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BEAM DYNAMICS NEWSLETTER

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edited by

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Contents

Introduction

This volume of the ICFA Beam Dynamics Newsletter contains the written versions of the presentations of ongoing and planned beam dynamics activities in the home laboratories which were made by the participants at the Fourth Advanced ICFA Beam Dynamics Workshop on Collective Effects in Short Bunches, held from 24 to 29 September 1990 at KEK, Tsukuba, Japan.

The Beam Dynamics Newsletter is intended as a channel for describing planned work and unsolved problems, and not as a substitute for journal articles and conference proceedings which usually describe completed work. The ICFA Beam Dynamics Panel hopes that by providing this channel it can stimulate international collaboration among the readers, and that unnecessary duplication of work can thus be avoided.

In May 1991, the ICFA panels on new acceleration schemes and technology and on beam dynamics will organize a joint workshop on "Beam-Beam and Beam-Radiation Effects in Colliding Beam Devices". This workshop will consider the following topics: (i) Beam-beam interaction in linear colliders, (ii) Beam-beam interaction in linear-circular systems, (iii) High field and nonlinear effects: pair production, etc., in e^+e^- and heavy ion colliders, (iv) Use of the high fields during collisions for the study of gravitational waves. The aim of the workshop is laying the ground work for a future workshop on the parameter search for a linear 10 TeV collider by identifying the physical phenomena involved and studying their variation with parameters.

The 5-th Advanced ICFA Beam Dynamics Workshop will be held in September 1991 on South Padre Island, TX, USA, on "The Effects of Errors in Accelerators, their Diagnosis and Correction". This workshop will (i) survey error sources, e.g. ripple, vibrations, nonlinearities such as error multipoles, chromaticity sextupoles, and insertion devices, and estimate their strengths, (ii) diagnose errors using the beam, including hardware, software and data handling aspects, (iii) survey and compare correction schemes, study dependence of tolerances on correction schemes. Various approaches to solve these problems, e.g. analysis, on-line and off-line simulation, and experimental observations will be considered.

In 1992 and 1993, two workshops are foreseen:

1. "High Performance Collider Issues" to provide a forum for the discussion of common beam dynamics problems in high performance circular colliders, i.e. B, τ-charm, Φ factories, etc.
2. "Nonlinear Dynamics of Single Particles" to study the impact of recent developments in nonlinear dynamics on the design of future accelerators, e.g. dynamic aperture calculations, long-term tracking, high-order maps, etc.

Details concerning these workshops are listed at the end of this newsletter.

The distribution of the newsletter worldwide is handled by Dr. Robert B. Palmer BNL for the USA and Canada, Dr. Anton Piwinski DESY for Europe and the USSR, and Dr. Susumu Kamada KEK for the rest of the world. Please get in touch with them for matters related to the distribution of the newsletter.

The sixth edition of this newsletter will be published soon after the fifth Advanced ICFA Beam Dynamics Workshop in September 1991. Readers who would like to publish the ongoing and planned beam dynamics activities of their home laboratory in this edition are invited to get in touch with one of the editors.

On-Going Activities on Beam Dynamics in the SSC Laboratory

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1 Lattice Design

Emphasis has been on the injector booster lattices. For longitudinal dynamics reasons, LEB (Low Energy Booster) and MEB (Medium Energy Booster) need higher γ_ts. Good-looking, imaginary-γ_t lattices are being developed.

More details are needed for the Collider, the HEB (High Energy Booster), and the transfer line lattices. Particularly: interaction region optics, fitting the terrain, etc.

2 Aperture

Collider aperture is set to be 5 cm with injection energy of 2 TeV.

Next is HEB aperture. It has to be good enough for injection and for slow resonance extraction. Present results indicate 5 cm aperture would be marginal (10σ), while 7 cm is acceptable. Decision yet to be made.

3 Operation Simulation

Activity last year has been slow. Simulated correction schemes for orbit and linear coupling effects. More of this activities planned in the coming year.

4 Nonlinear Dynamics

Attempted to understand the long term tracking results of the Collider. Detailed studies as a particle approaches the point of being lost yielded interesting effects (although not yet understood). Analysis with tracking and map techniques is continuing.

Differential algebra library ZLIB is being developed.

5 Synchrotron Radiation Shield

A 20- or 80-degree shield with $\approx$ 2-3 mm slot slides inside the vacuum chamber pipe. The pipe and the magnets will operate at 3.2 degrees instead of 4.2 degrees. Impedance contribution is small. Study is continuing.

6 Emittance control

This is an important issue for the SSC and will receive attention in the coming year. Next efforts will emphasize detailed simulations. Emittance growth comes, e.g., from:

- Beam-beam effects: Previous simulation studies are being continued. Emittance growth issue is the focus. Also need to develop detailed beam separation and crossing schemes.
- ground motion
- power supply ripples
- sensitivity during beam transfers
- transition crossing in MEB
- space charge effects in LEB and MEB

7 Upgrade Possibilities

Luminosity: A study reconfirmed the possibility of upgrade to 10^{34} $cm^{-2}s^{-1}$ level. Same study indicated that an ultimate level of 7×10^{35} $cm^{-2}s^{-1}$ might not be impossible.

Polarization: Present working model is 26 snakes in Collider, 6 snakes in HEB, 2 in MEB and one partial snake in LEB.

Crystal Beam Extraction: Possibility of extraction beam tail with a Si crystal was studied. A flux of 10^8/s of 20 TeV protons may be possible, which promises interesting fixed-target B-physics. Study is continuing.

Beam Dynamics Activities at CEBAF

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The principal beam dynamics activities at CEBAF are in support of the construction and commissioning of the superconducting recirculating linac. This work includes modeling of the injector chain, error studies for magnet and alignment specification, final lattice optimization, wakefield calculations, and modeling of multipass BBU for a 45 MeV recirculation during the test of the injector.

In addition, there are efforts to investigate further applications of superconducting RF technology (SRF) to TeV linear colliders, linac/storage ring B- or ϕ-factories, and FEL drivers.

1 Linear Colliders

Work on linear colliders has focused on what damping of transverse and longitudinal higher order modes is needed to make cumulative beam breakup acceptable. For the typical bunch spacing found in SRF designs, damping requirements are found to be strongly eased from what is necessary for recirculating linacs such as CEBAF. The implied reduction of the number and sophistication of HOM couplers has a strong cost impact. Other efforts in single and multiparticle phenomena are addressing the parametric constraints (alignment, wakefields, lattice period, RF power, HOM power, etc.) that must be considered for a self-consistent design.

2 B-Factories

Asymmetric B-factory scenarios that collide cw electron bunches from an SRF linac with a stored positron beam are found to be competitive with storage ring/storage ring approaches if the same beam-beam tune shift in the positron ring can be tolerated. This approach offers added flexibility since the positron bunch current is not limited by a beam-beam tune shift requirement for the electrons. This allows higher charge per positron bunch and, consequently, a lowered bunching frequency for the same average current in the storage ring. This may ease the coupled bunched instability situation considerably, and may also offer advantages in the IR with respect to long range beam-beam effects. The price for this flexibility is a highly disrupted and possibly strongly pinched electron beam, which can introduce longitudinal focusing modulations that may worsen the beam-beam limit for the positron beam. Two and three dimensional simulations indicate that proper matching can ease the pinching considerably, and further studies are underway to address this fundamental question both through theory and possible experiments.

3 FELs

A series of investigations has been undertaken to evaluate the possible advantages (reduced wakefields, tight RF control, and high average current) and parametric dependences of superconducting RF drivers for FELs. Modeling of the linac, RF control, and FEL dynamics is being pursued.

Beam Dynamics Activities at SLAC

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The following report is a summary of accelerator physics at SLAC. The people listed after each activity are contacts that can be used to obtain more detailed information.

1. SLC Status—Oct. 1989 (J. Sheppard, S. Ecklund)

The focus at the SLC this past year has been on increasing the luminosity. The goal is to obtain a luminosity which yields about 50–100 Z^0/hr when running at the Z^0 energy by 1992. Thus far during this run, the peak luminosity has been about 4 Z^0/hr. The SLC is now running at 120 Hz. Beginning at the source, the work on the new polarized source is progressing rapidly. The damping rings have some problems with a π-mode longitudinal instability. This is controlled in the North ring by temperature changes in the cavity and in the South by a feedback system. The emittance dilution in the linac has been under intensive study, and good progress is being made. The intensity has been increased to 4×10^{10} e^- and 2×10^{10} e^+, but usual running is somewhat lower than these peak values. The arcs have been fixed by using trajectory data to experimentally construct the 4×4 transport matrix. This method has been combined with trajectory bumps to move the measured optics very close to design. The final focus has an easier job matching to the incoming beam and small spots ($\sim 3.5 \times 3.5$ μm) are regularly achieved. Backgrounds are still a prime consideration during final focus tuning, but the situation has been improved considerably due to the addition of another collimation system at the end of the linac. This second set of collimators allows us to clean up the debris produced by primary collimation with a complete set of secondary collimators.

2. PEP (M. Cornacchia, M. Donald)

PEP ran this past summer in a quick-switch mode during the SLC running. The peak luminosity obtained was 4×10^{31} cm^{-2}s^{-1} and the total integrated luminosity during the run was 27 pb^{-1}.

3. B-Factory (A. Hutton)

A B-factory conceptual design report is presently in preparation by a collaboration of SLAC, LBL, and LLNL, and will be complete in January 1991. The design re-uses the PEP machine and adds a lower energy ring above it to achieve asymmetric energy, so the produced Bs are moving in the lab system. The interaction point has been designed for head-on collisions, but has the flexibility to be switched to a crab-crossing geometry with changes in the interaction region only. The design uses many bunches (1650) to achieve a design luminosity of 3×10^{33} cm^{-2}s^{-1} with a beam-beam tune shift of only 0.03. The coupled bunch problems will be handled by first damping the higher-order modes in the cavities and then by providing feedback both longitudinally and transversely.

4. Next Linear Collider (R. Ruth)

Initial designs of the damping rings and bunch compressors have been complete for some time. Presently there is ongoing work investigating tolerances to achieve no emittance dilution in the compressors. Multibunch effects have been explored throughout the NLC. Damped accelerating structures have been shown to work and have achieved Qs for higher modes as low as 8. Alternative methods (frequency spread) are being considered which would avoid the use of radial wave-guides.

*Work supported by the Department of Energy, contract DE–AC03–76SF00515

Emittance dilution is being studied in the linac with the aim of developing correction techniques for the particle trajectory which reduce the wakefield and chromatic dilution when the elements are misaligned by as much as $100\mu m$. Initial results look very promising.

The final focus work is presently dominated by the design and construction of the Final Focus Test Beam. This is a scaled final focus system which is being constructed at SLAC by a collaboration including SLAC, KEK, INP, Orsay and DESY. The FFTB will be located straight ahead at the end of the SLAC linac. It is a chromatically corrected focus, designed to produce flat beams which have dimensions of $\sigma_y \times \sigma_x = 0.06 \times 1.0$ μm. The detailed design is finished and construction has begun. Tuning studies are well underway.

Recently, a high power RF pulse compression system at 11.4 GHz has been completed at SLAC. Initial tests show a power amplification of about 5. A new type of RF compression, called SLED-II, has also recently been tested in low power tests. A factor of four in power amplification was achieved with much less delay line than the high power binary system tested above.

