ICFA Beam Dynamics Newsletter, No. 22

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1: Forwards

1.1 From the Chairman

Kohji Hirata kohji.hirata@kek.jp The Chairman
ICFA Beam Dynamics Panel

ICFA is an organization for the future high energy physics accelerators. The same applies to the *Beam Dynamics Panel*. Nevertheless, the mission of the panel is just *to encourage and promote international collaboration on beam dynamics studies for present and future accelerators*, including all types of accelerators. The reasons are as follows:

- The knowledge of the ”low energy” accelerators is as important as the high energy accelerators.
- High energy acclerators need low energy accelerators at least as injectors.
- In the end, all the accelerators are more or less the same from beam dynamics point of view.

As the chairman of the panel, also personally as a beam dynamicist, I like to think that we are allowed, expected, and have to study all the beams of all the accelerators, in the same way as a high energy physicist studies CP violation, for example. He does not study the CP violation in KEKB, for example, but studies the CP violation itself. In this way of thinking, all the beam dynamicists study the single issue, the nature of the beams in accelerators.

In the present editorial system of the *Newsletter*, one of six editors is responsible for each particular issue. It brings a good effects that each issue covers a little different categories, different regions, and different people and hence enriches the beam dynamics society.

1.2 From the Editor

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Dr. K.Hirata, Chairman of ICFA Beam Dynamics Panel, suggested to organize a special chapter of “Accelerators in China” in the Newsletter No. 22 when he asked if I would be the active editor for this issue. Had realized my dereliction of duty for too few articles attracted from Chinese institutions in the previous issues though, I felt that the better idea was to create a special chapter of “Accelerators in Asia” in this issue, especially when the 5th Plenary Asian Committee for Future Accelerators (ACFA) would be held soon. The information on the Newsletter No. 22 was announced during the ACFA meeting held in May 29 to 31 at Korea.

As a result, we received 12 contributions from Asia area, they are: Zuping Liu and Weimin Li, Beam Physics Activities at NSRL; C.C. Kuo, Beam Dynamics Activities at SRRC; Yuzheng Lin, Beam Dynamics Activities in the Accelerator Lab of Tsinghua University; Nan Huang et al, Beam Dynamics Activities in SSRF; Jiuqing Wang, Beam Dynamics Studies in BEPC; J. W.White, A Synchrotron for Australia? (Australia is a member of ACFA); Yoshihiro Funakoshi, Present Status of the KEKB; Jinyu Tang et al, Beam Dynamics Activity in HIRFL; Eunsan Kim, Beam Instability Studies in PLS Storage Ring; Yumin Jin, Second OCPA Accelerator School and

Chuang Zhang, APAC met in Korea. It is their contributions which make the Asian chapter true in this issue.

Two articles are still missing in this issue of the Newsletter, one is from India and another from Thailand. There were three interesting presentations from India in the ACFA meeting. Dr. A.S.Raja Rao reported the status of Synchrotron Radiation Sources INDUS-1 and INDUS-2 in the Centre for Advanced Technology at Indore. Dr. G.K.Mehta of Nuclear Science Centre, New Delhi, described its facilities in phased manner: phase one of 15 MV tandem and phase two of accelerator augmentation with a superconducting linac booster module. Dr. R.K.Bhandari reported the accelerator activities at Variable Energy Cyclotron Centre at Calcutta. From Thailand, Dr. W.Pairsuwan reported the progress of the Siam Photon Project in the National Synchrotron Research Center. The project contains a 1.0 GeV electron storage ring with four long straight sections for insertion devices and three beam lines & experimental stations. Many photos show the real progress of the project and it is scheduled to be completed by May 2001. Similar to the Thailand project, the Middle East Synchrotron Radiation Project called SESAME will be hosted by Jordan, reported by S. A. Khan in his letter to editor. Dr. I. Hofmann presents the studies on high-current beam dynamics at GSI and T.Raubenheimer and A.Seryi announce the Workshop on Ground Motion in Future Accelerators to be held in November 6-9, 2000 at SLAC . Our special thanks are going to those non-Asian authors for their contributions which make our issue not too special. We would also like to thank five new doctors in accelerator physics for the abstracts of their theses.

R.J. Macek of LANL is also writing an article for our Newsletter. However, he may have to catch the December issue for having trouble combining pieces that are in different formats of Word, PostScript and LaTex. This seems to be a common problem when the Word gets more and more popular. About half of the contributed articles for this issue of Newsletter are written in Word. It is a real headache to transfer them from Word files into LaTex especially if the documents contain figures and tables. A question raises here for discussion that if the format of our Newsletter should be changed from LaTex to Word? Dr. Jiuqing Wang has worked out to solve this problem and done a lot of other editing matters for this issue of Newsletter, whose efforts are highly appreciated.

2: Letters to the Editors

2.1 Jordan to host Middle East Synchrotron

Dear Members of the Accelerator & Beam Physics Community,

A synchrotron light source is an exceedingly powerful source of light generated by circulating charged-particle beams. It has become an important tool for scientific research and technological progress. Currently there are about fifty synchrotron light sources located in about twenty Nations. Jordan will be the first country from the Middle East to join this elite list of nations possessing a synchrotron light source. This is due to the generous gift of the BESSY-I Synchrotron by the German Government [Nature, pp. 507-508 (10 Jun. 1999)]. BESSY-I a 800 MeV machine and its successor BESSY-II a 1900 MeV machine are located in Berlin.

After an effort of several years the Middle East Synchrotron is at last becoming a reality. The Project is known by the acronym **SESAME** (Synchrotron-light for Experimental Science and Applications in the Middle East). Jordan was recently chosen as the site for hosting the relocated German Synchrotron [Nature, pp. 798 (20 Apr. 2000)]. The proposed synchrotron will be the seed for an International Centre built around the facility. Such a centre has been long overdue and it will be the first one of its kind in the region. The Centre will be operated and supported by its eleven member countries (Armenia, Cyprus, Egypt, Greece, Iran, Israel, Jordan, Morocco, Oman, Palestine and Turkey) with support from countries including, Germany, Japan, Italy, Russia, Sweden, Switzerland and USA [Nature, pp. 798 (20 Apr. 2000)]. SESAME will be open to scientists from any country in the region or elsewhere. A wide range of planned research programmes include, structural molecular biology, molecular environmental science, surface and interface science, micro-electromechanical devices, X-ray imaging, archaeological microanalysis, materials characterization, and medical applications.

It all started with the "Sinai Physics Meeting" in Dahab, Egypt in November 1995 [Physics Today, pp. 11-13 (Feb. 1996)]. This historic Meeting was conceived by Prof. Sergio Fubini [Physics Today, pp. 78 (Jan. 2000)] which led directly to the formation of the Middle East Science Collaboration (MESC) in 1997. Several Meetings have been since held (mostly in Europe) under the auspices of the United Nations Education, Scientific and Cultural Organization (UNESCO), European Laboratory for Particle Physics (CERN), Abdus Salam International Centre for Theoretical Physics (Abdus Salam ICTP) to name a few.

The grand project is under the very valuable political umbrella of UNESCO. Its new director-general, Koichiro Matsuura has very generously underwritten an additional amount of US$ 400,000 to expedite the project.

The idea of donating the BESSY-I Synchrotron came from Gustav-Adolf Voss a former director of Deutsches Elektronen-Synchrotron (DESY), Hamburg, Germany and Hermann Winick of Stanford Linear Accelerator Center (SLAC) in California [CERN Courier, pp. 28 (Summer 1998) and Physics Today, pp. 11 (Jul. 1999)].

This is not the first time that a synchrotron is being gifted and relocated, thanks to the generous support of those in charge of the original facilities. Recently the Japanese gifted a 1000 MeV synchrotron to Thailand [Physics Today, pp. 55 (Aug. 1999)]. Siam Photon Source is Thailand's first synchrotron light facility and is intended to serve scientists throughout Southeast Asia. The original synchrotron light source, called SORTEC, was located in Tsukuba Science City, near KEK, Japan's High Energy Accelerator Research Organization.

Here it would be very relevant to note that one of the key individuals who laid the ground work for what is turning out to be the Middle East's first synchrotron light source and a major international scientific research centre is none other than Abdus Salam, the Pakistani Nobel Laureate.

Late Professor Abdus Salam had visualized and devoted much of his life towards uplifting of Science & Technology in the Third World. Over thirty thousand individuals from the developing countries have benefited by visits to the "International Centre for Theoretical Physics (ICTP), Trieste, Italy", founded by Salam in 1964, under the auspices of the International Atomic Energy Agency (IAEA) with a very generous support from the Italian Government. In November 1997 on the occasion of his first death anniversary, ICTP was renamed as "Abdus Salam ICTP", to commemorate the memory of its founder. In his speeches and writings regarding the Middle East, Abdus Salam had visualized an international centre which did include a Synchrotron Laboratory as part of a larger scheme [Physics World, pp. 15 (Nov. 1999) and Physics Today, pp. 78 (Jan. 2000)]. In May 1983, at the Symposium on the Future Outlook of the Arabian Gulf University held in Bahrain, Salam had presented a very detailed proposal in which he reminded his listeners that *I have mentioned an international laboratory in material sciences for Bahrain, with specialisation in microelectronics and modern electronic communications, including space satellite communication, to help also with the banking communications needed at Bahrain. Such a laboratory was in fact proposed for the University of Jeddah. The idea was to emphasize science transfer in addition to technology transfer and to create international laboratories in the fields of materials sciences, including surface physics and a laboratory with a* **synchrotron radiation light source**. *The facilities created would have been of the highest possible international order; the laboratories would have been opened to teams of international researchers, who would congregate and work at Jeddah, just as they congregate now at the great laboratories in Hamburg, Geneva or Paris* [Abdus Salam, *Renaissance of Sciences in Islamic Countries*, Ed. H. R. Dalafi and M. H. A. Hassan, (World Scientific, Singapore, 1994)].

Another approach, a crucial one, to the Middle East Synchrotron would be by conducting a series of "Schools" on synchrotron radiation and related fields. Such Schools are yet to take place. ICFA can definitely initiate such Schools and play a pivotal role. These would train the potential users and more importantly promote international collaboration, among the countries & others involved, thus providing an excellent opportunity to the scientists to be catapulted into the forefront of the latest technological expertise. I would like to further add, that the *Accelerator & Beam Physics and associated technologies* are **not yet** part of the regular university curriculum in most parts of the world! The learning of such an important interdisciplinary science is done to a very large extent individually and through the very few Schools *when & where* available [ICFA Beam Dynamics Newsletter, No. **17**, 5-6 (Aug. 1998)].

Siam and SESAME are very unique facilities as they are built by relocating the very generously gifted synchrotrons. Several such facilities are required in the under-represented regions of the *world synchrotron map*. These, when built will immensely benefit the scientific community in the concerned regions by enhancing international cooperation and providing them the latest technological expertise.

Sincerely yours,
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3: Workshop Reports

3.1 The Second OCPA Accelerator School

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The Second OCPA Accelerator School was held at the Huangshan Beautylake Hotel of Huangshan city in China, from July 18 to July 27, 2000. Dr. Alex Chao from SLAC took the chairman for the school. The purpose of the school is to provide the students a basic knowledge on modern accelerators. The topics covered in the school include synchrotron radiation sources, high energy colliders, heavy ion accelerators, and medical application accelerators. After an introduction, the basic topics of transverse dynamics and longitudinal dynamics as well as collective instabilities were given. Some advanced topics, such as superconducting RF cavity, RF gun, laser acceleration and plasma acceleration were also introduced in the courses.

The school was organized by Overseas Chinese Physics Association and University of Science and Technology of China, and sponsored by OCPA, SRRC, South East Asia Theoretical Physics Association (Singapore), National Natural Science Foundation of China, IMP, IHEP, SSRC, Singapore Lee Foundation and USTC.

There are 74 students from two sides of straits between Taiwan and Mainland of China. They are from Synchrotron Radiation Research Center (Hsinchu), Tsinghua University (Hsinchu), Institute of High Energy Physics (Beijing), Institute of Modern Physics (Lanzhou), Shanghai Synchrotron Radiation Center (Shanghai), Tsinghua University (Beijing), Nanjing University (Nanjing), Beijing University of Science and Engineering (Beijing), University of Science and Technology of China (Hefei). Most of them are graduate students.

There are 18 lecturers from SLAC, ANL, BNL in USA, SRRC, Tsinghua University (Hsinchu), IHEP, IMP, SSRC, Tsinghua University (Beijing), USTC.

Every teacher was teaching conscientiously, and every student was studying hardly. The finally passing an examination, the students got good grades. That showed the school is successful. A lot of students said that most of the courses are high level, particularly Dr. Lee Teng gave a series lectures about synchrotron radiation just like pour water off a steep roof, having substantial content. Their feeling for the course arrangement is reasonable, from easy to difficulty, advance gradually in due order.

In studying life of ten days, the students not only study a lot of new knowledge, but also make many new friends, particularly the students from the two sides of straits between Taiwan and mainland of China established friendship.

After the intense school courses, most of the teachers and students took an excursion to visit the beautiful Yellow Mountain (Huangshan mountain) to get relaxation.

3.2 ACFA met in Korea

C. Zhang `zhangc@mail.ihep.ac.cn` Institute of High Energy Physics

The Fifth Plenary ACFA meeting was held in Kyongjy, Korea from May 29 to 31, 2000. Twenty-three members from 15 Asian institutions participated the meeting. Prof. S. K. Chung, President of POSTECH welcomed all participants.

During the Fifth ACFA Meeting, fourteen status reports were given, reflecting the continuous growth of the Asian community on the accelerator-based sciences and technologies in the last decade. Three Groups, i.e. Electronic publication Working Group, Network Working Group and Study Group for Physics/Detectors at Linear Colliders, reported their activities. The Asian Accelerator School had successfully held in November 1999 and JSPS-CAS collaboration in progress were reported and a plan on compilation of Asian accelerator catalogue and organization & program of APAC01 were presented and discussed.

Several collaboration items were proposed and discussed during the fifth APAC. The recent OECD Global Forum on High Energy Physics was reported. Prof. S. Kawabata of KEK is appointed to attend the further discussion, especially representing interests from non-OECD regions. The collaboration on the intense proton accelerators (IPA) were discussed, Prof. S. Fang of IHEP and Prof. B. Choi will collaborate to establish the Working Group on IPA.

According to the rule of the ACFA, Prof. W.Namkung of Korea, Vice-Chairman of ACFA 1998-2000, has become its new Chairman (2000-2002) respectively after Prof. H. Chen of China completed his term. Prof. D. D. Bhawalkar, Director of CAT, India, was elected as new Vice-Chairman. The membership of Pakistan is discussed in the meeting and Pakistan was accepted as a full member of ACFA.

The next ACFA Meeting will be held in Beijing during APAC01 period.

4: *Activity Reports*

4.1 A Synchrotron for Australia?

J W White

Australian National University,
Secretary for Science Policy,
Australian Academy of Science

The scientific and technological use of synchrotron radiation has been growing steadily in Australia since about 1990. Before that time ad hoc access to synchrotrons in a number of countries around the world had allowed x-ray crystallography, surface science, and some x-ray optics to be done. Australian use has blossomed (see Figure 4.1) since a report “Small Country Big Science” by the Australian Science and Technology Commission in 1991 which allowed a funding base to be developed between the universities, CSIRO, ANSTO, the Australian Research Council and government to build an Australian National Beamline at the Photon Factory in Japan.

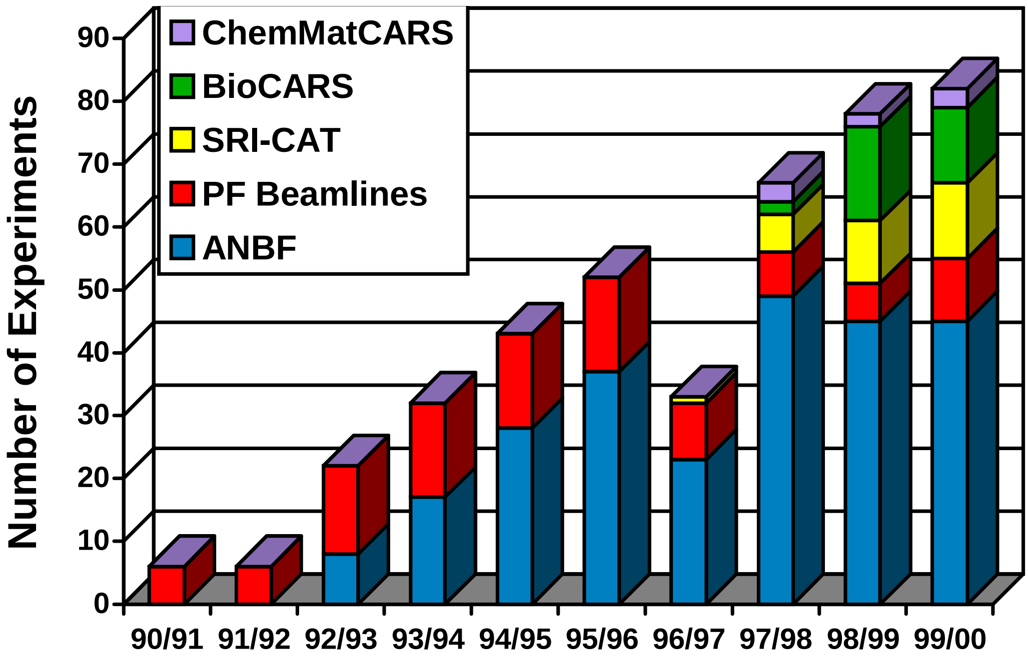

Figure 4.1: Growth of the Australian synchrotron user program funded by the ASRP and its predecessor the Australian National Beamline Facility program.

Australian synchrotron radiation developments are managed by the Australian Synchrotron Radiation Program (ASRP) whose proposal in 1995 for access to additional synchrotron radiation resources at the Argonne National Laboratory (CARS Consortium and SRICAT Consortium) was funded. The ASRP began in FY 1996/97, and numbers for 1999/2000 include extrapolations to June 30. The dip(Figure 4.1) in the 1996/97 usage numbers is due to an extended shutdown of the Photon Factory facility The Board of this program consists of representatives from universities, CSIRO and ANSTO. Part of the funding for the 1995 access program was to study an Australian synchrotron and the present developments in that respect stem from those studies which have been led by Dr John Boldeman at ANSTO.

Boomerang-the Proposed Australian Synchrotron

In 1999 the ASRP Board considered a series of documents giving the user demand, an international perspective of synchrotron uses and technical aspects of a reference design for an Australian synchrotron. This design is now being refined subsequent to consultations with members of the ANKA facility (Karlsruhe, Germany) and examination by an International Technical Committee chaired by Professor Yves Petroff, (European Synchrotron Radiation Facility Grenoble) and with members Professor Michael Hart (Director NSLS Brookhaven National Laboratory) and Professor Tadashi Matsushita (Director the Photon Factory Tsikuba Japan).

The proposed facility, Boomerang C the Australian Light Source, as proposed in 1999 is an extended version of the ANKA facility and an, in principle, design has been completed by the Accelerator Section of the FZK Laboratory in Germany (led by Professor Dieter Einfeld). The lattice of the parent ANKA facility, currently under construction, comprises four cells each having a dual Double Bend Achromat giving a total of 16 dipoles in the ring. Boomerang has six cells and thus 24 dipole magnets in the storage ring. As for the ANKA storage ring, the spacing between the six cells in the proposed facility is different from the internal spacing between the DBAs in each cell, thereby reducing the overall size of the lattice without any compromise in performance.

