DESY M - 88 - 01
January 1988

ICFA

International Committee for Future Accelerators

Sponsored by the Particles and Fields Commission of IUPAP

* * *

BEAM DYNAMICS NEWSLETTER

edited by

E. Keil and A. Piwinski

January 1988

CONTENTS

page

INTRODUCTION 5

BEAM DYNAMICS ACTIVITIES AT SSC CENTRAL DESIGN GROUP, A.Chao 7

BEAM DYNAMICS STUDIES AT LBL, S.Chattopadhyay 10

STUDIES ON PARTICLE DYNAMICS AT THE NOVOSIBIRSK INSTITUTE OF NUCLEAR PHYSICS, N.S.Dikansky 13

OTHER BEAM DYNAMICS INVESTIGATIONS AT THE TEVATRON, D.Johnson 20

PLANS FOR BEAM DYNAMICS WORK AT CERN IN 1988, E.Keil 21

BEAM DYNAMICS ACTIVITIES AT CEBAF, C.Leemann 26

BEAM DYNAMICS ACTIVITIES AT DESY, A.Piwinski 28

BEAM DYNAMICS WORK AT SLAC, R.D.Ruth 30

ONGOING AND PLANNED BEAM DYNAMICS ACTIVITIES IN KEK, T.Suzuki 33

SSC-MOTIVATED DYNAMICS EXPERIMENTATION AT THE TEVATRON, R.Talman 37

ACTIVITIES IN ITALY AND AT EUROPEAN SYNCHROTRON RADIATION SOURCES, S.Tazzari 40

FORTHCOMING BEAM DYNAMICS EVENTS 45

INTRODUCTION

The third meeting of the ICFA Panel on Beam Dynamics was held at Lawrence Berkeley Laboratory, Berkeley, Cal., USA, from 1st to 3rd October 1987. During the meeting the panel members and invited speakers gave talks on ongoing and planned beam dynamics studies in their home laboratories and/or regions. As already done after the second meeting of the Panel, these presentations will be published in a newsletter.

The Beam Dynamics Newsletter is not intended to be a substitute for journal articles, conference proceedings, ect. which usually describe completed work. It is rather intended as a channel for describing planned work and unsolved problems. The panel hopes that in this way international collaboration can be stimulated and unnecessary duplication of work can be avoided.

Readers who would like to use the Beam Dynamics Newsletter to announce their plans for future beam dynamics work and their unsolved problems are encouraged to get in touch with the panel chairman, Dr. E. Keil, LEP Division, CERN, CH 1211 Geneva 23, Switzerland.

Thanks are due to the SSC Directorate for its hospitality during the panel meeting, and to Prof. P. Waloschek for his help with this Newsletter.

BEAM DYNAMICS ACTIVITIES AT SSC CENTRAL DESIGN GROUP

Alex Chao, SSC CDG

Lattice Design

After the re-optimization of the phase advance per cell from 60° to 90°, a re-optimization of the interaction region design by varying the parameters (assuming the same modular structure) has confirmed that the CDR design is indeed close to a local optimum. The only recent basic change in the IR design has been an improved dispersion suppressor. (A. Garren, D. Johnson)

Various possibilities of IR layouts have been designed with the basic clustered racetrack geometry. Some of them include IR by-passes. No fundamental optical difficulties were found. (A. Garren, D. Johnson)

Aperture Experiments at Tevatron (CDG/FNAL, spokesman: D.Edwards)

This has been a high priority item. The first round of a total of 16 shifts (6 scattered, 10 dedicated) have been accumulated in March to May. A large amount of data were collected. Extensive tracking simulations were carried out to compare with these data. Results so far indicate that the agreement is remarkably good for moderate sextupole settings. For strong sextupoles, however, the agreement has been disappointing. For the first time, subtle features (e.g. resonance islands of order 5, 7, 19, and 26) in phase space are directly measured. A second round of experiemtns (approximately 14 shifts) will soon be proposed to Fermilab, partly to address this concern and partly to pursue further nonlinear beam dynamics effects. So far, there is no evidence of a need to change the 4 cm SSC aperture.

In addition to implications on the SSC aperture, this experiment represents a significant step for accelerator physics research. Proposals of similar collaboration with other reputable laboratories are welcome.

Operations Simulation

Operations simulation (i.e. modelling) has been one of the main efforts at CDG. The simulation workstation has now grown to a collection of 6 interconnected SUN terminals and a 800 Mbyte disk. The physics model is based on the TEAPOT program.

The present capacities include interactive graphics interface, calculation of lattice functions, chromaticity curves, tune resonance diagram, particle tracking, Fourier analysis, first turn closure. In the presence of linear coupling, it also calculates the beam tilt, the coupling coefficient and the coupled tunes. Further tool developments will be the inclusion of orbit correction, and the simulation of machine function measurements and operation with device failures. The immediate tasks, however, are to apply the tool as presently exists to simulate the decoupling operation and the operation of injection in the presence of persistent current effects. (L.Schachinger, R. Talman, T.Sun, R.Hinkins)

Analytic Tools Development

Useful analytic tools are developed for the calculation of the linear and nonlinear optics of a beam line. With the beam line elements as input, the output is the algebraic expression of the linear and nonlinear maps, which can be used to extract various physical quantities as the tune shifts, smear and resonance strengths. The tool is based on the algebraic manipulation program MAXIMA. It has been used to obtain the parametric evaluation of the various possible schemes envisioned for compensating the nonlinear magnet field errors. Application to the IR insertions is envisioned. (E.Forest, J.Peterson)

The trend of developing analytical tools along this line will continue. One possibility is to include the TPSA (truncated power series algebra, M. Berz) technique to produce higher order maps. Translation between the Taylor and Lie coefficients can be provided by the package. Techniques of symplectic integration will also be investigated.

Tracking Programs Development

The TEAPOT program development is mainly concentrated on its adoptation to the workstation environment. The RACETRACK program was substantially modified for SSC needs. These modifications include a more efficient random number generation, a faster and more reliable closed orbit finder, and analysis packages for the nonlinear maps. (E.Forest and B.Leemann) Some effort was also given to the development of MARYLIE3.0 and 5.0 in the past year. (A.Dragt)

Dipole Field Correction Schemes

Several possibilities have been suggested and will be studied:

- using windings for sextupole, octupole and decupole on the beam tube. (CDR)
- using the wedges in the coil packages to carry correction currents. (R.Talman, M.Green)
- introducing a set of correctors in the middle of half cells. The relative strengths of the F-, center-, and D-correctors per half-cell are given by Simpson's rule for three-point integration (1:4:1). (D.Neuffer)

Beam-beam Effects

A model of coherent beam-beam effect, following Hirata, is being studied. (M.Furman, A. Chao) Some disagreement with Hirata's model was found. The flip-flop solutions are found to be unstable. More stdies will continue.

An effort was launched to study the beam-beam effects particular to the SSC (J.Irwin and J.Tennyson), a notable example is the long-range beam-beam effect. Preliminary results indicate that long-range beam-beam effect is of importance to the stability of the tail particles (> 6-7 sigma) during colliding beam operation. This study is being continued.

Polarization

A model design of arcs with Siberian snakes was made (K. Steffen). The number of Snakes vary from 14 to 82. Each snake replaces one 17-meter dipole magnet.

A perturbation calculation was developed to estimate the loss of polarization during the acceleration process from 1 to 20 TeV in the presence of Siberian snakes. (A.Chao and T.Sun) It was found that in the absence of errors, the loss of polarization is tolerable with 64 snakes and is marginal with 32 snakes. This result needs to be compared with those obtained by other methods.

Interaction Region Quadrupoles

The tolerance of magnetic field errors in the final focus IR quadrupoles was systematically studied. In the colliding beam operation, the aperture is dominated by these errors. To maintain an adequate aperture for the beam, each of the final focus quadrupoles is to be equipped with multipole windings up to 12-th poles to compensate for the errors. (B.Leemann)

BEAM DYNAMICS STUDIES AT LBL

S. Chattopadhyay, LBL

On-going beam dynamics studies at LBL are performed in connection with the LBL 1-2 GeV Advanced Light Source, the SSC, Two Beam Accelerator, and Heavy Iron Fusion Accelerator Research (HIFAR). The ALS activities also include generic research on: (a) high brightness, low emittance storage rings for the TeV-scale future linear colliders, and (b) beam dynamics and optics of incoherent and coherent undulator radiation (Free Electron Laser studies are carried out in this context).

Advanced Light Source

One of our primary focuses is on the beam dynamics in presence of undulators and wigglers. Dynamic aperture of the high brightness lattice in presence of strong undulators is studied in terms of the linear and nonlinear effects and the symmetry breaking due to insertion of an undulator. ALS has a highly nonlinear lattice of modest size. There are very few but very strong nonlinear elements like sexupoles. Superior chromatic and dynamic behavior is obtained by 'clever' but sensitive cancellation of large lattice parameters. In particular, the betatron phase-shift between sextupoles is a crucial quantity and needs to be carefully controlled. Undulators affect the dynamic aperture through their effect on these phase shifts. ALS lattice can be used as a test bed to check various algorithms for finding stability boundaries. There is on-going recent collaboration with SLAC where the ALS lattice is used as a model to test the Hamilton-Jacobi technique proposed by Ruth and Warnock.