Klystron development at 11.4 GHz is proceeding rapidly with the goal of producing 100 MW with a pulse length of about 1 μs. The second prototype has thus far achieved a 50 MW pulse 0.5 μs long.

An accelerator structure test facility is under construction. This will use the output of the klystron and RF pulse compressor to power 11.4 GHz structures up to accelerating fields in excess of 100 MV/m.

5. General Accelerator Physics (R. Ruth)

Work continues on methods to calculate invariant surfaces very precisely. These surfaces have been used to generate transformations of phase space which can be used to bound the motion in a storage ring for a very long time. Stability has been guaranteed for times up to 10^8 turns in a rather nonlinear example lattice. In complementary work, very accurate full-turn maps are being generated with the hope of speeding up the tracking process for the numerical study of long-term stability.

Work is continuing on calculation of impedances including the effect of tapers. The energy loss due to coherent synchrotron radiation has been estimated for the very short bunches achieved in the bunch compressor of NLC. Large angle pair creation at the interaction point in an NLC is under investigation to determine the impact on design. A new method of collimation using strong nonlinear lenses has been developed. This method also helps protect collimators by defocusing the beam if it is accidentally mis-steered.

Transient multibunch effects are presently under study to evaluate the required feedback for B-factories. Beam-beam simulations are being carried out which include the effect of the distant crossings in the B-factory. The distant crossings seem to be very important and may require further separation of the beams.

Accelerator Physics Activities at LBL

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Accelerator physics activities at Lawrence Berkeley Laboratory span a wide range of disciplines such as High Energy Physics, Nuclear Fusion, Synchrotron Radiation-related Sciences and newly emerging fields employing widely tunable, coherent radiation in the form of Free Electron Lasers as in ultrafast Chemistry and the Life Sciences. Accelerator research and development is performed at LBL in the context of: (1) The Advanced Light Source (ALS) under construction at Berkeley; (2) the Asymmetric B-Factory Studies, a collaborative initiative with SLAC; (3) Infrared and Ultraviolet Free Electron Lasers, partly in support of the proposed Chemical Dynamics Research Laboratory at LBL; (4) Futuristic Collider Physics; (5) Heavy Ion Fusion Accelerator Research (HIFAR) and (6) SSC activities. We describe these activities briefly below. In addition, there are ongoing studies and research on medical accelerators, the Bevalac and possible radioactive beam facilities which we do not report for the sake of brevity. Due to the unique multidisciplinary nature of LBL's missions and projects, one of the unique features of LBL activities is that there is almost an equal amount of stress on the beam dynamics of photons as on that of charged particles.

Advanced Light Source (ALS) Activities

LBL has been heavily involved in the design and construction of the third-generation light source ALS on its site for quite a few years now. The project is now just past the middle of its construction period and is expected to be completed by beginning 1993. At present the ALS team is just beginning to commission the 50 MeV linac injector and the first electron beam from the gun has just been observed and controlled.

The accelerator physics studies have been and continue to be intensive. In the course of these studies, much has been learnt on the fundamental issues of accelerator physics that are generic to low-emittance storage rings used for many applications e.g. high-brilliance synchrotron radiation sources, storage-ring based FELs, damping rings for linear colliders, compact light sources for lithography, etc. Advances have also been made in mathematical and theoretical techniques for analyzing nonlinear dynamics of storage rings and other accelerators. Some of the forefront beam dynamics activities include the linear and nonlinear effects of undulators and wigglers on the electron dynamics, properties of high frequency beam coupling impedance, effects of free space radiation impedance, intricate collective and single particle issues that limit beam lifetime, control of multibunch instabilities and trapped ions and overall control of the storage ring with multi-user-nature of its operation. Sophisticated mathematical programs such as GEMINI, FUTAGO, etc. have been developed using differential and Lie-algebraic techniques that allow analysis of the electron beam dynamics. The code TRACY has been developed to allow quick implementation for the control system and easy interface with GEMINI and FUTAGO. With applications to compact storage rings and fringe-field dominated transport lines in mind, the code COSY-INFINITY has been developed based on an enhanced differential algebra package.

In parallel with electron beam dynamics, much work is also being focused on formulation and theoretical description of photon beams generated by bending magnets and undulators in the

*This work was supported by the Director, Office of Energy Research, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

storage ring. These studies are aimed at proper description of the photon beam taking into account their temporal and spatial coherence properties, diffractive effects, effects of electron beam size and divergence, etc. An important revelation has been the usefulness of Wigner Distribution Functions in a semiclassical description of the photon beam with coherence.

Asymmetric B-Factory Studies

A recent initiative brought forth by LBL, in collaboration with SLAC, is the "Asymmetric B-Factory" based on the PEP (Positron Electron Project) ring at the SLAC site. In the proposed facility, fundamental CP-violation studies and topics in B-meson physics would be advanced by creating pairs of B-mesons and their antiparticles, moving in the laboratory frame, by hetero-energetic collisions between electrons and positrons.

A preliminary feasibility study of a 9×3.1 GeV collider at a luminosity of $3 \times 10^{33} cm^{-2}s^{-1}$ in the PEP tunnel has already been completed in 1989, as a joint effort by LBL, SLAC and Caltech. Presently, a Conceptual Design Report is being prepared for such a facility, to be published in early 1991. The various aspects of the physics and design of such a collider is being worked on intensely. Recently Lawrence Livermore National Laboratory has joined in these efforts.

The particular aspects being worked on at LBL, in addition to collaborative coordination and management, are the theoretical studies of the asymmetric beam-beam interaction in the strong-strong regime, study of coupled bunch instabilities, novel RF beam feedback systems, RF cavity design with low impedance, high frequency impedance measurement, collider lattice and interaction region design, vacuum requirements and strategies for relevant beam dynamics experiments. In February 1990, LBL hosted an international workshop Beam Dynamics Issues in Asymmetric High-Luminosity Colliders. In addition there is frequent exchange of ideas and concepts on B-factories with other laboratories interested in such a facility worldwide.

Investigation of Infrared and Ultraviolet Free Electron Lasers

Free Electron Lasers (FELs) combine the physics and technology of modern charged particle accelerators and optics. They depend, for their operation, on the creation of an efficient and resonant electromagnetic coupling between high quality electron beams and photons. FELs offer the possibility of producing high-flux, tunable, coherent radiation in the infrared (3-50 mm) and ultraviolet (30-1000Å), where no comparable conventional lasers exist today. They hold considerable promise for advanced studies in the dynamics of chemical reactions and for probing the mechanisms and processes in the biological world. This latter application to the various newly emerging fields of life sciences is especially challenging, with potentially rewarding scientific consequences, should the technology of FELs be capable of extension down to the wavelength regime of the biological "water-window" (~40Å).

In the past few years, accelerator physicists and optical physicists at LBL have launched a series of investigations into the physics and technology of Free Electron Lasers for applications both in the Infrared (IR) and the Ultraviolet (UV) wavelengths. The thrust of our investigation in the IRFELs (where the technologies of electron linacs and optical cavities have matured to a point that successful lasing has already been observed at several laboratories) has been in the direction of their spectral and temporal stability and reliable operation, both of which are crucial for specific scientific experiments in chemical dynamics. Our research into UVFELs, on the other hand, has concentrated on the physics and technology of various accelerators (e.g. storage rings, linacs, etc.), undulators and optical components that will allow generation of short wavelengths. The goal of UVFEL research has been to develop a strategy of shorter wavelength generation via FELs that will eventually be capable of extension to the 40Å"water-window" with continued R&D.

One of the most challenging aspects of the IRFEL is to achieve a high degree of stability in the wavelength and timing of the FEL output. The stability is an issue that becomes crucial for an advanced user facility, but has not been fully addressed at existing FELs built so far for experimental purposes. The FEL stability depends critically on the energy stability of the driving RF linac and frequency selectivity of the optical cavity. Our exploratory investigations have led to two important conclusions: (1) a low frequency (1.3 GHz, L band) side-coupled RF structure in the standing-wave mode as the linac of choice for a stable IRFEL; (2) use of an intra-cavity grating as a necessary frequency filtering element to achieve relative wavelength stability of 10^{-4} and beyond.

These significant results were the input to the subsequent Conceptual Design Report for the Chemical Dynamics Research Laboratory (CDRL), being proposed by LBL to the US Dept. of Energy. Prior to detailed engineering design, further explorations are undertaken to assure the stability via parametric simulations of various RF feedback and feed forward techniques. Extensive beam dynamics computer simulations for electron beam transport including space charge and optical FEL simulations including effects of diffraction, intra-cavity grating, finite size outcoupling mirrors with holes, etc. are being performed to establish tolerances for the electron beam fluctuations in energy, timing and charge, as far as stable lasing is concerned. Preservation of electron beam quality and stability via near-isochronous and achromatic transport to the FEL cavity is being studied through designs of special magnetic guiding channels using higher order beam optics codes. All these studies are focused on the ultimate goal of achieving the required spectral purity and stability of the laser for useful scientific experiments.

In our exploratory studies on UVFELs, we have embarked on the task of critical evaluation of short wavelength generation by modern high-brightness storage rings, in the wavelength range around 400Å. The technologies of circular electron accelerators, long undulators of exceptional field quality and optical components (x-ray optics, multilayer mirrors, etc.) all come into play in this investigation. Various scenarios for storage-ring based short wavelength FELs are being worked out, e.g. scenarios involving an FEL oscillator in the ring, an FEL amplifier in the ring, an amplifier in a bypass, a damping ring driven by a linac, etc. Detailed calculation of the storage ring beam dynamics and FEL physics (both small gain and high gain) and a thoughtful assessment of the undulator and optics technology will be required.

We plan to continue these studies from the point of view of specific hardware components as exist in the state-of-the-art technology and more importantly, the extendibility of the concepts developed so far to even shorter wavelengths down to 40Å. A considerable amount of effort is being spent in computations and relative assessment of storage rings vs linacs as drivers of FELs from the point of view of the physics and technology of accelerators and FELs.

Futuristic Collider Physics

Mindful of the limitation of large electron and positron storage rings, physicists have turned toward linear electron-positron colliders in their long-range thinking. With Lawrence Livermore National Laboratory (LLNL) and SLAC, LBL has been exploring the potential of a futuristic linac called the Two Beam Accelerator (TBA), which might derive its microwave power from a FEL or a relativistic klystron. Conceived at LBL, the TBA is now being investigated, in several configurations, at LBL as well as other laboratories. Designs are being developed and evaluated by LBL researchers, in collaboration with colleagues from LLNL and SLAC. Aspects of both microwave power generation and high-gradient acceleration are being worked on. The techniques of power extraction from FELs or CARMs (Cyclotron Auto Resonant Masers), dependence on drive beam's energy and current, breakdown studies, methods of bunching and chopping, collective instabilities in the beams, etc. are all being studied in this context. As a byproduct to linear collider and final focusing studies, interaction of an electron beam with a plasma has attained renewed interest and importance.

Various exotic schemes of beam-plasma interaction have emerged as worthy of further study e.g. plasma adiabatic focuser, plasma compensation, ion-focused FELs, ion-channel lasers, etc.