The extension of the design has a number of consequences:

- The number of long straight sections is increased to six allowing up to six insertion devices of traditional design;
- The number of available short sections is increased to three;
- The circumference of the ring is now 163.8 m;
- With the same magnet field strength of 1.5 T for the dipoles, the energy of the ring increases to 3 GeV making the facility very competitive with other third generation storage rings under construction;
- The emittance of the ring with distributed dispersion is reduced to 16 nm rad which will produce very high brilliance beams.

Although the extension of the original ANKA design leads to a modest increase in cost, the overall cost of the facility remains attractive because of the use of many of the components from the ANKA facility.

The two economic assessments done in 1999 and the technical assessment by the International Technical Advisory Committee were satisfactory, the latter making suggestions about the emittance and staffing levels for construction and operation. Currently the economic impact assessment in progress is likely to report in October 2000. There will be some decision on the Australian light source later in the year 2000.

4.2 Report on High-current Beam Dynamics at GSI

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We report about beam dynamics work, which is related predominantly to space charge effects in heavy ion (or proton) machines. It is performed in connection with intensity increases for the GSI heavy ion facility, and the development of a next-generation facility for heavy ions (radioactive beam facility/ nuclear physics), antiproton physics and plasma physics/ inertial fusion applications. For this future facility a 100-200 Teslameter synchrotron is envisaged for acceleration of U^{28+} (possibly even lower charge states) to $\approx$ 1 GeV/u at a rate of typically 10^{12} ions per second and subsequent fragmentation. For antiproton physics protons are accelerated to 30 GeV for the antiproton production, with subsequent collection and cooling rings, and a high-energy antiproton storage ring working at 13 GeV. For plasma physics/inertial fusion short (50 ns) bunches of maximum intensity (corresponding to 10...100 kJ energy) of heavy ions are expected to lead to a significant boost in plasma target experiments and modeling of heavy ion fusion drivers.

`http://www-aix.gsi.de/ hidif/`.

4.2.1 Multiturn-injection optimization with space charge and linear coupling

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We have studied an optimization procedure using the MIMAC-code for multiturn injection into the SIS including injection optics, septum, fully self-consistent 2D space charge calculation as well as skew quadrupoles. The use of linear coupling has been studied experimentally at the CERN PS booster [1] as a mechanism to improve multiturn injection, and at the AGS Booster [2] where turn-by turn measurements were used to study the coupled injection scheme. In our study we apply the optimization procedure to the SIS high current synchrotron, which is characterized by a relatively small vertical acceptance of 50π mm·mrad compared with the horizontal acceptance of 200π mm·mrad. The linac beam has parameters $\epsilon_{x,b} = \epsilon_{y,b} = 4$ mm·mrad, $I = 10$ mA, $Z = 28, A = 238$ at energy 11.4 MeV/u. In the simulation a new beamlet of macroparticles is added at each passing near the septum, and the closed orbit is bumped as in the real machine.

The following features describe the optimization process:

1. the main loss occurs on the septum, depending on the number of turns N_t used for injection, and the horizontal tune q_{x0}, which is first optimized for maximum efficiency

2. the amount and velocity of emittance exchange depends on the distance $\delta = q_{x0} - q_{y0} - n$ of the working point from the difference resonance, and we search for an optimum vertical tune, while restricting the coupling strength to a value not exceeding the vertical acceptance limitation

3. since the emittance exchange is proportional to the single particle emittance of the injected particles (which increases during injection with decreasing orbit bump), we find that a significant reduction of beam loss is obtained by delaying the injection with respect to the orbit bump, hence reducing the number of injected turns accordingly

4. space charge varies during multiturn injection, hence it is appropriate to re-optimize the working point with space charge

Results on the efficiency variation with the horizontal tune (showing maxima for tunes away from resonance conditions) are shown in Fig. 4.2; and in Fig. 4.2 the effect of an injection delay (including space charge).

Linear coupling is found to lead to approximately 20% higher maximum efficiency by using also the vertical acceptance. The most effective use of linear coupling is obtained for optimization towards minimum loss including an injection delay at the beginning of the orbit bump, which brings the efficiency close to the design goal at very low loss level. We thus predict by simulation that we can store 1.7×10^{11} of U^{28+} with a septum loss of only 6% (12% including full space charge, but not yet fine-optimized working point) compared with the usual losses of about 30%.

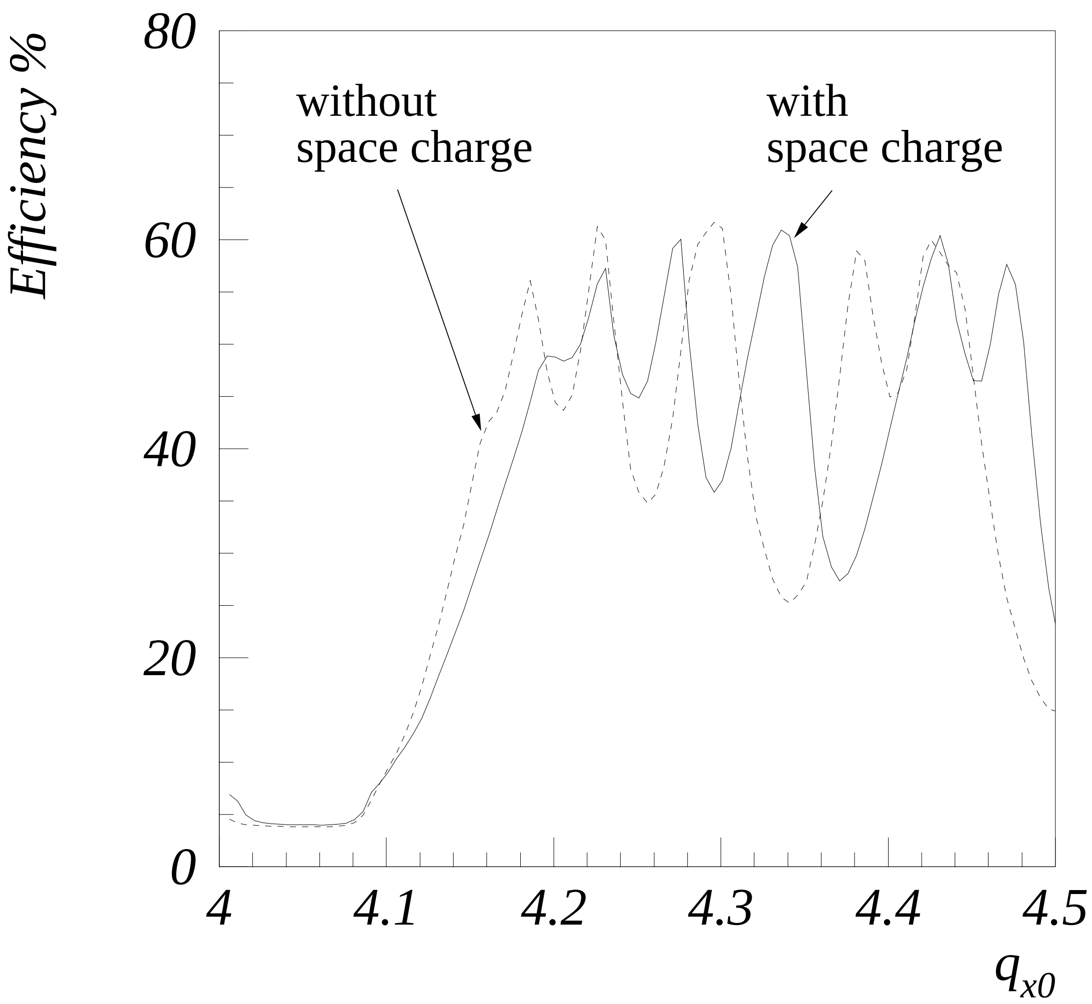

Figure 4.2: Efficiency for 27-turn injection into SIS with linear coupling and $q_{y0} = 3.29$

4.2.2 Vlasov simulation of the longitudinal instability

O. Boine-Frankenheim `o.boine-frankenheim@gsi.de`

A ‘noise-free’ Vlasov code is developed to study the longitudinal instability in space charge dominated coasting and bunched beams. The integration (Vlasov simulation) is performed on a grid in longitudinal phase space using a time splitting scheme. Each time step the longitudinal

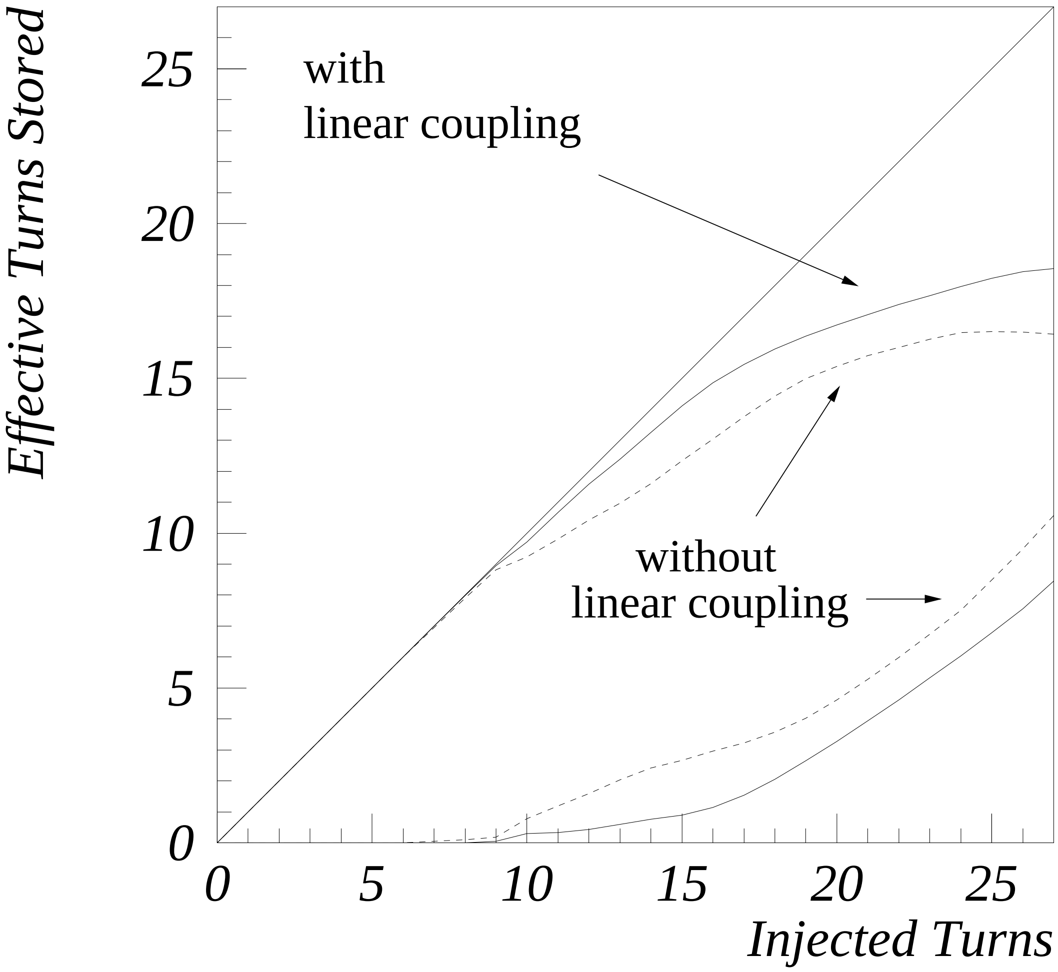

Figure 4.3: Delayed multiturn injection including space charge correction of working point

electric space charge field is calculated from a Poisson solver on a grid in (r, z) space, assuming a transversely uniform beam of radius a in a conducting beam pipe of radius b. Other possible contributions to the total electric field (like eg. cavity-like structures, ferrite inserts) are calculated each time step using their impedance representation. Intrabeam scattering and cooling processes (electron cooling or laser cooling) can be included within an additional Fokker-Planck term. We successfully used the code, including the Fokker-Planck term, to simulate the saturation of the longitudinal instability observed in the ESR [3, 4]. More recent work focuses on advanced storage ring concepts discussed at GSI and elsewhere, that often require operation far outside the stability boundaries provided by Landau damping. Whether a machine can be operated in such a regime depends on the phase space dilution after saturation of the microwave instability. We use our Vlasov code to analyze the saturation mechanisms in space charge dominated coasting and bunched beams [5]. As an example Fig. 4.4 shows the evolution of the microwave instability in a HIDIF storage ring for a broadband impedance of $Z_{bb}/n = 50$ Ω. The broadband impedance is centered close to the cutoff harmonic of the beam pipe. The Vlasov code is used to determine the maximum resistive ring impedance that can be tolerated for a given storage time.

4.2.3 Transverse halo studies

O. Boine-Frankenheim `o.boine-frankenheim@gsi.de`
A crucial issue for high current ring machines is emittance growth and beam loss due to mismatch and the subsequent formation of a space charge induced beam halo. The mismatch can be either caused by the injection process or by the crossing of ring resonances [6]. For different initial mismatch conditions (eg. symmetric or asymmetric), distribution functions (eg. KV, Waterbag, SG), focusing lattices and space charge tune shifts ($0.05 - 0.5$) we are currently trying to identify the relevant collective beam modes. We find eg. that even for a mostly symmetric initial mismatch strongly asymmetric modes can be excited. One of the results we would like to extract from our simulations studies is the range of applicability of the core-particle model for beam halo calculations [7] that relies on the assumption of a stable beam core performing pure envelope type oscillations only. We simulate the time evolution of initially mismatched beams with a 2D Particle-In-Cell (PIC) code implemented on a parallel computer (16 computing nodes connected via a high-speed Myrinet network) dedicated to beam dynamics simulations. In order to achieve a more homogeneous resolution of the low density halo and the high density core, without increasing the number of simulation particles, we are currently working on an improved PIC scheme with dynamical macro-particle merging and splitting. In addition, together with E. Sonnendrücker (Universite Louis Pasteur, Strasbourg, France), we are developing a 2D Vlasov code.

4.2.4 Space charge effects near transition energy

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Bunch compression against space charge is an important issue in applications like high-power proton drivers (for neutrons, muon or neutrino facilities etc.) or high-intensity heavy ion rings as considered for radioactive beam facilities or inertial fusion. Ignoring space charge it seems attractive (for particles of a few GeV/u) to lower the stringent rf voltage requirements in a 90° bunch rotation scheme by working closer to transition energy. For high-intensity bunches, and below transition, this is, however limited by space charge effects, which become drastically

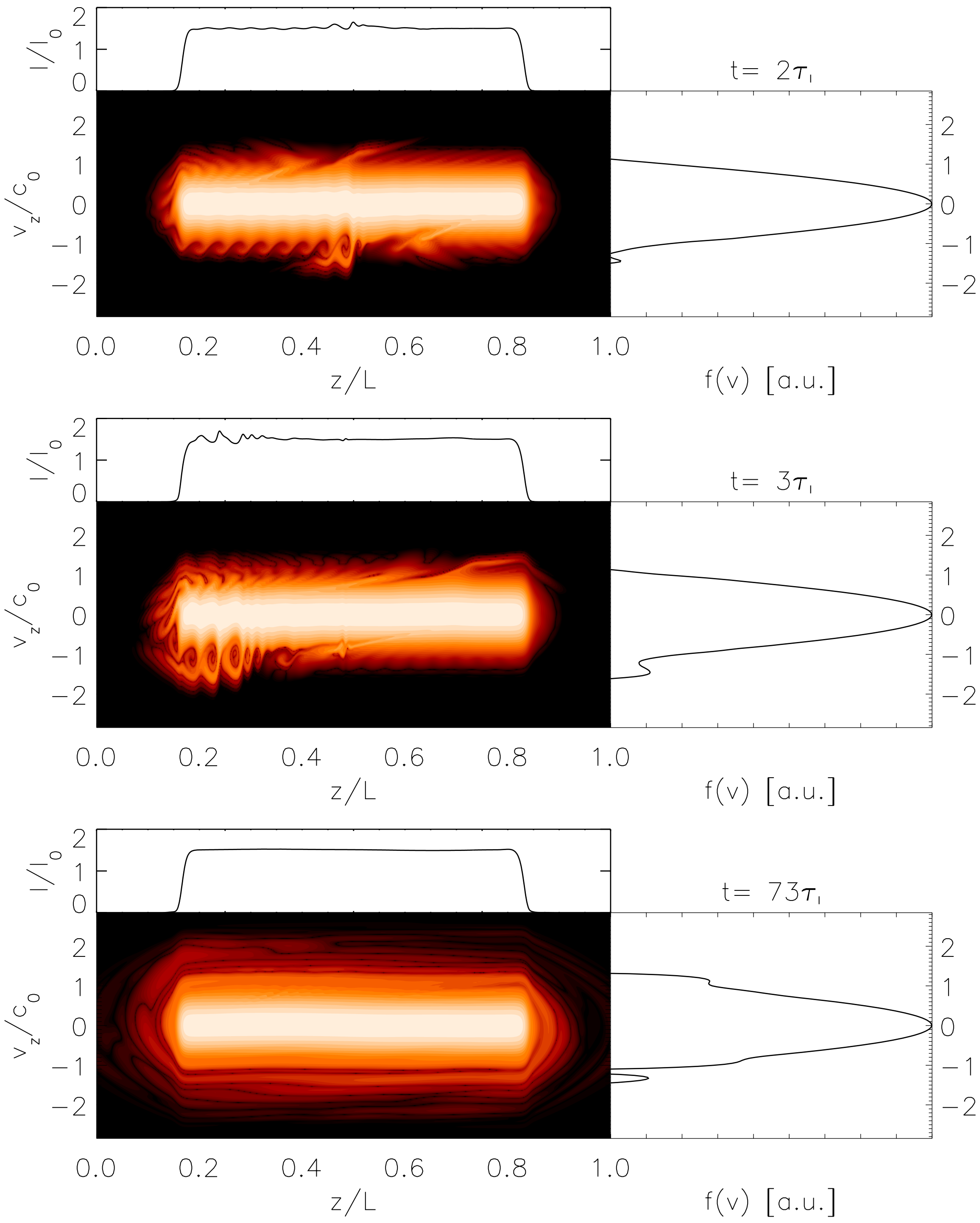

Figure 4.4: Contour plots of the distribution function $\ln f(z, v_z)$ together with the line density $\rho_L(z)$ and the velocity distribution $\ln f(v_z)$ obtained from the Vlasov simulation.

enhanced when transition energy is approached.

