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Publication Date

1993-05-01

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SLAC-PUB-6150
SLAC/SSRL-0025
LBL-34031
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STATUS OF THE VARIABLE MOMENTUM COMPACTION STORAGE RING EXPERIMENT IN SPEAR[*]

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Abstract

Variable momentum compaction lattices have been proposed for electron-positron colliders and synchrotron radiation sources to control synchrotron tune and bunch length. To address questions of single particle stability limits, a study has been initiated to change the SPEAR lattice into a variable momentum compaction configuration for experimental investigation of the beam dynamics. In this paper, we describe a model-based method used to transform SPEAR from the injection lattice to the low momentum compaction configuration. Experimental observations of the process are reviewed.

I. INTRODUCTION

The recent interest in low-momentum compaction electron-beam colliders and storage rings arises from their inherent short-bunch characteristic. The short bunches translate directly to higher luminosity, in the case of colliders, or brighter and potentially coherent synchrotron radiation in the case of storage rings.[1,2]. Hence, the performance of future accelerators and synchrotron light sources may be enhanced by operating in the low momentum compaction regime. The potential gain in performance has motivated a collaboration between SLAC/SSRL and UCLA to investigate the possibility of modifying SPEAR to operate in the low momentum compaction regime and to experimentally study the single-particle dynamics in this regime. Similar experiments are being conducted at UVSOR[3] and NSLS.[4]

The current SPEAR lattice configuration, designed for low emittance and high brightness operation, has tunes of 6.818 and 6.721 in the x and y planes, respectively, and a momentum compaction of 0.017. The natural one-sigma bunch length is approximately 5 cm long. Some future light sources and colliders will likely have bunch lengths in the millimeter to sub-millimeter range. To simulate the short-bunch dynamics of these machines, the SPEAR bunch length must be reduced by a factor of 10 or more. Consequently, the momentum compaction value must be reduced by a factor of at least 100, since the bunch length is proportional to the square-root of the momentum compaction. We expect, however, that the effects of reducing the momentum compaction on either dynamic aperture or bunch stability to manifest themselves even before this is achieved. One of the main goals of our experiment is to study these effects.

II. LOW MOMENTUM COMPACTION LATTICE FOR SPEAR

a. Single-Configuration Approach: Direct Injection

To achieve low momentum compaction without significant hardware changes, the designers have shaped the dispersion function around the ring so as to yield a low average dispersion value. Since SPEAR was originally designed as a collider, and is now operated as a synchrotron light source, the current lattice inherits two low-beta insertions. The forced oscillation of the dispersion function and the quadrupole geometry in the low-beta insertions produce a relatively large mismatch in the beta-functions. Thus, the physical aperture is a concern for our low momentum compaction lattice. A low momentum compaction magnetic lattice has been developed for SPEAR for direct injection testing by carefully matching the dispersion function along the arcs to that of the low-beta insertions.[5] This lattice has a relatively small dynamic aperture, approximately +/-10 sigma, with full transverse coupling. The beam stay-clear for this lattice is acceptable for testing, despite the beta-function mismatch. The tunes are 4.42 and 7.28 for x and y, respectively.

Even though the lifetime of stored beam in this lattice was short (on the order of minutes), the maximum stored current reached 0.5 mA. Unfortunately, the current was below the detection limit of the BPM system, so orbit measurements and corrections were not possible. One cause of the short lifetime could have been modelling errors in setting up the configuration. Calculations have shown low momentum compaction lattices to be very sensitive to quadrupole strength values (See below). Small discrepancies between the machine and its model could mean the difference between a positive momentum compaction value and a negative one.

b. Multiple-Configuration Approach: Magnet Ramping

An alternative to direct application of the single-configuration approach is the multiple-configuration procedure. Here, we apply small changes in the strength of the quadrupoles to take SPEAR slowly from its operating low emittance configuration to a final low momentum compaction lattice. The incremental changes in the quadrupole strength are accomplished through a series of configuration ramps between intermediate lattices. This method avoids the complications associated with a direct insertion and allows the opportunity to study effects that may occur during the process of reducing the momentum compaction. We have produced 100 intermediate lattices for the purpose of testing this approach. The lattices were created by

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[*] Work supported by Department of Energy contract DE-AC03-76SF00515.

Presented at the Particle Accelerator Conference (PAC 93), Washington, DC, May 17–20, 1993.

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MAD[6] with local constraints placed on the machine functions and tunes. A total of eight contraints were used, corresponding to eight families of quadrupoles in SPEAR. Figures 1a and b show the machine functions for two of these lattices. Figure 2 shows the variation of the momentum compaction value along this path. Notice the sensitivity of the lattices to quadrupole strength near the end point. The end lattice has characteristics similar to those of the low momentum compaction lattice used in the direct injection test. The tunes, however, are held constant at the injection tunes of 6.818 and 6.721 in the x and y planes, respectively.