Heavy Ion Fusion Accelerator Research (HIFAR)

The Heavy Ion Fusion Accelerator Research (HIFAR) program at the Lawrence Berkeley Laboratory has as its basic objective the assessment of the suitability of heavy ion accelerators as drivers for Inertial Confinement Fusion (ICF). The HIFAR program addresses the generation of high-power, high-brightness beams of heavy ions, the understanding of scaling laws in this novel physics regime, and the validation of new accelerator strategies to cut costs. The program includes approximately thirty individuals, of which approximately half a dozen pursue primarily theoretical topics. The experimental program includes a high voltage (2 MV) injector test stand, a multi-beam accelerator (MBE), and advanced magnetic quadrupole development. In addition, a close collaboration is maintained with physicists at Lawrence Livermore National Laboratory who are studying beam transport in the reactor vessel, final focus, and advanced recirculator accelerator designs for HIF/ICF purposes.

The major concern of the HIFAR theory program is maintaining beam quality during transport and acceleration in a HIF induction linac. Due to the high space charge depression of the tune, emittance growth from transverse oscillations is a serious concern. A 2-D particle-in-cell code, SHIFTXY, has been written and extensively tested to study the excitation of coherent beam modes driven by external non-linear focusing fields and image forces. The code is presently being used to compare theory with transverse emittance growth measurements in the MBE-4 accelerator.

A second area of concern regarding emittance growth is beam behavior during longitudinal compression. In a real HIF driver, the beam must be compressed longitudinally in the accelerator from a multi-microsecond duration at injection to 100 ns or less at exit. This compression must be done in an adequately smooth fashion to prevent emittance growth and possible excitation of longitudinal instabilities. A number of numerical tools have been developed to optimize acceleration "schedules" for the MBE-4 accelerator and hypothetical drivers. A current series of experiments is underway to determine how well these schedules work in practice for beam current amplifications of 2:1 and greater.

Finally, a great deal of work is being spent of analysis of the resistive longitudinal instability. This instability arises from the interaction of the beams space charge and current with the induction cells which have both resistive and capacitive response. The great length (multi-kilometer) of a hypothetical HIF driver implies that even large growth lengths (~400 m) may prove problematical. Currently, we are examining various methods to minimize growth and excitation of the instability. These methods include increasing the capacitance of the system, feed-forward techniques for longitudinal acceleration error control, and the possibility of introducing longitudinal velocity spread both within individual beamlets and from beamlet to beamlet. We are simultaneously using a 1-D version of SHIFTXY to benchmark the efficacy of these strategies.

SSC Activities

After several years of involvement in the SSC-Central Design Group at LBL, we continue to collaborate with the recently established SSC Laboratory in Texas. Our efforts included assistance with the redesign of the Low Energy Booster as the original generic SSC conceptual design underwent site-specific modifications. We also worked out a new overall layout and associated collider lattice in which experimental areas are clustered together, refining an idea for diamond-shaped "bypass" sections. In addition, large scale effort on the construction of the superconducting quadrupoles for the SSC are continuing, together with significant involvement in the project management.

Accelerator Physics Research at Brookhaven National Laboratory

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At Brookhaven National Laboratory there are several groups that do research on particle accelerator physics and technology. The following gives a summary of the field of interest for each group and their responsibilities.

1 CAP

The Center for Accelerator Physics (CAP) is a group of research which is supported by other departments and divisions. The main goal is the development of an Accelerator Test Facility (ATF) made of a 100 MeV electron linac for the production of beam bunches as short as few picoseconds with a peak current in excess of a hundred amperes. A small transverse emittance is also required. The ATF will be used to experiment on novel ideas of particle acceleration, to demonstrate acceleration at large gradient values using micro-structures and for developing a free electron laser with variable wavelength. The group is also involved in the conceptual study of electron-positron linear colliders.

2 NSLS

The National Synchrotron Light Source (NSLS) has the responsibility of the operation of two electron storage rings and of the related injector for the production of radiation in the Ultraviolet and X-ray range. Upgrades are also studied and imp lemented which employ conventional and superconducting wigglers and undulators. There is extensive theoretical research to investigate performance limitations and the interaction between the beam and the surrounding. A compact light source storage ring is also at the present being commissioned. The ring is made of two 180° conventional magnets with 60 cm bending radius. The future plane is to replace the magnets with superconducting ones.

3 AGS

The largest accelerator operating on site is the Alternating Gradient Synchrotron which accelerates 12 proton bunches to an energy close to 30 GeV. The accelerating cycle lasts less than three seconds. The performance of the accelerator is of course well established and several directions for improvement are being investigated, mostly in the area of injection, extraction and crossing of the transition energy. By far the largest improvement will derive by the incoming commissioning of the AGS Booster, which accelerates protons from the 200 MeV linac to 1.5 GeV at the repetition rate of 7.5 pulses per second. With the Booster the beam intensity in the AGS is estimated to increase to 5×10^{12} protons per bunch. A considerable amount of accelerator physics study has been done for the conceptual design and the determination of the performance limitations of the Booster. Space charge effects and multiturn strategies have received a considerable amount of effort because of their importance.

*Work performed under the auspices of the U.S. Department of Energy.

Recently, heavy ions of Oxygen and Silicon have been accelerated in the AGS to about 15 GeV with a collaboration between the Physics department, which operates two 15 MV Tandems, and the AGS department. With the Booster, it will possible to accelerate very heavy ions like Au completely stripped. A large amount of accelerator physics work is at the moment done for the preparation of the Booster commissioning including, for example, analysis and correction of closed errors and magnet imperfections and tuning of the transfer lines and of the accelerator itself. The field quality of the Booster magnets which have been produced is measured and the results compared to the theoretical requirements.

Another field of research which focus around the operation of the AGS is the acceleration of polarized protons. This has been demonstrated successfully in several occasions and exploited for experiments. An extensive theoretical work to determine the causes and the correction methods of beam depolarization has been done and it is still continuing. This includes also the conceptual study of Siberian Snakes.

In order to allow for the increase of the proton beam intensity and the acceleration of heavy ions and polarized protons, the AGS is continuously upgraded in several areas like, for instance, vacuum and rf.

4 RHIC

The Relativistic Heavy Ion Collider (RHIC) is the largest and most important project for BNL. The project has been recently approved for construction which it is scheduled to last seven years. At the same time about four years of R&D have been spent. Design work for the project has been done so far by the Accelerator Development department, which includes the Magnet Division, the Engineering Division and the Accelerator Physics Division. The Magnet Division has the task of the design and of demonstrating the feasibility of superconducting magnets and of determining experimentally the field quality. This type of work is conducted in parallel with similar research for the SSC design and experimental program.

The conceptual design of the RHIC is the responsibility of the Accelerator Physics Division. Four major milestones were imposed: the search for and the finalization of the lattice, determination of the effects of magnet imperfections and the corresponding methods of correction, estimating of the collider performance limitations and of possible future upgrades, and preparation of a computer modelling of the collider for commissioning and operation. Given the nature of the particles involved, the effects of intrabeam scattering have been carefully estimated and included in the design requirements. Other issues investigated are: crossing of the transition energy, collective effects including the interaction of the beam with the vacuum chamber and other components, design and demonstration of stochastic cooling for bunched beams, long range numerical simulation up to a million turn for both magnet imperfections and beam-beam interaction.

The Accelerator Physics group has also been involved with the design of the Low Energy Booster (LEB) for the SSC. The group has also investigated the feasibility of a 30 GeV Stretcher Ring for a 100% duty cycle extraction, to be added to the AGS, and of a small heavy ion storage ring (CHISR) with electron cooling for atomic physics experiments.

Beam Dynamics Activities At Cornell Laboratory of Nuclear Studies

REPORTED BY MICHAEL BILLING
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The storage ring CESR has just begun operations after a one month shutdown in October of 1990 to convert the storage ring to a one interaction region electron-positron collider. This new upgrade of the storage ring is called CESR-Plus. During the shutdown the CUSB detector was removed and the accelerator optics in that interaction region were reconfigured into a mini-beta arrangement with the permanent magnet quadrupoles removed. The permanent magnet quadrupoles in the interaction region housing the CLEO II detector remain. The 7 x 7 bunches are separated horizontally at the 13 parasitic crossing points and for injection the beams are also separated horizontally in the single interaction region. CESR-Plus operations have begun with a vertical beta at the interaction region of 1.5 cm. and after three weeks of HEP operations peak luminosities have exceeded 1.2×10^{32} cm^{-2}s^{-1} with an achieved vertical beam-beam tune shift parameter of 0.030. Beam currents are not presently limited by instabilities or the beam-beam interaction.

Studies were completed in the Spring of 1990 to determine the feasibility of two upgrade paths for CESR-Plus. The first of these Phase II schemes, an extension of the Pretzel scheme, employs a single IP, tune of 13 lattice and 14 x 14 bunch collisions. The second of the two, called the delta-E scheme, has the two beams differing in energy from the "nominal" beam energy by +/-0.9% and uses the dispersion in the arcs to separate the approximately 30 x 30 bunches occupying the same vacuum chamber. The delta-E scheme also has a bypass region necessary to make up for the path length differences and within which each beam occupies its own vacuum chamber and has its own optics. The studies during the Spring of 1990 focussed on new designs for horizontal separators, accelerator hardware layouts, optics designs including linear and non- linear optics effects from operating both beams off-axis in the quadrupole and sextupole magnets with modelling of the optics confirmed with beam measurements in CESR. Both options for increasing the number of bunches in CESR have been shown to be viable, though each has its own requirements for engineering R&D. A third plan, which was subsequently proposed by R. Meller, has CESR-Plus operating with multiple trains of bunches. The bunches in each of the trains are in adjacent RF buckets and the separation at the interaction point is accomplished by an angle crossing. There will be a test in CESR-Plus of this scheme in the next few months.

Planning is underway for an upgrade of the present facilities to "B factory" luminosities in both asymmetric and symmetric operation. The present "CESR-B" design focusses on an asymmetric collider having 3.5 GeV and 8 GeV storage ring energies with a luminosity of 3×10^{33} cm^{-2}s^{-1}. A symmetric option at 5.3 GeV on 5.3 GeV and luminosity of 10^{34} cm^{-2}s^{-1} is also considered, requiring only a change in the Interaction Region optics hardware and redistribution of RF cavities. The accelerators would fit into the existing CESR tunnel and reuse some of the existing CESR-Plus hardware. The design report will be completed in January of 1991.

Besides the linear and non-linear optics studies for CESR-Plus phase II upgrades mentioned above, machine studies activities during the last year have focused on beam dynamics issues relevant to the conversion of CESR to the single IP, CESR-Plus. These studies included injection and collisions in prototype optics using CESR, preliminary explorations of the tune plane, and development of a system for aligning the collisions at the interaction point. A sequence of studies with flat beams and equal β^*'s have given preliminary results, but refinements of some specific optics design problems are necessary before further attempts of reaching the large values of the vertical tune shift parameter anticipated based on initial weak-strong simulations. Additional studies have investigated horizontal-vertical localized coupling corrections, the development of a MIRABILE style beam dynamics measurement system and the development of an automatic tune plane scanning program. Future studies will provide experimental support for the CESR-B program with investigations of high tune (low emittance) optics, and a crossing angle experiment. During the next year we also expect a continued strong experimental program to optimize our operation of CESR-Plus.

Beam Dynamics Work at the University of Maryland

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Work of the Maryland group and its collaborators is devoted primarily to the treatment of linear and nonlinear beam dynamics using transfer maps. These maps in turn are often conveniently calculated, manipulated, and analyzed with the aid of Lie algebraic methods. Using this approach, it has been possible to carry out realistic calculations to high order for physically relevant quantities such as chromaticities, anharmonicities, nonlinear resonance effects, and linear and nonlinear lattice functions. It has also been possible to design aberration free systems including beam expansion telescopes, final focus systems, and high order achromats. Calculations are routinely carried out through third order. When necessary, they can be carried out to arbitrary order. That is, both the computational algorithms and their computer implementation have been developed to compute, manipulate, and analyze the transfer map for an arbitrary system to arbitrary order.