Another important area of activity has been the study of impedance beyond the "cutoff" of beam tube. This is relevant for very short bunches (10-20 ps) as is the case for the ALS. Issues under study include high-frequency behavior and appropriate power law roll-off of the impedance as a function of frequency, single localized structure vs. periodic structures, various diffraction and optical resonator models, general perturbation theory, 'trapped modes" beyond 'cutoff', impedance of a 'curved" vacuum chamber as a whole, the so-called free space impedance, impedance calculations of transversely coupled beam tube segments as in the ALS with antechamber, and impedance measurement techniques. LBL hosted a Workshop on Impedance Beyond Cutoff, August 18-21, 1987 where accelerator physicists from CERN, Frascati, CEBAF, SLAC, ANL, LBL, LANL and LLNL participated.

Beam dynamics studies on the ALS are directly relevant to Damping Rings for Linear Colliders, including wiggler lattices, and for short wavelength (40 Å) storage-ring based FELs. Physics issues being studied in this connection are zero momentum compaction lattice, collective effects, and new techniques to improve brightness.

In the area of beam dynamics and optics of undulator radiation, our studies have been and are continuing in the following topics: formulation of a new phase-space method for describing radiation based on Wigner distributions and taking 'diffraction' into account (completed), study of electron beam-radiation overlap and the effect of finite beam size on the brightness, the 'start-up' of a high-gain FEL in analogy to 'spontaneous' growth of microwave instability in storage rings, and study of infrared (oscillator) and UV (single pass) FELs.

SSC

In connection with SSC, we have studied: (1) Higher-order nonlinear invariants of the discrete synchrotron map. (2) Algorithm to generate "noise" with arbitrary correlation times. (3) Integration of perturbation theory with tracking e.g. canonical integrators as tracking codes. This allows routine evaluation of "maps" to machine precision and perform perturbation analysis on these maps. (4) Hamiltonian-free perturbation theory based on generalized phase-advances. This has found powerful applications in 'spin-orbit' coupling in storage rings and in 'integrating' with the 'empirical' mapping technique using Hamilton-Jacobi method. (5) Coherent beam-beam effects with long-range interactions.

Two-Beam Accelerator

Particle dynamics in the steady-state FEL portion of a FEL-based TBA has been studied. A steady-state FEL is a periodic long structure where the electron beam energy, lost by the FEL action, is replenished once a period with a short induction accelerator unit. Longitudinal dynamics has been studied by a 1-d simulation code. Results show that after an initial start-up period, particle detrapping from the ponderomotive wave is minimal in a steady-state FEL of several kilometers. Simple linear model of particle diffusion has been constructed and found to be adequate.

As an application to TBA, the suppression of FEL side-band instability by waveguides has been studied. An mm-range FEL is considered to be inside a waveguide. Frequency shift $\Delta\omega$ of the sidebands depends on the group velocity v_g of the structure; $\Delta\omega \propto (1-v_{||}/v_g)^{-1}$. The group velocity $v_g \approx v_{||}$, resulting in sidebands shifted far away from the fundamental, thus essentially removing the sidebands.

Transverse resistive wall instability in Relativistic Klystrons has also been studied and found to be benign.

Heavy Ion Fusion Accelerator Research (HIFAR)

HIFAR is a program of research to explore the physics and technology of using an induction linac (pulsed power) to generate Inertial Confinement Fusion Power. For a practical plant, one needs several megajoules of energy deposited in a few mm size pellet in about 10 ns, several times a second. Energy is expected to be delivered by ion beams e.g. mega-amps of protons @ 10MeV or kiloamps of uranium @ 10 GeV (50 Mev/nucleon). Heavy ions are attractive as an extrapolation of well established technology.

The accelerated bunch of ions must be kept short, consistent with economy and transverse containment, in order to exploit the efficiency of the induction accelerator for shrot intense pulses of current. At the same time, the emittance and momentum spread must be kept low to permit final focusing of the beam on a target a few mm in size 5 to 10 meters inside a reactor vessel. Collective effects dominate particle motion throughout the accelerator. The Debye length is 1/10 to 1/20 of the beam radius. Space charge suppresses the phase advance from 60° to 6°. Severe potential well distortion of the beam distribution occurs even in the absence of perturbation waves.

Transport of such a beam without emittance growth has been demonstrated experimentally in scaled experiments and confirmed theoretically, both at LBL. The theoretical studies involved extensive simulation, combined with simple thermodynamic analyses using "smooth approximation". The key parameters are the unperturbed phase advance σ_0 per cell and space charge depressed tune, σ. For $\sigma_0 \approx 60\text{-}70°$, it was found that the rms emittance is preserved but gross adjustments of beam phase space takes place. Density profile changes for $\Delta Q/Q_0 \approx 1/8$ to 1/6. For $\sigma_0 \approx 90°$, one observes the expected beam envelope instability. These effects are all understood in terms of electrostatic energy/unit length. Nonlinear distortion of the beam distribution gives rise to changes in the beam emittance.

Continuing theoretical investigation focuses on: (a) analysis and extensive plasma simulations of longitudinal space-charge waves excited by errors in the accelerating voltage; (b) the time-dependent problem of correction of misaligned centroid due to ion momentum variation of up to 20% at a given quadrupole location arising from shaping the accelerating voltage to adjust bunch length; (c) Final time compression at the exit of accelerator by a factor of ten lending to a momentum tilt that is acceptable by the lens system; and (d) Neutralization of space-charge by external injection of electrons in the reactor vessel.

STUDIES ON PARTICLE DYNAMICS AT THE NOVOSIBIRSK INSTITUTE OF NUCLEAR PHYSICS

N.S.Dikansky

VLEPP - Colliding Linear Electron-Positron Beams

The VLEPP project was first reported at the Internation Seminar on Problems in High Energy Physics and Thermonuclear Fusion which was devoted to the 60th anniversary of academician G.I.Budker in April of 1978. Later on the project was published in the proceedings of ICFA-2 (1979) and International Conferences in 1983 and 1986.

The major problems in beam dynamics are connected with practical realization of the acceleration of a single highly-intense electron (and also positron) bunch in a linac with extremely low emittance. An analusis of the collision effects is also needed to investigate the problem of achievement high luminosity.

These problems were studied and successfully resolved by 1978 (V.E.Balakin, A.V.Novokhatsky, V.P.Smirnov and N.A.Solyak).

Studies have been made of the structure of the radiation fields determining to a considerable extent the longitudinal and transverse dynamics of a single bunch. The method of numerical calculation of the fields in the accelerating structure has been developed and approximate analytical formulae for the amplitude values of the fields have been derived according to a physical model.

It has been that the optimal choice of the parameters of the bunch and accelerating field enables one to achieve a highly-efficient acceleration of a single bunch and a sufficiently low energy spread.

The transverse dynamics of a single bunch has been studied. The action of the radiation field has been shown to lead to the development of transverse instability of a single bunch.

The method has been suggested of suppressing the transverse instability. Its essence consists in the introduction of a linear change in particle energy along the bunch by a phase tuning of the accelerating field (this method is not similar to Landau damping despite some common features).

The mechanisms of increasing an effective emittance of the bunch have been considered when the transverse instability is suppressed by the proposed method. An increase of the initial emittance is due to an unstable position of the quadrupole lenses and accelerating sections (stochastic heating of the beam).

The beam-beam effects have been analysed as well. The beam-beam effects are shown to considerably attenuate when using plane rather than round bunches.

At present the results of research in beam dynamics in a linac are used in the calculation of the technical parameters of the VLEPP facility which are required to obtain the 2 x 1 TeV colliding beams and the $\gtrsim 10^{32}$ cm^{-2} s^{-1} luminosity.

Studies of Beam Dynamics at VEPP-4

I n t r o d u c t i o n

At present the VEPP-4 device is in the stage of reconstruction with the aim at:

a) increasing the luminosity;

b) providing the proper conditions for studying the processes in the two-photon physics.

An increase in luminosity up to (5-8) 10^{31} $cm^{-2}s^{-1}$, at an energy of up to 6 GeV is expected to be achieved by decreasing the β -function and by creating a regime with 2 bunches in each beam.

The next step in the modernization of VEPP-4 is to be an obtaining of longitudinally-polarized beams and of the beams with monochromatized interaction energy.

Accordingly, the following works on beam dynamics are in progress:

1. Studying of the collision effects. Much attention should be paid to the investigation of the life time of the beams, i.e. to the dynamics of large amplitudes. The possibilities of computer simulation are restricted on account of a time-consuming counting and, consequently, an analytical approach is being evolved. In addition, the work are being performed dealing with an influence of the non-ideal magnetic system on the collision effects.

2. Obtaining of longitudinally-polarized beams. Longitudinally-polarized beams are assumed to be used for designing the experiments in the Υ -meson region. Various depolarizing effects are under analysis.

3. Obtaining of colliding beams with monochromatized interaction energy. Monochromatization of the interaction energy will allow the experimental capabilities of the device in the range of narrow resonances to be extended. The approaches to gain the monochromatization are being studied.

The first approach is based on the beam expansion in vertical direction using electrostatic skew-quadrupole lenses to ensure the different expansion signs for electrons and positrons. The major obstacle for this approach is the beam-beam effects violating the monochromatization.

The second approach is to use the structures with radial expansion in energy. The beam monochromatization in such a structure has been estimated using special high-frequency resonators with radial field gradient, placed on both sides of the collision place.

4. Coherent instabilities. The works are in progress on studuing coherent instabilities in connection with the programme of increasing luminosity and of obtaining high currents.

Electron cooling

The device "Solenoid model" is designed to analyse electron cooling in the range of low relative velocities of the particles, $\lesssim 10^6$ cm/s. The measurements are performed in a single-flight scheme. The basic parameters of the device are: energy of H^- or H^+ ions 1 MeV, length of the cooling section 2.4 m magnetic field of the solenoid up to .4 T, and electron density of the cooling beam up to $2 \cdot 10^9$ cm^{-3}. Special measure have taken to obtain small transverse distortions of the magnetic force lines. After correction, the magnitude of the field distortions on the azis is $\sqrt{\langle \Delta B_\perp^2 \rangle}/B \simeq 5\ 10^{-5}$ throughout the cooling section.