Our studies are carried out on two levels:

1. **Analytical studies.** From the longitudinal envelope equation we have obtained a longitudinal invariant I_L which expresses energy conservation (details see Ref. [8]):

$$\frac{z_m'^2}{2} + \frac{k_{z0}^2}{2} z_m^2 + \frac{K_L}{z_m} + \frac{\epsilon_L^2}{2 z_m^2} = I_L \tag{4.1}$$

The first term is equivalent to a kinetic energy of coherent motion, the second one the "rf potential energy", the third term the "Coulomb energy" of the bunch (with the longitudinal perveance $K_L = -3\, g\, N\, (Z^2/A)\, r_p\, \eta/(2\, \beta^2\, \gamma^3)$, g-factor $= 0.5 + 2\, \ln(R_p/R_b)$, and the fourth term the "incoherent kinetic energy" expressed by the emittance ($\epsilon_L = |\eta| z_m (\delta p/p_0)_0$, with the slip factor given by $\eta = 1/\gamma_t^2 - 1/\gamma^2$). Noting the dependence on η of the space charge and emittance terms in the energy conservation equation, it is obvious that in the limit of $|\eta| \to 0$ the space charge term by far dominates the emittance term, and compression therefore only deals with space charge. We have introduced a dimensionless space charge parameter Σ, which is the ratio of "Coulomb energy" over "thermal energy", $\Sigma \equiv 2 K_L z_m / \epsilon_L^2$, and find that the rf voltage for a bunch rotation with compression by the factor χ scales like

$$V \propto \frac{1}{\chi^2} \left[\eta + \frac{\Sigma_f \eta}{(1+\chi)} \right] \tag{4.2}$$

Moreover, an extra coherent momentum spread appears during the rotation, which is roughly proportional to $\sqrt{1+\Sigma_f}$ (for strong compression with $\chi << 1$) and does the compression work against space charge. This sets a clear limit to the useful approach to transition for a fast bunch compression scheme: $|\eta|$ is limited by the requirement that Σ_f should not exceed significantly unity.

Simulation studies. We have compared the analytical studies with our code PATRIC. This is a particle-in-cell program solving the equations of motion in 3D, whereas Poisson's equation is solved in cylindrical $(r - z)$ geometry assuming a perfectly conducting beam pipe [9]. PATRIC therefore treats the betatron motion in smooth approximation (symmetric in x and y). Space charge is calculated correctly also for short bunches, where the g-factor approximation to the space charge electric field becomes incorrect. Computer simulation confirms that the analytical expressions can be applied also to rms-equivalent non-parabolic bunches by using $z_m = \sqrt{5} z_{rms}$ (and similar for the momentum spread), provided that space charge is not too strong. In our simulation of Gaussian bunches we have found significant momentum tails in the compressed bunches due to the nonlinear space charge force, containing typically 5% of the total intensity, even for moderately large space charge. From a practical point of view they might be beyond the momentum acceptance of the ring (or extraction beam line) and therefore add to the beam loss and activation problem in a high power ring.

Introducing further complications arising from a spread in η due to a betatron tune shift by space charge, as well as higher order terms in the momentum deviation is still under development.

4.2.5 Extreme cooled beams

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On the basis of the results of several experiments we verify theoretically that in the ESR and

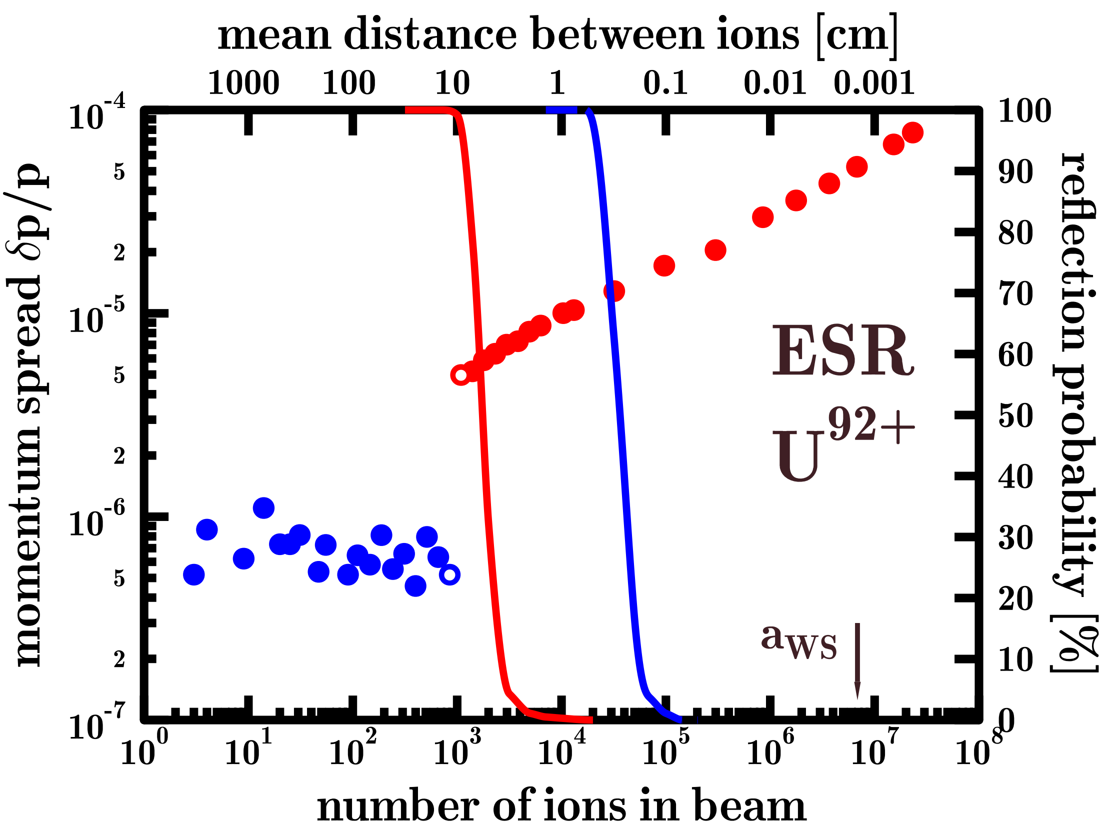

Figure 4.5: Experimental momentum spread (points, left scale) of stored uranium ions in the ESR together with th calculated reflection probability (lines, right scale). (After ref. [11])

in the SIS chains of ions have been detected whose particles are so cold that by their mutual Coulomb repulsion they cannot pass each other any more. The first set of experiments is by Steck *et al.* [10] on the anomalous longitudinal temperature reduction of strongly electron cooled heavy ions in the ESR and in SIS at very low density. When a few ions (initially about 10^7) are injected and then electron cooled they decay slowly in time by scattering with the rest gas, thus lowering the density. At a critical number of particles of about 10^3 the momentum spread suddenly drops down from $\delta p/p = 5 \times 10^{-6}$ to 5×10^{-7}, see Fig. 4.5. This may be explained by the assumption that intrabeam scattering is completely inhibited.

To verify this assumption we calculated the probability of reflection or interpenetration of two particles under the given transverse and longitudinal temperatures [11]. As a result, the left curve of reflection probability drops sharply about at this point of number of ions where the machine experiments exhibit the anomalous longitudinal temperature reduction. Thus, at the achievable momentum spreads Coulomb order in a chain like fashion is reached at particle distances of the order of centimeters. This effect has been observed and explained for various species of ions ranging from C^{6+} to U^{92+}. The right curve applies to the ultracold temperatures if there were no disturbances in the lattice.

The second set of experiments concerns the Schottky mass measurements of projectile fragments from the FRS in the ESR [12]. Here the situation is similar as above: low number of particles ($< 3\times10^3$) and small momentum spread ($< 7\times10^{-7}$). The measured frequency change δf of ions with the same charge but with small mass difference δm is given by $\delta f/f = -\alpha_p \delta m/m$, where $\alpha_p = 0.14$ is the momentum compaction factor. It has been found that particles with $|\delta f| < 80$ Hz systematically experience deviations from their known mass systematics, i.e. heavier (lighter) masses are shifted to higher (lower) frequencies. A simple model provides an explanation: Ions with slightly different masses are formed in separate chains which, due to the dispersion, run on orbits which are slightly shifted from the central orbit. If the difference in radius is larger than the thermal diameter given by the remaining transverse temperature, then these chains will not interact and their measured Schottky frequencies will correspond to the known systematics. However, if the two Coulomb chains come close to each other they will lock into a common frequency, i.e. the higher frequency is lowered and the lower one becomes larger. The results are in good agreement with the experiment.

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4.3 Present Status of the KEKB

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This article describes the present performance of the KEKB whose commissioning started on December 1st 1998 focusing on a comparison of the actual performance with its design goals. This report also describes how the commissioning team has been struggling against problems which prevent them from approaching the design goals with an emphasis on beam-beam performance and a single beam blowup in the positron ring. This report mainly deals with the commissioning from the beginning of 2000. The commissioning of earlier period was described in other papers [1] [2].

4.3.1 Introduction

The KEKB B-Factory is one of second generation electron-positron colliders. It has two significant features of a“very high luminosity” and an “energy asymmetric collider”. These features come from requirements of B meson physics which studies very rare processes and aims at detecting the CP violation in the B meson system.

The design luminosity is $1 \times 10^{34}/\mathrm{cm}^2/\mathrm{sec}$. Other design parameters related to the luminosity also fit with this design luminosity. Design beam currents are 2.6A and 1.1A for the positron and electron beams, respectively. Design parameters of the horizontal and vertical beta functions at the IP for both beams are 0.33m and 10mm, respectively. Design goals of the beam-beam parameters for both beams are 0.039 and 0.052 in the horizontal and vertical directions, respectively. Beam energies are 3.5 GeV for Low Energy Ring (LER e+) and 8 GeV for High Energy Ring (HER, e-). The requirement of energy asymmetry inevitably leads us to a double ring collider. From the standpoint of machine design, this double ring feature enables a “high current-multibunch” approach like synchrotron light sources, which is vital to get to a higher luminosity. In addition to these features, the KEKB has adopted a challenging scheme of the (horizontal) crossing angle of ± 11 mrad. A motivation of the crossing angle is to simplify the IR design and to suppress effects of parasitic collisions [3].

So far, the design goals above have not been fully accomplished yet. Table 4.1 summarizes the present performance of the KEKB related to the luminosity together with the design parameters. This article describes how the present performance has been attained and what limits it.

4.3.2 Present performance

4.3.2.1 Brief history

Fig. 4.6 shows histories of the beam currents. As is seen from the figure, there have been steady increases of the beam currents. The increase rates, however, are not very remarkable this year. As is described in another section, the present beam current limitation does not come from instabilities but from some hardware heating problems. Fig. 4.7 shows a history of the luminosity. Contrary to the case of the beam currents, we see a remarkable increase of the luminosity. The peak luminosity was $6.7 \times 10^{32}/\mathrm{cm}^2/\mathrm{sec}$ at the end of last year. The record peak luminosity of the KEKB so far is $19.2 \times 10^{32}/\mathrm{cm}^2/\mathrm{sec}$ which was recorded on

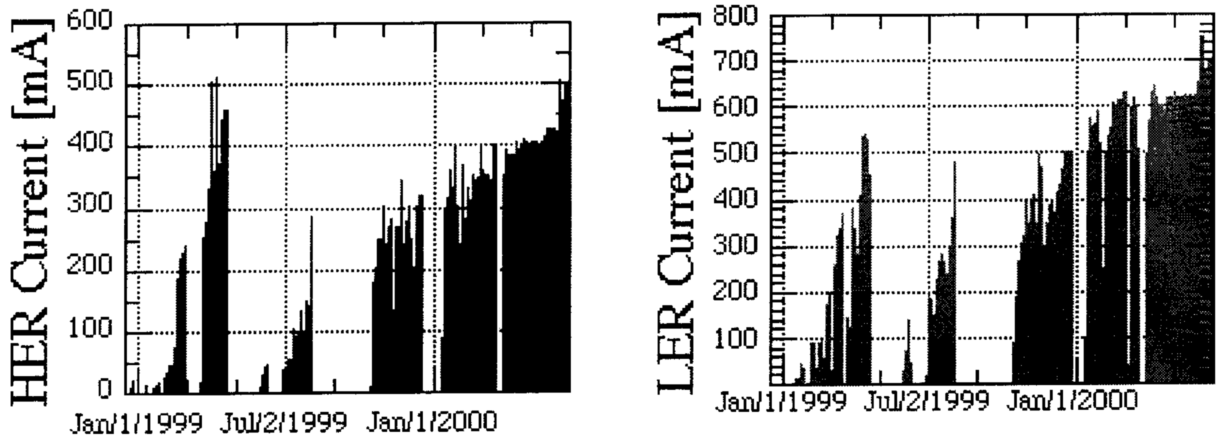

Figure 4.6: Histories of the beam currents.

May 29 2000. Actually, the peak luminosity almost tripled this year. As is discussed in the next section, this improvement in the luminosity has been brought mainly by squeezing beta functions at the IP and other optimization of the beam-beam effect. Some related parameters at this record luminosity are summarized in Table 4.1 compared with the design values. As shown in Table 4.1, β_y^* is now lower than the design.

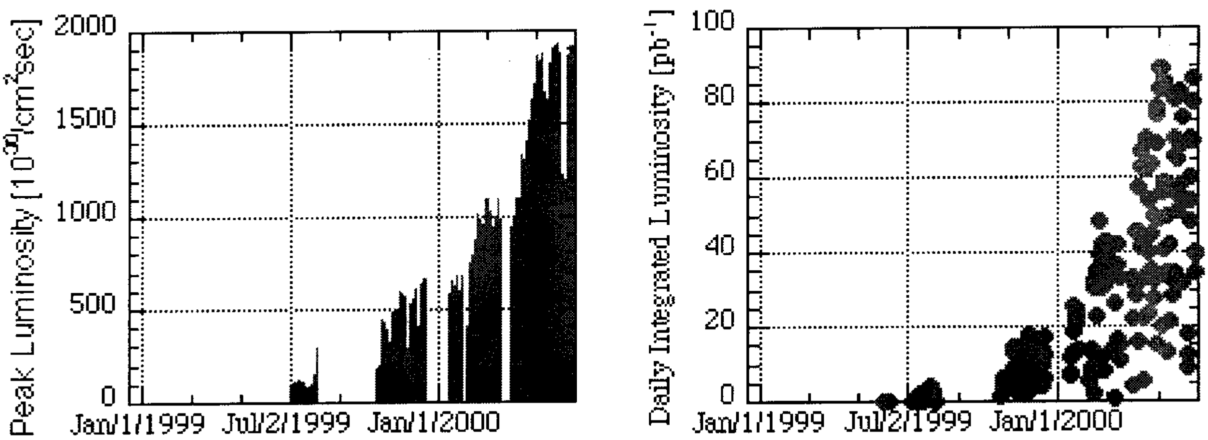

Figure 4.7: History of the luminosity.

4.3.2.2 Beam-beam parameters

It is shown in Table 4.1 that the vertical beam-beam parameter of the HER is notably low compared to the design value. This is a consequence of the following two reasons. One reason is that the bunch current of the LER is limited by the hardware heating problem in usual operations. The bunch current of the LER in Table 4.1 is much lower than the design. The other is a single beam blowup in the LER.

To see how seriously these problems limit the beam-beam parameter (and the luminosity), an experiment with fewer number of bunches was carried out. In this experiment, we used 188 bunches which is about 1/6 of that in the usual operation. The bunch current could be increased up to near the design, since the heating problem is less serious with the fewer number of bunches. In the usual operation, the bunch spacing is 4 RF buckets (8nsec) and the LER single beam blowup is serious as shown in Fig. 4.10. In the experiment, however, the bunch spacing was 24 RF buckets and the LER single beam blowup was not visible with this bunch spacing.

Table 4.2 shows a result of the experiment. ξ_y of the HER with 188 bunches was much higher than that with 1069 bunches. On the other hand, ξ_y of the LER got smaller than the case of 1069 bunches. This is because the HER beam is in turn blown up with this situation. Since the LER beam is apt to be blown up due to the beam-beam interaction in the usual operation, most part of beam-beam tuning has been devoted to suppress the beam-beam blowup of the LER. It may be possible to suppress this HER beam-beam blowup with more beam-beam tuning and to get even higher ξ_y of the LER. With this 188 bunch operation, we obtained the luminosity of $4.04 \times 10^{32}/\mathrm{cm}^2/\mathrm{sec}$ with almost no beam tuning. This luminosity multiplied by a factor 6 is higher than the present record of the luminosity. This means that the LER single beam blowup and the beam current limitation from the hardware heatings limit the present peak luminosity seriously.

The beam-beam parameters which we obtained so far are still low, if compared with the design. However, they are not disastrously low even with the (horizontal) crossing angle which we intentionally introduced. Actually in the usual operation, we have not encountered any clear phenomena induced by the synchro-betatron resonance from the crossing angle.

4.3.2.3 Specific luminosity

Fig. 4.8 shows a specific luminosity as function of the product of the beam currents in some typical fill. As is seen in the figure, the specific luminosity is not constant at relatively low beam currents. Since no single beam blowup of the LER is seen at the low beam current, this indicates that the beam-beam blowup is not negligible even at the low currents. The tendency for the specific luminosity to increase even at the low beam currents is reproduced by a beam-beam simulation [4].

4.3.2.4 Integrated luminosity

The daily integrated luminosity in Fig. 4.7 is that recorded by the physics detector(Belle). The delivered luminosity by the KEKB accelerator is about 10% higher than the recorded one. The total integrated luminosity from the beginning of the KEKB is 5104 pb^{-1} as of June 15 2000.

4.3.3 Road to Present Luminosity

4.3.3.1 Working point

A relatively extensive tune survey was done in the middle of last year. We found that a region near the design tunes gave a relatively good luminosity. However, the design tune itself did not bring the best luminosity last year [5]. Fig. 4.9 shows a history of luminosity improvement. Only some turning points for the luminosity jump are plotted. Also shown in the figure are histories of the horizontal and vertical tunes for the LER. The HER tunes are more or less the same as those of the LER. Roughly speaking, lower horizontal and vertical tunes give better results. The best luminosity in the figure is achieved with almost the same tunes as the design. The tune search in Fig. 4.9 was done in trial and error ways in daily tuning. The best tune found this way is coincided with the design tune which was determined from a strong-weak

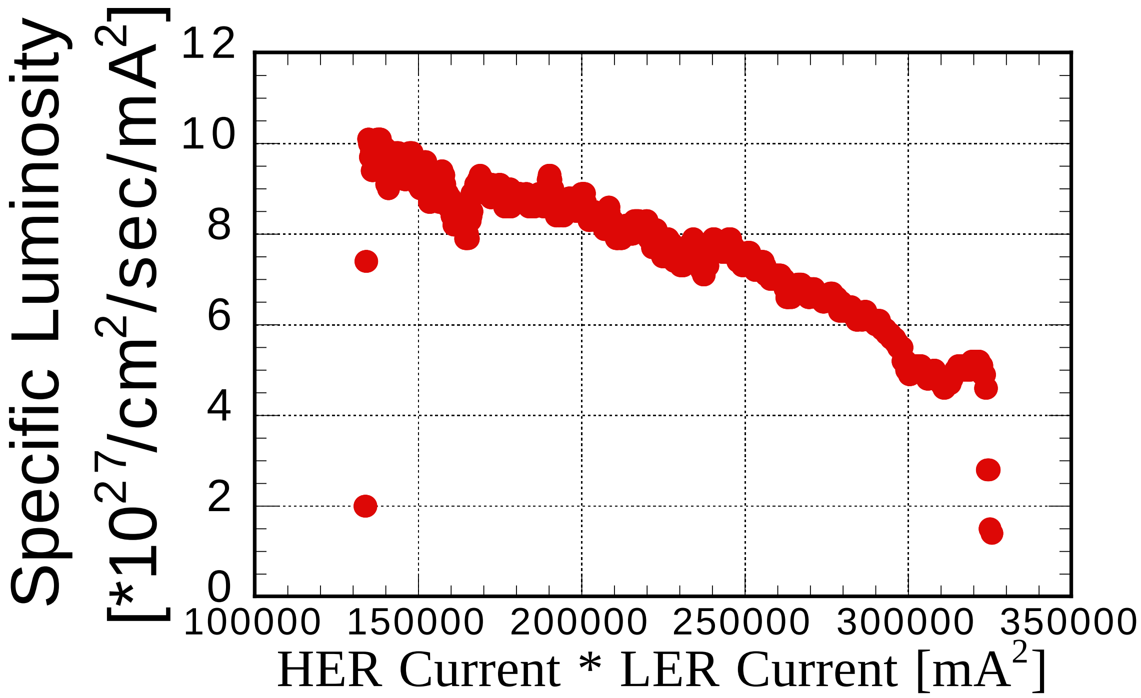

Figure 4.8: Specific luminosity.

beam-beam simulation [3]. In Fig. 4.9 the luminosity from a new strong-strong beam-beam simulation [4] [7] is also shown. The effectiveness of the design tunes are also confirmed by the new simulation. Moreover, the measured luminosity is roughly reproduced by the simulation. Therefore, we have now more confidence in predictive power of the beam-beam simulation.

