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RESEARCH IN ACCELERATOR PHYSICS (THEORY)

Progress Report

May 15, 1993 - October 31, 1993

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I. INTRODUCTION

This is the Technical Progress Report of the grant DE-005-87ER40374 for the period 5/15/93 - 10/31/93. We will present a brief description of the present status, expected effort during the remainder of the project, and some of the results of our activities since the beginning of the current project.

The group started with five members including the principal investigator. Since then, one research scientist left the group at the end of August. In addition, one postdoctoral research associate will leave us in mid-November, and the last graduate student in our group will finish the doctoral work in December. As a consequence, during the second half of the current project period, there will be only two members working in the group, S. Ohnuma (P.I.) and J. Shi (Sr. Research Assoc.).

Our association with the SSC Laboratory has continued with one-month stay of S. Ohnuma in June-July, mostly working for the high energy booster group, and J. Shi's collaboration with Yiton Yan of the Accelerator Physics Group at SSCL. J. Shi stayed two months at CERN to work with its LHC group (Walter Scandale and Frank Schmidt). The collaboration with the Texas Accelerator Center, which began in 1986, finally ended in August when L. Xiu completed the measurements on HESQ (Helical Electrostatic Quadrupole).

Participation by each member, 5/15/93 - 10/31/93

1.	S. Ohnuma (P.I.)	Professor	35% (cost sharing) during academic year; 2.5 months in summer.
2.	J. Shi	Sr. Research Assoc. (SSC National Fellow)	8/01/93 - present 8/01/92 - 7/31/93)
3.	G. Wang	Research Assoc.	11/02/92 - present (*)
4.	L. Xiu	Research Scientist	5/15/93 - 8/31/93
5.	Y. Chae	Graduate RA (50%)	5/15/93 - present (**)

(*) Will leave the group on 11/11/93.

(**) Will graduate in December 1993.

II. EXPECTED EFFORT DURING THE REMAINING PERIOD

During the remainder of the current project period, from 11/01/93 to 5/14/94, we anticipate the following percentage of time two remaining members will spend:

1. Importance of Multipole Components and Their Harmonic Components in Limiting the Aperture of Superconducting Rings: Ohnuma (50%), Shi (40%)

G. Wang will spend the remaining ten days to write a report on what he has done since joining the group in November 1992. Ohnuma and Shi will try to complete the project as much as possible before the expected end of the project in August 1994. A proposal for one-time extension from 5/15/94 to 8/31/94 is being submitted and this progress report is an attachment to the proposal.

2. Development of a Transport Model for Beam Diffusion Caused by Tune Modulation: Shi (60%)

During this summer, Shi has generalized the transport theory to study the one-dimensional (horizontal) betatron oscillation in the presence of tune modulation. (See III. 3, page 4) In the remaining period of the current project period, he will continue the effort to generalize the concept of flux to understand the beam loss mechanism caused by tune modulation. The goal is to derive the dependence of loss rate on tune modulation in two-degrees-of-freedom.

Our activities will continue to the end of August 1994 if the proposal to extend the project from May 15 to August 31, 1994 is approved. The proposal has been submitted with this report as its attachment.

III. STATUS AND MAIN RESULTS

1. Final Test of HESQ (Xiu, Ohnuma)

The project has been supported mostly by the Texas National Research Laboratory Commission (TNRLC) from April 1991 to March 1993. The final results were presented at the 1993 IEEE Particle Accelerator Conference as a poster paper (DOE/ER/40374-71). Tests are still in progress but it is independent of our current grant from DOE.

2. Activities of Y. Chae at Argonne (Chae)

Chae will graduate in December this year as the final Ph.D. from our group. Specific works done by him during this period are:

a) Effects of helical insertion devices on beam dynamics.

There is an increasing interest in the utilization of circularly or elliptically polarized light for some experiments. For this, one needs helical insertion devices. One type of helical device considered is the crossed device originally conceived by Onuki. The magnetic field of crossed insertion devices is a superposition of horizontal and vertical planar devices whose field can be expressed in a simplified form

$$B_x = B_0 \sin(kz), \quad B_y = B_0 \sin(kz - \alpha), \quad B_z = 0.$$

In the range of parameters considered for a 7 GeV ring, he found by tracking the linear as well as nonlinear effects of helical devices that the overall effects are not worse compared with those of the Type-A planar insertion devices. In the course of our study, errors in tracking code RACETRACK have been identified and appropriate corrections have been made.

b) Coupling impedance of apertures in accelerator beam pipes.

This will be the main subject of Chae's dissertation containing his original ideas. The longitudinal coupling impedance of a hole in an infinite screen and of a hole in a rectangular wave guide has been evaluated. Using the variational method, he succeeded in deriving a closed form for the coupling impedance and showed the broad band nature of small hole coupling. The results were compared with the numerical calculation (MAFIA) to demonstrate a good qualitative agreement in a wide frequency range. The refinement of the variational method is still in progress.

3. New Calculation of Diffusion Rate (Shi)

In order to study the particle loss by diffusion in the presence of tune modulation, we have decided to approach the problem using an entirely new technique in accelerator physics. It is based on the theory of phase space transport which evaluates the flux across partial barriers in phase space. In this model, the dependence of loss rate on the modulation frequency and modulation amplitude can be calculated directly without resorting to time-consuming multi-particle tracking. Preliminary results we have obtained are quite promising.