So far detailed measurements have been performed of the friction force longitudinal with respect to the magnetic field. Great difference has been revealed in the cooling of positively and negatively charged ions at low relative velocities of the particles. The maximum friction force for H^- ions is roughly 4 times larger than that for protons and equals $\sim$ 30 eV/m and the corresponding cooling decrements is $\sim 3\ 10^{+5}$ s^{-1}.

Studies have been made of the suppression, by a magnetic field, of the intrabeam scattering in the electron beam.

Further efforts are focused to the cooling of transverse velocities. To obtain the transverse cooling it is necessary to have a high degree of compensation of the electron space charge by the ions of the residual gas. At present, a major obstacle is the development of the axi-unsymmetrical instability leading to ion heating and to a partial destruction of the compensation.

VEPP-2M. Collision Effects at VEPP-2M with a Superconducting "Snake" off

In the 1985-87 runs the electron-positron storage ring VEPP-2M operated with a superconducting magnetic snake installed at the ring. Its maximum field achieved 8.T.

1. An increase in luminosity, proportional to a growth of the horizontal emittance is gained provided that the ultimate values of the spatial charge are achieved, $(\xi_z)_{max}$ and $(\xi_x)_{max}$.

2. With compensation of a snake-introduced distortion of the magnetic structure of the storage ring, there may occur a violation of the mirror symmetry of the shifts in betatron phases μ_z and μ_x between the collision points. An influence of the asymmetry $\Delta\mu_z$ on an increase of the vertical size (Fig. 1) and of $\Delta\mu_x$ on the ultimate current of the colliding beam (Fig. 2) has been observed experimentally.

3. A lengthening of the "natural" longitudinal sizes of the bunches, connected with an installation of the snake and with a growth of the opposing currents, restricts the possibility of decreasing the vertical β -function at the collision point down to β_{z0} = 0.3 cm. At VEPP-2M, starting with $\beta_{z0}/\sigma_s \simeq$ 1.5 a substantial decrease of the maximum spatial charge is observed.

4. The radiation damping decrements, introduced by the snake field, result in increasing the space-charge parameter $(\xi_z)_{max}$ at low energies of VEPP-2M. The magnitude of the effect reduces with

increasing the energy of the storage ring. For $(\xi_z)_{max} \gtrsim 0.04$ ($E \sim 400$ MeV) a three-fold increase of the radiation decrements has no influence on the maximum

Spread of spin frequencies

The frequency spread of the spin precession vs. the nonlinearities of the magnetic structure has been also studied at VEPP-2M. Measurements have been experimentally made of the depolarization rate with spin-flip by a resonant radio-frequency field. Depolarization has been shown to be minimum in the regime of sextupole corrections, which corresponds to a zero chromatism of radial betatron oscillations. In this case, the spread of spin frequencies is $\delta\Omega \simeq 2\ 10^{-7}\ \omega_s$ (ω_s is the resolution frequency).

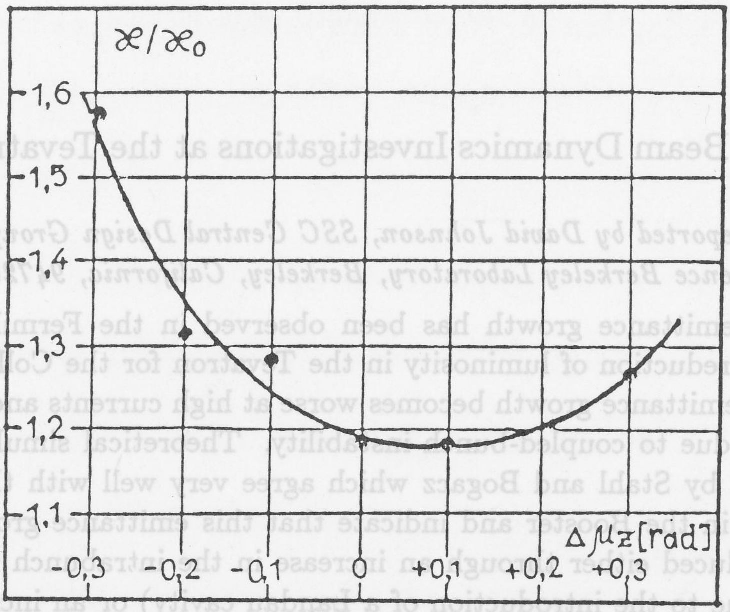

Fig. 1. A relative increase of the vertical emittance of the colliding beam $\varkappa/\varkappa_0$ vs. the magnitude of $\Delta\mu_z$ at fixed ξ_z.

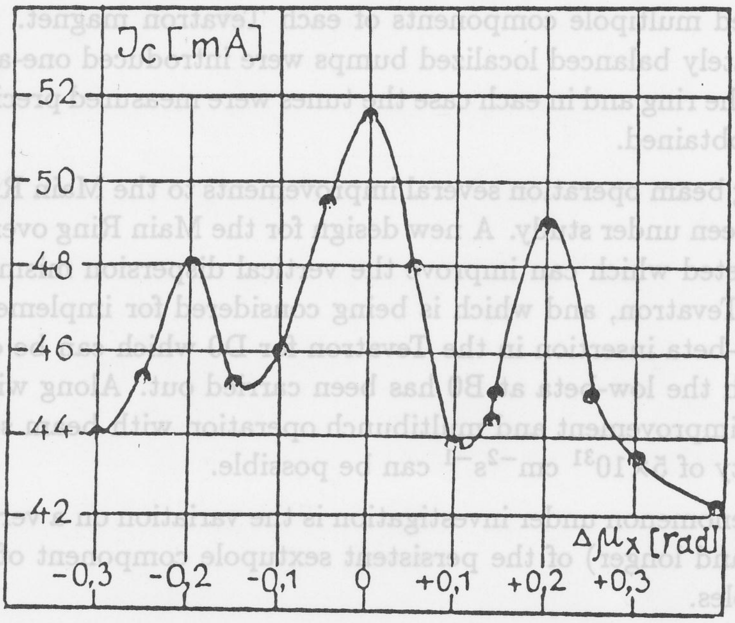

Fig. 2. The ultimate current of the colliding beam vs. the value of $\Delta\mu_x$. E = 390 MeV, $\Delta\mu_z = 0$, $\nu_x = 3.0588$, ν_z = 3.0974.

Other Beam Dynamics Investigations at the Tevatron

Reported by David Johnson, SSC Central Design Group,
Lawrence Berkeley Laboratory, Berkeley, California, 94720

Noticeable emittance growth has been observed in the Fermilab Booster which causes a reduction of luminosity in the Tevatron for the Colliding Beam program. This emittance growth becomes worse at high currents and is thought to be partially due to coupled-bunch instability. Theoretical simulations have been performed by Stahl and Bogacz which agree very well with the observed beam behavior in the Booster and indicate that this emittance growth can be significantly reduced either through an increase in the intrabunch synchrotron tune spread (due to the introduction of a Landau cavity) or an increase in the interbunch tune spread. Another possible cure would be through the use of an active damper. Experiments to reduce the emittance growth are underway. In a related emittance improvement, beam has been transferred from the Booster into the Main Ring at 9 GeV instead of the design energy of 8 GeV. This will reduce beam blow-up due to low-field effects in the Main Ring.

Detailed comparison of beam performance in the Tevatron with tracking calculations have been performed by Collins, Gelfand, Henna, and R. Johnson using the measured multipole components of each Tevatron magnet. In this experiment accurately balanced localized bumps were introduced one-at-a-time at many places in the ring and in each case the tunes were measured precisely. Good agreement was obtained.

For colliding beam operation several improvements to the Main Ring and the Tevatron have been under study. A new design for the Main Ring overpass at D0 has been completed which can improve the vertical dispersion mismatch in the transfer to the Tevatron, and which is being considered for implementation. A design for a low-beta insertion in the Tevatron for D0 which can be operated in conjunction with the low-beta at B0 has been carried out. Along with antiproton production improvement and multibunch operation with beam separators a design luminosity of 5×10^{31} cm^{-2}s^{-1} can be possible.

Another phenomenon under investigation is the variation on a very long time scale (minutes and longer) of the persistent sextupole component of the superconducting dipoles.

PLANS FOR BEAM DYNAMICS WORK AT CERN IN 1988

E. Keil

CERN, Geneva, Switzerland

The CERN accelerator complex will be operated for proton and lepton acceleration from mid-March till end-August, and for $\bar{p}p$ colliding beam physics with the S$\bar{p}$pS from September till December. The plans for beam dynamics work in the individual accelerators are adapted to this schedule.

1. PS Machine

The preparation of the new $\bar{p}$ production beam, in 5 short bunches at 26 GeV/c, is going on. It is based on several RF harmonic number changes during acceleration, with intensity close to 2×10^{13} p/p, which needs a new powerful beam loading compensation of the RF cavities, to be installed during the next shutdown. It is hoped that this new beam will be operational in the second half of 1988.

The maximum energy of the 4 PSB rings will be raised to 1 GeV in 1988, to allow better PSB-PS transmission, and thus an intensity increase of the 20 bunches high intensity beam for the SPS by easing the space-charge problems.

The Q_H dependence of sextupolar resonance width at low energy, observed last year, has disappeared; these resonances are no longer excited. This seems to be linked to the change of the injection quadrupoles during the last shutdown. The fast radial instability occurring at 14 GeV/c after trapping of high intensity beams by the 200 MHz RF system was not investigated further.

