Stanford Linear Accelerator Center (SLAC, USA), the University of California at Los Angeles and the University of Rome ”La Sapienza”. The meeting will center on three accelerator physics topics: Single Particle Nonlinear Dynamics, Creation and Manipulation of High Phase Density Beams, and Physics of High Energy Density Beams. Detailed information available at
`http://pbpl.physics.ucla.edu/~laraneta/arci98/index.html`.

6.2 ICFA Beam Dynamics Newsletter

Editors in chief

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6.2.1 Aim of the Newsletter

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.

6.2.2 Categories of the Articles

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. New Doctoral Theses in Beam Dynamics

   Please send announcements to the editors including the following items (as a minimum):

   (a) Name, email address and affiliation of the author,
   (b) Name, email address and affiliation of the supervisor,
   (c) Name of the institution awarding the degree,
   (d) The title of the thesis or dissertation.
   (e) Date of award of degree. (For a while, we accept the thesis awarded within one year before the publication of the newsletter.)

   A *short* abstract of the thesis is also very desirable.

8. Editorial

All articles except for 6) and 7) 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 instructions below.

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

6.2.3 How to Prepare the Manuscript

Here, the *minimum* preparation is explained, which helps the editors a lot. The full instruction can be found in WWW at

`http://www-acc-theory.kek.jp/ICFA/instruction.html`

where you can find the template also.

Please follow the following:

- Do not put comments (%) when sending the manuscript through e-mail. Instead, you can use `\comm` as `\comm{your comments}`.
- Start with `\section{title of your article}`. **It is essential**.
- Then put your name, e-mail address and affiliation.
- It is *useless to include any visual formatting commands* (such as vertical or horizontal spacing, centering, tabs, etc.).
- Do not define new commands.
- Avoid TEXcommands that are not part of standard LATEX. These include the likes of `\def`, `\centerline`, `\align`, ...
- Please keep figures to a minimum. The preferred graphics format is Encapsulated Postscript (EPS) files.

6.2.3.1 Regular Correspondents

Since it is impossible for the editors and panel members to watch always what is going on all around the world, we have started to have *Regular Correspondents*. They are expected to find interesting activities and appropriate persons to report them and/or report them by themselves. We hope that we will have a ”compact and complete” list covering all over the world eventually. The present *Regular Correspondents* are as follows

Liu Lin (`liu@ns.lnls.br`)	LNLS	Brazil
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Ian C. Hsu (`ichsu@ins.nthu.edu.tw`)	SRRC	Taiwan

We are calling for more volunteers as *Regular Correspondents*.

6.2.4 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. (See below).

6.3 World-Wide Web

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.

6.4 ICFA Beam Dynamics Panel Organization

The mission of ICFA Beam Dynamics Panel is *to encourage and promote international collaboration on beam dynamics studies for present and future accelerators*. For this purpose, we publish *ICFA Beam Dynamics Newsletters* three times a year, we sponsor *Advanced ICFA Beam Dynamics Workshops* and *ICFA Beam Dynamics Mini-Workshops*, and we organize *Working Groups* in the panel to promote several important issues.

Chairman K. Hirata
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