(a) Rational tune values. We start with a simple case of rational tune value in one-degree-of-freedom (horizontal). Without tune modulation, particle motions are bounded by unstable manifolds of resonances which essentially define the dynamic aperture. When a tune modulation is introduced, it drives a particle across the boundary resulting in a loss. The one-turn map is now time-dependent because of the modulating tune. The dependence can be removed by modifying the map to a multi-turn map so that the motion is again periodic with many-turn period. Once this is done, one can estimate the flux on the unstable manifolds which are associated with (usually) high-order resonances. The most difficult task in this procedure is to locate the highly unstable periodic orbits corresponding to the multi-turn picture. The conventional numerical method of root-finding is not very effective. Shi has developed a very efficient algorithm for locating the closed orbits by means of a variational principle in Hamiltonian dynamics.

(b) Irrational tune values. For this case, Shi has used a sequence of rational numbers to approximate the irrational number under consideration. Calculation of the flux has shown that the loss rate remains approximately constant as the sequence approaches the irrational number. This finding has been confirmed by multi-particle trackings by computer.

The work to extend the method to two-degrees-of-freedom is in progress.

4. Integrable Polynomial Factorization for Symplectic Map Tracking (Shi)

During the previous project period, Shi developed (in collaboration with Y. Yan of the SSC Laboratory) a scheme to convert a symplectic map in the form of Dragt-Finn factorization into a product of exactly soluble Lie transformation which is associated with integrable polynomials. (See DOE/ER/40374-66; Phys. Rev. E48, 1993) Since then, Shi has improved the method such that it can now convert

a Taylor map directly, order-by-order, into the Lie transformation in the form of integrable polynomial factorization. This eliminates the necessity of going through the Dragt-Finn factorization. Advantages of the new scheme are:

1. the total number of nonlinear kicks in the final symplectic map, which is directly related to the computing time for tracking, is further reduced; for example, the sixth-order map has only 159 instead of 504.
2. elimination of the Dragt-Finn factorization procedure makes the method more accurate.

5. Physics of Magnet Sorting in Superconducting Rings (Wang, Shi, Ohnuma)

The questions we have asked are: Can we learn anything about the importance of various multipole field components in superconducting magnets from the vast accumulation of tracking results? Is it really hopeless to try to understand why some so-called seed numbers, which are used to generate certain magnet arrangements, give much better (or worse) dynamic aperture than other seed numbers? What justifications if any exist in the art of magnet sorting?

From the outset, we realized that this is an ambitious and risky undertaking. The effort may end up with a negative conclusion contributing little to our knowledge of the aperture limitation in superconducting rings.

During the past five months of our project, we have made a good start in this topic mostly due to the arrival of G. Wang in November 1992. We are now confident that some interesting results will be available for reporting at the EPAC94 in June 1994.

As the model of a ring, we have used a lattice quite similar to the high energy booster (HEB) of SSC. The total number of regular cells is 116 and each cell can contain four, six or eight dipoles. In addition, we included two long straight and four short straight sections to make the model more realistic. In order to facilitate a study of many cases, we have developed our own tracking codes. Two codes were made independently in order to test the reliability of each. With double precision on VAX and single precision on CRAY, two codes agree quite well for more than a hundred thousand turns. Usually one or two thousand turns are used for a quick survey but the maximum turn number for a few selected cases is as high as two millions.

Most of our work is with normal and skew sextupoles but the importance of octupoles is also studied. Since the dynamic aperture is rather sensitive to the choice of initial launch point in phase space, we have decided to define a linear

aperture as the shortest distance from the origin in the four-dimensional phase space (normalized) during the tracking. The linear aperture defined in this manner is relatively insensitive to the choice of launch point.

So far, we have established a definite correlation between the aperture and the harmonic components of resonance-driving integrals. This is clear from Fig. 1 where a particular form of the "figure-of-merit" calculated from some forty harmonic components is plotted as a function of linear aperture for three different situations: random, one-parameter sorting, and two-parameter sorting. The two-parameter sorting used here has been developed by G. Wang and seems to be superior to the one by M. Li (DOE/ER/40374-56). Another scheme of two-parameter sorting is now being investigated but results are not yet available.

In Fig. 2, fifty cases are compared to see the effectiveness of sorting. It is clearly seen that some cases giving a rather poor aperture in one-parameter sorting gets a substantial improvement when two-parameter sorting is applied. This suggests the significant contribution from the skew sextupole since one-parameter sorting is done for the normal sextupole. An interesting question of how one can relate this to relevant harmonic components will be studied as more examples become available.

In order to find out if an arrangement giving a good aperture in one thousand turns will maintain an equally good aperture (relatively speaking) in a million turns, we have tracked a few cases for over a million turns. One such example is shown in Fig. 3 in which the turn number is plotted as a function of linear aperture. Beyond a few hundred thousand turns, there is no substantial reduction in the linear aperture, assuring that a "good" arrangement found with one or two thousand turn tracking will remain "good" over a million or more turns.

Obviously we have many more questions to be answered. The correlation of aperture with the expansion coefficients of one-turn map is one example. We intend to pursue the study of this question in the remaining six months and, if possible, beyond that to the end of August 1994.

Fig. 2

Seed = 24

IV. OTHER ACTIVITIES

Sho Ohnuma visited KEK in Japan, Tsinghua University and Institute of High Energy Physics in Beijing, China, in May 1993. The trip report for this has already been submitted to the DOE.

He spent one month during summer at the SSC Laboratory. His work was on the chromaticity correction in HEB with b_2 (normal sextupole) changing in a complex manner during ramping. The work is being continued by Mingyang Li and Peilei Zhang,

Jicong Shi spent three months, June to August, at CERN working with the LHC group there. The trip was supported by the Texas National Research Laboratory Commission with a partial support from CERN.