The study of coherent effects in ion-ion collisions - and possibly the creation of a quark-gluon plasma - require highly relativistic and heavy projectile ions. The CERN accelerator chain linac 1-PBS-PS-SPS proved able to accelerate light ions (d, α and O^{8+} in 1986) to an energy of 200 GeV/nucleon, an order of magnitude above what can be achieved anywhere else.

Making use of the fact that a (modified) ion source delivers a mixture of oxygen (95%) and sulphur (5%) ions, the heavier S^{16+} were accelerated as "passengers" of the O^{8+} beam, with enough total intensity to allow controlled acceleration. The two beams with almost equal charge-to-mass ratio diverge in radial position at PS transition energy; thus manipulations of the low-level RF allow eliminating either of the ion species. This way the SPS was fed - "à la carte" - with fairly intense O^{8+} beam for setting-up, and with S^{16+} beam for physics.

For the future, the possibility of accelerating heavy ions such as Pb is being explored and a design study - involving a new ion source, RFQ and replacement of linac 1 - has been launched. For the PSB, open beam dynamics problems are : (i) possibilities of "open-loop" acceleration of about 10^6 charges/pulse; (ii) vacuum pressure needed to avoid excessive beam losses due to loss-capture of electrons in the rest gas ?

2. PS Booster

It is at the very highest ($\sim 10^{13}$ p/ring) and very lowest ($< 10^9$ charges/ring, for heavy ions) intensities, both of them to be produced in pulse-sharing mode, that beam dynamics problems appear.

When approaching 10^{13} p/ring - achievable by means of a bunch-flattening 2nd harmonic cavity - not all rings follow : Ring 4 is haunted by a loss near the ejection flat top, at about 750 MeV, for an intensity level beyond 7 10^{12} p/p. Observations hint at a longitudinal instability, where all 5 bunches move in phase, with a higher-order mode we were yet unable to classify.

The low-level beam control system, recently upgraded to enable ions to be accelerated, apparently is also less "touchy" at high proton intensity as the 2nd harmonic cavity better tracks the fundamental one.

Further improvements are hoped for with a local solid-state grid driver for the fundamental cavities (1 per ring) which also tackles beam loading by feedback; prototype tests with beam are scheduled in 1988.

3. AA and ACOL

For the compensation of nonlinear beam envelope distortion in the antiproton collector, calculation and design of sextupole windings located in the aperture of quadrupoles in zero dispersion straight sections are completed. Implementation will take place at the beginning of 1988. The scheme is based upon first order perturbation theory. Second order perturbation calculation using symbolic algebra have been started but the results have not yet been tested.

4. LEAR

A new system of "distributed sextupoles" (pole face windings on magnets or shimming) is under study to avoid high order chromatic effects ($Q'' = \Delta Q/(\Delta p/p)^2$ etc.) as well as 3rd and 4th order resonances, excited by the short 6-pole lenses used at present. These and other measures are necessary to be able to store beam at 2 MeV and maybe 200 keV.

Electron cooling has been installed and tested in November. The influence of the solenoidal field of the cooler has been studied and compensated. Even stronger (superconducting, $\int B d\ell \simeq 4$ Tm) solenoids will be used in the jet-set (internal target), detector to be installed in SS2 of LEAR and in a "spin-splitter" arrangement to polarize the circulating $\bar{p}$-beam. Compensation schemes (possibly strong longitudinal fields close to the main solenoid) are under study (including spin dynamics) in collaboration with the user teams.

5. EPA

In 1987, EPA has reached a performance well beyond the design figures for both electrons and positrons. For 1988, much routine operation is foreseen, mainly for tests with the SPS. Test in EPA are planned on the clearing of rest gas ions, on an increase of the energy to the nominal value of 600 MeV and on bunch slicing, i.e. the ejection of a bunch in two pieces by a septum.

6. SPS

The machine development activity up to the end of September 1987 has concentrated in the SPS around the injection and acceleration of positron and electron beams. At low intensity (less than 10^{10} particles per bunch, 4 bunches equally spaced in the machine), the only problems encountered are linked to remanent field and eddy current effects which are particularly strong at 3.5 GeV/c following the hadron acceleration cycle at 450 GeV/c. Careful tuning has produced a loss-less acceleration up to 18 GeV/c, the maximum energy allowed by the available RF voltage.

Above around 10^{10} particles per bunch, a fast loss occurs after a about 10 to 50 turns. This observation is compatible with the calculated threshold for the transverse mode coupling instability.

In November and December the $p\bar{p}$ collider operated with ACOL, the improved antiproton source. In order to digest the increased supply of antiprotons and produce more luminosity, six bunches of each species were injected into the SPS.

Bunches are separated horizontally by 3σ in 9 of the 12 possible interaction points by electrostatic separators, in order to decrease the strength of the beam-beam effect. Whereas in the past the $Sp\bar{p}S$ collider has operated in a weak-strong regime, it now progressively approaches the strong-strong regime as the intensity of the $\bar{p}$ bunches increases towards that of the protons. A careful adjustment of the transverse sizes of the two beams is needed in order to alleviate the detrimental effects of the beam-beam interaction in this new and more delicate situation, and to reach a compromise between luminosity and background. Time has been allocated to further experiments on the particle dynamics in the presence of strong nonlinearities.

7. LEP

The dynamic aperture in LEP will be determined by tracking with more effects simultaneously than in earlier calculations : sextupoles, alignment and excitation errors, closed-orbit correction, beam-beam forces and synchrotron oscillations. The perturbation method for the analytical determination of the dynamic aperture will be extended to two transverse dimensions. The prospect for obtaining transverse polarization in LEP will be studied analytically and by computer simulation, using a new approach based on stochastic differential equations, and new computer programs. Work continuous on the effect of superconducting RF cavities on the transverse and longitudinal motion of single and coupled bunches, on bunchlengthening for short bunches which is still not satisfactorily understood, and on synchro-betatron resonances driven by dispersion, closed orbit errors and impedances in the RF cavities, including higher satellites than the first.

The beam-optics program MAD will be expanded to include more Lie-algebraic operations (i.e. concatenation under user control, distortion functions, etc.), on-line graphics using the GKS standard, polarization in SMILE style, and synchrotron radiation losses.

In preparation of the injection tests into one octant of LEP in summer 1988 and of LEP commissioning proper in 1989, specifications of the essential control-computer procedures will be further developed, and the initial beam dynamics experiments will be planned. The model program foreseen will be based on MAD, incorporate most beam-dynamics aspects, and respect the constraints associated with real-time computing. Work on transfer-function analysis of short bunches is being pursued for on-line measurement of coupling impedances and beam stability margins.

Beam Dynamics Activites at CEBAF

C. W. LEEMANN

Newport News, Virginia 23606, USA

Introduction

Design and preparation of commissioning procedures of the CEBAF accelerator, presently under construction at Newport News, Virginia, are the main objectives of ongoing work in beam dynamics and accelerator physics in generlal. Given this, the content of present work is not qualitatively different from that reported in the last ICFA Beam Dynamics Newsletter (Ref. 1), the main difference being greater depth and detail in basically the same areas.

The CEBAF accelerator will provide a cw electron beam of at least 4 GeV energy (with the potential for significant energy upgrades), 200 μA averaged current, and high beam quality ($\epsilon_N \sim 1\mu$, $\sigma_E/E \sim 2.5 \cdot 10^{-5}$). These parameters will be achieved by passing the beam up to four times through two superconducting linacs located in the straight sections of the racetrack-shaped layout. Each of these linac segments consists of 200 superconducting 1500 MHz Cornell-type five-cell cavities and provides at least 0.5 GeV energy gain.

Issues

The key problems to be addressed are the formation of high-quality beam at the low-energy front end, the maintenance of this beam quality throughout the acceleration cycle, and most importantly the establishment of stability against beam breakup (BBU).

Overview of Ongoing Work

Optics and lattices. Based primarily on the code DIMAD, a design is being refined that minimizes synchrotron radiation effects and that emphasizes modularity, "operability", and detailed error analysis to ensure appropriate behavior over the $\sim$ 5 km of beam path length in the accererator (contacts: R.York, J.Kewisch, D.Douglas).

Collective effects and simulation. Simulations of a "first kind" analyze behavior of the imperfect machine, and test feedback loops and proposed running-in sequences, i.e., interpretation of beam diagnostics and activation of correctors. This work is largely based on extensions of the PETROS program. The "second kind" of simulation models collective effects, primarily the multipass BBU.

The code developed, TDBBU, is a user-friendly program, best suited to the Cray X-MP computer. It is being used to fully explore all aspects of the multipass BBU. It has been bench-marked against an analytical code that also is very useful to study parametric dependencies (contacts: J.Bisognano, G.Krafft).

"Field calculations". A key ingredient in collective effects studies is the knowledge of the impedance or equivalently the wakefields. This is pursued with the Weiland code group as well as by analytical approaches. MAFIA for 3-D problems is seeing increasing use, a complete impedance inventory for the machine has been established, and intensive interest and activity is focussed on the high-frequency limit. Apart from these rf calculations, magnetostatic design proceeds, based primarily on POISSON (contacts: J.Bisognano, S.Heifets).

Beam diagnostics. Mainly component design, this serves as input to the machine simulation codes (contact: R.Rossmanith).

Injector/Beam Formation. Studies up to a few MeV of beam energy based on PARMELA are the heart of this effort's beam dynamics aspect; obviously rf and source technology are key ingredients (contacts: W.Diamond, C.Sinclair).