4.3.4 Squeezing β_x^*/β_y^*

As shown in Fig. 4.9, we squeezed β_x^*/β_y^* of both rings from 1m/10mm to 0.7m/7mm in the middle of March this year. Just after squeezing, we did not see much increase in the luminosity. However, the luminosity was raised gradually after that and the record peak luminosity of the KEKB so far was recorded with these beta values. At the beginning of June, β_x^*/β_y^* of both rings were successfully squeezed to 0.5m/6mm. However, we did not see any increase of the peak luminosity but we did see even some significant decrease in spite of relatively intensive efforts on the luminosity tuning. We have not understood the reason for this decrease. Since β_y^* is comparable to the bunch length, shortening of the bunch length may be needed to raise the luminosity by squeezing the beta functions further.

4.3.4.1 IP beam diagnostics and corrections

Since the KEKB is a double ring collider, the IP beam diagnostics and corrections are much more complicated and then much more important compared to the case of conventional single ring colliders. We have to take care of (1) IP orbit offset, (2) (vertical) crossing angle, (3) waist points, (4) IP x-y coupling and (5) IP dispersion.

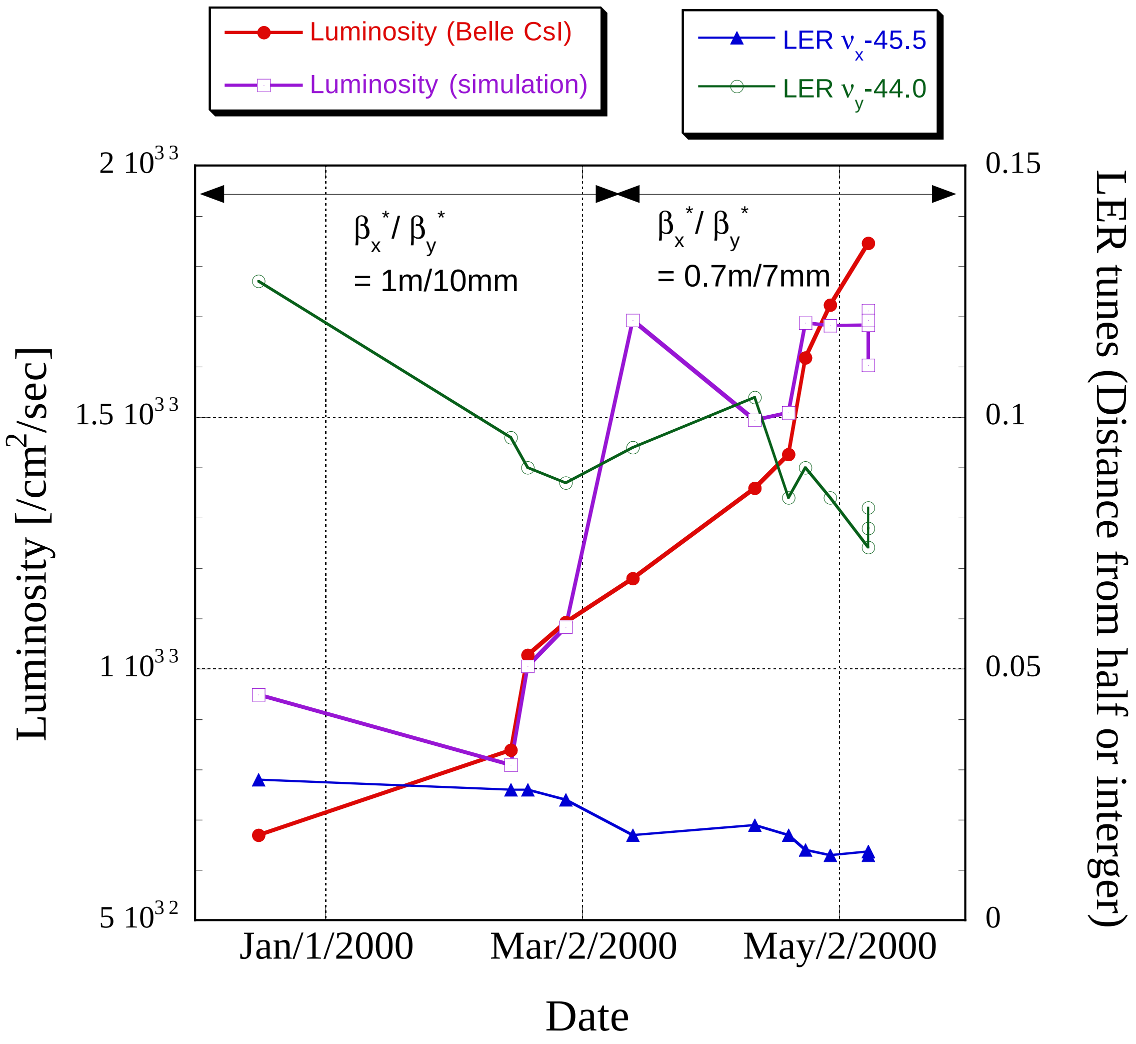

Figure 4.9: History of the luminosity improvement.

Our method to detect the IP offset is based on the beam-beam scan observing the beam-beam deflection [5]. We have an orbit feedback system to maintain the zero-offset condition once found [6]. This system makes orbit bumps at the IP both in the horizontal and vertical directions based on information from the BPMs of the two beams around the IP. The repetition rate of the feedback is 2 or 3 seconds which is restricted by the speed of orbit measurements by the BPMs. A detection of the vertical crossing angle is done as a part of the beam-beam deflection scan. The beam-beam scan in the horizontal direction is done by scanning the collision point. The vertical crossing angle is detected as an asymmetric pattern of the vertical beam-beam kick during the horizontal scan [5]. A removal of the vertical crossing angle can be done by removing this asymmetric pattern. The orbit feedback system also takes care of the crossing angle condition. Coinciding the waist points of the two rings and the collision point is also an important tuning item [5]. A simulation shows that the IP x-y coupling combined with the crossing angle is harmful for the beam-beam interaction [7]. A trial to measure the IP x-y coupling by using a pair of single-pass BPMs near the IP is in progress [8]. The IP dispersion is corrected in the usual dispersion correction process as is described below. All these corrections mentioned above are directly connected to the luminosity and accumulation of these corrections played an important role in increasing the luminosity.

4.3.4.2 Energy transparency

In the KEKB, the beta functions at the IP and the emittances both in the horizontal and vertical directions are designed to be equal. The radiation damping time is also equalized by using wiggler magnets in the LER. A systematic study on the effects of the wiggler magnets has not been done, since the excitation of the wiggler magnets changes the ring circumference and it takes several days to re-align magnets for the purpose of equalizing the circumference. At the first introduction of the wigglers last year, we saw some improvement in the specific luminosity. However, the improvement was very small.

In the usual operation of the KEKB, the LER beam is apt to be blown up. This may be because the bunch current of the HER is effectively much higher than that of the LER compared to the design ratio which is the inverse of the beam energy ratio (see Table 4.1). Just after refilling the beams, the LER beam is in the region of the single beam blowup. In this region, it seems that the LER beam is even more sensitive to the beam-beam effect and the LER beam has a tendency to be blown up further. In the situation where the LER beam is seriously blown up due to the beam-beam effect, the luminosity is raised by enlarging the HER beam size intentionally. When we make the HER beam size be enlarged gradually, the LER beam shrinks and the luminosity gets higher. At some optimum ratio of the vertical beam sizes, the luminosity gets the maximum. To maximize the luminosity, it is important to look for the optimum ratio of the beam sizes and to keep the ratio. We have constructed a feedback system for the purpose of keeping the ratio constant. This feedback controls the HER beam size by making an orbit bump, which creates a vertical dispersion around the ring, at a pair of sextupoles.

As is shown in Table 4.1, the fractional parts of the betatron tunes are similar for both rings. They are not exactly the same. This is because the luminosity is not very sensitive to the HER tunes and we did not care the HER tunes very much. No systematic study on the relationship between the tunes of both rings has been done. In the early days of the commissioning, we tried the beam collision with the exactly same tunes. At that time, however, we found no particular advantage of equalizing the tunes.

4.3.4.3 Optics corrections

Since the KEKB uses the unusual tunes which are very close to the integer or half-integer resonance as shown in Table 4.1, optics corrections are important to narrow the stop bands of the resonances. In addition to the global beta corrections, global x-y coupling corrections, global dispersion corrections and continuous close orbit corrections (CCC) are done in the KEKB [9]. The global beta functions and x-y coupling are measured by making some single kicks by steering magnets. The global x-y coupling and global dispersion corrections are important in the sense that decreasing the zero-current emittance contributes to the increase of the luminosity. An injection efficiency is also improved by these corrections. In the global dispersion correction process, the vertical dispersion at the IP is also corrected. We found that this is very important to raise the luminosity.

The KEKB adopted a "non-interleaved sextupole scheme" and the pairs of sextupoles magnets are connected with $-I$ transformers [3]. An asymmetric (symmetric) bump at a pair of sextupoles can create dispersion (x-y coupling) around the rings and the x-y coupling (dispersion) can be localized between the pair of sextupoles. The x-y coupling and dispersion corrections are done by combining multiple orbit bumps at pairs of sextupoles. Usually we do not use skew quadrupoles for the x-y coupling corrections.

Since the optics parameters are sensitive to the closed orbit distortion with the non-interleaved sextuple scheme, it is very important to keep the closed orbits the same. CCC is always running during the operation with the repetition time of 20 or 30 seconds. For the closed orbit correction, it is important to remove offsets of BPMs. Offset measurements for all BPMs were done by using beams [10]. The measurements were done basically by detecting changes of closed orbits when changing strength of quadruple magnets beside BPMs.

4.3.5 Performance Limitations

4.3.5.1 Beam current limitation

In the present KEKB, beam instabilities do not limit the beam current so far as the bunch-by-bunch feedback system works well and the vertical chromaticity of the LER is rather large. In the HER, when the feedback was switched off at a high beam current, the beam was lost and the strong dipole oscillation was observed [2]. This instability could be induced by the fast ions. In the LER, the feedback is also needed to suppress an instability which may be induced by the photoelectrons. In addition, a relatively high vertical chromaticity (typically 7 or 8) is also needed to suppress an instability. With a lower vertical chromaticity, some sudden beam loss occurs at a high beam current sometimes, although the nature of the instability has not been investigated.

The current limitation of the present KEKB come from heating problems of two types of hardware components. One is movable masks which are vital to cut off the beam tail and suppress the detector background. The other is bellows near the IP. For both of these, replacements to the new versions, which are expected to solve the heating problems, will be completed in this summer.

4.3.5.2 LER single beam blowup

Fig. 4.10 shows a current dependence of the LER beam size both in the single beam and the two beam cases. The beam sizes in the figure is values at the IP which is translated from the

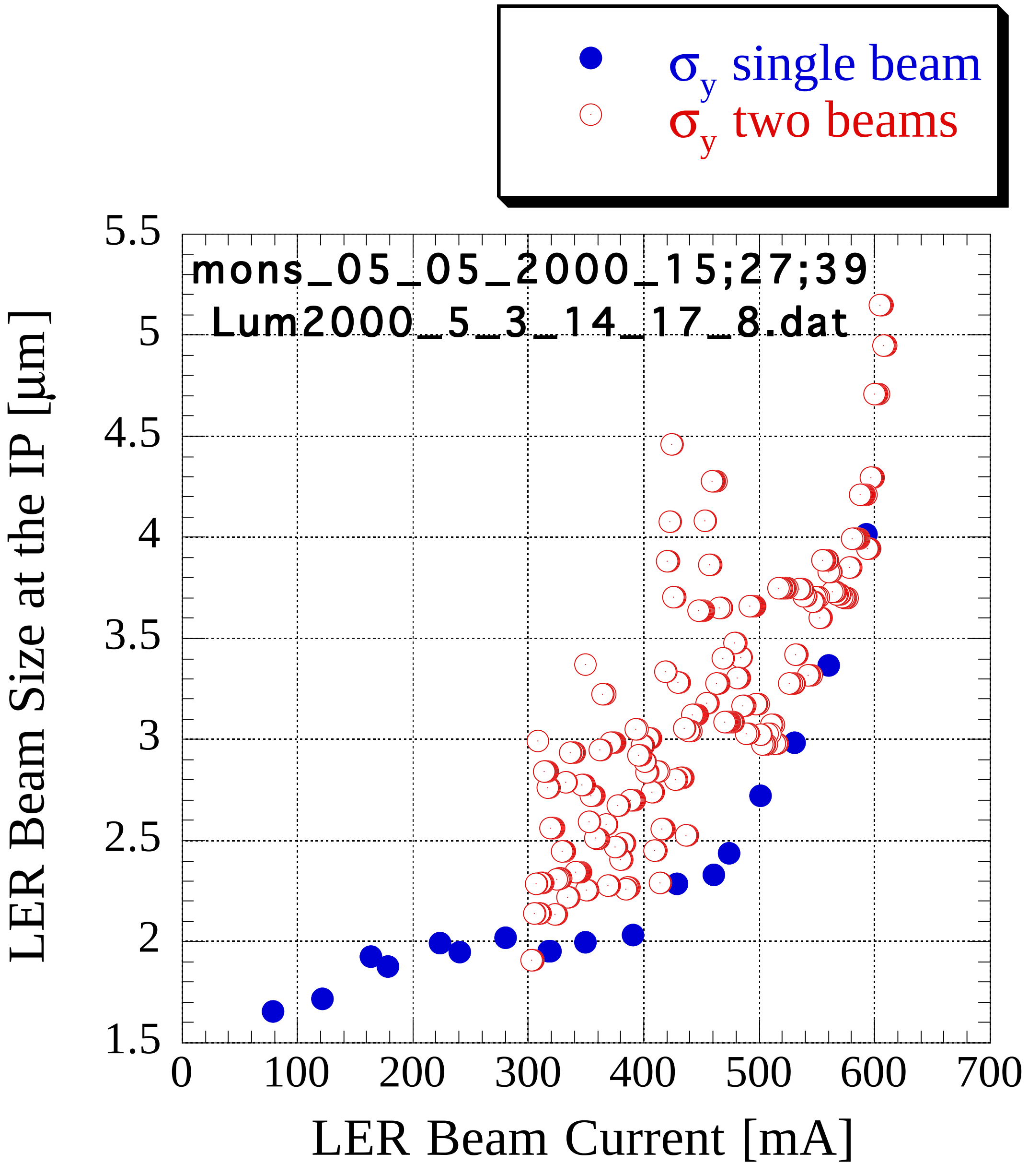

Figure 4.10: Current dependence of the LER beam size (single beam and two beams).

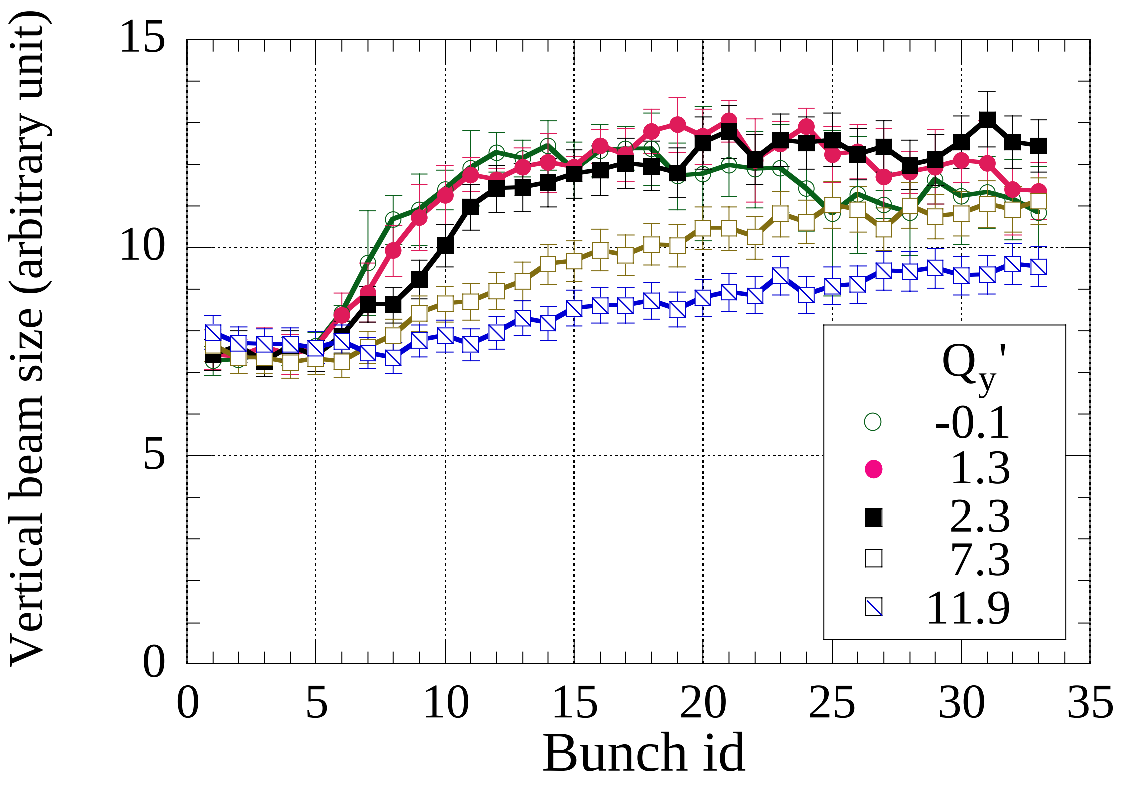

Figure 4.11: LER beam size of each bunch in a train measured by a fast gated camera (with different vertical chromaticities).

measurement point by using the design optics. Every 4th RF bucket was filled with a beam except for a 10% abort gap and some train gaps in both cases. As we can see from the figure, there is a serious beam blowup dependent on the beam current even in the single beam case. The present understanding for this single beam blowup based on phenomelogical observations and some beam studies [12] is that the blowup is induced by a single bunch instability in an environment of a photoelectron cloud [13]. Since the photoelectron cloud is built up by the successive passage of bunches, the blowup occurs only in the multibunch operation. From the chromaticity dependence of the beam blowup (see Fig. 4.11), the strong head-tail instability seems to be responsible for the beam blowup [12].