Most work is for single particle systems. However, recently Lie algebraic and map methods have been used to treat moments of distributions of noninteracting particles. By these methods it has been shown that, for the physically interesting case of six dimensional phase space, there are three independent invariant "mean square" emitances that can be constructed from second order moments. Invariants have also been constructed in terms of higher order moments. With regard to interacting particles, some work has been done on space-charge effects, and preliminary indications are that in some cases Lie algebraic methods may be far superior to particle in cell calculations both with regard to computer speed and for the computation of nonlinear effects.

Work is currently being carried out on the use of map methods for the long term tracking of hadron colliders such as the SSC. In particular, methods are being developed for the kick factorization of maps. Some preliminary calculations indicate that the use of map methods for long-term tracking gives results that are comparable to those obtained by conventional methods, but map methods may be as much as two orders of magnitude faster. Moreover, they can be used to produce far more realistic models of actual machines than those provided by conventional methods.

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Beam Dynamics Studies for the TRIUMF Kaon Factory

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TRACKING TOOLS (R. V. Servranckx)

Further studies of the optical properties of the KAON rings demand a substantial increase in the tracking speed of DIMAD, the computation of transfer maps to orders higher than two (possibly 15) and the analysis of such transfer maps. Tracking speed has been increased by a factor 2.5 by optimizing the symplectic tracking algorithm and removing from the tracking operation all the overhead used to generate the ring lattices with alignment and field errors. A further factor 2.5 was obtained by the use of the Vector Facility available on the IBM 3090 computer at the University of Victoria.

The tracking is now done in a separate program using a lattice input file created by DIMAD. This program can also produce a one-turn Differential Algebra (DA) map of any order (practical maximum 20). The computer package DALIE will be used to compute useful optical properties of the rings from their DA maps. The DA maps will also be used to do multiturn tracking over 20000 turns or more. Tests of the new program and the DA tracking will continue until the end of 1990. The DALIE package will be installed and tested during January and February 1991.

ORBIT STUDIES (U. Wienands)

Collimator Simulation

Because of the high intensities in the KAON Factory it will be important to localize any losses by the use of collimators. In order to assess the efficiency of various collimating schemes a special element routine has been written for DIMAD, describing in detail the traversal of a particle through absorber material. Simulated effects include ionization energy loss, multiple Coulomb scattering, and elastic nuclear scattering. Inelastic nuclear scattering probabilities are estimated but particles undergoing inelastic events are considered lost.

Siberian Snakes

A complete analytical description has been developed for helical Siberian snakes (180° spin rotators) consisting of discrete dipole magnets, including the limit of a smooth helical field. Using the results from this work the snake design for the 30 GeV Driver (main ring) has been optimized, reducing both the orbit excursions and the field integral needed. It is now practical to build the snake with room-temperature dipole magnets. The snake in the Driver will cancel all important depolarizing resonances and thus allow polarized beams to be accelerated with almost no depolarization.

BEAM STABILITY (R. Baartman)

Single-Particle Resonances

Betatron and synchro-betatron resonances are being studied analytically. Of particular interest are the synchrotron sidebands of betatron resonances because in the KAON Factory rings, the space-charge and chromatic modulations of the betatron tune are large and comparable with the synchrotron tune.

Single-Bunch Collective Effects

The stability of beams with unusual longitudinal distributions is being investigated using the Vlasov equation approach. The problem is complicated by the fact that space-charge forces deform the potential well. An iterative approach has been developed for finding stationary distributions in longitudinal phase space in the presence of space-charge forces.

Coupled-Bunch Instabilities

Coupled-bunch instability calculations are being made in order to derive specifications for the active dampers. Longitudinal instability thresholds of the (usually neglected) higher-order radial modes are lower than expected. For example, the next to lowest dipole mode has a lower threshold than the lowest sextupole mode even though the latter has the larger growth rate in the absence of Landau damping.

LONGITUDINAL COLLECTIVE EFFECTS (S. Koscielniak)

Longitudinal Emittance Dilution

Multi-particle simulations have been used to compare the effectiveness of frequency modulation of a high harmonic cavity with single and double-sideband amplitude modulation. The emphasis has been on achieving fast resonant amplitude growth while minimizing distortions of the bunch shape.

Space-Charge Dominated Beams Hollow in Longitudinal Phase-Space.

Simulations show that non-linear steady-state fields can give rise to transient mis-matching phenomena which can drastically alter the distribution in a few synchrotron oscillations. When the steady-state fields are artificially compensated a correspondence can be made with mode-coupling instability theory through the identification of coherent radial-mode frequencies and intensity thresholds.

Coupled-Bunch Stability with Empty Buckets.

A given conventional mode, with constant phase-shift between bunches, gives rise to perturbation frequency components at several harmonics of the revolution frequency. An impedance spanning such a set of frequencies will couple the components together. Stability for the hybrid modes has been considered for up to 3 narrow impedances.

MAGNET WAVEFORMS (M. K. Craddock, R. Baartman)

With the aim of simplifying the rf system in the 50 Hz 3 GeV Booster various magnet waveforms have been investigated — harmonic, dual-frequency, various admixtures of second harmonic, and an "ideal" waveform giving constant bucket area for constant, and therefore minimum peak, rf voltage. In this case the magnetic field rises very slowly at first but faster and faster as top energy is approached. Although the programmable power supplies needed are more expensive than resonant ones, there should be an overall cost saving since the rf voltage would be reduced from 750 kV to 500 kV. There are beam dynamic advantages also: the slow initial rise avoids the usual increases in space-charge tune shift and in synchrotron tune, and the microwave stability criterion is satisfied throughout the cycle.

Beam Dynamics Activities at the CERN PS Complex

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The different topics are listed below in the frame of the various projects and/or kinds of beams.

1 Sp$\bar{p}$S

1.1 $\bar{P}$ PRODUCTION BEAM

BR (PS Booster):

a) A local feedback has been installed to reduce beam loading by lowering the R and Q of the RF cavities.

b) As the situation concerning longitudinal coupled bunch instabilities has degraded, studies to improve the present longitudinal feedback are going on.

c) Studies of the coupling impedance of septa and kickers as well as better RF-bypass circuits on vacuum flanges are in progress.

PS:

a) Same as point a) above.

b) A "one turn longitudinal feedback" to cure logitudinal coupled bunch instabilities has been successfully put into operation. A reduction of 12 db of the cavity impedances on the two nearest sidebands has been obtained.

1.2 $\bar{P}$ ACCUMULATION

AC (Antiproton Collector):

a) A reduction (100 to 50° K) of the stochastic cooling electrode temperature has allowed to reduce by a factor three the unnorm. $\bar{p}$ emittances ($\epsilon_x \approx \epsilon_y \approx 5\pi$mm.mrad, $dp/p = 0.18\%$).

b) Studies, measurements and optimisations on the machine dynamic aperture allowed to reach 220 π mm mrad acceptances in both planes.

c) Many studies were devoted to the optimisation of the $\bar{p}$ yield with different Li lenses and transfer line optics. A 36 mm lens increased the yield by 20% and a yield of 6×10^{-8} $\bar{p}$ per proton on the target is obtained with a more reliable 34 mm lens in operation. In the near future a plasma lens and a new high current magnetic horn will be tested.

AA (Antiprotons Accumulator):

a) Coherent quadrupolar instabilities and high order non-linear resonances, due to trapped ions, were respectively studied and cured by improving the electrostatic clearing and installing a vertical betatron shaking.

b) The quadrupolar pick-up was also used to optimize the betatron matching between PS and AA and between AC and AA.

c) A faster cooling rate was obtained by increasing the bandwidth of the betatron cooling from 4-8 to 2-8 GHz and the bandwidth of the momentum cooling from 2-4 to 1-4 GHz.

1.3 $\bar{P}$ ACCELERATION IN THE PS

Studies on non linear effects at high energy led to correct the PS machine optics in order to optimize the PS - SPS transfer efficiency and matching. The present total transfer efficiency, from the AA stack to the PS extraction, are now larger than 95 %.

2 Low energy $\bar{p}$ (LEAR)

The main studies are devoted to increase the beam life time at very low energy ($<$ 300 MeV/c).

a) The recent installation of pole face windings has allowed compensation of the sextupole resonance $Q_x + 2Q_y = 8$ which was limiting the dynamic aperture during the stochastic extraction at low energy.

b) A wide band transverse feedback has been required to damp the transverse instabilities (horizontal and vertical) appearing during the e- cooling of low energy beams at high density ($N = 10^9$ $\bar{p}$'s, $p < 300$ MeV/c, $dp/p \approx 10^{-4}, \epsilon_x \approx \epsilon_y \approx 2\pi$mm.mrad)

c) Intense experimental activities are going on to study collective effects on very cool beams and to measure the machine coupling impedance.

3 SPS Fixed Target

In the BR, using a second harmonic RF system allowed putting more protons into the emittances of the SPS fixed target beam and led to a new PS record intensity.

In the BR & PS, the studies and modifications at points a) & b) of the production beam were also beneficial for the stability of this high intensity proton beam ($> 2 \times 10^{13}$ p/pulse).

4 O^{8+} and S^{16+} ions

Studies and measurements were performed to better understand and to optimize the separation of the two ion beam at transition in the PS .

5 Pb ions

Detailed studies on this project have been done and some are in progress :

a) ECR source.

b) Low Energy Beam Transfer Line (including a RFQ) between the source and the LINAC.

c) LINAC structure (Interdigital H or modified Alvarez).

d) Effects of rest gas with not completely stripped ions (Pb^{53+}) in the BR and PS machines.

e) Different aspects in the ions acceleration like: "frequency loop", debunching-rebunching at intermediate energy in the BR and bunch merging at injection in the PS.

f) Studies were also done to anticipate the necessary modifications to produce the Pb beam intensity and characteristics for the ions-ions option of the LHC project. In these studies the possible use of LEAR or PS or AA machines as intermediate storage and cooler rings were analyzed and compared.

g) Some R&D is done on the production of heavy ions with laser beams.

6 ISOLDE

This project is under construction (first beam is foreseen at the end of 1991). The main beam dynamics activities concern essentially the BR machine, i.e.:

a) Stabilize and operationally produce a beam with an intensity $> 3 \times 10^{13}$ p/pulse (considered at present as a "record" intensity).

b) Loss management, i.e. how to avoid losses at critical points (e.g. septa).

7 PS slow extraction at 24 GeV/c

Even if such a beam has a rather low intensity (2×10^{11} p/pulse) it is necessary to reduce as much as possible the losses in particular on the septa and to reduce the damage caused by the $e^{\pm}$ synchrotron radiation on the external electrode (cathode) of the electrostatic septum. A new and better scheme (new configuration of the optics with electrostatic electrodes on the inside position) has been studied and it is now under implementation.

8 e^+e^- for LEP

For LIL, the design and the construction of a new front end (gun + buncher) with better reliability is finished and the commissioning is just starting.

In the PS, at slightly higher intensity than the operational one, coherent vertical instabilities induced by CO trapped ions have been observed in the e^- beam. Experimental studies on coherent, incoherent and missing bunch effects confirmed the present theories on the subject. The coherent instabilities have been cured by a narrow band transverse feedback.

