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RESEARCH IN ACCELERATOR PHYSICS (THEORY)

Technical Progress Report

March 11, 1995 - August 31, 1995

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Introduction

This is the Technical Progress Report of the Grant DE-FG03-94ER40853 for the period of 03/11/95 - 08/31/95. Since we have already submitted a Technical Progress Report for the period of 05/15/94 - 03/10/95, this Technical Progress Report should be more appropriate than a Final Report for the period of 03/11/95 - 05/14/95. A brief description of the present status, expected effort during the remainder of the project, and some of the main results from our work will be presented in this report.

Participation by each member, 3/11/95 - 8/31/95

1. S. Ohnuma (P.I.) Professor 45% (cost sharing) during
academic year, 2 weeks in summer.
2. J. Shi Res. Assist. Prof. 3/11/94 - 5/14/95 70% FTE,
5/16/95 - 8/31/95 100% FTE.

During May 1995, Ohnuma visited KEK (Japan) for one week. The expenses for the trip was paid from the special university funds for research and also by KEK. The purpose of the trip was to discuss a possible future collaboration between our group at UH and the new accelerator group at KEK for the design of a high intensity proton synchrotron. This machine would be used for physics experiments (for example, neutrino oscillation) and as a spallation neutron source. It may even be a part of the future muon collider complex in Japan. KEK is going to be reorganized into three separate laboratories, two of which (high energy physics and synchrotron light source) already exist. The third laboratory will be added when the Institute for Nuclear Study (INS) of Tokyo University moves from Tanashi, Tokyo to the KEK site at Tsukuba. One of the members of this new group is Shinji Machida, who worked in our group some years ago before moving to the SSC Laboratory. Another one is Ken Takayama who was also supported by this grant as a senior research physicist. We are keeping in touch with the project director, Prof. Yoshiharu Mori of INS, so that Ohnuma can work at KEK next summer for three months or so. We feel this contact is important for the similar project in US centered at the Oak Ridge National Laboratory.

Status of the Project and Expected Effort During the Remaining Period

1. Study of tune modulation

Experiments in hadron accelerators have shown that the beam lifetime is substantially decreased when betatron tunes are modulated due to power supply ripples, ground motions, or synchro-betatron coupling. During last couple of years, we have developed the concept of chaotic transport in terms of flux across resonances to study the particle escape due to this tune modulation. It was shown that the transport theory provides a computationally efficient means of studying the particle escape and estimating the parameter dependence of the escape rate. Many puzzling phenomena observed in the beam study experiments can be understood with the transport theory.

During this project period, we have analysed the experimental results of the nonlinear beam experiments on the SPS of CERN by using the transport theory. In the SPS experiments, the particle loss rate was measured when the dominant resonance is the fifth-order resonance from sextupoles. We therefore studied the flux across the fifth-order resonance, which should characterize the particle loss rate. In Fig. 1, the flux (ζ) is plotted as a function of the modulation frequency for different modulation amplitude. It shows that the particle loss rate due to the tune modulation strongly depends on the modulation amplitude but weakly depends on the modulation frequency. This phenomenon has been observed in the SPS experiments but could not be understood without using the transport theory. As it was observed in the experiments, the effect of the tune modulation increases more than linearly with the modulation amplitude. In Table 1, a comparison is given between the amplitude dependence of the flux and the amplitude dependence of the particle loss rate measured in the SPS experiments. As the modulation amplitude ($\delta\nu$) is increased from 1.1×10^{-3} to 1.65×10^{-3} , both the flux and the loss rate are doubled. The particle loss due to the tune modulation is therefore well characterized by the flux when the modulation is weak. As $\delta\nu$ is further increased to 2.2×10^{-3} , the particle loss rate is increased by a factor of 10 while ζ is only increased by a factor of 4. This discrepancy could be due to the additional particle escape along the vertical plane in the experiments when the modulation is strong. Even though flat beams were used (ratio of the vertical to horizontal beam size is 1:10) and the

linear coupling was well corrected in the experiments, the particle escape along the vertical plane can be dominant when the modulation is strong as it was observed in the experiments [1]. The flux here has, however, only counted in the particle escape along the horizontal plane.

The results of this study have been summarized in a paper titled "Chaotic Transport in Time-dependent Symplectic maps" which has been submitted to Phys. Rev. Lett.