To cure this single beam blowup, we installed a large number of so-called "C-York" magnets in the LER. A C-York magnet is composed of two button-shaped permanent magnets and a C-shaped iron york. The number and configuration of the C-York magnets have been upgraded step-by-step. In the present configuration, the C-York magnets are attached on the vacuum chamber in every 10cm of the drift space in the arc section (they cover about 50% of the whole arc). The magnets are installed both inside and outside of the chamber so that they generate quadrupole field. To cancel out the effect of the field seen by the beam, the polarity of the magnets was inverted in every 20cm. The vertical magnetic field at the chamber wall was 250 G. It was expected that the magnetic field confined the photoelectrons around the chamber wall and the beam blowup was suppressed. However, the C-York magnets brought no remarkable improvement in the blowup except for the case of a long bunch spacing, although a simulation predicts effectiveness of the C-York magnets. We have not yet understood the reason why the effect of the C-York magnets is so weak. We are now planning to install solenoid magnets instead of the C-York magnets in this summer.

4.3.5.3 Beam-beam blowup

The beam-beam blowup has been considerably improved by the method described in this article. However, there is still some beam-beam blowup even at relatively low beam currents as is seen in Fig. 4.8 and 4.10. Also in the strong-strong beam-beam simulation, the blowup at the low beam current is reproduced even if there is no optics errors [4]. The simulation also shows that the luminosity and the beam-beam parameters are increased even with this beam-beam blowup by using lower vertical emittance. This may suggest that we should go for a lower emittance optics.

Recently, an opinion was proposed that the specific luminosity at the low beam currents is affected not by the beam-beam blowup but by the single beam blowup of the LER, although no beam blowup is observed with the beam size meter (interferometer) at the low beam current in the single beam case. This opinion is based on observations that the specific luminosity seems to be determined only by the LER beam current even in different conditions (different number of bunches and different horizontal emittance). This issue is still under discussion.

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4.4 Beam Instability Studies in PLS Storage Ring

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The PLS storage ring is routinely being operated with the beam of 170 mA at 2.5 GeV in the full-bunch mode for user time. Beam instabilities in PLS sometimes occur troubles in the machine operation even if insertion device with narrow gap does not be operated. It is important to provide stable beam with good quality for the storage ring experiments. Therefore, most of time in machine study has been investigated to cure beam instabilities. So far, the machine study was mainly concentrated at the beam with 2.0 GeV. We report the results of the machine study and future activities on the beam instabilities.

4.4.1 Observation of coupled-bunch instabilities

Several coupled-bunch instabilities have been observed and they are all caused by the high coupling impedances of the rf cavities. We describe typical characteristics of coupled-bunch instabilities that are observed in PLS storage ring.

4.4.1.1 Longitudinal coupled-bunch instability

- (1) 758 MHz resonant frequency does not lead to beam loss at least up to 250 mA. The growth of the oscillation amplitude saturates to a certain value. But, the longitudinal beam oscillation leads to horizontal beam blow-up and occurs fluctuation in beam size.
- (2) 1300 MHz resonant frequency also leads to horizontal beam blow-up and appears to be similar to the instability 758 MHz mode.

4.4.1.2 Transverse coupled-bunch instability

- (1) 1070 MHz resonant frequency leads to a beam blow-up horizontally. The instability takes place a lot of problems during beam injection and the storage time; e.g., beam is stored at a certain limited current, it is suddenly lost after a violent beam oscillation.
- (2) 830 MHz resonant frequency also enlarges the beam horizontally and appears to be similar to the instability 1070 MHz mode. It also leads to beam loss during beam injection and the storage time.

4.4.2 Cure of coupled-bunch instabilities

Beam instabilities could be suppressed by changing rf cavity temperatures and currents of sextupole magnets. Threshold beam current was increased and then 300 mA beam at 2.0 GeV could be stored during 8 hour. The temperatures of four rf cavities were set to 37.3C, 46.6C, 45.1C and 36.7C, respectively. The currents of sextupole magnets were set to 135 A and 87 A for SD and SF, respectively.

4.4.3 Other instability

Ion instability in PLS storage ring was observed in full bunch mode (468 bunches). We observed that the ion instability could be cleared by running the beam below 400 bunches.

4.4.4 Future activities in beam instabilities

- 1. We need to identify the higher order modes in each rf cavity. We are going to measure the resonant frequencies changes for temperature of each rf cavity. By this activity, we can select a proper set of rf cavity temperatures to suppress the longitudinal coupled-bunch instabilities completely.
- 2. We are investigating the dependence of the coupled-bunch instabilities on the betatron tune more systematically. Then we can choose a proper betatron tune and chromaticity that can escape transverse coupled-bunch instability and provide larger dynamic aperture.
- 3. Transverse feedback system will be upgraded in this summer. Longitudinal feedback system will be tested further.
- 4. Through these activities, we expect to be able to store more stable beam and higher beam current in machine operations of 2.5 GeV as well as 2.0 GeV.
- 5. More effects in beam instabilities will be dedicated to raise beam brightness. They will require optimization in beam parameters such as beam lifetime, coupling constant, vertical beam size and beam current per bunch, bunch length and etc..

4.5 Beam Dynamics Activities at SRRC

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The Synchrotron Radiation Research Center is located in Hsinchu, Taiwan. Since 1993, the 1.5 GeV storage ring has been operated for more than 7 years. A number of development projects have been accomplished. For example the operation beam energy increased from 1.3 GeV to 1.5 GeV in the storage ring and booster synchrotron in 1997 and 2000, respectively. A transverse beam instability damping system is in use. All available long straight sections have been accommodated with insertion devices, such as wiggler and undulators. To keep the beam orbit stable, we use a real time orbit feedback system, both in the horizontal and vertical planes, in the routine operation. We need a longitudinal wide-band bunch-by-bunch feedback system to cope with the longitudinal instabilities and it is in the testing stage in the time being. We also plan to install a superconduting wavelength shifter in a short straight section in the coming year. Moreover, a superconduting RF cavity is under construction and the system is expected to be ready in 2003. We continue to strengthen the reliability of the infrastructure of the facility, such as electricity and water-cooling systems, air temperature handling units, etc. In such way, the temperature control has been upgraded to keep its regulation within a few-tenth of degree centigrade. Up to date, there are 13 photon beamlines open for the public users and will be increased to 20 beamlines next year.

On September 21, 1999, a devastating earthquake of 7.6 on the Richter scale (7.3 on the magnitude) struck central part of Taiwan and caused more than two thousand loss of life and serious infrastructure damage. Fortunately, our institution and staff suffered from minimal direct damage. The machine was restarted once the normal power electricity and water supply was restored about a week later after the major earthquake. We found no severe movement of any element in the accelerators and the normal operation recovered in a short time.

Other than the above-mentioned activities, the machine optics was carefully calibrated via beam orbit-based model calibrations. It was found that the machine linear optics was well reproduced as the predicted if the sextupole magnets were turned off. However, in the case that the sextupole strengths were set to the normal operation values, we found that the beta-beat could be as high as 10%. It is attributed to the improper alignment of the sextupole magnets. With the measured machine transfer matrix, we apply a real-time orbit feedback system to keep the orbit stability within a few micron meters.

In order to understand the nonlinear behavior, we performed a series of experiments in the transverse and longitudinal planes. We employed turn-by-turn beam position monitors as well as a dual-scan streak camera to detect the nonlinear beam motion and compared with the theoretical calculations. For example, we observed the motion of the bunched beam near 3-, 4-, 5- and 6-order resonances in the horizontal plane. We measured the beam motion both in the horizontal and vertical planes near the coupling resonance lines. We detected the behavior of the beamlets in a bucket due to parametric resonance in the rf phase and rf amplitude.

Theoretical studies provide a full map of the dynamic aperture of the detailed particle tracking using Lie-algebra method. This study includes the nonlinear components in the insertion devices too. The higher-order modes (HOMs) of the existing cavities, especially in the longitudinal modes, induced unacceptable longitudinal coupled-bunch instabilities for the routine operation beam current at 200 mA. The bunch-by-bunch damping system is not available yet. Therefore several ways to reduce the instability strength, such as precise cavity temperature tuning and second plunger adjustment, had been tried out, but the instability level was still high. Detailed simulations show that harmful HOMs can not be eliminated by the changes of the second plunger or with the variation of the cavity temperature. As mentioned above, the rf amplitude modulation near the second harmonic of synchrotron frequency can generate beamlets inside an rf bucket. Using this method we found that the HOMs of the beam spectrum could be reduced by a factor of 10 dbm. The beam quality hence was acceptable for the routine operation. The lifetime was about 10 hours at initial stored beam current 200 mA.

4.6 Beam Physics Activities at NSRL

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NSRL(National Synchrotron Radiation Laboratory) Phase II Project is going full steam ahead this year. The project was launched in 1997, and will be completed in 2001. In order to make fuller use of the facility, we are to add 8 more experimental stations and 8 new photon beamlines accordingly, insert an Undulator in the ring, and enhance the quality, stability and long-term reliability of the light source as well. The project is one of the efforts to meet with the increasing requirements of Chinese scientific and technological development, approved and chosen as one of ”key scientific projects” by the National Development Planning Committee. Its total budget is 118 million Chinese Yuan (roughly, 14 million US dollars). For those who knew little about NSRL and HLS (Hefei Light Source): HLS ring is an 800 MeV electron storage ring, 66.13 meters long in circumference, divided into 4 quadrants by four 3.36 m long straight sections. One of the long sections is occupied by the ring's injection system, while the others are for insertion devices. There are 12 bending magnets, 32 quads powered in 4 or 8 families, and 14 sextupoles in 2 families in the ring. Every 3 bends and 8 quads make up a TBA type cell. The typical stored beam current is at present from 150 to 180 mA. The HLS lattice allows different configurations. GPLS (General Purpose Light Source) is so far the operational one. With its moderate emittance of 134 nm·rad and a comparatively long beam lifetime, typically longer than 10 hours, GPLS serves most users satisfactorily. On the other hand, a configuration named HBLS (High Brightness Light Source) is a goal of the upgrading project, featuring stronger focusing and a much lower emittance of 27 nm·rad. On the machine side, the goals of the Phase II Project upgrading plans are: (1) Regular operation of GPLS with typically 300 mA accumulated current in every fill, with more-than-8-hour lifetime. (2) Alternatively, routine HBLS operation with 150 mA current of 4-hour lifetime. (3) Reduction of unscheduled breakdown time and “injection/machine tuning” time, so as to assure effective user time no less than 70%, or usually more than 4000 hours per year, and an annually available integrated beam intensity of 600 A-hours, about the present users' Ampere-hours doubled. (4) For each SR station that requires, keep the vertical drift of the light source point within 30 microns. To realize HBLS, which is technically more demanding, a lot of beam dynamics studies have been carried out these years and are described elsewhere. It is planned to reconstruct the ring's injection system, i.e., using thyratron-type pulsed current power supplies instead of the old gap-switch type triggers, and having four ferrite kickers installed in one straight section to produce a lattice-independent, well shaped and localized orbit bump. The removal of old air-coil kickers will give room for two additional sextupoles to save the super-periodicity and multiple symmetry of the sextupole configuration. As calculations have proved, such an improvement will enlarge the ring's dynamic aperture significantly. The ring's RF cavity has also to be rebuilt to provide higher RF voltage for a sufficient Touschek lifetime. So far, many new hardware parts have been installed, such as: new vacuum chamber sections with better shielding at the bellows to reduce impedance, new NEG pump sections, new front-ends at photon ports, upgraded ring magnet power supplies and so on. The control system and the beam diagnostics system have been largely reconstructed to keep pace with technology development. The new software is developed in the frame of the internationally shared EPICS system. Another achievement was made in 1999 when a new insertion device – a 6 Tesla Super-conducting Wavelength Shifter (WLS) was dedicated. It successfully delivered SR light with a characteristic wavelength down to 4.8 angstroms to an XAFS experimental station, so as to expand the applicability of the facility for the benefit of some hard X-ray users in China. The WLS was fabricated at the Kurchatov Scientific Center, Russia. The key step in its commissioning was taken when we, according to beam dynamics calculations, adjusted 2 families of quads to compensate the vertical tune shift resulted from its strong field. We had to turn off the WLS during 200 MeV injection because it is too strong for the low energy electrons to survive. Then, after ramping to 800 MeV, we first adjust the quad strengths to reduce the vertical tune to such an extent that the beam was still there and enough room was made for the effect of WLS field. It took 6 minutes for the field to be turned on fully, as the quads were adjusted slightly during and after the whole turning-on time. The beam loss in the procedure was trivial. More work is planned to further compensate the beta function beatings and carefully correct the closed orbit. Other beam physics activities at NSRL are also going on. Of them three important subjects are: (1) Study on ion-trapping and consequent beam instabilities [3]. (2) Study on multi-bunch instabilities, its effect on beam accumulation and an RFKO (RF Knock-Out) system as its cure [4]. (3) Study on beam loss mechanism, behavior of stray electrons and shower electrons resulted from the former hitting the wall, and a BLM (Beam Loss Monitoring) system [5].

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4.7 Beam Dynamics Activity in SSRF

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4.7.1 SSRF Project

Shanghai Synchrotron Radiation Facility (SSRF) [1] is a third generation light source, which is optimized to provide high brightness and high flux X-ray photon beams in energy from 0.1 to 40 keV. The accelerator complex consists of a 300 MeV linac, a 3.5 GeV booster and a 3.5 GeV storage ring. The project is now in R&D phase. The 3.5 GeV storage ring is the principal component of SSRF. Its design would be optimized to meet the following goals: 1)circumference is less than 400 m, 2)emittance is around 10 nm $\cdot$ rad, 3)beam current is 200$\sim$300 mA for multi-bunch mode and 5 mA for single-bunch mode, 4)beam lifetime is longer than 15 hours, 5)beam position stability is about 10$\%$ beam size at photon source points.

4.7.2 Beam Dynamics Activities

The beam dynamics group has been in charge of the storage ring lattice design and beam stability analysis. In the following, some topics of interest are outlined.

4.7.2.1 Lattice Design

The performance of the Light Source is determined primarily by the design of the storage ring lattice. To achieve the design goals, extensive studies have been carried out. Several possible lattice structures, such as Double-Bend-Achromatic(DBA) and Triple-Bend-Achromatic(TBA) lattice, have been studied. As it can meet the requirements for the design goals and allow for a large number of insertion devices, a DBA lattice has been chosen as the basic structure of the SSRF storage ring. The lattice consists of 20 DBA cells, which are divided into 10 super-period with 7 m and 5 m long insertion straight sections. Each DBA cell contains 2 dipoles, 10 quadrupoles and 7 sextupoles. In the initial design [1] of the DBA lattice, its circumference is 384 m with high β_x (15m) in the middle of insertion straight sections. To obtain high flux density, low $beta_x$ in some of insertion straight sections is needed. As a result, the circumference of the storage ring has been increased to be 396 m to match the hybrid-mode lattice. Furthermore, low emittance mode with non-zero dispersion in the straight sections has also been examined. The main parameters of the lattice in different operation modes are shown in Table 4.3.

4.7.2.2 Optimization of Dynamic Aperture

For high injection efficiency and large beam lifetime, the storage ring should have large enough dynamic aperture. The dynamic aperture of the storage ring lattice is determined by the nonlinear magnetic fields, such as sextupoles and magnet errors. In the SSRF storage ring, there are two families of sextupoles in the arcs for chromaticity correction. The dynamic aperture with those chromaticity-correction setupoles is only a few millimeters. To enlarge the dynamic aperture, four families of sextupoles distributed in the dispersion free region have been introduced for harmonic corrections. Extensive studies on optimization of locations and strengths of the sextupoles have been carried out. It was found that a non-symmetry arrangement of the defocusing chromaticity-correction sextupoles in the arcs may obtain large enough dynamic aperture and momentum acceptance both for the high beta mode and hybrid beta mode. Moreover, the effects of magnet errors and insertion devices on the dynamic aperture have been also studied by numerical simulations. It was shown that the dynamic aperture and momentum acceptance are large enough with magnet errors and insertion devices.

4.7.2.3 Injection Analysis

A Four-kicker scheme is utilized for injection into storage ring to take care of stored and injected beams for accumulation of beam current up to 300 mA. The amplitude of the fast injection bump orbit is 12.5 mm. Two bumpers are located in one straight section, while the other two are located in the arc. One thin fast septum and one thick DC septum are used to deflect the coming beam by total angle 139.6 mrad. Simulations of the injected beam during injection process were made by using RACETRACK code. The angle of the injected beam was optimized and the allowable tolerances of the fast kicks and septa magnets are estimated. Beam Orbit Control Electron beam orbit stability is crucial for successful operation of the third generation Light Sources. To address this issue, SSRF storage ring will be equipped with a quasi-static closed orbit distortion (COD) correction system and a fast orbit feedback system. The quasi-static COD correction system consists of 140 BPMs and 76 horizontal and vertical combined dipole correctors. And the fast orbit feedback system is composed of 40 high precise BPMs and 40 high-bandwidth dipole correctors, which are located on both sides of the insertion straight sections. The effects of many sources, e.g., magnet alignment errors, magnet power supply ripples, tunnel temperature, random vibrations and plane vibrations, on the beam COD and motion have been studied. Numerical simulations of the quasi-static COD correction and fast orbit feedback have been carried out. It turns out that the rms quasi-static COD may be reduced to be smaller than 0.2 mm by the quasi-static COD correction system, and the fast orbit motion may be suppressed by the orbit feedback system with a factor of 3∼5.

4.7.2.4 Impedance Budget

The impedance for the various components of the vacuum chamber envelope was estimated. In SSRF, the dominant contributors to the impedance of the ring is the RF cavities. The total inductive impedance is less than 0.7 Ω. However, since some elements and transitions, such as the narrow-gap insertion device vacuum chamber, are not accounted for in the estimation given above, so a more realistic and conservative value of 1.8 Ω will be used for the instability analysis.

4.7.2.5 Collective Effects and Instabilities

The beam current limitation and instability are very important topics for the third generation Light Source like SSRF. Intensity dependent phenomena such as potential well distortion, bunch lengthening, microwave instability, and head tail instability etc. due to broad band impedance of the beam surrounding vacuum chamber, and the growth rate of longitudinal and transverse coupled bunch instability due to HOMs in rf cavity were studied. The microwave instability threshold current with SPEAR scaling on is 2.5 mA. This means that from 0 to 2.5 mA, both the bunch length and energy spread remain at the zero-current values. Our calculations show that if all the HOM Q values of the RF cavities can be reduced to less than 1000, neither longitudinal nor transverse feedback will be needed. However, if narrow-gap insertion devices would be introduced in the storage ring, a transverse feedback may be needed to damp the resistive wall induced instability due to narrow-gap insertion device vacuum chamber.

4.7.2.6 Beam Lifetime

Beam lifetime due to various processes vs Touschek effect, quantum lifetime due to betatron and energy oscillations, elastic and inelastic gas scattering etc., were studied. The beam total lifetime with 1% horizontal-vertical coupling and 8 mm full gap insertion device is 22 hours.

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4.8 Beam Dynamics Activities in the Accelerator Lab of Tsinghua University

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Beam dynamics activities in the Accelerator Lab of Tsinghua University can be divided into two category: one is on electron storage rings; another is on electron linear accelerators.