This work is documented in published papers and informal Technical Notes available from CEBAF.

Outlook

Future work will deepen the ongoing effort and focus on other modes of operation, i.e., with higher bunch charges (peak currents) and more widely spaced bunches. The feasibility of acceleration of a low-emittance beam of $\sim$ 500 A peak current has been tentatively established and will be pursued further. Efforts to design front ends to launch such beams, investigations into polarized beams and spin optis, and studies of possible positron beams will also be pursued further.

Reference

1. *Beam Dynamics Newsletter,* International Committee for Future Accelerators, Sponsored by the Particles and Fields Commission of IUPAP, DESY M-87-01, January 1987.

BEAM DYNAMICS ACTIVTIES AT DESY

A. Piwinski

Deutsches Elektronen-Synchrotron, DESY, Hamburg

1. Optics

A nonlinear canonical formalism was developed which includes nonlinear coupling between horizontal and vertical and synchrotron oscillations. The results can be used for six-dimensional symplectic tracking with arbitrary and varying energy (D.P.Barber, G.Ripken, F.Schmidt).

A linear six-dimensional formalism is being developed which includes space charge forces (I.Borchardt, H.Mais, E.Karantzoulis, G.Ripken).

The computer code RACETRACK was modified to include both nonrelativistic velocities and acceleration. The program was used to study the acceptance of DESY3 (F.Schmidt).

2. Magnet errors

Two somewhat different procedures for specifying the azimuthal order of the bending magnets were developed for DESY3 and HERA. For DESY3 where the protons are in the machine for only some milliseconds, all low order nonlinear betatron resonances (including 4th order) close to the working point were minimised. The validity of the technique was confirmed using the modified RACETRACK code. The field in each magnet was measured and they were installed in the best order (E.Karantzoulis, J.Maidment).

For HERA with a much larger number of magnets the best order cannot be chosen from the sample of all magnets because of storage problems. Therefore, a procedure was proposed where, from a stock of about 20 magnets, a smaller number of magnets (1-5) was chosen such that the sum of all resonance widths became a minimum. All resonances were taken into account up to the 6th order including second order terms (F.Willeke).

3. Polarisation

The code SMILE (S.Mane) which includes high order spin resonances was installed at DESY, and HERA optics were investigated (D.P.Barber).

The theory for the compensation of dangerous Fourier components of the equilibrium spin axis was extended by including a periodic weighting function (D.P.Barber, G.Ripken).

4. Instabilities

Mode coupling in the case of localized wake fields is being investigated in connection with feedback systems. It turns out that a compensation of this type of instability is not possible by reactive or resistive systems.

5. Feedback

A procedure to damp multibunch oscillations by a narrow-band feedback system and frequency splitting between bunches was developed. Instead of a difficult broad-band system where the band width is approximately the inverse of the passage time between bunches a simpler narrow-band system can be used where the damping rate is given by $\pi\Delta f/N/(ln(N-1)+C)$ (with Δf =total frequency spread, N=number of bunches, C=Eulers constant). This feedback system can be applied to transverse and longitudinal oscillations where the frequency splitting can be produced by rf quadrupoles and detuning of a transmitter to another harmonic number (R.D.Kohaupt).

This feedback procedure was tested in PETRA for longitutinal oscillations. Three bunches were excited independently by noise in the cavities. The frequency splitting was achieved by detuning one of the two transmitters to the harmonic number 3841 instead of 3840, and the old feedback system for the barycentric mode was applied. The observed damping rates were in agreement with the calculations (D.Heins, R.D.Kohaupt, W.Kriens, M.Lenecke, K.-H.Mathiesen, H.Musfeld, S.Paetzold).

6. Ground motion

Distortions of closed orbits were investigated as a function of the frequency of plane ground waves. Strong focusing (periodic FODO structure) was taken into account.

First measurements in the HERA tunnel below a main street show ground wave amplitudes smaller than $2\mu m$ which causes orbit distortions smaller than 0.2σ. The characteristic frequency was about $4Hz$. Since the two rings have different optics the two colliding beams will be moved against each other by about the same amount. The effect on the beam-beam interaction must be studied carefully (J.Rossbach).

BEAM DYNAMICS WORK AT SLAC

Ronald D. Ruth

SLC

The damping rings are running routinely now (Ewan Paterson). Bunch lengthening has been observed and studied by the damping ring commissioning group. The longitudinal wakes due to all objects in the beam environment have been calculated. The theory and experiment agree very well. In the short term, to eliminate the effects of bunch lengthening, the aperture of the ring-to-linac transport line is being enlarged so that it can accept the larger energy spread caused by the bunch compression of the lengthened bunch. In addition the bunch will be pre-compressed in the ring by pulsing the rf to induce a quadrupole oscillation. This has been tested and works well. In the long term modifications to the vacuum chambers may be necessary.

In the linac, the simultaneous steering of e^+ and e^- has been commissioned and is improving (John Seeman). The e^+ and e^- trajectories in the linac has been simultaneously corrected to 250 μm for e^- and 350 μm for e^+. This is expected to improve to the single beam level (150 μm) with various hardware fixes. Emittance dilution is a factor of 2 to 4 in the linac. The energy spread can be routinely measured with a wiggler. The final energy is 53 GeV, but routine commissioning is being done at 47 GeV with an energy spectrum of about 0.2–0.3% in both beams. Future studies will include slow and fast feedback on position and energy, landau damping, and feedback on tails to minimize wakefield effects.

In the arcs, there have been large systematic errors observed in the betatron phase advance (A. Hutton). This led to large coupling and large magnification of the spot size. This has been controlled to a large extent by applying 'phase fix' (moving magnets and adjusting backlegs). The systematic placement error was roughly 200 μm. Phase fix has improved the situation dramatically although there are still some residual coupling and residual magnification induced by the arcs. Studies are continuing.

In the final focus, 5 μm spots have been observed for the electron beam and 20 μm for the positrons (W. Kozanecki). The 5 μm spots are not yet routine and are greatly influenced by the problems in the arcs. Thus far, the 2nd order chromatic correction has not been commissioned (necessary to go from 5 μm to 2 μm). Future work will include the chromatic correction, beam-beam deflection as a guide to colliding beams and the beamstrahlung radiation monitor.

In PEP, the mini-beta has been installed and will be commissioned with single beams in Nov.-Dec. of 1987 (M. Donald). Colliding beams for high energy physics are scheduled for next summer.

Miscellaneous Studies

In the field of impedances and wake fields there has been much discussion and work on the impedance above cutoff or wake fields at short distances including the effects of curved chambers (Bane, Chen, Kheifets, Morton, Palmer, Sands, Warnock). Work is continuing and differences of opinion are being resolved.

Accurate position measurements are needed for linear colliders. Work is beginning on estimating the effects of neighboring discontinuities on beam position measurement (Morton).

In the field of nonlinear studies (dynamic aperture and optimization of chromatic correction). There has been much progress on invariant curves via solutions of the Hamilton-Jacobi Eq. (B. Gabella, R. Ruth, R. Warnock). In one degree of freedom the method works up to the dynamic aperture. The results of two degrees of freedom also look promising and work is continuing.

As a companion to this approach, Hamilton-Jacobi tracking is also being studied with the aim of creating full turn maps for an arbitrary lattice. This works well in one degree of freedom and is still being implemented in two degrees of freedom. In the future we hope to close the loop on the Hamilton-Jacobi approach to use it as a tool for optimizing. On the perturbation theory side work has been completed on the canonical description of a 2nd order achromat (Kheifets, Fieguth, Ruth).

TeV Linear Colliders

Work is just beginning on the design of a next generation linear collider at SLAC with a center of mass energy of 1 TeV. Parameter studies are ongoing (Palmer, Wilson). Damping rings with emittance $\epsilon_{nx} \simeq 2 \times 10^{-6} m$ are being explored (Morton, Palmer, Raubenheimer, Rivkin, Ruth). Future studies will include detailed lattice designs, dynamic aperture and sextupole solutions, vertical emittance studies, intrabeam scattering, and bunch lengthening studies. On the experimental side we are planning an experiment to be done on the SLC damping rings to achieve $\epsilon_x/\epsilon_y = 100$.

There is much effort being devoted to the search for an RF power source. This has led to a collaboration (SLAC, LLNL, LBL) on relativistic klystrons. Theoretical work is ongoing on efficient power sources with 5-10 GW of peak power and 50 nsec pulse widths (R. Miller, P. Morton, R. Palmer, R. Ruth). This makes use of magnetic compression and induction acceleration of intense relativistic electron beams developed at LLNL. On the experimental side there is a joint effort with LLNL at the ARC facility at Livermore (Allen, Eppley, Lavine, Ruth, Miller, Morton, Vlieks, the Klystron Group), (D. Birx, G. Westenskow, S. Yu at LLNL). The first "pre-experiment" was an 8.6 GHz klystron which made use of the ARC beam to produce 70 MW peak power. The next experiment which is specifically designed for the ARC beam ($\sim$ 1 MV, $\sim$ 1 KA) should produce up to 500 MW at 11.4 GHz in a 50 nsec pulse. First results are expected in the beginning of 1988. Ongoing and future studies will include transverse optics with space charge, beam break-up, RF breakdown, field emission, and stability of the phase of the RF.

The linac structures which will be powered by this device are being developed (G. Loew, H. Hoag). Future studies of structures will include techniques for damping the long range transverse wake fields (Palmer, Wilson). The study of the linac lattice together with tolerances, wake fields, and "Landau Damping" are on-going and will continue (Bane, Ruth).

The final focus designs are just beginning (Chao, Brown, Palmer, Spence). Future work will include design studies, tolerance specification and magnet designs.