Table 1: A comparison of the $\delta\nu$ dependence of the particle loss rate measured in the SPS experiments and ζ . $D_{1.1}$ and $\zeta_{1.1}$ are the values of the loss rate and ζ at $\delta\nu = 1.1 \times 10^{-3}$, respectively.

$\delta\nu$ (10^{-3})	Loss rate	ζ
1.1	$D_{1.1}$	$\zeta_{1.1}$
1.65	$2 \times D_{1.1}$	$2 \times \zeta_{1.1}$
2.2	$10 \times D_{1.1}$	$4 \times \zeta_{1.1}$

2. Multi-Parameter Sorting of Dipoles for Large Superconducting Rings

The presence of unavoidable multipole errors in superconducting magnets is known to be the main cause for limiting the dynamic aperture of large storage rings. Sorting of dipoles, in which dipoles are installed in the ring according to a certain sequence based on the measured multipole errors, is a way to reduce the adverse effects of random multipole errors without an increase in the cost. In order to reduce the effects of several multipole components simultaneously, we have developed a multi-parameter sorting scheme. In this sorting scheme, the multipole components are represented by a multi-dimensional vector and the sorting is based on the normal of the vector and the Euclidean distance between the vectors. The effectiveness of this sorting scheme has been studied on a test lattice which is similar to the high energy booster (HEB) of SSC. It was found that this sorting scheme is very effective in increasing the dynamic aperture when all the multipole components up to the 7th-order are included provided that there are enough dipoles in a sorting group. Since the installation of LHC dipoles has to be planned in such a way that it will cause as little

interruption of LEP operation as possible, it is expected that a large number of LHC dipoles must be stored before the installation. The multi-parameter sorting with a large number of dipoles in each sorting group is thus possible for the LHC.

Since a large nonlinearity in the ring can lead to a strong amplitude dependence of the tunes, which could result in crossings of dangerous resonances, a weaker amplitude dependence of the tunes is desirable for a stable operation of the accelerator. We have therefore studied the effect of sorting on the amplitude dependence of the tunes in terms of the normal form analysis of the one-turn map and the direct calculation of the average phase advance during tracking. The method of normal form analysis is very effective for calculating the amplitude dependence of the tunes. The direct calculation of the average phase advance during tracking was used to check the result of the normal form analysis. Our study has shown that the multi-parameter sorting of dipoles in large superconducting rings is very effective on the reduction of the amplitude dependence of the tunes and the improvement of the linearity of the phase-space region occupied by the beam.

Currently, we are preparing a paper to summarize the main result of this study. The paper is to be submitted to Particle Accelerators. In the remaining project period, we are going to apply this sorting scheme on the LHC lattice.

3. Integrable Polynomial Factorization for Symplectic Map Tracking

For large storage rings, extensive computer simulations are necessary to investigate the long-term stabilities. The conventional approach in which trajectories of particles are followed element by element through accelerator lattice is rather time-consuming for these studies. A substantial computational as well as conceptual simplification is achieved by studying the stability with symplectic one-turn maps. The major difficulty in map methods is the construction of symplectic maps which can model actual machines with desired accuracy and can be directly used for tracking. Recently, methods are being developed to convert the Taylor map into a product of Lie transformations associated with integrable polynomials. It has been shown that integrable polynomial factorization is quite promising for the long-term tracking study. During this project period, we have made a computer program which can be used to construct the integrable polynomial factorization map either

directly from an one-turn Taylor map or from the Dragt-Finn factorization of an one-turn map. Currently, we are debugging and testing this program. During the remaining project period, we will study the usefulness and effectiveness of the integrable polynomial factorization scheme on the long-term tracking study in large storage rings. A comparison study of the dynamic aperture of the LHC lattice by using the integrable polynomial factorization map and by element-by-element tracking will be conducted.

Fig. 1. ζ as a function of the modulation frequency for different modulation amplitude when $\nu_0 = 0.2114$ (solid curves). Asteroid points are the scaled rate of the particle loss due to the modulation estimated from the multi-particle tracking study. The scaling was done in such a way that the loss rate equals to ζ at $\omega = 1/241$ and $\delta\nu = 10^3$. The points plotted along each solid curve are for the same $\delta\nu$ as that of the curve which is indicated on the curve.