4.8.1 Electron storage rings

Under the collaboration with IHEP, China, a variety of subjects on electron storage rings is researched. The longitudinal microwave instability of a single bunched beam in a circular accelerators is systematically studied with perturbation approach and multi-particle tracking approach. The instability would lead to the growth of the bunch length and the increase of energy spread of the beam. Using action-angle variables (J, ϕ),a matrix form of linearized Vlasov equation and a radiation damping factor are deduced in term of generalized Laguerre polynomials and trigonometric function, and a corresponding code MAC is developed. The calculation shows that using action-angle variables can ensure good convergence; expanding in terms of polynomials can avoid the confusion of collective modes with incoherent modes. With the MAC code, some researches on the microwave instability in Beijing Electron-Positron Collider (BEPC), IHEP are carried out. Based on our previous multi-particle track code, some improvements, such as adding spectrum analysis and adopting parallel algorithm are made. From the simulating result with the code, a clear picture of mechanism and process of microwave instability is shown, it is useful to discuss the process of the mentioned microwave instability [1]. And based on the Haissinsky equation, the effects of narrow-band impedance on longitudinal static distribution of bunch are also studied [2].

In order to increase the luminosity, the technique of multi-bunch collision in a same ring has been employing in many colliders. An analytic treatment of multi-bunch potential well distortion for a two-beam storage ring is performed. The longitudinal wake effects on the beams are separated into the mode loss, the synchrotron tune shift and the coherent multi-bunch coupling. An analytic formulas are deduced, which describes the mode loss and the synchrotron tune shift experienced by a given bunch within the two-beam , as a function of the high order mode's parameters. From the analytic result, one can know how to modify the existing configuration of parasitic cavity modes so that make the resulting potential well distortion effects be minimized. When the RF cavities are symmetrically distributed about the interaction points, the two beams will have same beam loading effects, so one can compensate the phase shift of the two beam using the same method as in one beam case [3].

4.8.2 Electron linear accelerator

In the aspect of the electron linear accelerators, several topics are studied, such as the wake-field effects in next generation linear accelerator colliders, the problem of the back bombardment of electrons in RF thermionic guns, the nonlinearity effect in the electron beams in the X-band linac and the beam dynamics in the backward traveling wave(BTW) electron linacs as well as BBU effect in induction linear accelerators.

& The wakefield effects in next generation linear accelerator colliders

Two kinds of accelerating structures in next generation linear collider, including detuned disk-loaded structure and damped detuned disk-loaded structure are studied. A variation method is used to compute the RF parameters of both monopole modes and dipole modes in metal disk-loaded wave-guides. Good agreement is found between computed and experimental results. It provides one useful tool to calculate the wakefield of the tapered disk-load waveguide in next generation linear colliders.

& The problem of the back bombardment of electrons in RF thermionic guns

As it is well known that the back bombardment of electrons in thermionic guns seriously restricts the beam performance and its application. We put forward that shorting the length of first and second cavities can decrease the back bombardment power sharply and obtain electron bunches with better qualities, and adding a short drift section between the second and third accelerating cavities can improve the longitudinal properties of the beams to meet the demand of the magnet. A RF gun, which consists of 1/2+3 cavities with an on-axis coupling structure operated in the mode at 2856MHz,has been manufactured for the Beijing Free Electron Laser (BFEL).The commissioning shows that with the developed RF thermionic gun, the back bombardment effects are well suppressed as one expected [4].

& Nonlinearity effect on the electron beam in the X-band linac

Low energy electron linacs have widely used to several fields in the world, such as radiography, radiotherapy ,irradiation and science research. We are studying the X-band standwave linac for compact linacs. In order to pursue higher shunt impedance, the cavities are optimized by decreasing the beam aperture , and then becomes larger. The condition of paraxial beam is no longer satisfied in this case. The nonlinearty of RF fields becomes serious. We study the nonlinearty effect of RF field by Fourier Series Method [5]. And the codes CAV and TRACK are developed to simulate the beam dynamics. A 6 MeV X-band with on-axis coupler standing-wave electron linac has been developed including taking the nonlinear RF field into account.

& Beam dynamics in backward traveling wave accelerating structure

Compared with the general disk-loaded accelerating structure, the backward traveling wave accelerating structure (BTW) with the optimized cavity shape has higher effective shunt impedance, and shorter filling. At the same time, it can operate more stable. We have studied the longitudinal and transversal particle dynamics, as well as design method of BTW accelerating waveguide with buncher [6]. Based on above studies, a 9 MeV BTW accelerating tube at mode with frequency 2856 MHZ as radiation source for industry CT has designed and is under manufactory.

& Beam breakup instability (BBU) effect in induction linacs

BBU effect in induction linear accelerators is a serious problem, which can deteriorate the quality of beam, even lead to beam loss. The BBU effect in induction linac is researched in term of theoretical analysis, cavity design and microwave measurement. From a pill-box cavity model, the formulas of wake field are derived in induction accelerating cavity and the dependence of wake field is discussed on different beam stimulation. MAFIA code is used to calculate the HOM's transverse impedance of induction cavity with ferrite absorber and the simulated result is consistent with measured one [7].

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4.9 Beam Dynamics Activities at BEPC

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Beijing Electron Positron Collider (BEPC), a single ring e^+, e^- collider serving for both high energy physics experiments and synchrotron radiation application, has been well operating since May 1989 [1]. From 1993 to 1999 the BEPC upgrades were conducted [2] [3] [4]. In the meantime many meaningful accelerator physics related experiments have been done. As the future program in the coming years at IHEP, to further upgrade BEPC with multi-bunch pretzel scheme (BEPCII) is being investigated. In the following, the efforts on the improvement of the BEPC performance, the beam instability study carried out on BEPC and the progress on the BEPCII design will be reported.

4.9.1 BEPC luminosity upgrades

For BEPC luminosity upgrades, the mini-β optics was believed to be the most effective way. The original proposal was to install a pair of compact permanent quadrupole magnets into the detector region to suppress the vertical β function at the interaction point (IP), β_y^*, from 8.5 cm to 3.6 cm. But later it was found that the bunch length of BEPC can not be shortened to less than the proposed β_y^* even though the total RF voltage was increased from 0.8MV to 2.0MV by adding another two RF cavities, and efforts were made to reduce the coupling impedance by shielding the 66 small cavities formed by bellow flanges and removing two idle kickers. Therefore the mini-β lattice had to be modified. Instead of adding the permanent quadrupole magnets, the insertion quads of Q1 and Q2 were moved towards the IP by 35 cm and 45 cm respectively to allow the operation of $\beta_y^* = 5\ cm$.

Since 1996 extensive calculations of optics and machine studies were done in order to obtain the proper operation modes for beam injection and collision with $\beta_y^* = 5\ cm$, as well as for energy ramping and closed orbit adjustment between injection and collision. After a great amount of commissioning with tune scan and coupling compensation, the peak luminosity at J/Ψ energy of 1.55 GeV reached 4.9$\times 10^{30} cm^{-2} s^{-1}$, with the maximum vertical beam-beam parameter about 0.033. The hadronic event rate seen by the BES (BEijing Spectrumeter) detector in routine operation was doubled. Top-up injection was also tested to raise the efficiency and the integral luminosity when the energy of linac was promoted from 1.3 GeV to 1.55 GeV.

For performing mini-β scheme on BEPC, high RF voltage is supplied to shorten the bunch length. But when the RF voltage was raised to as high as 1.3 MV, the vertical beam size enlarged and the luminosity went down. The mechanism of the phenomenon is still not fully understood. A possible explanation [5] to the problem is that if RF voltage is so high that σ_l/β_y^* becomes less than the optimal value, the luminosity may decrease resulting from the mitigating of averaging over betatron phase as well as the increasing of resonance. To confirm this, the code BBC (Beam Beam with Crossing angle) [6] with a few modifications was used to simulate the beam-beam interaction in BEPC. A group of simulations were done on the relation between luminosity and σ_l/β_y^*, where σ_l is the rms bunch length. It's found that the most optimal σ_l/β_y^* for BEPC is about 0.9$\sim$1.1. The machine study results agreed with the simulation. From the operation experience the normal RF voltage for beam collision is chosen as 0.6$\sim$0.8 MV.

There are two interaction points in the storage ring of BEPC, but only one detector has been installed for physics experiment. So it's possible to increase the luminosity by adopting the Single Interaction Point scheme (SIP). For this purpose, the power supplies of the two insertion quads near the north IP were changed to individually adjustable during BEPC upgrade, thus a direct way to design a SIP lattice for BEPC is to keep the optics outside the north pair of separators (SP) the same as double IP case, but the vertical phase advance between two north SPs changed to π. During machine studies in the first half of 1998, some positive result was achieved with this SIP scheme [7]. But there are still many problems to be solved before bringing SIP scheme into routine operation. For example, beam always blows up when the beam current is more than 50 mA and the best performance achieved in machine studies was not so repeatable. Further study on the background issues, adjustment of the tunes, closed orbit and other parameters to enhance the performance of SIP is being underway. SIP experiment is also useful for it serves as one basis of the future multi-bunch collision scheme at BEPC.

¿From 1996 we started to use the beam based alignment method and orbit response matrix analysis to check the strength and misalignment errors of magnet in the storage ring. By measuring the response matrix, we surveyed the whole storage ring in the case that the solenoid and skew quadrupoles were off, and found that the gradients of most quadrupoles had more or less deviations from the designed value, and the polarities of three steering magnets were wrong. With the above errors rectified, the discrepancy of the measured betatron tune to the designed value became 1/4 of the original deviation in horizontal plane and 1/10 in vertical plane. An automatic system for response matrix measurement, analysis and operation mode adjustment is being developed. As a first step to apply beam based alignment on BEPC, additional windings will be added to 32 quadrupoles during this summer shutdown so that the strength of each quadrupole can be individually adjusted within $\pm 3\%$ of its normal setting value. Since there is one BPM located near each of the 32 quadrupoles, the center of each quadrupole can be determined by adjusting the beam orbit in that quadrupole to such a position where a variation of that quadrupole strength will create a minimal distortion to the beam orbit. After placing the beam in the center of quad, the relative BPM offset can be known from the reading of the adjacent BPMs. It is expected that the quadrupole to BPM offset on BEPC can be calibrated to less than 0.2mm and the excursion of closed orbit can be corrected to within 1mm.

4.9.2 Commissioning of synchrotron radiation mode

A five periods permanent magnet wiggler (3W1) was installed in the storage ring in June 1996. The commissioning of the dedicated synchrotron mode at 2.2 GeV was very successful and the beam current intensity reached 100-140 mA with a lifetime over 20 hours by filling 50 to 60 bunches. Recently a new lattice configuration aiming at operating machine at 2.5 GeV has been developed.

For the parasitic mode operation with wigglers, both calculation and experiment have been done to study how to compensate the perturbation on the tune, β function, energy spread and emittance of colliding beams due to wigglers. In calculation, it's found that local compensation is the most effective if each 2 quads located on the two sides of wigglers can be adjusted independently. But this scheme needs more power supplies to the quads. Under present power supply scheme, global compensation can be done by adjusting the quads in the arc region to restore the tune, and the individually controlled 4 quads near IP to restore β_y^*. Calculations show that with global compensation, the perturbation of the lattice parameters can be minimized to the level being acceptable to the physics experiment. Preliminary machine studies done with the global compensation scheme corresponded well to the calculation. Affections on the beam lifetime, luminosity and background due to the orbit and synchrotron radiation generated by the wigglers will be checked later.

4.9.3 Beam instability studies

Many current dependent phenomena have been observed and analyzed during operation and machine studies for years [8]. The focal points in recent years are bunch lengthening, dust effect, beam ion instability and photo-electron instability.

Bunch lengthening due to potential well distortion and microwave instability is measured with a system of streak camera. A scaling law is attained by fitting the substantial data of bunch length taken under different beam conditions:

$$\sigma_l(cm) = 0.651 \times (\frac{I_b(mA)\alpha_p}{E(GeV)\nu_s^2})^{1/3.49} \tag{4.3}$$

where α_p is the momentum compaction, I_b the bunch current, ν_s the synchrotron tune, E the beam energy.

Due to the serious bunch lengthening predicted by the scaling law, it's of no sense to further reduce β_y^* in the present ring to enhance the luminosity. An essential way to abate bunch lengthening is to reduce the coupling impedance. The information of coupling impedance can be obtained from the longitudinal distribution of the bunch, which is measure by the streak camera. With a purely inductive impedance assumed, the inductance of the whole ring deduced from the measured bunch length at the low bunch current is 520nH, corresponding to the low frequency impedance $|Z/n|_0$=4.1Ω, which is consistent with what we obtained from other methods. Further study is being done on the analysis of the bunch distribution vs beam current to infer the impedance model of the storage ring so that some hints can be acquired to reduce the impedance for future upgrade of BEPC by modifying some components of the vacuum chamber.

In the routine operation of synchrotron radiation mode, sudden reduction of the beam lifetime was observed with the following features: it may happen at any beam current in single bunch or multi-bunch pattern; beam lifetime may be recovered spontaneously, or by shaking the beam transversely; it's not repeatable when the beam is injected again under the same machine condition; it happens neither in the case of colliding beam nor positron beam. So we conjectured that the rapid decrease of beam lifetime may be due to the dust effect and the dust may come from the vacuum pumps, especially from the distributed ion pumps(DIP). In the experiment, we tried to switch off partial DIPs in the ring, but keeping the vacuum not drop significantly in a quite long time. The dust effect was clearly reduced. The influence due to the lumped vacuum pumps being switched off for a short period was also observed. This indicates that the dust may come from the vacuum pumps. To understand the problem more clearly, new sensitive beam loss monitors will be distributed along one fourth of the storage ring this summer. If the beam loss is due to dust, it may happen near where the dust appeared. A possible way to refrain from the dust effect is to operate with positron beam. Several shifts have been spent on positron running at SR mode with no sudden beam lifetime drop recorded.

In parallel with the dust effect, ion effects have been studied. A simulation code for ion trapping and fast beam-ion instability has been developed on the basis of "weak-strong" interaction model. Recently we investigated the coupled bunch oscillation sidebands in detail under different multi-bunch filling patterns with a 1.5GHz spectrum analyzer. Some sidebands was successfully reproduced by the simulation code and the growth time of the instability given by simulation was comparable with the synchrotron radiation damping time.

The beam photoelectron instability (PEI) in positron beams has been studied experimentally on BEPC under the cooperation with KEK colleagues in recent years [9]. A computer code has been developed to simulate the PEI. The growth behavior of the PEI corresponds semi-quantitatively with observation. In the simulation, the production rate of the photoelectron plays a very sensitive role affecting the quantitative result. It will be very meaningful to measure the yield of the photoelectron directly in the beam tube. A special detector which can characterize the photoelectron cloud has been fabricated and will be installed at a sensitive position on the vacuum chamber in this summer. We expect to get some measurement result later this year.

4.9.4 Future upgrade of BEPC: BEPCII

With the Beijing Tau-charm factory being shelved, to upgrade BEPC by means of micro-β and multi-bunch collision, namely BEPCII, is considered as a practical and economical way to continue exploring the rich physics at J/Ψ energy range. At least a one order increase of present luminosity at 1.55 GeV is required. ¿From the accelerator aspect, the further increment of BEPC luminosity comes from the following two ways [10]:

- To reduce the β_y^* to about 1∼1.5 cm.
- To adopt multi bunch collision with pretzel orbit.

Since the normal operating betatron tunes of the present BEPC lattice are set at 5.8/6.8, a reasonable configuration of pretzel orbit would permit operation with 6 bunches per beam. To further increase the number of bunches each single bunch will be replaced with 2 or 3 ones in a "train" on the pretzel anti-node, and the pretzel orbit will be extended through the interaction region, creating a horizontal crossing angle at the IP.

The idea of adopting pretzel scheme in BEPC appeared first on the 1991 workshop of BEPC luminosity upgrade. From 1995 to 1998, two scenarios of pretzel scheme, i.e., the horizontal separation scheme and vertical separation scheme are investigated in parallel [11]. Not only calculation but also a few machine studies have been done on both scheme. Though both schemes seem feasible in the aspect of physical aperture, the vertical separation scheme has the fatal drawback that the severe coupling arising from the vertical orbit in sextupoles leads to vertical emittance growth and its correction is very difficult. Since the final phase of BEPCII will adopt bunch train operation, a horizontal crossing angle is needed to provide sufficient separation of the two beam at the multi parasitic crossing point near the IP. This can be achieved by designing the pretzel orbit asymmetric with respect to the diameter that includes the IP. An additional advantage of the asymmetric pretzel orbit is that the perturbation on the beam parameters due to the pretzel orbit can be automatically compensated. Thus the positron beam and electron beam will be of the same character.

Two horizontal separators located symmetrically around the north IP are used to yield the pretzel orbit. The horizontal betatron phase advance between the separator and the north IP is chosen as $\pi/2$, so an adjusting of the separator voltage brings the beam into collision at the south IP while preserving separation elsewhere. At least $9\sigma_x$ separation should be provided between the beam centerline at parasitic collision points and $10\sigma_x$ from each beam center to the wall of the vacuum chamber. A pair of horizontal separators around the south IP are used to adjust the crossing angle of collision. The vertical separators are used for the separation at the south IP during injection. A preliminary lattice for this pretzel scheme has been designed.

To reduce β_y^*, either a pair of permanent quadrupole magnets or superconducting magnets should be placed as near as possible to the IP, depending on the outer diameter allowed by the detector. So the interaction region should be carefully designed with compromise of detector design.

On the other hand, it requires that the bunch length be well controlled around 1$\sim$1.5cm. Besides that the 500MHz superconducting RF cavity will be adopted for high RF voltage of 3MV, the coupling impedance of the vacuum chamber should be well controlled, say less than 1 Ω [12] so as to abate the bunch lengthening effect. The parasitic loss due to the short bunch length should be also carefully studied. Some components such as the bellows, the flanges, kickers will be modified to reduce impedance, and new components such as the horizontal separators will be designed with low impedance.

The beam dynamics issues such as solenoid coupling compensation scheme, chromaticity correction and dynamical aperture, multi-bunch instabilities and beam-beam effects etc. will be seriously studied.

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4.10 Beam Dynamics Activities at HIRFL-CSR

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4.10.1 Beam dynamics in HIRFL upgrading[1-4]

4.10.1.1 Longitudinal matching in HIRFL

In order to improve the injection efficiency of the Sector Focusing Cyclotron (SFC) axial injection system and to compensate the remained imperfect longitudinal matching between SFC and SSC (Separated Sector Cyclotron), we designed two linear bunchers which work in half-frequency bunching mode compared with SFC RF frequency. Linear bunching waveform gives good bunching efficiency and the half-frequency bunching mode allow the 50% lost particles due to the mismatch regain. The design of two bunchers is to accommodate the large acceleration range (Carbon to Uranium, 0.5∼12 MeV/u) at SFC. To get good transmission efficiency of whole HIRFL, we studied also the rebuncher functions in BL1 beam line (connecting SFC and SSC) and gave new working modes and the new parameters for the two rebunchers. Four modes are for the large acceleration range at HIRFL. The auxiliary rebuncher B2 should take also task to compensate the energy loss from stripper or the energy difference between the value for extracted beam from SFC and the required one by SSC. The buncher should work at 20∼110 kV amplitude and 22∼54 frequency range.

4.10.1.2 Space charge effect in a very low energy beam line

In the beam line of very low energy of order 1∼10 keV/u, beam intensity of teens μ A can give rise to important space charge effect. We studied the space charge effect in the SFC axial injection line, especially together with the bunching process. The combination of two bunchers is designed to weaken the effect and to get good injection efficiency at higher beam intensity. As the transversal space charge effect is easily compensated by the focusing elements in the injection line, we focused our study on longitudinal space charge effect. By using a program

SCEBUN based on Disc-model, we can simulate the effect in detail numerically. The space charge effect is very sensitive to the beam energy and the injection voltage (or extraction voltage at ion source) which is proportional to the mass to charge ratio:

$$V_{inj} = \frac{1}{2}\frac{q}{m}(B\rho_0)^2 \tag{4.4}$$

With maximum 25kV extraction voltage at ECR ion source, in order to reduce the space charge effect, we divide the ion beams into different mass to charge ratio ranges and use different injection radius ρ_0 (2.5cm, 3.0cm and 3.6cm), so V_{inj} stays mainly in 15∼25 kV.