ONGOING AND PLANNED BEAM DYNAMICS ACTIVITIES IN KEK

T. Suzuki

KEK, Ibaraki-ken, Japan
and
CERN, Geneva, Switzerland

1. OPERATIONAL RESULTS OF TRISTAN

The TRISTAN electron-positron collider started operation last November and now achieves the maximum luminosity of $8 \times 10^{30} cm^{-2} s^{-1}$ with an energy of 26 GeV/beam. The integrated luminosity is 230 nb^{-1}/day. The total integrated luminosity of 4.7 pb^{-1} for AMY interaction region. It is now shut down and with more room temperature RF cavities, the energy will be boosted to 28 GeV in the autumn of this year. The energy will be further increased with the addition of superconducting RF cavities.

The luminosity is limited by the injected current (possibly by beam-beam effect because no separator is used). The maximum total current at injection is 9.5 mA for 2 electron and 2 positron bunch operation.

Wigler magnets are used at injection which increases the emittance by a factor 20 and reduces the beam-beam interaction. It is quite effective. The beam-beam tune shift is not measured at injection.

The single bunch current limit is 3.8 mA, but with this current the lifetime is very short (several minutes). The current of 3.2 mA/bunch is the practical upper limit with sufficient lifetime. The mode coupling instability limit is estimated to be about 4.5 mA from the measured tune shift of 0.01/mA. The synchrotron tune is about 0.06. There seems to be some weak instability below the threshold of transverse mode coupling instability. The instability seems to depend both on synchrotron and betatron tunes though no systematic survey has been made. The TRISTAN operation is now mainly for physics experiments. The transverse mode coupling instability was actually observed at 3 mA/bunch in an optic to reduce the natural emittance, in which the beta-function at RF is about twice larger.

Now, with the limited injected current, a smaller emittance is preferable for luminosity. The emittance is reduced to about half the natural by changing the radiation damping partition number. This is achieved by increasing the RF frequency by 2.5 ~ 3 kHz. The beam-beam tune shift at the maximum energy is 0.032 vertically and 0.020 horizontally. The tune shift limit seems to be larger than 0.03.

To increase luminosity, it is also important to reduce a vertical beam height. With much effort, the emittance coupling ratio is reduced to 1.8%. The simulation predicts the ratio less than 0.5%. Further study is needed.

The information presented here is based on letters from K. Oide because I am away from KEK since the beginning of this year.

2. BEAM-BEAM EFFECTS AND LUMINOSITY

K. Hirata analyzed the tune shift of coherent dipole oscillations induced by beam-beam effects. It is an extension of the works of Piwinski and Talman. He found that the tune shift is reduced by a factor two compared with the expression of Piwinski both horizontally and vertically. It gives a basis for monitor free luminosity measurement (see R. Talman, last Newsletter).

It agrees with the experiment at TRISTAN. The measurement techniques and experimental results are reported by T. Ieiri et al.

K. Hirata developed a mapping formulation for the beam size for beam-beam interaction and bunch lengthening. He took into account collective force, radiation damping and betatron oscillations. The distribution function is always taken to be Gaussian before interaction. His method is somewhat similar to that of Kamiya and Chao, but he takes into account nonlinearity of beam-beam force and is more interested in equilibrium beam size (fixed point in mapping). In this way, he found qualitative agreements between the theory and multi-particle tracking. Recently, he extended the formalism to asymmetric beam case and qualitatively explained the flip-flop phenomena.

He admits that the Gaussian approximation is crude and includes some unphysical features because of the lack of parameters. I prefer the method to deal with the distribution function itself (e.g. Fokker-Planck equation or fluid dynamics) if it is possible. In this case, however, such saturation effects as radiation damping, Landau damping and the nonlinearity in distribution function should be taken into account to discuss the equilibrium beam size. This seems not so easy. More work is needed.

3. TRANSVERSE MODE COUPLING INSTABILITY

T. Suzuki worked at CERN on coherent synchrobetatron resonances. He extended the previous theories to a finite length impedance and found that the coherent synchrobetatron resonances are strongly suppressed if the cavity is longer than about a half betatron wavelength. His method can treat any combination of different impedances while taking into account their locations.

T. Suzuki also analyzed the effect of chromaticity on transverse mode coupling instability. This work is preliminary and still in progress. The weak transverse instability found at TRISTAN may be explained by the m = -1 head-tail effect.

The theory of transverse instability seems to me rather in good shape. It agrees with simulation and experiments rather well. This may be partly because Sacherer's equation for transverse case is linear in dipole distribution function at least when incoherent motions are linearized as found by F. Ruggiero.

4. BUNCH LENGTHENING

K. Hirata applied his mapping formalism to bunch lengthening. Though his theory is limited only to a constant wake case at present, he obtained a qualitative agreement with multi-particle tracking which is different from the predictions of mode coupling theory. One possibility of the difference from the mode coupling theory may be due to the localization of impedance. This should be studied. The difficulty of the longitudinal mode coupling theory was described in the last Newsletter.

A violent bunch length oscillation was observed at TRISTAN and reported by G. Horikoshi at the Washington conference. With the change of parameters (e.g. inclusion of wiggler magnets), the oscillation became less violent, but still there. The oscillation was predicted analytically before by Y. Chin and K. Yokoya, but the theory seems to disagree with experiment. The computer simulations of Weiland and Brandt also show oscillations. More work is needed.

I hear in CERN that several people at different places are working on the problem of bunch lengthening. It is still an unsolved problem and certainly more work is needed. Certainly, we should include nonlinearities in some way.

5. OTHERS

K. Yokoya worked on beamstrahlung and is applying Lie algebraic techniques to a polarized electron beam problem, but details are not available.

At KEK, interest is also directed to its future plans, a hadron facility and a linear collider. Certainly several works should have been done, and I regret that I cannot report on these here.

SSC-Motivated Dynamics Experimentation at the Tevatron

Reported by Richard Talman, SSC Central Design Group,
Lawrence Berkeley Laboratory, Berkeley, California, 94720

During the spring of 1987 an accelerator physics experiment, E778, motivated by the desire to reduce uncertainties in the SSC design, was performed at the Fermilab Tevatron. Its completion is scheduled for the winter of 1988.

The first purpose of the experiment was to confront the single particle nonlinear tracking calculations, which are important in projecting SSC performance, with experimental observations, to test their reliability. This included quantifying the degree of nonlinearity by the "smear" parameter, which is the fractional rms deviation of the Courant-Snyder amplitude. A second purpose was to correlate phenomenological accelerator performance like injection efficiency and particle lifetime with the value of this smear parameter. A third purpose was to investigate the sensitivity of beam dynamics to externally imposed tune modulation.

The guiding principle of the experiment was that the Tevatron is a *linear* vehicle upon which nonlinear elements are superimposed. The nonlinear elements available are two sets of eight closely-spaced, series-wired, sextupoles. The beam emittance could be reduced with scrapers or increased with a noise source. Tune modulation with variable frequency and amplitude could be performed using an ac-powered quadrupole.

The main data-taking sequence consisted of establishing a small emittance coasting beam, deflecting it with a kicker, and then recording the centroid beam positions for the 1000 subsequent turns in each of two adjacent beam position monitors (BPM's.) From this data the phase space motion of the beam centroid could be tracked and quantities like tune and smear extracted.

The simplest interpretation of the observed data treats the centroid as a single particle, but for nonzero emittance this picture is clouded by decoherence, (Landau damping.) Decoherence due to momentum spread and coupling could be reduced by chromaticity adjustment and decoupling, but amplitude dependent detuning due to the imposed sextupoles is inherent to the experiment.

After confirming that the Tevatron was essentially linear as expected, smear measurements were performed and found to agree to better than ten percent accuracy up to smear values of 0.12. For larger sextupole strengths the agreement deteriorated rapidly, probably because of particle loss and the above-mentioned decoherence. Measurements of the maximum stable amplitude (the "dynamic aperture") agreed well with tracking calculations. Injection diagnostics functioned satisfactorily up to the largest sextupole settings for a typical injection offset of 1.5mm. A slow particle loss occurring over several seconds during this experiment was however not understood and will be studied further.

In this experiment capture into stable nonlinear resonance islands was, as far as is known, observed directly for the first time. Since island chains such as this are an essential ingredient of all nonlinear dynamics theories this promises to be a fruitful research area. The tunes of particles captured into a stable island lock onto the precise rational fraction corresponding to the particular resonance. This defeats the above mentioned decoherence and a centroid signal is observable over many seconds; precision measurement of its tune confirms the resonance identification. Qualitative observations, such as those indicated in Fig. 1, near 2/5 and 5/13 horizontal tune resonances, further corroborate the explanation. For Figs. 1a,c,e, on the left, the small amplitude tune was 0.41, just above 2/5, while for Figs. 1b,d,f, on the right, the base tune was just below 2/5. When the particles are kicked their tunes are shifted down. In Fig. 1c it can be seen that after one second some particles remain captured in the 2/5 island chain and, from Fig. 1e, some still are after five seconds. In Fig. 1d no particles are trapped after one second, presumeably because all particle tunes were shifted down from 0.395 so none came near 2/5. For both base tunes capture at 5/13 can be observed, (see Figs. 1c and 1d,) but the "lifetime" on this island is much shorter as can be seen from Figs. 1e and 1f.