9 LEP high luminosity

For such a project the e^+ production rate in LIL has to be increased by a factor of three. Studies are in progress to increase the primary beam power (energy and intensity) on the production target by increasing the RF power in the accelerating structures.

10 B-Meson Factory

A feasibility study of a B-factory has been done in collaboration with the PSI Institute (Villigen, CH). The essential machine characteristics are :

a) Asymmetric energies : 3.5 + 8 GeV.
b) Max. luminosity : 10^{34} cm^{-2} s^{-1}.
c) It could be installed in the ISR tunnel.
d) It will use the present accelerators (LPI, PS, etc.) as injectors, without affecting LEP, SPS, LHC operations.

11 LHC project (feasibility study)

As the LINAC2, BR and PS will be part of the LHC injectors, a large activity is going on in order to foresee the necessary machine modifications to provide the required beam characteristics. Essentially the PS has to supply a high intensity (1.4×10^{13} p/pulse) with a transverse density ($\epsilon_x^* = \epsilon_y^* = 10\pi$mm.mrad norm.) three times higher than the present capabilities. The basic scheme of the main modifications can be listed as:

LINAC2

Replace the present Cockcroft-Walton preinjector by an RFQ to increase the beam brightness.

BR

a) Monoturn injection.
b) Acceleration on $h = 1$.
c) Increase the extraction energy from 1 to 1.4 GeV to reduce space charge effects in the PS.

PS

a) Increase injection energy to 1.4 GeV.
b) Inject two BR batches (2×4 bunches).
c) Accelerate to 26 GeV/c on $h = 8$.
d) Adiabatic debunching and capture on $h = 140$ (or other) to provide the necessary bunch spacing and shaping.
e) Extract to the SPS.

Further options to this basic scheme are:

a) H^- source.
b) Doubling of the LINAC2 energy (50 to 100 MeV)
c) H^- injection into the BR.
d) Acceleration on $h = 2$ in the BR (leading to a single batch PS injection).

Even small blow-up of say 10% in transverse emittance can be harmful. At present, theoretical and experimental studies are in progress to analyze:

a) Space charge effects both at BR and PS injection energy.
b) Use of a 2nd harmonic RF to reduce the bunch peak current to limit space charge effects at low energy in the BR.
c) Transverse instabilities at PS transition.
d) Transverse and longitudinal instabilities during debunching and rebunching in the PS at 26 GeV/c.
e) Improvements in the PS optics to minimize non linearities at high energy and optimize the matching to the SPS.

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Beam Dynamics Activities in SL Division

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1 Introduction

Beam dynamics activities in the SL Division of CERN are reported concerning the existing Sp$\bar{p}$S collider, the existing LEP e^+e^- storage ring, and the LHC project.

2 Dynamic Aperture Experiment in the SPS

At the SPS dynamic aperture experiments are performed [1, 2, 3] to study non-linear particle motion. The SPS is a very linear machine at 120 GeV, so that it can be made non-linear in a controlled manner by eight additional strong sextupoles. The sextupoles are powered in such a way that low-order effects, i.e. first order resonances are suppressed and high order resonances can be studied. In this way a situation is investigated that is somewhat similar to the LHC with its large high order multipole errors. The experimental results are then compared with tracking studies. If the tracking can predict the nonlinear effects including the dynamic aperture, our confidence in those studies for strongly nonlinear machines like the LHC will be increased.

2.1 Results

The nonlinear detuning and the short-term dynamic aperture, i.e. particle loss after seconds, have been recorded for several initial conditions. The corresponding tracking studies show a remarkable agreement with the experiment in this short-term range. It was however discovered that there is a slow diffusion process that leads to particle loss after minutes of storage time. This diffusion process may be caused by tune modulation due to power supply ripple. An additional tune modulation indeed shows a decrease of the stability border in the tracking as well as in the experiments. After having found a reproducible experimental procedure first results are obtained that will be compared with tracking. Moreover it could be shown that reducing the nonlinear detuning with octupoles can increase the dynamic aperture.

2.2 Future Work

A first task will be to see if tracking can predict the dynamic aperture in the presence of tune modulation. More experiments are necessary as only one complete set of data could be taken up to now and the problem of the dependance of the dynamic aperture on the frequency of the modulation is not yet resolved. Tracking strongly suggests that low frequencies of about 10 Hz are more dangerous than high ones like 200 Hz. To settle those questions we will have more experiments at the SPS next spring.

3 Beam Dynamics Studies with LEP

LEP is an e^+e^- collider with about 27 km circumference. Four e^+ and four e^- bunches are accelerated through LIL, EPA, PS and SPS, and injected into LEP at 20 GeV. The operating energy of 46 GeV in LEP is reached by ramping. Four experiments – L3, Aleph, Opal, and Delphi – are installed in four low-β insertions. LEP Has been in operation since August 1989. Half the design luminosity and half the design current are achieved routinely. The integrated luminosity for 1990 is 6 pb^{-1}. Beam dynamics work is going on in the following areas:

Coupling: The skew fields in LEP are stronger than expected, and most noticeable at injection. A good fraction is due to a magnetization of the Ni layer between the Al vacuum chamber and the Pb shielding, introduced in the fabrication process. Work is in progress to demagnetize sectors and to check that the coupling is reduced.

Injection: Work is going on to measure and hopefully improve the dynamic acceptance, the accumulation rate, and the saturation current.

Luminosity: The luminosity is currently limited by a vertical beam blowup leading to a maximum beam-beam tune shift $\xi_y \approx 0.02$. Synchro-betatron resonances are one suspected cause. They will be measured and hopefully compensated by orbit and dispersion bumps. Beam-beam effects will be measured, using the coherent modes. The tunes will be optimized, and the differences in the phase advances between the interaction points will be measured and equalized.

Collective effects: Measurements of transverse mode coupling will be continued as a function of the bunch current. The results will be used to update the LEP impedance model. Measurements of bunchlengthening will be continued with a streak camera.

Polarization: Some $9 \pm 2 \pm 2$ percent polarization have been observed. Next year, this figure will hopefully be increased by better orbit correction in general, and by polarization-specific correction techniques, e.g. harmonic bumps near the spin tune, leading to an accurate energy calibration of LEP. The simulation of the spin motion with programs such as SLIM, SMILE, and SITF will be continued. An experiment with a spin rotator in an odd interaction point will be prepared, as a demonstration of spin-rotation around all four LEP experiments.

Preparation for the three LEP upgrades: The behaviour of the first few superconducting RF cavities will be closely studied, as a preparation for the later installation of many cavities to raise the LEP beam energy beyond the W pair production threshold. A pretzel scheme to increase the number of bunches in each beam to up to 36 in principle will be installed partially and simulated with fewer bunches. A crash programme to double the number of bunches in each beam to eight is under way. Both upgrades need the installation of a configuration with 90° phase advance in the arcs instead of the present 60°.

4 LHC Beam Dynamics Studies

The LHC is a 7.7 TeV proton-proton Collider which is being designed for a high luminosity of the order of 10^{34} $cm^{-2}s^{-1}$. This performance requires both a large number of particles per bunch (10^{11}p) and a large number of bunches per beam (4725), and as a consequence the LHC beams are prone to single bunch as well as to multibunch instabilities. The broad-band part of the beam- environment coupling impedance will be reduced by adequate shielding of the bellows and pumping ports (a technique successfully used in LEP) and possibly of the kickers. The resistive-wall contribution will be reduced by copper coating the inner surface of the beam pipe which is cooled at 5K. The beam pipe, which also serves as a synchrotron radiation shield has holes to allow an efficient cryopumping on the vacuum enclosure at 2K. The residual impedance of the various shields and of the pumping holes are being calculated.

The minimum invariant transverse emittance of the beams, $\epsilon_n = \sigma^2\gamma/\beta = 3.75 \times 10^{-6}$m, is determined by the allowed values of the beam-beam tune shift. It has to be verified that the LHC dynamic aperture, which is limited by the magnet errors, is sufficient for this value of the emittance. This is being done by long term computer tracking using MAD and SIXTRACK. A correction scheme "à la Neuffer" for the systematic sextupole, octupole and decapole errors, and a magnet sorting scheme to minimize the effects of the random sextupole errors have already been implemented. The tracking evaluation is done in presence of these correcting measures.

The effect of beam-beam synchro-betatron resonances induced by the existence of a crossing angle in the LHC has been evaluated by Computer tracking. Satellites of resonances up to 12-th order are seen, but do not perturb significantly the particle dynamics. The excitation of coherent beam-beam modes in the situation of the LHC and taking into account the long range forces is being studied.

A special insertion for ep collisions in which the LEP beam is bent up into the LHC beam plane and back has been designed, taking into account the special requirements of the ep detector.

5 MAD Developments

The new version 8 of the MAD program has been completed. The dynamic memory manager has been replaced by the CERN-written ZEBRA package which has been used successfully in more than 100 other programs for high-energy physics data analysis.

The input language has been extended to use an object-oriented approach. Accelerator elements are described in terms of classes of objects, providing easy selection of single elements in a large machine. A powerful mechanism has been implemented for writing tables of selected optical functions and/or element parameters in selected positions of the machine. These tables are generated and written under control of a dynamic table handler, and can be read directly by the LEP control system.

MAD contains a plot module with various options to plot data from internal tables. The tables can also be fed into a stand-alone plot program.

The new version has been used successfully for about one year. New features with respect to previous versions include: Matching constraints for elements of the transfer matrix and for algebraic combinations of quantities; Calculation of Electron Beam Parameters; Deferred evaluation of lumps; Speed-up of time-critical subroutines; Intra-beam scattering in the Bjorken-Mtingwa style. A test version of MAD includes polarization calculations in SITROS style.

A new MAD Programmer's Manual and a MAD Physics Manual are in the works.

Beam Dynamics Activities at LURE

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1 Introduction

LURE houses two storage rings operated as dedicated synchrotron radiation sources:

- the X-ray source DCI is a positron storage ring initially designed as a collider for high energy physics, and eventually devoted to synchrotron radiation generation. At the operation energy of 1.85 GeV, its critical wavelength is 3.4 Åand its beam emittance 1.4 10^{-6} m.rad. The initial lifetime exceeds 50 h for a typical stored intensity of 320 mA. A 5-pole superconducting wiggler is routinely operated with a maximum field of 4.8 T, which brings λ_c down to 1.1 Å.
- Super-ACO is a VUV storage ring designed as a synchrotron radiation source. Presently it is equipped with 4 undulators, and 14 beam lines are installed providing photon beams to 23 experiments. The general characteristics are:
  - $E_{\max}$ = 0.8 GeV
  - λ_c = 18.3 Å
  - circumference = 72 m
  - emittance = 3.7 10^{-8} m.rad.
  - Structure : expanded Chasman-Green D.B.A.

In contrast to many other rings, the two main modes of operation, with 24 and 2 bunches, share equally the production time. In routine conditions the performances of the machine are:

- 24 bunches, I = 400 mA, τ = 3.3 h, E = 0.8 GeV
- 2 bunches, I = 200 mA, τ = 2.1 h, E = 0.8 GeV
- FEL operation, 2 bunches, I = 80 mA, τ = 2 h, E = 0.6 GeV

2 Beam Dynamics Studies on Super ACO

Many beam dynamics studies have been performed on Super ACO this year [1], we present here only 2 of them.