4.10.1.3 SFC central region

SFC must accelerate very large range of species and energies; therefore, multiple sets of injection parameters are needed to weaken the space charge effect etc. Three sets of injection parameters have been chosen to accelerate ions from Carbon to Uranium, viz. lower injection radius $\rho_0 0 = 2.5$cm for light ions, $\rho_0 = 3.0$cm for medium heavy ions and $\rho_0 = 3.6$cm for heavy ions. The central region should meet the requirements of the orbit centralization and RF voltage range. The small acceleration turn number ($n \leq 50$) for heavy ions is taken compared with n¿110 for light ions, and this is for decrease the beam loss in vacuum as the beam of low energy and high charge state has big charge change cross section with residual gas.

4.10.1.4 Influence and elimination of residual 1^{st} harmonic magnetic field in SSC injection region

Due to historic reason, there exists quite important residual 1^{st} harmonic magnetic field (about 10Gauss) in the SSC injection region. It has been imposing problem to the beam tuning. Now we are studying its influence on the injection efficiency and the method to eliminate it or decrease the field level. It is evident that the field generates serious radial precession in the injection region when SSC operating at h=2, in the case the radius increment due to acceleration is only about 6∼9mm. The solutions we are going to take are to compensate the local field distribution by iron shims with coils and to transform the residual 1^{st} harmonic field into 2^{nd} harmonic one by putting shim in the opposite valley, which is much less important.

4.10.1.5 Feasibility of accelerating high energy proton in SSC

To meet the recent requirement of accelerating high-energy proton HIRFL, we studied the potential capability of accelerating proton beam at both cyclotrons SFC and SSC. For SFC itself, it can accelerate proton beam up to 31 MeV, and the major limitation is RF frequency range. For the combined acceleration of SFC and SSC, the limitation is the disappearance of vertical focusing at high energy (∼230 MeV). But to accelerate the proton of 125∼230 MeV, we have to overcome the difficulty that SSC works at h=1 mode. In that case, the injection turn separation is very small and the total acceleration turn number is bigger than 1200. We will take experiments to study the feasibility.

4.10.2 Beam dynamics in CSR project[5-9]

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4.10.2.1 Numerical simulations of electron cooling process of heavy ions

Electron cooler is an important device in the heavy ion storage ring. The mathematical model for simulating the cooling process of heavy ions has been improved from the usual used one. With the improved model, the cooling force varies continuously and monotonously in all the ion velocity range. The transversal and the longitudinal components of the cooling force are correlative. The simulation results have been compared the experiments done in TSR accelerator (Heidelberg, Germany), and they are well coincided (the maximum deviation is less than 3 times). In the numerical simulations, we took the particle oscillation model for both longitudinal and transversal motions in the storage rings and also considered the dispersion in the cooler section and the space charge effect of the electron beam. With this improved model, we designed the accumulation modes in both CSRm and CSRe and studied the problems concerning the internal target experiments in CSRe.

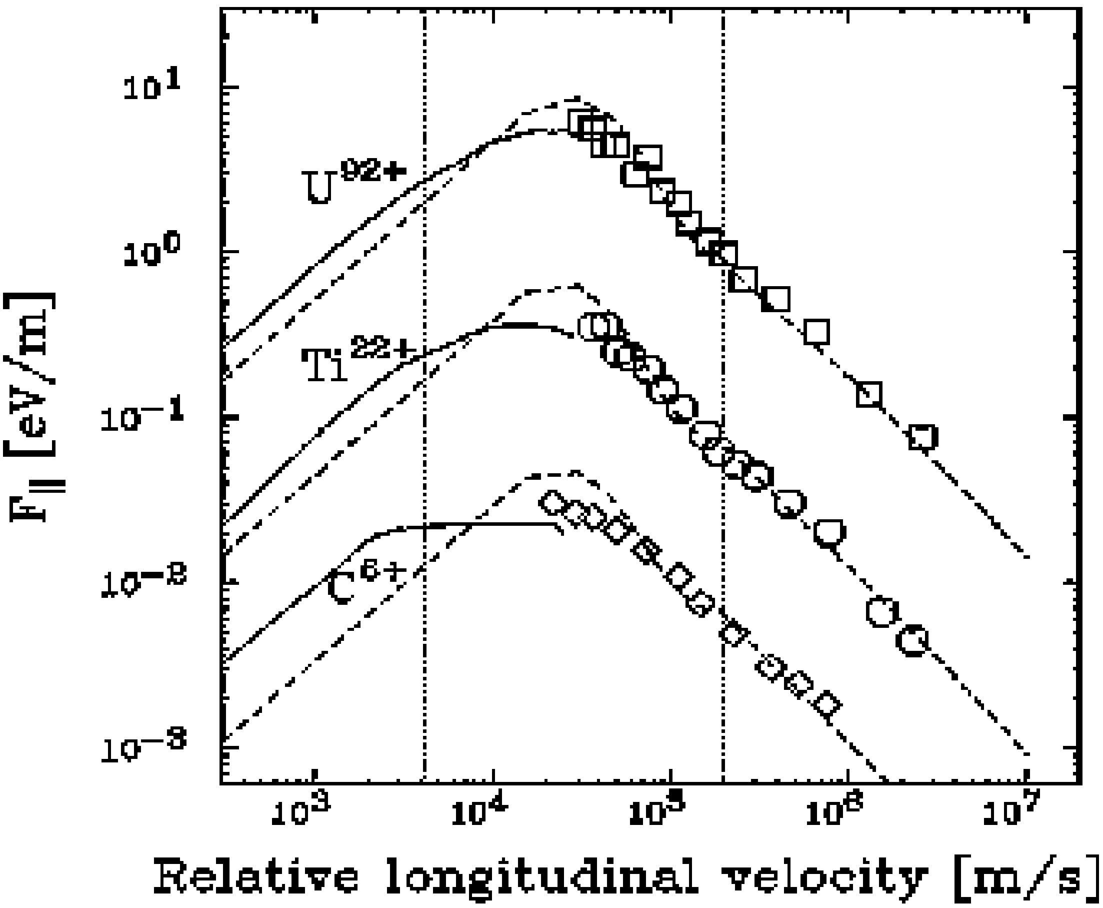

Figure 4.12: Comparison of the improved model and the experimental results. Where solid lines with marks ○ and ◇ are experimental results, dashed lines are improved model.

4.10.2.2 Study for the beam accumulation in CSR rings

In order to get high efficiency of beam accumulation in the main and experimental Cooling Storage Rings (CSRm and CSRe), different methods have been studied. At last, two methods have been chosen for the application in CSR rings, one is multiple multi-turn injection plus electron cooling, and the other is single multi-turn injection plus RF stacking plus electron cooling. The accumulation methods were successfully verified in the TARN-II accelerator (Tokyo University, Japan). In the case of low energy injection, the multiple multi-turn injection plus electron cooling has the advantage due to the short cooling time.

4.10.2.3 Lattice design of big beam acceptances

Both transversal beam acceptance and longitudinal beam acceptance are critical characteristics in storage rings. In order to get maximum acceptance within limited ring apertures (reasonable price), the detailed studies and therefore the optimized lattice design have been done, especially for the experimental ring CSRe where the internal target experiments and radioactive ion beams need big ring acceptances.

1) Acceptances in CSRm

Transversal: A_h=200 π mm.mrad (ΔP/P=$\pm 0.15\%$)
Longitudinal: A_v=30 πmm.mrad
Momentum: ΔP/P=1.25% (ε_h=50 πmm.mrad)

The required apertures for the bending magnets and Quadrupole are $140\times 60mm^2$ and $160\times 100mm^2$, respectively.

2) Acceptances in CSRe

The required apertures for the bending magnets and Quadrupole are 220 $\times 70mm^2$ and 280 $\times 140mm^2$, respectively.

4.10.2.4 Other beam dynamics studies in CSR

We have also studied the mass resolution power in CSRe. By using the Shottky noise measurement of ions' cycling frequency spectrum, we can measure the small difference of masses of different radioactive isotopes. The resolution power is

$$R_q = (\frac{\gamma_1^2}{\gamma^2} - 1)\frac{\delta_p}{p} \tag{4.5}$$

Two working modes are used for the high-resolution mass measurement: normal mode and isochronous mode.

1) Normal mode (low γ_t)

It is needed to take small transition energy factor γ_t and to make the momentum-spread δp/p as small as possible by using electron cooler. For example:

γ_t=2.624, γ=1.395 (beam energy 370 MeV/u) , δp/p$\sim\times 10^{-6}$

The resolution power can reach $R_q \sim 10^{-6}$. Because the electron cooling needs time order of second, this method is suitable for the measurement of isotopes with the life time longer than second.

2) Isochronous mode (γ_t=γ)

In this case, the resolution power Rq is irrelative to the momentum-spread δp/p. We can use time-of-flight method to measure the mass by taking some tens of turns. The resolution power can reach $R_q \sim 10^{-5}$, and it is suitable for the measurement of isotopes with the life time of order of 10 μs.

Non-linear behavior and beam instability induced by large amplitude oscillation have also been studied in the preliminary stage, and some practical non-linearity corrections have been finished. Beam dynamic aperture losses due to alignment errors and field errors have been done through numerical simulations, therefore, the requirements for these errors in CSR and relative correction scheme are also given.

4.10.3 Matching between HIRFL and CSR [10]

Because CSR uses the existing HIRFL as its pre-accelerator, the matching between the accelerators is very important. Beam injections to CSRm from both SFC and SSC have been studied and proved feasible. Different matching modes have been designed to accelerate ions from Carbon to Uranium in the energy range of $100 \sim 900$ MeV/u, in order to get the high beam transmission efficiency and the machine utilization efficiency. In the case of SFC as injector, the circumference of CSRm is 34 times of that of SFC at extraction, and SFC will be adjusted little bigger extraction radius from the nominal 0.75m to 0.754m. The original two injection modes (section 2) designed for the injection from SSC are also applicable for the injection from SFC. The advantages of the injection from SFC are that higher transmission efficiency and higher accelerator reliability (SSC offline). Only in the case we need high-energy beam of heavy ions from CSRm, it is necessary to use the combination of SFC, SSC and CSRm, and in the case beam stripper is used to raise the charge state before the injection to CSRm. The characteristics requirements for the injected beam and some ring parameters in CSRm have been given in the base of matching study.

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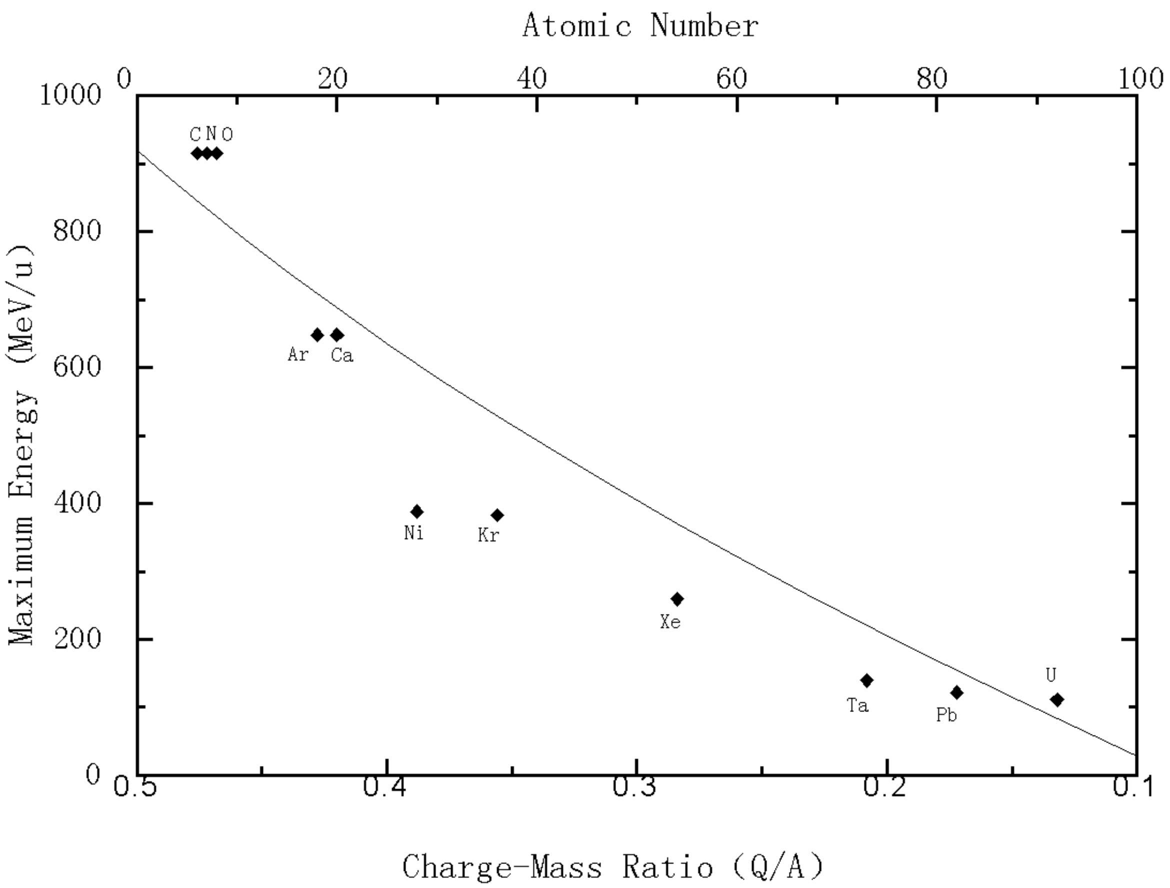

Figure 4.13: Maximum beam energy from SFC and CSRm matching. Solid line represents maximum energy with Q/A value (lower abscissa)

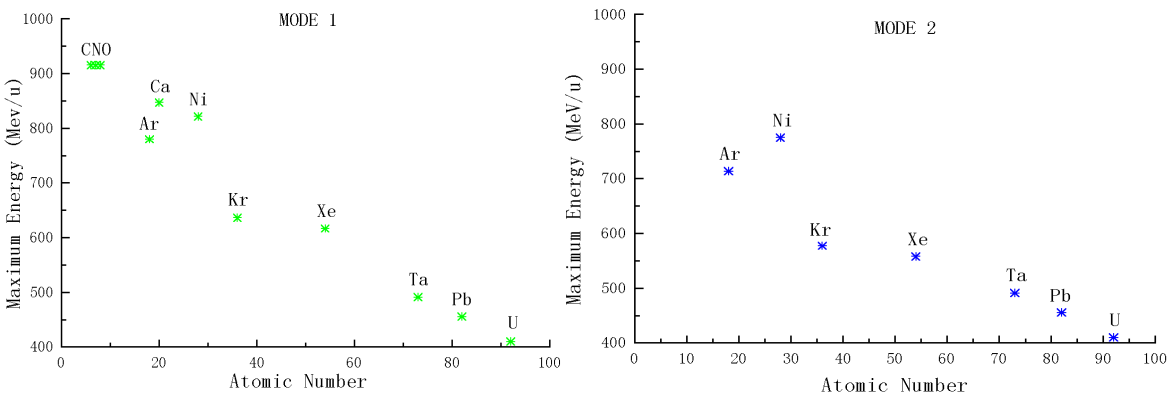

Figure 4.14: Maximum beam energy from SFC, SSC and CSRm cascade matching a) mode 1: $h_{SFC/SSC/CSRm}$=3/4/32; b) mode 2: $h_{SFC/SSC/CSRm}$=3/6/32;

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4.11 New Doctoral Theses in Beam Dynamics

4.11.1 Anke-Susanne Müller

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Supervisors: Prof. Dr. H.-G. Sander (Heinz-Georg.Sander@uni-mainz.de), Universit”at Mainz, Germany and Dr. J. Wenninger (Jorg.Wenninger@cern.ch), CERN, Geneva, Switzerland

Title: Precision Measurements of the LEP Beam Energy for the Determination of the W Boson Mass

Date: May 2000

Abstract: The measurement of the mass of the W boson requires an accurate determination of the beam energy and a good understanding of the accelerator to guarantee stable running with high luminosities at high beam energies. In this thesis a reliable method was developed to measure the horizontal detuning with amplitude which turned out to be an important stability criterion for the high energy optics. The detuning with amplitude was measured for various optics using measurements of the center-of-charge position of a bunch oscillating after a single excitation. In general there is a reasonable agreement of measurements and predictions of the simulation program.

The beam energy of is used as a kinematic constraint in the determination of the mass of the W boson. An error on the beam energy therefore translates into an uncertainty on the W mass. The impact of beam parameters like center-of-mass energy and asymmetries of electron and positron beam energies on the measurement of the mass of the W boson is studied with generator level Monte Carlo.

The standard procedure of the energy calibration above the W^+W^- threshold of 80 GeV is based on precise energy determinations in the energy range from 40 to 60 GeV with resonant depolarization measurements and on magnetic extrapolations to the respective physics energies (80 to 102 GeV). Since such extrapolations involve systematic uncertainties, alternative methods have been developed and studied which are based on measurements of the energy loss due to synchrotron radiation. Since the energy loss increases with the fourth power of energy, observable sensitive to the energy loss per turn can be used to determine the beam energy. Measurements of the radiation damping in transverse coherent oscillations and the analysis of the sawtooth-like horizontal orbits in the ring were studied as a means to derive the beam energy. The uncertainties of these two methods were found to be too large to

serve as a cross check for the standard extrapolations. The required relative uncertainty is of the order of 10^{-4} (or 10 MeV). The beam energy measurement based on the analysis of synchrotron oscillations however provides a powerful and reliable high precision cross check for high energy calibration. The dependence of the synchrotron tune on various parameters was studied in detail to control systematic effects on the analysis. The error was found to be in the range from 20 to 30 MeV. Future experiments and studies are expected to reduce this uncertainty.

4.11.2 Yun Luo

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Institution: IHEP

Title: Study of Foreign Particle Induced Beam Instabilities in BEPC and BTCF

Date: August 14, 2000

Supervisor: Prof. C. Zhang (zhangc@mail.ihep.ac.cn), IHEP

Abstract: Foreign particle induced beam instabilities, including ion trapping, fast beam-ion instability and electron cloud effect in Beijing Electron-positron Collider (BEPC) and Beijing Tao-Charm Factory (BTCF) were studied in this thesis.

BEPC has operated as a dedicated synchrotron radiation source more than two months every year and since 1998, the multi-bunch and partial filling has been adopt, so the investigation of the ion trapping in BEPC turned out to be important. We calculated the linear trapping condition of ions along the ring in detail and got the ion trapping ratio under different filling modes and different beam currents. The linear two beam theory of ion trapping was used to explain the ion induced coupled bunch sideband. Based on the strong-weak model, we developed an ion trapping simulation program, which could give full span sidebands and the growth time for ion induced instability. The simulation result successfully reproduced the experimentally observed sideband, and gave a reasonable growth time.