A magnet ramp test of SPEAR through these intermediate lattices was conducted recently. Initially , a current of 3.5 mA was stored at 2.3 GeV in the low emittance configuration. To gain aperture, the energy was then reduced to 1.8 GeV to decrease emittance. Next, we down loaded the quadrupole strength values for each new configuration and slowly ramped through successive lattices. This process was successful until we reached intermediate lattice number 25. At this point, partial beam loss occurred due to head-tail instantiability, caused by the y-chromaticity becoming negative. As we continued ramping along the path with 0.23 mA current (below the head-tail threshold), the beam was completely lost at intermediate lattice number 30. This time, we believe the beam was lost because of the dynamic aperture limitations, as confirmed by simulations using the KRAKPOT[7] tracking code.

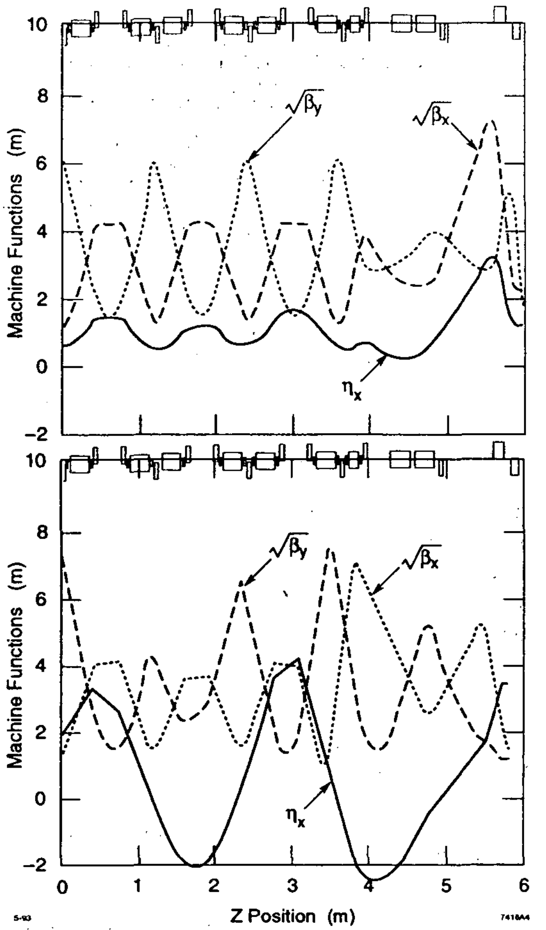

Figure 1. Machine functions of (a) SPEAR low emittance lattice, (b) lattice at the end of the multi-configuration path.

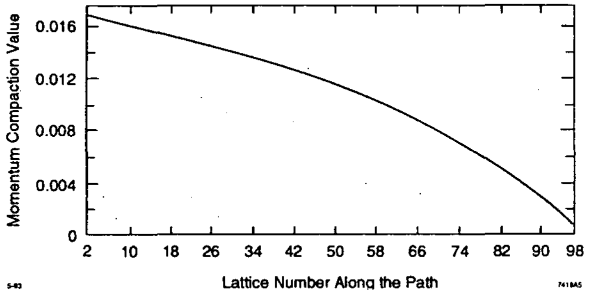

Figure 2. Calculated momentum compaction values along the multi-configuration path.

III. WORK IN PROGRESS

a. SPEAR Model Upgrade

Thus far, we have explored limits that may impact future low momentum compaction experiments in SPEAR. In particular, both the direct injection and multi-configuration tests have indicated the need for a more accurate model. Since our initial tests, progress has been made toward in-situ calibration of the SPEAR model.[8]

b. Dynamic Aperture Improvement

Another problem apparent from the simulations is the limit on dynamic aperture. Since the lattices used in the injection test as well as the final lattice in the multi-configuration path experiment have a relatively small dynamic aperture (+/- 10 and 6 sigma, respectively), we are planning to employ octupoles to redue the amplitude-dependent tuneshift. The effect on dynamic aperture is shown in Figs 3a and b. Simulations show that octupoles can increase the dynamic aperture significantly. We also continue to explore other multi-configuration paths. To aid this effort we have developed a multi-step path design program which can automate this process by fitting the momentum compaction value directly.[9]

c. 6-D PLM System

To enhance our on-line lattice diagnostic capability, a six-dimensional Phase-space Linearity Monitor (PLM)[10] has been developed and is being tested in SPEAR. This system enables us to investigate resonances that develop along the multi-configuration path by measuring the beam centroid coordinates (x,x',y,y',dE/E,t) at every turn. The PLM will be used to characterize and verify the dynamic aperture and to study nonlinear effects[11,12] in future experiments. A schematic diagram of the PLM system is shown in Fig. 4.