2.1 Insertions

Due to the low energy (800 MeV) and the high field (1 T), they have a strong effect on the beam behavior. When an undulator is inserted, the fourth order symmetry is destroyed, a beat of the β_z function is introduced (70%), the vertical focusing effect leads to a vertical tune shift (0.1) and the non linear part of the field drives fourth order resonances which react on dynamic aperture. We studied by simulation with the BETA code the dynamic of the beam in terms of beam gas and Touschek lifetimes.With 4 undulators closed, they are reduced respectively by 35% and 50%. The sinusoidal field model is not fully satisfactory and some adjustment was needed to account for experimental results.

2.2 ELECTRON FILLING TEST

Super ACO was designed for positron filling (no clearing electrodes). Recently, a 3 days shift was used to test electron beam behavior. For large currents (400 mA) the beam lifetime as compared to the one with positrons is reduced by 20%. At lower current (< 200 mA) and independently of the number of the bunches the lifetime reduction become more and more severe. With 2 bunches below 100 mA the lifetime decreases dramatically.

Attention was given to the problem of microlosses of beam current observed with e^- but not with e^+. They are understood [2] as the result of photoionised dust particles being raised by the electron beam. For low energy rings and moderate currents, dust particles can stay oscillating around the beam leading to short lifetimes in competition with positive ion trapping effects.

3 Status of CLIO

The CLIO ("Collaboration pour un Laser Infra-rouge à Orsay") project involves an FEL dedicated 50 MeV RF linear accelerator. The goal is to make a tunable laser (2-20 μm) with high peak power (MW range) and medium average power (a few tens of Watts).

The commissioning of the injection system is in progress [3]. The 4 MeV injector is completed. It consists of a pulsed thermionic gun, a 500 MHz subharmonic pre-buncher and a standing wave (3 GHz) buncher.

4 Prospective Development

The machine group presently is in the first stage of a study of a new machine in order to supersede DCI. The main features are:

- E_{max} = 2.15 GeV
- λ_c= 2.5 Å(from the magnets)
- I_{max} = 0.2 A
- Number of insertions ≥ 12 (4 or 5 m long)
- Total length ≤ 200 m (8 periods)
- Expected emittance : 3.5 10^{-8} mrad.
- Structure : expanded Chasman Green D.B.A.

We use the knowledge acquired on our previous storage rings. The machine will be operated with positrons due to the importance for the users of the time structured beams.

Discussions are in progress to define the best parameters for both VUV and soft X-rays, temporal structure and maximum flux.

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[2]P. Marin LURE, Anneaux RT/90-01.
[3]J.C. Bourdon et al. (to be published) FEL 90, Paris 1990

Electron–Positron Related Beam Dynamics Activities at PSI

L. RIVKIN
Paul Scherrer Institute, Villigen, Switzerland

B–Factory design related work

Since the completion of the joint CERN–PSI feasibility study earlier this year, the work (in collaboration with CERN) continues on several general topics that are relevant to high luminosity electron–positron colliders.

1. **RF–System Studies.** *(P. Marchand)*
   The prototypes of the single cell, normal conducting 500 MHz cavity and HOM couplers have been built and measured. Use of superconducting cavities as well as hybrid systems composed of both normal conducting and superconducting cavities (in particular a very interesting case of idle sc cavities), is under study.
2. **Beam-beam simulations.** *(S. Milton)*
   Limits on the luminosity due to the beam-beam interaction, especially in the case of comparable bunch length and beta function at the interaction point (high "disruption" regime), are being studied with simulation codes. New approaches to the problem, both software and hardware options, are under investigation.
3. **Positron capture dynamics.** *(H. Braun)*
   Detailed simulations of the positron capture dynamics have been written. Comparisons with experiments on the existing positron sources at CERN and SLAC are under way.
4. **IP design and backgrounds calculations.** *(R. Eichler, R. Abela)*
   Synchrotron radiation backgrounds calculations for the asymmetry of 8 GeV on 3.5 Gev with tilted solenoid separation scheme have been reassumed. An improved Monte–Carlo program has been tested and earlier background estimations were confirmed.
5. **IP optics, lattice issues, collective effects.** *(L. Rivkin)*
   Low beta insertion optics, sextupole correction schemes and dynamic aperture calculations, bunch lengthening estimates are among the topics. Limitations due to the coherent radiation are investigated and an experiment on LEP to check the estimates is being planned.

Synchrotron Light Source Design
(R. Abela, W. Joho, L.Rivkin, U. Schryber)

Design of an up to 2 GeV ring for production of synchrotron light has been started. An eight fold symmetric, 180 meter long ring with TBA/combined function bends lattice would provide 7 nm emittance (at 1.5 GeV) beam with lifetime in excess of 10 hours. Straight sections for the insertion devices are 8 meters long. Energy ramping from 600 MeV to the operating energy as well as the use of positrons are being considered.

Beam Dynamics Activities at DESY

A. PIWINSKI
Deutsches Elektronen-Synchrotron DESY, Hamburg

1 B-Factory Activities

The B-Factory study group is currently investigating an asymmetric collider consisting of 2 equally sized rings in the PETRA tunnel. The energy asymmetry is 3.3. The interaction region layout is based on permanent magnetic quadrupoles which focus both the high and the low energy beam. The focussing section is followed by a 10 m long soft combined function magnet which separates the two beams without generating too much synchrotron radiation. Coupled bunch instabilities become more severe than in previous cases under study. A luminosity of $3 \cdot 10^{33}$ cm^2s^{-1} appears to be possible (F. Willeke).

2 Instabilities and Feedback

The main activities concentrate on coupled bunch motion including the higher internal modes of the bunches, which is important for the protons in HERA (K. Balewski).

The current limitation due to instabilities and the nonlinear particle motion was considered in detail (J. Feikes). The "overshoot" phenomenon has been rediscovered and has been understood theoretically.

The theoretical investigations of feedback systems based on the multi-bunch considerations have continued. Although multi-bunch feedback systems for all three directions have been successfully tested in PETRA, the noise transfer through those systems in future machines is a central problem (H. Hoeber, R.D. Kohaupt). The solution of these problems by special signal processing (filtering) has been investigated theoretically (M. Schweiger).

3 Contributions to the DESY-THD Linear Collider Study Group

Damping Rings: Studies of nonlinear dynamics have been performed for various types of low-emittance damping ring lattices with special emphasis on dynamic aperture in the presence of errors. As a result, a lattice type with local cancellation of nonlinear distortions proves to be superior to other (e.g. FoDo-like) structures. Based on this lattice, a practical damping ring has been laid out which is capable of delivering 2 μs long bunch trains with a repetition frequency of 50 Hz and a normalized emittance of $\gamma\varepsilon_x = 4.1 \cdot 10^{-6}$ m.

Final Focus Optics: Higher order chromatic effects limiting the momentum acceptance of final focus systems have been investigated. Taking the CLIC final focus design (Napoly, Zotter 1989) as a starting point, it is shown that these effects can be suppressed to a large extent by including additional sextupoles in the lattice. With this optimization, a final focus optics for 250 GeV beam energy with a momentum bandwidth of ± 1.2 % and $\beta_x^* = 3$ mm, $\beta_y^* = 0.3$ mm has been designed (R. Brinkmann).

Positron Supply: Since our design requires $1.2 \cdot 10^{12}$ positrons every 20 ms, conventional positron converters will probably be insufficient. We are now investigating the Novosibirsk scheme using high energy undulator radiation as well as a novel recovery scheme using radiative deceleration in long wiggler sections.

Alignment Jitter: Tolerances of quadrupole alignment jitter in the main linac are specified to be 20 nm. Continuous vibration measurement and local magnetic dipole kick compensation is being considered. Jitter tolerance studies will be continued (J. Roßbach).

4 Polarization Studies

The construction of the polarimeter for measuring vertical polarization continues. The laser has been installed and the design of the special vacuum pipe for the photon-electron interaction region is complete. (HERA Polarimeter Group)

The SITROS program which calculates spin depolarization by a tracking technique will be upgraded in collaboration with the SL Accelerator Physics Group at CERN. The aim of the upgrade is to improve the sampling of the phase space and the simulation of radiation effects so that comparison with results of the program SMILE can be made (D.P.Barber, M.Boege).

Investigation of closed orbit correction schemes for polarization optimization continues (E. Gianfelice).

5 Intra-Beam Scattering

The rise times of bunch dimensions and energy spread due to intra-beam scattering in presence of linear coupling between horizontal and vertical betatron oscillations are being calculated. The distribution of skew quadrupoles and solenoids along the ring is taken into account as well as the variation of the amplitude functions and dispersions (A. Piwinski).

6 Fast Ground Motion at HERA

Closed orbit motion in the HERA electron ring has been measured with high accuracy in correlation with ground motion in the HERA tunnel. Using standard pick-up monitors and averaging techniques, the resolution on orbit measurement was 10 μm. The spectrum of orbit motion is remarkably similar to the ground motion spectrum with dominant components in the 1 - 10 Hz range. Also the rms orbit amplitude of $\sigma_z \approx 2\ \mu$m (scaled for $\beta_z = 1$ m) fits well.

To predict the motion of the HERA proton closed orbit, the mechanical stability of the superconducting quadrupole magnets has been investigated. Vibration measurements at the quadrupole coil at He temperature show rms amplitudes as much as 0.8 μm.

Finally, measurements of the ground wave propagation velocity have been performed in the HERA-tunnel (W. Decking, K. Flöttmann, J. Roßbach).

7 Nonlinear Effects of Wigglers and Undulators

Analytical and numerical studies have been performed to investigate particle dynamics due to inherent as well as spurious nonlinearities of undulator fields. The role of the fast oscillating terms is emphasized (J. Roßbach).

Beam Dynamics Activities in the Kaon Factory Division

E. SHAPOSHNIKOVA
Institute for Nuclear Research, Moscow, USSR

The Kaon Factory Division in INR was organized in 1987. Before this moment it was a beam dynamics laboratory of Linear Accelerator Division and scientific activities were devoted to the problems of intensive linacs.

In the Proposal of Moscow Kaon Factory (MKF) the linear accelerator of Meson Factory is to be used as the injector for the Booster being the first step of the MKF accelerator complex. Construction of an intense 600 MeV linear accelerator of protons and H^- ions is under way at the INR (Institute for Nuclear Research of the Academy of Sciences of the USSR, Troitsk, Moscow Region).

The linac consists of the low-energy part of the Alvarez type to the energy 100 MeV operating at the frequency 198.2 MHz, and the high-energy part with the maximum energy 699 MeV at frequency 991.0 MHz. The high-energy part of the linac comprises 27 cavities. Each cavity consist of four disc and washer tanks. The total current is to be 0.5 mA with the pulse current 50 mA at the pulse duration 100 μs and repetition rate 100 Hz.

The tuning of the whole initial part of the accelerator with beam has been started in April 1990 when the proton energy 100 MeV and pulse current of 10 mA have been obtained. The acceleration to the maximum energy 600 MeV is planned for 1991.

In the second part of the linac the radio frequency increases by the factor of 5. As a result the longitudinal acceptance is decreased by the same factor, so we have a problem with particles near the separatrix. At the same time the particle loss for meson factories with average current 0.5 mA is restricted strongly. Therefore it is necessary to investigate carefully possible causes of particle loss and to take additional steps to eliminate them. To simplify the technology the high-energy part consists of tanks with a constant phase velocity, which also creates some specific features.

We studied the effect of perturbations on the longitudinal motion of particles in a stepped-phase-velocity linac. The use of the concept of the equivalent phase velocity of a cavity provides a method of compensating for the deviations in some parameters by changing the others, since their independent decrease is sometimes impossible to obtain technologically. It is found also that definite spatial variation of the accelerating field within each module substantially increases the longitudinal acceptance.