BTCF supplied an opportunity for us to investigate the fast beam-ion instability (FBII). The ion trapping simulation code was easily to be improved for FBII in the electron ring of BTCF. The growth time of FBII in BTCF electron ring was obtained about 1.7 ms with simulation tracking under the design filling pattern at vacuum pressure of 1.0 nTorr, which was close to the theoretical prediction. Using this program, we checked the dependencies of FBII growth time on the vacuum pressure, bunch number, bunch current and bunch interval.

The electron cloud effect has been studies in BEPC for years. In this thesis, the recorded data by the single pass beam position monitor (SPBPM) in the fifth IHEP-KEK joint beam-photoelectron instability experiment in BEPC were processed and analyzed. The effects of beam imaginary force, secondary electron and space charge force were previously investigated. We found that there was no need to cut the bunch into pieces since the displacement of the electron was very small when a bunch passed by. At the electron cloud equilibrium distribution, the secondary electrons took up about 26% of the total charges. The space charge force of the electrons could be ignored. Also a turn-by-turn tracking program was developed. The growth time was about 2 ms under the experimental condition. By now, we couldn't find a sharp and short range wake function of electron cloud as other machines. Further study is in progress.

4.11.3 Kaizhi Zhang

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Title: Research on beam breakup instability of linear induction accelerators

Date: April, 2000

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Abstract: Beam break instability(BBU), resulted from interaction between beam pulse and induction accelerating cavity, will deteriorate the quality of beam, even lead to beam loss. This thesis focuses on the research of BBU in order to damp it in induction linac.

Transverse impedance of accelerating cavity reflects the degree of interaction between beam and cavity. This thesis describes the principle, method and results of coaxial bi-wire measurement of transverse impedance, and the measured impedance are 1482Ω/m of 850MHz for 10 MeV accelerator cavity, 867Ω/m of 375MHz for vacuum cavity and 820Ω/m of 753MHz for dielectric cavity respectively. To confirm the measurement result, the code of MAFIA is used to calculate the transverse impedance and the calculated result is consistent with measured one.

Thereafter the theory of BBU is analyzed. From a Pill-box cavity model, the formulas of wake field are derived in induction accelerating cavity and the dependence of wake field is discussed on different stimulation. Then, the motion equation of beam centroid is solved under the effect of transverse wake field in the form of transportation matrix, and a formula describing the variation of beam centroid is given.

At last a code named CBBU is written to simulate BBU. First, we investigate the general form of BBU in induction linac, then analyze the effect of related parameters on BBU. Furthermore, some induction linacs in design or in operation are simulated. The simulation shows that, if the magnetic field is too weak, beam breakup instability will lead to beam loss, which was verified in the process of tuning of 10 MeV accelerator. Under suitable magnetic field distribution, the gain factor of BBU in induction linacs consisting of new vacuum cavity or new dielectric cavity are 9.25 and 7.75, respectively, which is far below the design gain of 20.

4.11.4 Shinian Fu

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Title: Physical Study on the Low-Energy End of an Intense-Beam Proton Linac

Date: September, 1999

Supervisor: Prof. Xialing Guan and Shouxian Fang (Guanxl@alpha02.ihep.ac.cn, fangsx@alpha02.ihep.ac.cn) IHEP

Abstract: In the recent decade, some large laboratories in the world proposed intense-beam proton linear accelerators for various purposes, such as transmutation of nuclear wastes, clean nuclear power production, tritium production or spallation neutron sources. Nuclear scientists of our country paid a close attention to this new trend and put foreword a proposal to

develop an accelerator- driven clean nuclear power system, to meet the demand for the nuclear power in our countrys economic development in the future. This dissertation describes my study on some physical issues of the low-energy end of an intense-beam linac. Chapter 1 reviews the development and present status of the high-current proton linac and discusses the technological basis in our country to develop such an accelerator. Chapter 2 makes a theoretical investigation on a major reason of the halo formation. A new study method–fundamental-mode equivalence is proposed for the study of the beam-halo formation in a periodical focusing channel. At the end of this chapter, some multiparticle simulations on a real accelerating structure are performed to study the beam halo formation and emittance growth due to mismatch in transversal and longitudinal directions. Chapter 3 presents a novel accelerator scheme–simultaneous acceleration of positive and negative ion beams with an equal current. The emittance growth in low energy beam can be expected very small because the strong space- charge will be neutralized by the two beams with each other. In the high-energy section, space charge effect can be halved for the same total beam current as in the case of a single beam. The accelerator composition is outlined. Some low-energy subsystems are preliminarily designed, including H+ and H- ion sources, merging magnet, RFQ and DTL accelerators. Some possible options for the high-energy section are also discussed. The MEBT between the RFQ and the DTL is designed for JHF proton linac in Chapter 4. TRACE3-D is modified to include a new transport element–RF chopper. The modified code is then applied to the design of the MEBT for the purposes of beam matching and chopping. A new idea is proposed in the MEBT design: magnification of a beam deflection by means of a quadrupole magnet. In this way, the demanded deflecting field is greatly reduced, and the MEBT is not obviously lengthened. PARMILA simulation results show that the design is satisfactory to our design requirement. The RF deflector cavity is regarded as one of the key element in JHF linac because its transient property has a great impact on the beam-loss control of the JHF accelerator complex. A careful design of the deflector cavity is delineated in Chapter 5, together with some measurements of a cold-model cavity. The geometry of the cavity is optimized using MAFIA code, aimed at a low power demand at a fast transient time. To reach a fast transient time, the cavity with a pair of large coupling loops is re- deigned using HFSS code for the purpose of a low loaded Q value. After lot of simulations with various schemes, the loaded Q is finally decreased lower than 10, and thus, the transient time is greatly shortened. A cold-model cavity was manufactured according to the design. A series of measurements in frequency domain with a network analyzer and in time domain with an oscilloscope confirmed the low loaded Q value and the fast transient time. To save the total demanded RF power further, a new idea to couple the two deflector cavities was initiated, and it has been confirmed by HFSS simulation and measurements. Another important element in the MEBT- beam rebuncher is designed with SUPERFISH and MAFIA in detail in Chapter 6.

4.11.5 Yongbin Leng

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Institution: University of Science and Technology
Title: Development of Longitudinal Impedance Measurement System and its Experiments
Date: May, 1999
Supervisor: Prof. Yuanji Pei and Guicheng Wang, University of Science and Technology

Abstract: An automatic measurement system using wire method was established to measure the energy loss parameter K, longitudinal wake function and coupling impedance of vacuum chambers. The hardware of the system is based on HP high performance instruments and controlling computer, consisting of pulse generated model, bunch simulated model, signal sampled model and controlling model. The data acquisition and accession software was developed in HP VEE. The completed system has several specialties as following: ability of getting measured results including energy loss parameters and wake functions for various bunch lengths; a large various range of simulated bunch lengths, the σ is from 80ps to 125ps and the $\Delta\sigma$ is less than 1ps; high precision, the measuring errors are about 21% for energy loss parameter K, 26% for wake function and 25% for coupling impedance; ability of giving the both results in time domain and frequency domain without changing the hardware of the system.

The measured and computed results of two pillboxes were compared and the differences between them are relatively small. Several vacuum chambers in NSRL ring were measured with this system such as standard flange CF100, CF150, bellows with flanges, chambers with BPM, racetrack shape ceramic chambers with metal film coating and without metal film coating. All results of them were given including K-σ curves, longitudinal wake functions, coupling impedance and broadband model, additionally the $Z_{||}/n$ curves were calculated and the limited values when $n \to 0$ were given. The measured results show that the metal film coating in the ceramic chamber can optimize its impedance performance greatly. The energy loss parameter K of ceramic chamber with metal film is about 1/4 of without metal film, the $Z_{||}/n$ also reduces from 1.43Ω to 0.3Ω, the relation is the same as K. All results can be used to estimate the impedance of the whole ring and analyze the beam instability of NSRL.

Table 4.1: Present performance compared with the design. (Values in a parenthesis are the design values.)

	LER	HER	
Hor. Emittance	18	30	nm
β_x^*/β_y^*	0.7/0.007 (0.33/0.010)		m
Beam Current	465 (2600)	420 (1100)	mA
# of bunches	1146 (2833)		
Bunch Current	0.41 (0.96)	0.37 (0.41)	mA
# of trains	8		
Bunches/train	159		
σ_x^*/σ_y^*	112/1.7	145/1.7	
Bunch spacing	8 (2)		nsec
Bunch Length (calculation)	5.9@9.0	6.4@5.0	mm@MV
ξ_x	0.039 (0.039)	0.032 (0.039)	
ξ_y	0.036 (0.052)	0.018 (0.052)	
ν_x	45.51 (45.52)	44.519 (44.52)	
ν_y	44.07 (44.08)	42.176 (42.08)	
Lifetime	105@565	302@397	mim@mA
Luminosity (Belle CsI)	19.2×10^{32} (1.0×10^{34})		$/\mathrm{cm}^2/\mathrm{sec}$

Table 4.2: Result of beam-beam experiment.

# of bunches	1069	188
ξ_x/ξ_y (LER)	0.039/0.036	0.030/0.025
ξ_x/ξ_y (HER)	0.032/0.018	0.030/0.032
bunch current (LER)[mA]	0.53	0.70
bunch current (HER)[mA]	0.37	0.30
Luminosity [/cm^2/sec]	1.92×10^{33}	4.04×10^{32}

Table 4.3: Main parameters of SSRF

Lattice mode	High Beta Mode	Hybrid Beta Mode
Circumference (m)	396	396
Energy (GeV)	3.5	3.5
Emittance (nm.rad)	12.1(4.6*)	11.7(5.7*)
Tunes (H/V)	18.81/8.73	22.19/8.23
$\beta_{x,y}$ at IDs (m)	12.0/3.5	12.0/3.5
12.0/2.5	0.95/3.5	

* denote with dispersion at IDs

Table 4.4: Longitudinal Matching Efficiency between SFC and SSC with Bunching Modes

Mode	h1/h2	f_{BUN} (MHz)	f_{RF1} (MHz)	E_1 (MeV/u)	f_{RF2} (MHz)	E_2 (MeV/u)	η (%)
1	$1/2$	5.5-9.33	5.5-9.33	3.5-10	8.25-14	37.9-124.8	50
$1'$	$1/2$	2.75-4.67	5.5-9.33	3.5-10	8.25-14	37.9-124.8	100
2	$3/4$	6.5-14	6.5-14	0.54-2.5	6.5-14	5.6-27.1	100
3	$3/2$	13-16.5	13-16.5	2.16-3.5	6.5-8.25	23.3-37.9	50
$3'$	$3/2$	6.5-8.25	13-16.5	2.16-3.5	6.5-8.25	23.3-37.9	100
4	3/6	5.5-9.33	5.5-9.33	0.39-1.11	8.25-14	4.0-11.7	50
$4'$	3/6	2.75-4.67	5.5-9.33	0.39-1.11	8.25-14	4.0-11.7	100

Note: modes with prime are for half-frequency bunching. $h1$, $h2$ are harmonics for SFC and SSC. f_{BUN}, f_{RF1}, f_{RF2} are RF frequencies of the buncher, SFC and SSC respectively. E_1, E_2 are extraction energies from SFC and SSC. η is the theoretical efficiency of longitudinal matching.

Table 4.5: Comparison of two accumulation modes in CSRm

	$^{12}C^{6+}$	$^{238}U^{72+}$
Energy (MeV/u)	50	10
Injection currentPPS	2.1×10^{12}	8.2×10^{9}
Cooling time (ms)	2675	136
Multiple multi-turn injection + E-cooling		
Particles of accum.	1.0×10^{8}	2.0×10^{6}
Multi-turn injection + RF stacking + E-cooling		
Particles of accum.	1.5×10^{9}	1.1×10^{6}

Table 4.6: Acceptances in CSRe

Normal Mode	Isochronous Mode
A_h=250 π mm.mrad (ΔP/P=±0.5%)	A_h=20 π mm.mrad (ΔP/P=0.7%)
A_v=80 π mm.mrad	A_v=20 π mm.mrad
ΔP/P=2.6% (ε_h=10 π mm.mrad)	ΔP/P=0.7% (ε_h=20 π mm.mrad)

Table 4.7: SFC acceleration range and maximum energy from CSRm

h_{SFC}	h_{CSRm}	Q/A	f_{SFC} /MHz	E_{SFC} /(MeV/u)	f_{CSRm} /MHz	E_{CSRm} /(MeV/u)
1	34	0.255-0.5	6.0-11.773	4.18-16.37	6.0-11.773	305.1-915.5
1	68	0.234-0.255	5.5-6.0	3.50-4.18	11.0-12.0	262.2-305.1
3	17	0.198-0.234	14.0-16.5	2.52-3.50	7.0-8.25	193.9-262.2
3	34	0.085-0.198	6.0-14.0	0.46-2.52	6.0-14.0	38.7-193.9
3	68	0.078-0.085	5.5-6.0	0.39-0.46	11.0-12.0	32.6-38.7

Note: h_{SFC} is the SFC acceleration harmonic number, f_{SFC} is its RF frequency, E_{SFC} and E_{CSRm} are beam energy of SFC and CSRm respectively. Beam magnetic rigidity from SFC is taken 1.15Tm.

Table 4.8: Matching parameters with SFC, SSC and CSRm combination

Mode	h SFC/SSC/CSRm	f_{SFC} /MHz	f_{SSC} /MHz	f_{CSRm} /MHz	E_{SFC} /(MeV/u)	E_{SSC} /(MeV/u)
1	3/4/32	6.50-14.00	6.50-14.00	6.50-14.00	0.54-2.52	5.61-26.9
2	3/6/32	6.00-9.33	9.00-14.00	6.00-9.33	0.46-1.12	4.77-11.67

5: Announcements of the Beam Dynamics Panel

5.1 Advanced ICFA Beam Dynamics Workshops

5.1.1 Workshop on Ground Motion in Future Accelerators

Tor Raubenheimer tor@slac.stanford.edu SLAC
Andrei Seryi seryi@slac.stanford.edu SLAC

Stanford Linear Accelerator Center, November 6 - 9, 2000

The 22nd Advanced ICFA Beam Dynamics Workshop will be held at SLAC and will be devoted to ground motion and its effects on future accelerators. Ground motion and vibration can be a limiting effect in synchrotron light sources, hadron circular colliders, and electron/positron linear colliders.

Over the last several years, there has been significant progress in the understanding of the ground motion and its effects, however, there are still many problems and questions which need to be resolved including measurement techniques, classification of the motion, and modeling its effect on the accelerator.

The dedicated Workshop will be useful to collect the data, resolve outstanding issues, sharpen the contradictions, outline further studies and unify the worldwide efforts to ensure that our community would be ready to solve the challenges of the future machines.

The Workshop will be primarily focused on the following problems:

- Measurements of ground motion: methods, accuracy, interpretation, ongoing and suggested experiments.
- Interpretation and classification of ground motion: fast/slow, diffusive/systematic, etc.
- Modeling ground motion, methods to evaluate accelerator performance in terms of ground motion.
- Beam independent methods to cure ground motion effects, including passive damping, inertial stabilization, interferometry for stabilization, etc.
- Tunnel construction techniques and their influence on ground motion problems.

Web site of the Workshop:
http://www-project.slac.stanford.edu/lc/wkshp/GM2000/

International advisory committee (ICFA Beam Dynamics Panel Members):

Pisin Chen	SLAC
Weiren Chou	Fermilab
Yoshihiro Funakoshi	KEK
Kohji Hirata	Sokendai/KEK
Ingo Hofmann	GSI
Sergei Ivanov	IHEP (Protvino)
John M. Jowett	CERN
Kwang-Je Kim	ANL
Jean-Louis Laclare	SOLEIL
Helmut Mais	DESY
Luigi Palumbo	Univ.Rome/LNF-INFN
Claudio Pellegrini	UCLA
Elcuno A. Perelstein	JINR
Dmitri Pestrikov	BINP
Jie Wei	BNL
David H. Whittum	SLAC
Chuang Zhang	IHEP(Beijing)

International Program and Organizing Committee

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Norbert Holtkamp	FNAL
Michel Mayoud	CERN
Christoph Montag	DESY
Olivier Napoly	CEA Saclay
Tor Raubenheimer	SLAC
Lenny Rivkin	PSI
Robert Ruland	SLAC
Andrei Seryi	SLAC
Vladimir Shiltsev	FNAL
Shigeru Takeda	KEK
Nobu Toge	KEK
Sasa Zelenika	PSI

Local Organizing Committee

Tor Raubenheimer	SLAC
Marc Ross	SLAC
Andrei Seryi	SLAC

Registration

The registration fee for the Workshop is $100. See the Workshop web page for more details.

5.2 ICFA Beam Dynamics Newsletter

5.2.1 Aim of the Newsletter

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

5.2.2 Categories of the Articles

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

The categories of articles in the newsletter are the following:

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

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

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

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

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

   (a) Name, email address and affiliation of the author,

(b) Name, email address and affiliation of the supervisor,
(c) Name of the institution awarding the degree,
(d) The title of the thesis or dissertation.
(e) Date of award of degree. (For a while, we accept the thesis awarded within one year before the publication of the newsletter.)
(f) A *short* abstract of the thesis is also very desirable.

8. Editorial

All articles except for 6) and 7) are by invitation only. The editors request an article following a recommendation by panel members. **Those who wish to submit an article are encouraged to contact a nearby panel member**.

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

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

5.2.3 How to Prepare the Manuscript

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

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

where you can find the template also.

Please follow the following:

- Do not put comments (%) when sending the manuscript through e-mail. Instead, you can use `\comm` as `\comm{your comments}`. It is defined as \newcommand\comm[1]{}.
- Start with `\section{title of your article}`. **It is essential**.
- Then put your name, e-mail address and affiliation.
- It is *useless to include any visual formatting commands* (such as vertical or horizontal spacing, centering, tabs, etc.).
- Do not define new commands.
- Avoid TEXcommands that are not part of standard LATEX. These include the likes of `\def`, `\centerline`, `\align`, ...
- Please keep figures to a minimum. The preferred graphics format is Encapsulated Postscript (EPS) files.

5.2.3.1 Regular Correspondents

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

Liu Lin (`liu@ns.lnls.br`)	LNLS	Brazil
S. Krishnagopal (`skrishna@cat.ernet.in`)	CAT	India
Ian C. Hsu (`ichsu@ins.nthu.edu.tw`)	SRRC	Taiwan

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

5.2.4 Distribution

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

W. Chou	chou@adcon.fnal.gov	North and South Americas
Helmut Mais	mais@mail.desy.de	Europe* and Africa
Susumu Kamada	Susumu.Kamada@kek.jp	Asia** and Pacific

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

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

5.3 World-Wide Web

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

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

(which happens to be in Japan). For reasons of access speed, there are mirror sites for Europe and the USA at

http://wwwslap.cern.ch/icfa/
http://www.slac.stanford.edu/grp/arb/dhw/dpb/icfa/icfa.html

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

5.4 ICFA Beam Dynamics Panel Organization

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

Chairman K. Hirata

Chief Editors of ICFA Beam Dynamics Newsletter K. Hirata and J. M. Jowett

Editors of ICFA Beam Dynamics Newsletter W. Chou, S. Ivanov, H. Mais, J. Wei, D.H. Whittum, and C. Zhang

Distributers of ICFA Beam Dynamics Newsletter W. Chou, H. Mais, S. Kamada

Leader and Subleader of Future Light Source Working Group K. J. Kim and J. L. Laclare

Leader and Subleader of Tau-Charm factory Working Group E. A. Perelstein and C. Zhang

Leader of High-Brightness Hadron Beams Working Group W. Chou

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