4. CONCLUSION

The complicated task of developing a low momentum compaction lattice for SPEAR with the current hardware configuration has led us to explore

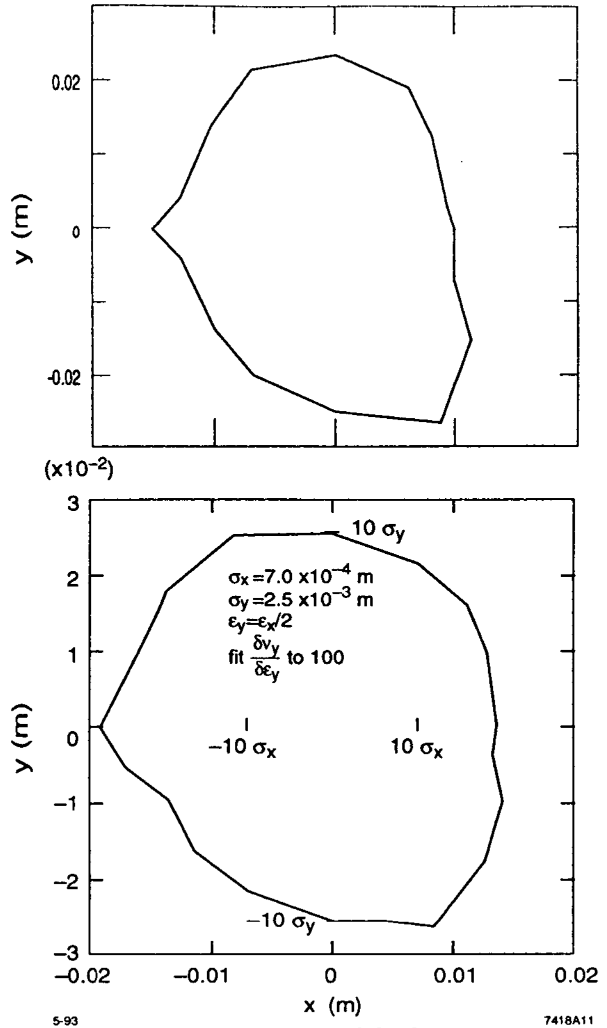

Figure 3. Dynamic aperture of the low momentum compaction lattice used in the direct injection test, (a) tracking without octupoles, and (b) tracking with octupoles.

alternatives. The experience gained from these initial tests has helped to determine the limitations of the storage ring and to prepare the necessary tools and procedures for performing future experiments including a SPEAR model upgrade, study of octupoles for dynamic aperture improvement and the PLM monitor system for on-line lattice diagnostics. We hope that these new tools and procedures will aid in achieving the goal of operating SPEAR in a low momentum compaction regime.

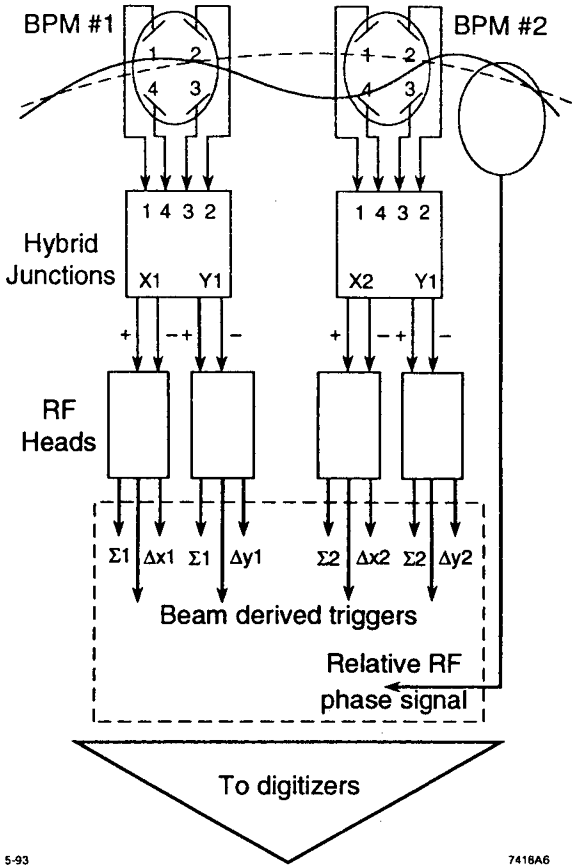

Figure 4. Block diagram of the 6-D PLM system.

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