We have revised some aspects of the ΔT- procedure, developed by K. Crandall for tuning of the LAMPF linac. We investigated ΔT-procedure features connected with using the bunches instead of single particle for tuning of the ion linac. Also we consider ΔT-procedure for real cavities with deviations of their parameters from design values.

In 1987 INR has obtained the funding for the design of Kaon Factory Proposal. In accordance with this proposal after charge exchange injection from Linac the H^+ beam is accelerated in the Booster from 0.6 GeV to 7.5 GeV and in the Main Ring from 7.5 GeV to 45 GeV. At the end of acceleration the 45 GeV beam is transferred from the Main Ring to the Extender and then extracted slowly with 100 duty cycle. Circulating current equals 2-3 A.

The MKF lattices were chosen on the basis of the following requirements:

1. Crossing of transition was to be avoided in both rings.
2. Straight sections with zero dispersion are necessary for RF cavities for Booster and Main Ring as well as for the insertion of the Siberian snakes.

3. To avoid microwave instability without additional longitudinal painting high real γ_t=18 in Booster and small real γ_t=6.6 in Main Ring are needed.
4. Suppressing of depolarizing resonances in both rings.
5. Realization of large dynamic aperture for decreasing of losses.
6. Slow extraction with small losses (10^{-3}).

For simulation of injection and acceleration with space charge code LONGBED is developed.

To analyze nonlinear motion including high order resonance (10) differential algebra Lie code is being developed.

Beam Dynamics Activities in KEK

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1 Activities on Accelerator Theory

The accelerator theory group of KEK is attached to the TRISTAN Division and its main activities are concerned with electron storage rings and linear colliders.

Recently, an accelerator department of a graduate school has been founded in KEK and Suzuki gave a lecture on basic accelerator theory. Lecture notes are planned. He now works with his student Toyomasu on beam breakup problems in linear colliders. Analysis of coupled-bunch instability is also planned. Emphasis is on Landau and BNS damping. Suzuki has worked on theories of synchro-betatron resonances for some years. Extensive computer work is planned. Analysis of the experimental data at TRISTAN etc. is planned. He also works on synchro-betatron resonances in proton synchrotrons. His application is to TRIUMF Kaon factory.

Yokoya is mainly working on theoretical problems in the linear collider and the B-factory projects at KEK. In connection with the B-factory project, he works on coupled-bunch instability, bunch lengthening, etc. In connection with the linear collider, he has worked on the beam-beam effects in general for some time. He has also done interesting work on the ratio of the beam-beam parameter and the coherent tune shift in circular accelerators. This work is based on the Vlasov equation. Recently, he is working on impedance problems which include, for instance, the impedance of obstacles such as beam scrapers, the short-range impedance, etc.

Oide is also working on theoretical problems in the linear collider and the B-factory projects, sometimes in collaboration with Yokoya. He has worked on the final focus system in linear colliders. He also worked on a bunch lengthening problem with Yokoya. He is now working on the optics and beam dynamics problems in the design of the B-factory at KEK. He is also developing SAD (Strategic Accelerator Design, a KEK version of optics program) in collaboration with Kuroda, Kikuchi, Ohmi et al.

Hirata had stayed in CERN for about two years and returned to KEK early this year. He has done several interesting things in CERN. He has worked on the instability problem of coherent beam-beam interaction with E. Keil and has shown that a large ratio in the circumference of asymetric beam colliders such as in B-factory projects is not favourable. This important work is reflected in the recent B-factory designs. Actually, he has worked on the coherent beam-beam problem for some time and published several interesting papers. He has also worked on bunch lengthening, correction to the Oide limit in the final focus system of linear colliders, algorithms to treat radiation effects in simulation, etc. In addition to the B-factory design, he is now working on the design problems of a phi-factory project ($E = 0.5$ GeV/beam, $L = 3 \times 10^{33}$ cm^{-2}s^{-1}).

Kamada is working on optics and lattice related problems and TRISTAN operational problems in collaboration with several people in the operation group. He is also working on the design problems connected with the conversion of TRISTAN main ring to a synchrotron radiation source (E = 10GeV, I = 100mA, 30-100 bunches). The problem he attacks are dynamic aperture, alignment, vibration, etc. Also important is a multi-bunch instability and its cures. These are about all of the theory group members except that Yamamoto is now working at SLAC.

Other interesting theoretical work includes free-electron laser problems (Takayama), the transverse space charge limit(Machida), analysis of intra-beam scattering by the Fokker-Planck equation(Mori), the beam-beam simulation for the crab crossing (Koiso, Oide), the observation of multi-bunch BBU in the Photon Factory linac(Ogawa, Shidara, Asami), etc.

2 TRISTAN Results

Beam-beam measurement is done. The objective is to estimate the emittance by measuring the coherent beam-beam mode frequency. Theoretically, Hirata and Yokoya worked on this. Synchro-betatron resonances are measured and analyzed partly by Satoh, Nakajima et al. Bunch length is also measured by Nakajima, Satoh et al. The polarization of electrons in the main ring was measured to be 40% at 29 GeV by inverse Compton scattering using a laser beam(Nakajima et al.) The operation conditions are analyzed by a simulation method (Kamada, Fukuma et. al.)

3 Future Projects

The JLC(Japanese Linear Collider) is a long-range project of KEK. Theoretically, mainly Yokoya and Oide are working on it. Now the Test Accelerator Facility (TAF) is in progress. The aim is to construct a 1.54 GeV injector linac and a damping ring. The design of the damping ring is in progress. Not only theory, but also hardware work is in progress.

A shorter-range project is the B-factory project. The design work is headed by Kurokawa and Satoh. Theoretically, Oide and others are mainly working on the design. The energy is either 3.5×8GeV or 2.46×12GeV, depending on the physics aimed at. The luminosity is planned to be 2×10^{33} $cm^{-2}s^{-1}$ in the first stage and will be boosted to 10^{34} $cm^{-2}s^{-1}$ by using crab crossing.

After achieving 300 pb^{-1} integrated luminosity in the main ring of TRISTAN (with superconducting quadrupole magnets, etc.) in several years, it is planned to convert the main ring into a synchrotron radiation source operated at 10 GeV. The design work is in progress.

Several people in KEK and elsewhere in Japan are interested in a Phi-factory. Hirata is mainly working on the design study.

The JHF(Japanese Hadron Facility) is a project of INS, University of Tokyo, but several people from KEK are collaborating. This is a project to build a 1GeV proton linac(Yamazaki et al.) and a storage ring feeding a 200 μA output current for neutron and meson physics, etc. The design work is headed by Kihara.

The PS Collider project is to build a heavy ion collider of 5-7 GeV/beam in energy and the luminosity of 10^{25} to 10^{27} $cm^{-2}s^{-1}$ or higher. The main objective is to study high density nuclear states. The present proton synchrotron will be used as an injector. Since the intra-beam scattering lifetime is severe, a coasting beam design will be adopted. The design work is headed by Mori.

Activities of Accelerator Research at INS

AKIRA NODA
INS, University of Tokyo

1 Operating Facilities

1.1 OPERATING SYNCHROTRON

An electron synchrotron with a repetition rate of 21 Hz is operated since 1961 and now the energy range covered by this machine is from 150 MeV to 1200 MeV. The circulating beam intensity amounts to 10^{11} electrons/pulse (2×10^{12} electrons/second). A typical feature of this machine is a photon tagging system, which enables to identify the photon energy produced by bremsstrahlung with the energy resolution of ± 5 MeV.In order to increase the duty cycle of the tagged-photon beam, a special beam extraction and a beam-transport system, which enlarged a macroscopic duty cycle up to 20%, was constructed in 1985 and an effective tagged photon intensity was raised up to 10^6 photons/second[1].

1.2 SF CYCLOTRON

An ordinary AVF cyclotron with K-number of 67 is under operation since 1974. Recently an ECR ion source is completed together with an axial injection system and ions with masses lighter than 40 (ions up to Ar) have been accelerated[2].

1.3 HEAVY-ION SYNCHROTRON-COOLER RING, TARN II

On one hand, TARN II is a heavy-ion synchrotron which can accelerate protons an ions with charge to mass ratio of 1/2 up to 1100 MeV and 350 MeV/u, respectively. As an injector, the SF cyclotron, above mentioned, is used and acceptable ion by TARN II is limited up to Ne because of necessary minimum magnetic rigidity during injection. Beams of protons and alpha particles are already accelerated up to the highest energy attainable under the present facility of the electric power station, which will be enlarged to enable full excitation of TARN II in a year. The overall acceleration efficiency still remains around 50% and is expected to be improved by applying an amplitude modulation to the RF voltage during beam capture process. The special feature of the acceleration system of TARN II exists in its wide sweep range of frequency (0.5 - 8.0 MHz) due to rather lower injection energy (2.7 MeV/u for the case of Nitrogen)[3].

On the other hand, TARN II is a cooler ring in which the momentum spread and emittance of the circulating beam are cooled down by an electron beam cooling method. Proton with kinetic energy of 20 MeV, alpha, deuteron and molecular hydrogen with the kinetic energy of 10 MeV/u are already studied. By applying an electron cooling and increasing the beam density, a coherent phenomena is observed in the Schottky signal, as shown in Fig. 1 [4]. Peak splitting due to collective motion can be seen for the condition higher than a certain intensity.

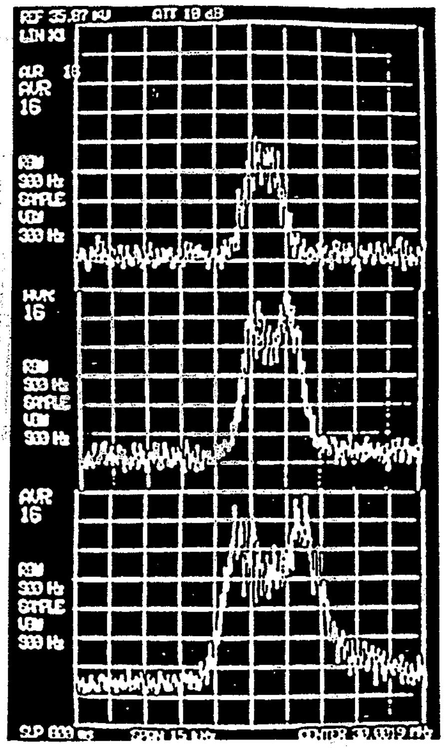

Figure 1: Longitudinal Schottky Signal Spectra. From the top, numbers of protons are about $3 \cdot 10^7$, 10^8 and $3 \cdot 10^8$

2 Future Project

2.1 Japanese Hadron Project JHP

As a future project, INS is proposing Japanese Hadron Project (JHP) which consists of a 1 GeV proton linear accelerator with the average current of 200 μA and a compressor /stretcher ring and heavy-ion linac to accelerate radioactive nuclei produced by an intense proton beam (Fig. 2)[5]. This project is developed in collaboration with KEK. High intensity proton linac is mainly developed at KEK and INS makes emphasis on acceleration of radioactive beam because it is needed to provide a necessary data for astrophysics. For this purpose, a system composed of an isotope separator online (ISOL) as an ion source, RFQ linac with split-coaxial type, drift tube linacs with Interdigital-H structure and Alvarez types is proposed. This system aims at acceleration of radioactive nuclei with mass number up to 60 to the energy of 6.5 MeV/u. The resonators of the linacs are designed to enable future acceleration ions with mass number up to 238 by improvement of the RF power. As a preparatory work for such project, INS is developing a target which separates radioactive nuclei by an ISOL and an RFQ linac with a split-coaxial type. A study with a cold model has been already finished and an high power cavity which can accelerate ions with charge to mass ratio greater than 1/30 from 1 KeV/u to 45.4 KeV/u with an RF frequency of 25.45 MHz is also already been constructed and will start a test of beam acceleration at the end of this year[6].