With observations like these made quantitative one hopes to test recent theoretical models. Especially important is the influence of external tune modulation which appears to be important in accelerator operations and is both theoretically and experimentally straightforward. Peggs has suggested that the ideas of Chirikov and others be incorporated in a kind of "phase diagram", as in Fig. 2. The axes are modulation frequency Q_m and amplitude q. In the lower left corner Q_m and/or q are small enough that particles trapped in the island migrate completely around the island in a time shorter than the period with which the island position moves. This gives adiabatic stability. Another boundary in this phase plot separates regions in which, by the Chirikov criterion, overlap of the island sidebands caused by the modulation results in chaotic motion. Another boundary corresponds to the absence of modulation sidebands because the modulation depth is less than the island spacing.

Preliminary data, consistent with these ideas, was acquired in the three regions indicated with horizontal bars in Fig. 2. As Q_m increased at fixed q the decay rate of the stable islands increased. For the next phase of the experiment a more sophisticated data logger, based on a Sun workstation, is planned. This will permit measurement on all relevant time scales.

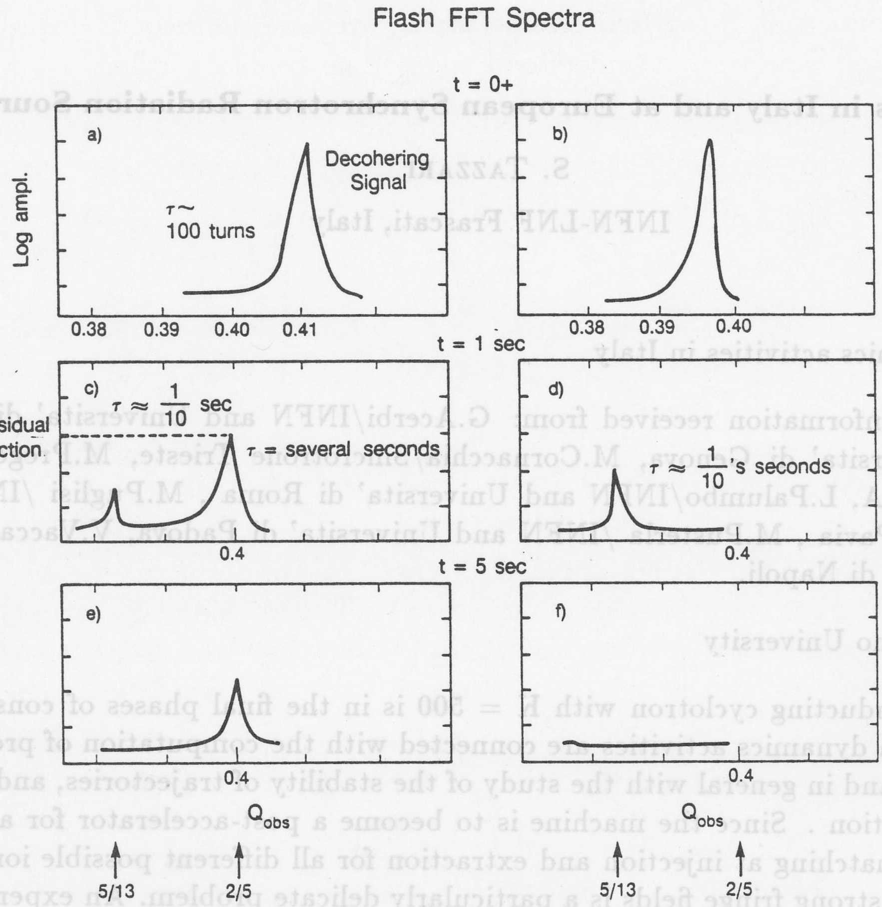

Figure 1. Flash FFT spectra demonstrating capture into stable resonance islands. The different parts are explained in the text.

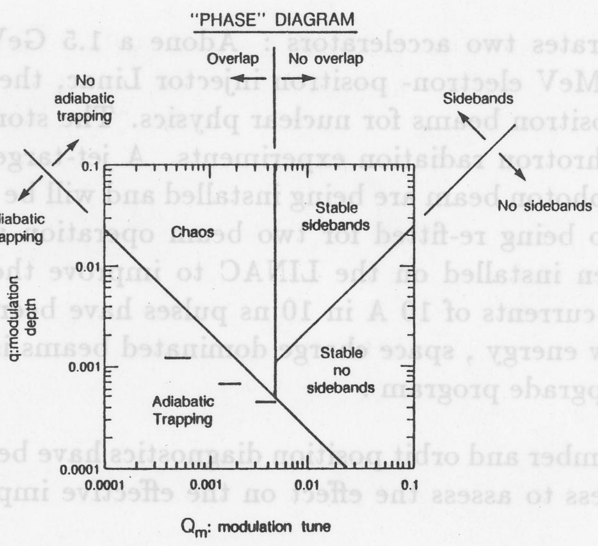

Figure 2. "Phase diagram" indicating theoretically anticipated behavior for different ranges of modulation parameters.

Activities in Italy and at European Synchrotron Radiation Sources

S. TAZZARI

INFN-LNF Frascati, Italy

1. Beam dynamics activities in Italy

Based on information received from: G.Acerbi/INFN and Universita' di Milano, M.Conte/Universita' di Genova, M.Cornacchia/Sincrotrone Trieste, M.Preger/LNF, A.Renieri/ENEA, L.Palumbo/INFN and Universita' di Roma , M.Puglisi /INFN and Universita' di Pavia , M.Pusterla /INFN and Universita' di Padova, V.Vaccaro/INFN and Universita' di Napoli.

1.1 INFN/Milano University

A superconducting cyclotron with K = 500 is in the final phases of construction. The main beam dynamics activities are connected with the computation of proper field configurations and in general with the study of the stability of trajectories, and of injection and extraction . Since the machine is to become a post-accelerator for a Tandem , phase space matching at injection and extraction for all different possible ions and in the presence of strong fringe fields is a particularly delicate problem. An experiment on a two-beam device consisting of a SC FEL and a normal conducting Linac structure is in progress.

1.2 LNF / Laboratori Nazionali di Frascati dell'INF.

The Laboratory operates two accelerators : Adone a 1.5 GeV electron/positron storage ring and its 350 MeV electron- positron injector Linac, the latter also used to produce very high flux positron beams for nuclear physics. The storage ring is used for nuclear physics and synchrotron radiation experiments. A jet-target and an improved Compton backscattering photon beam are being installed and will be commissioned early in 1988. The ring is also being re-fitted for two beam operation and a new gun and buncher section have been installed on the LINAC to improve the positron injection efficiency. Electron peak currents of 10 A in 10 ns pulses have been obtained from the gun. The dynamics of low energy , space charge dominated beams is also being studied in connection with this upgrade program .

The ring vacuum chamber and orbit position diagnostics have been changed in 1987; experiments are in progress to assess the effect on the effective impedance seen by the beam.

A first design study for the third generation, low emittance Trieste SR source has been completed. In connection with this work the code RACETRACK has been installed, to compare its results with those from other codes.

In the framework of R&D on electron/positron colliders, the costruction of a SC, 30 MeV, low emittance LINAC with recirculation (for energy doubling or recovery) has been funded and is in progress. The beam dynamics in the room temperature injector and in the four five-cell 500 MHz SC cavities is being studied (including space charge) mainly with the Los Alamos code PARMELA. The design of the recirculation channel, under study, is constrained by beam quality requirements: it should be achromatic, isochronous and imaging. It is planned to use the LINAC for a high efficiency (through energy recovery), high power f.e.l. in the infrared. The interaction of the beam with the radiation field and the problems of the energy recovery system are being studied.

1.3. ENEA/TIB Frascati

ENEA operates in the field of microtrons , small Linacs for industrial applications , race track microtrons and and single pass FEL's. Dynamics of high current microtrons is being studied : 150 mA in 6 ms long pulses have been obtained on a 20 MeV machine and 200 mA in 4 ms pulses on a 5 MeV one. An 80 MeV racetrack is in the final stage of design and should be operational in '88.

Significant activity is in progress on single pass FEL's : a 10 mm device has lased and is being upgraded in view of achieving higher efficiency, a microwave Cerenkov FEL has also lased.

1.4 INFN/ Rome University La Sapienza (Dip.Energetica)

Electromagnetic radiation from relativistic particles passing by discontinuities in the vacuum chamber or traversing cavity like structures are being studied. Coupling impedances, radiation losses and wake potentials are derived. Problems and codes connected with the collective behavior of particle beams in low emittance lattices for SR sources are also being studied (in collaboration with LNF). A design study for a conventional magnet synchrotron x-ray source Lithografy has been developed.

1.5. INFN/Universities of Trieste, Pavia, Pisa, Lecce

A collaboration has been set up to study , design and build a 140 KeV proton RFQ. An approximate analytical solution of the differential non linear equation describing the motion of a particle in a RFQ accelerator has been worked out. The problem of transverse stability in RFQ devices has also been treated.

1.6. INFN/Universities of Padua and Bologna

Beam-beam stability in proton synchrotrons (such as EHF) and proton storage rings (such as L.H.C.) is being studied (in collaboration with CERN, SPS Accelerator Group). In particular the typical non-linear effects (Tuneshift, Dynamical Aperture, etc...) are under computation with the intention of extending the already obtained bidimensional case (in phase space) for the transfer-map, to four and six dimensions. The normal form method for simplectic dynamics reveals very promising in comparison with LIR algebra approach (MARYLIE) as far as approximations are concerned. Beam-beam effects can be easily added to the transfer-map. Polarization calculations and transverse and longitudinal 'Painting' are investigated at the injection LINAC-BOOSTER in the

EHF Project. Tracking studies including the spin-motion are also under investigation.