2.2 Collaboration with KAON Factory at TRIUMF

The society of nuclear physics in Japan expects INS to take an important role in collaboration with kaon factory project at TRIUMF in Canada as INS is an institute operated for common use among universities all over the country. Such a discussion has just started.

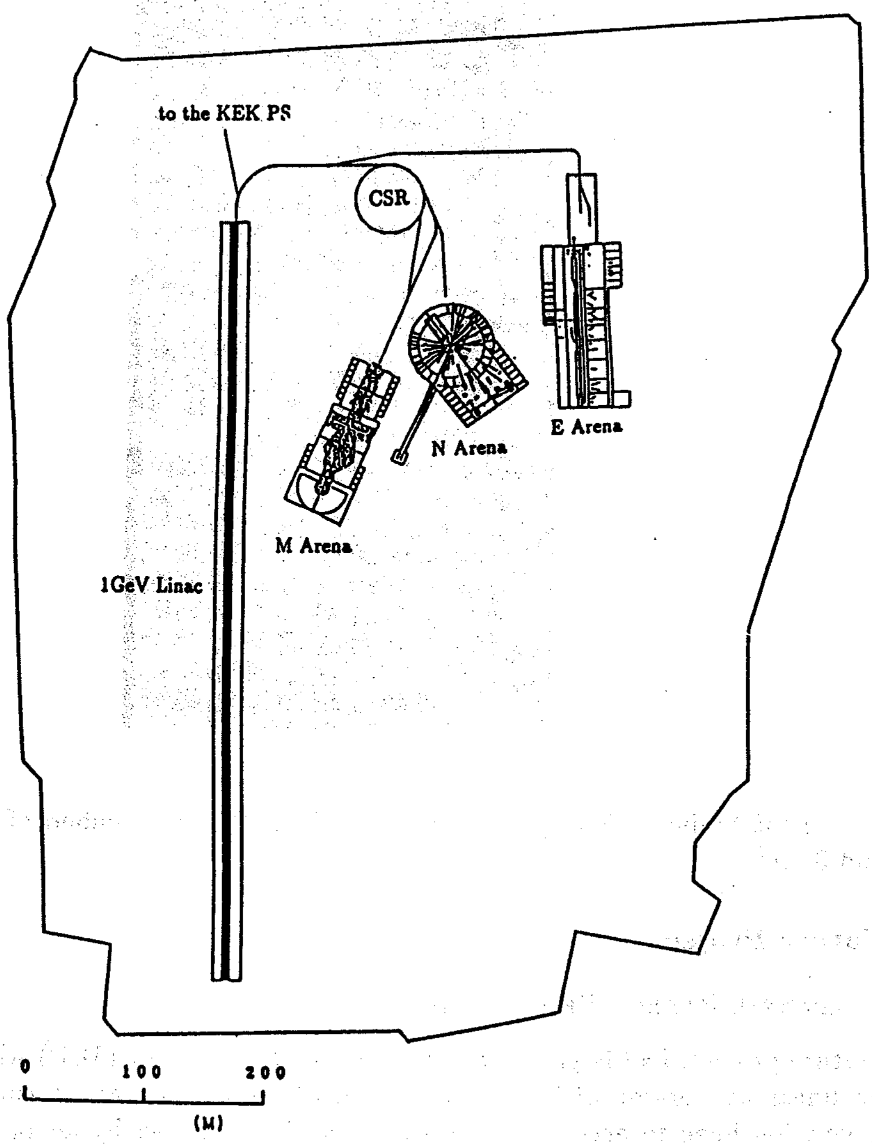

Figure 2: Layout of the Accelerator Complex of Japanese Hadron Project

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[5]M. Kihara, "Present Status of the Japanese Hadron Project", Part. Accel. 32 (1990) 1.
C. Ohmori, "Design of the Beam Transport Lines of the Japanese Hadron Project" [II], INS-J-174

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Forthcoming Beam Dynamics Events

Workshop on novel concepts for e+e- flavor factories and related beam dynamics issues, Santa Monica, CA, USA, 13 - 16 Feb 1991. Contact: Melinda Laraneta; Physics Department; UCLA; Los Angeles, CA 90024; USA. Tel [1] (213) 825 4649, Fax [1] (213) 206 1091, E-mail laraneta at uclahep.

Computing in high energy physics '91 – CHEP91, Tsukuba City, Japan, 11 - 15 Mar 1991. Contact: Yoshiyuki Watase; Ohu; Tsukuba, Ibaraki 305; KEK National Laboratory for High Energy Physics. Tel [81] 298 64 1092 Fax [81] 296 64 3136 E-mail chep91 at jpnkekvm.

3rd Annual international industrial symposium on the Super Collider (IISSC), Atlanta, GA, USA, 13 - 15 Mar 1991. Contact: Ms Pamela E Patterson Conference Manager; International Industrial Symposium on the Super Collider (IISSC); P O Box 171551; San Diego, CA 92197; USA. Tel [1] (619) 490-0164, Fax [1] (619) 490-0138. Deadlines 13 Feb 1991 (early reg):App 21 Sep 1991:Abs 13 Mar 1991:Pap

Course on rf engineering for particle accelerators (CERN Accelerator school and Rutherford Appleton Laboratory), Oxford, UK, 3 - 10 Apr 1991. Contact: Mrs S von Wartburg; CERN Accelerator School; SL Division; CH-1211 Geneva 23; Switzerland. E-mail casral at cernvm.cern.ch. Fees CHF 1100 incl. full board and Proceedings. Deadlines 15 Jan 1991:App.

1991 IEEE particle accelerator conference, San Francisco, CA, USA , 6 - 9 May 1991. Contact: M Allen; SLAC; P O Box 4349 (Bin 68); Stanford, CA 94309; USA. Tel [1] (415) 926 2820; E-mail matallen at slacvm; Deadline 3 Dec 1990:Abs.

Workshop on beam-beam and beam radiation effects in colliding-beam devices: High intensity and nonlinear effects, UCLA, Los Angeles, 13 - 17 May 1991. Contact: C Pellegrini, Physics Department UCLA; 405 Hilgard Ave; Los Angeles, CA 90024-1547; USA. E-mail pellegrini at uclahep.

Fourth ICFA school on instrumentation in elementary particle physics, Trieste, Italy, 20 - 31 May 1991. Contact: Prof L Bertocchi, ICTP, P.O. Box 586, I-34100 Trieste, Italy. Deadline 15 Jan 1991:App.

12th International conference on magnet technology (MT-12), Leningrad, USSR, 24 - 28 Jun 1991. Contact: B N Zhukov, MT-12 Scientific Secretary, Efremov Scientific Research Institute of Electrophysical Apparatus, 189631 Leningrad, USSR. Tel [7] (812) 265 6046, Fax [7] (812) 463 9812. Deadline 30 Nov 1990:Abs

US Particle Accelerator School - Credit courses in beam physics, U of Illinois, Urbana-Champaign, Illinois, 3 - 14 Jun 1991. Contact: USPAS c/o Fermilab MS125; P.O Box 500, Batavia IL 60510, USA. Tel [1] (708) 840-3896; Fax [1] (708) 840-4343; E-mail uspas at fnal.

8th COMPUMAG conference on the computation of electromagnetic fields, Sorrento, Italy, 7 - 11 Jul 1991. Contact: COMPUMAG Secretariat, Dipartimento di Ingegneria Elettrica; Universita di Napoli "Federico II"; Via Claudio, 21; I-80125 Napoli; Italy Tel [39] (81) 768 3171 Fax [39] (81) 61 68 97 E-mail uncompum at inacriai.earn Deadlines 15 Nov 1990:Abs 8 Jul 1991:Pap

5th Advanced ICFA beam dynamics workshop on the effects of errors in accelerators, their diagnosis and correction, South Padre Island, TX, USA, Sep 1991. Contact: A Chao; SSC Laboratory Suite 260; 2550 Beckleymeade Ave; Dallas TX 75237-3946; USA. Tel [1] (214) 708-3032, Fax [1] (214) 298-5451.

Course on advanced accelerator physics (CERN Accelerator School and NIKHEF-H, Amsterdam), Noordwijkerhout, Netherlands, 16 - 27 Sep 1991. Contact: Mrs S von Wartburg; CERN Accelerator School; SL Division; CH-1211 Geneva 23; Switzerland. E-mail casnik at cernvm.cern.ch.

3rd International Linear Collider Workshop, Protvino USSR, September 1991. Contact V. Balakin, INP Novosibirsk.

US Particle Accelerator School - Credit courses in accelerator physics and technology, U of Texas, Austin, Texas, USA, 6 - 17 Jan 1992. Contact: USPAS c/o Fermilab MS125; P.O Box 500, Batavia IL 60510, USA. Tel [1] (708) 840-3896; Fax [1] (708) 840-4343; E-mail uspas at fnal.

ICFA workshop on low emittance sources (photocathodes and rings), Alma Ata or Naramberd, Mar/Apr 1992.

Course on magnet measurement and alignment (CERN Accelerator school), Hyatt Continental Montreux, Switzerland, 21 -27 Mar 1992. Contact: Mrs S von Wartburg; CERN Accelerator School; SL Division; CH-1211 Geneva 23; Switzerland. E-mail bryant at cernvm.cern.ch.

3rd EPAC - European particle accelerator conference. Berlin, Germany, 7 - 11 Apr 1992. Contact 1: H Henke, TU Berlin; Germany. Contact 2: EPAC Secretariat; c/o Mme Ch. Petit-Jean-Genaz; CERN; CH-1211 Geneva 23; Switzerland.

6th Advanced ICFA beam dynamics workshop on high performance collider issues, unknown place, spring 1992. Contact: E Keil; CERN; CH-1211 Geneva 23; Switzerland. Tel [41] (22) 767-3426, Fax [41] (22) 783-0552. E-mail keil at cernvm.cern.ch

15th International conference on high energy accelerators, Hamburg, FR Germany, 20 - 24 Jul 1992.

ICFA Workshop on design of a 10 TeV linear collider, Berlin or Alma Ata, before/after Int. Acc. Conf.

7th Advanced ICFA beam dynamics workshop on nonlinear dynamics of single particles, unknown place, autumn 1992 or spring 1993. Contact: E Keil; CERN; CH-1211 Geneva 23; Switzerland. Tel [41] (22) 767-3426, Fax [41] (22) 783-0552. E-mail keil at cernvm.cern.ch

Course on general accelerator physics (CERN Accelerator School), Finland, Sep 1992. Contact: Mrs S von Wartburg; CERN Accelerator School; SL Division; CH-1211 Geneva 23; Switzerland. E-mail bryant at cernvm.cern.ch.

Joint US-CERN Particle Accelerator School - Nonlinear Particle Dynamics, unknown place, autumn 1992. Contact: CERN Accelerator School, Mrs S von Wartburg, SL Division, CH-1211 Geneva 23, Switzerland. E-mail turner at cernvm.cern.ch.

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