1.7. INFN/ Naples University

Plasma wave acceleration is being studied . An experiment at microwave frequencies is in progress. By working in the microwave region lower plasma density is needed and larger physical dimensions can be used to ease the study of basic principles. Stochastic cooling using the microwave Cerenkov effect is also being studied in connection with ACOL and the SPS collider.

Diffractive energy losses suffered by ultrarelativistic particles interacting with variously shaped surrounding conductors are being studied. Conclusive results are being obtained for cylindrical pipes or circular holes in a conducting plane.

1.8 Trieste Synchrotron Light Source (Sincrotrone Trieste)

A third generation synchrotron radiation facility is currently under construction in Trieste. The facility consists of a 2 GeV storage ring optimized for low emittance electron (or positron) beams. The design incorporates 12 long straight sections in which wigglers and undulators produce intense SR beams. Various options for the injection system, currently under investigation, include a linac plus a full energy booster, as well as a full energy LInac.

The beam dynamics studies associated with the design cover a wide rannge of subjects. The requirements for a small emittance has led to the study of various lattices that offer the best compromise between small emittance and large dynamic aperture. The linear and nonlinear effects of wigglers and undulators are also important topics of study. The strong focussing required to achieve a small emittance and the great orbit stability asked for by the users, make these lattices particularly sensitive to the effect of orbit errors. Simulations and theoretical studies are under way.

The experimental requirements for short bunches and high circulating currents demand a very careful study of collective instabilities and of the impedance of the ring. These effects are being evaluated with special emphasis on ways of damping the accelerating cavities parasitic modes.

The possibility of using the injector Linac for FEL experiments in the infrared (oscillator mode) and the XUV (amplified spontaneous emission mode) regions is being studied.

1.9. INFN/ Genoa University

Role of the multiple Coulomb scattering as chaos generator in the beam-beam interaction. Compensation, through low-energy electron beams, of the space-charge borne nonlinear forces in the beam-beam interaction in hadron colliders.

Design of a small (proton) ring to investigate beam behaviours during multicrossing of nonlinear elements. In collaboration with CERN and with the Universities of Padua and Trieste the separation of the two spin states of antiprotons in LEAR is being worked on .

2. Beam dynamics activities at Synchrotron radiation dedicated sources in Europe.

Based on information received from: W.Brefeld/HASYLAB/DESY, J.L.Laclare/ESRF, M.Sommer/LURE/Orsay, V.Suller/SRS/Daresbury, E.Weihreter/BESSY.

2.1 European Synchrotron Radiation Facility (Grenoble)

The work being pursued includes :

The optimization of various low emittance lattices by the choice of the best working points, the compensation of resonance driving terms and the minimization of tune shifts on momentum and on amplitude. The problem of aperture , with all its technical complement of tracking codes,analytical approaches etc., is a central one and is being attacked from various angles.

The study of the sensitivity of lattices to errors, of alignment and magnetic field tolerances , of the effects and the correction of orbit errors, of the effects on aperture of nonlinear field components in the lattice magnets and in insertion devices, and of matching of insertion devices into the lattice.In addition the flexibility of the lattice and its abilityu to accomodate a variable number of wigglers and undulators has been investigated.

New developments in the in-house tracking codes : the non linear effect of insertion devices on beam dynamics and treatment of synchrotron motion have been implemented in the BETA code.

The effect of ground vibrations on the beam emittance and on the beam stability .

The study of single beam and collective effects and of instability thresholds , including the investigation of the electromagnetic properties of the beam surroundings . The contribution of various elements of the vacuum chamber to the coupling impedance has been estimated by computing wake potentials and the loss parameters with the TBCI code.

2.2 SRS, Daresbury, U.K.

An upgrade of the SRG was carried out from October 86 to March 87. The upgrade is designed to increase the spectral brilliance of the source through reduction of the beam emittance by more than a factor of 10. The 8-fold FODO structure of the storage ring lattice was changed to a 16-fold FODO structure by installing additional quadrupoles in each straight section together with new vacuum chambers and pumps. The upgrade was completed on schedule and within the capital budget of approximately one million pounds. The installation phase was completed in March 87 and recommissioning followed. The source came back into scheduled operation for experimental science in mid June.

Measurements with a pinhole X-ray camera and also using the visible component of the synchrotron radiation show that the beam emittance at 28 eV is as predicted 0.1 mm-mrad. The vertical coupling has not yet been measured precisely but is less than 3%. The typical beam size is 1.0 mm horizontal and 0.1 mm vertical (sigma values). The normal beam current at the start of a run is between 150 and 200 mA with a beam lifetime at 100 mA. (The RF is 500 MHz with a harmonic number of 160). In multibunch, currents of over 500 mA have been stored at the injection energy 600 MeV.

Great attention is being paid to the stability of the corrected closed orbit and the alignment of the synchrotron radiation beams. The accuracy of the new button beam position detectors is also being measured carefully. One of the first topics for accelerator physics studies will be the measurement of single bunch length as function of energy and current in order to characterize the impedance of the new vacuum chambers.

The flexibility of the lattice and its ability to accomodate a variable number of wigglers and undulators has been investigated.

New developments in the in-house tracking codes: the non-linear effects of insertion devices on beam dynamics and treatment of synchrotron motion have been implemented in the BETA code.

The contribution of various elements of the vacuum chamber to the e coupling impedance has been estimated by computing wake potentials and the loss paramenters with the TBCI code.

2.3 Super ACO (LURE,Orsay)

The facility is being commissioned using positrons and with the low emittance optics.

Emittance, transverse dimensions confirm the computations. Bunch length and lengthening are somewhat better than expected, Touschek life-time is by 25 % shorter than computed value. but the simple bunch transverse threshold is 40 mA to be compared to the nominal value of 20 mA.

The main problem to solve is the longitudinal multibunch oscillation for more than three bunches.The application programs developed for machine operation were of great help during all this phase.Three insertions will be installed on the machine during the next months, compensation schemes and beam steering programs are ready.

2.4 BESSY (Berlin)

A 1.5 GeV third generation low emittance storage ring (BESSY II) is being designed.

To obtain more physical insight in the low emittance conditions and to optimize a TBA-type lattice, analytical calculations using symbolic algebra are being performed.

Work is also in progress on an experiment to investigate bunch lengthening effects at BESSY I, with the aim of obtaining experimental data on the frequency dependence of the machine effective impedance . The experiment will take advantage from the fact that at BESSY I the bunchlength can be varied over a large range using different optics and the existing double RF system.

The COSY machine, a compact storage ring for x-ray lithography is in the commisioning stage. Experiments are in progress to learn more on lifetime limitations and emittance broadening effects at low injection energies.

FORTHCOMING BEAM DYNAMICS EVENTS

International Workshop on "Constracting VUV soft X-ray Synchrotron Radiation Facilities", Taipeh, Taiwan, Republic of China, 22-27 February 1988. Contact: E.Yen, Synchrotron Radiation Research Center, Roosevelt Road, Sec.1, 10757 Taipeh, Taiwan.

Workshop on "RHIC Performance", Brookhaven, March 21-26, 1988. Contact: A.G.Ruggiero, Brookhaven National Laborary, Upton, Long Island, New York 11973, USA.

Advanced Beam Dynamics Workshop on "Aperture-Related Limitations of the Performance and Beam Lifetime in Storage Rings". Lugano, Switzerland, April 11-16, 1988. Contact: E.Keil, CERN, Geneva, Switzerland.

Spring Meeting of the American Physical Society, Baltimore,MD, April 18-21,1988. Contact: M.Month, Brookhaven National Laboratory, Upton N.Y. 11793, USA.

Seminar on "Beam Dynamics and Luminosity", Erice, Sicily, May 21-28, 1988. Contact: G.Torelli, Istituto Nationale di Fisica Nucleare, Pisa, Italy

Specialised CAS course on "Superconductivity in Particle Accelerators", DESY, Hamburg, Germany, 30 May - 3 June 1988. Contact: Mrs. S.von Wartburg, CERN, Geneva, Switzerland.

European Particle Accelerator Conference, Rome, Italy, June 7-11, 1988. Contact: S.Tazzari, INFN-LNF Frascati(Rome), Italy

Joint ICFA-INFN Workshop on "Physics of Linear Colliders", Capri, Italy, 14-18 June 1988. Contact: R.B.Palmer, SLAC, Stanford, CA 94305, USA.

7th International Conference on "High-Power Particle Beams", Karlsruhe, Germany, 4-7 July, 1988. Contact: G.Kessler, Kernforschungszentrum Karlsruhe, Karlsruhe, Germany.

1988 US Particle Accelerator School, Cornell University, Ithaca N.Y., 1-12 August, 1988. Contact: US Particle Accelerator School, Fermilab, Batavia, Il 60510, USA.

8th International Symposium on "High Energy Spin Physics", University of Minnesota, Minneapolis, 12-17 September 1988. Contact: Sandy Smith, School of Physics and Astronomy, University of Minnesota, Minneapolis, Minnesota 55455, USA.

Main CAS course on "General Accelerator Physics", Salamanca, Spain, 19-30 September 1988. Contact: Mrs. S.von Wartburg, CERN, Geneva, Switzerland.

1988 Linear Accelerator Conference (Linac 88), Williamsburg, VA, USA, 3-7 October. Contact: C.W.Leeman, CEBAF, Newport News, VA 23606, USA.

Joint US-CERN course on "Beam Observation, Measurement, Diagnosis and Correction", Capri, Italy, 20-26 October 1988. Contact: Mrs. S.von Wartburg, CERN, Geneva, Switzerland.

National Accelerator Conference, Dubna, October 25-27, 1988. Contact: N.S.Dikansky, Institute of Nuclear Physics, Novosibirsk 90, U.S.S.R.

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