SPEAR 3 INJECTION KICKER*

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Abstract

The design of the SPEAR 3 injection kicker system is presented. This system will include three kicker magnets and their associated pulsers. The magnet design is based on the DELTA kicker magnets, which present a low RF impedance to the beam, and are relatively straightforward to construct. The pulsers use cascaded IGBT stages that are based on the modulator pulsers developed by a SLAC/LLNL collaboration for the NLC. Design considerations and the results of prototype tests will be discussed.

1 INTRODUCTION

SPEAR 3 is a major upgrade to the SPEAR storage ring to be completed in 2003 [1]. The injection line into SPEAR will remain unchanged, but new kicker magnets will be installed as part of the SPEAR 3 vacuum system. SPEAR 3 is being designed to accomodate "top-off" mode for constant current loads in the machine. Therefore, repeatability and reliability are important in the choice of components.

2 INJECTION BUMP

The SPEAR 3 injection bump uses three magnets and spans two cells of the standard DBA lattice. The first kicker, K1, is located slightly more than $3\pi/2$ in phase advance in front of the injection septum. A deflection of 2.2 mrad generated by this kicker positions the stored beam the required 22 mm off axis at the injection septum. The final kicker, K3, deflects the beam back on axis at the end of the bump. The middle kicker, K2, located immediately in front of the septum, introduces the 1.2 mrad deflection angle required to close the bump.

K1 and K3 are constrained in position by the magnets of the cells and are positioned as closely together as possible to minimize the required strength of K2. K2, of course, must be next to the septum and it is the only kicker which is constained in size by the adjacent hardware. It has been designed to have the maximum allowable length of $.6$ m.

3 KICKER MAGNET DESIGN

The kicker magnet design is a tradeoff among several parameters, most notably beam impedance, field strength, field uniformity, and ease of construction.

3.1 Beam Impedance

In a storage ring, the kicker operates only at a very low duty cycle. Therefore it is important that the design of the kicker does not have any major negative impact on the stored beam. For this reason, the kicker design should have a very low beam radio frequency (RF) impedance. The model for such a design is a grounded stripline kicker that has been developed at DELTA [2].

One important contribution to beam impedance is the broadband impedance, one which spans a large frequency range. Typically, such large impedances are caused by abrupt transistions or discontinuities in the vacuum chamber. A ferrite loaded kicker requires the insertion of a conductively coated ceramic piece in the vacuum chamber to avoid these discontinuities. Experience with such chambers has shown it is often difficult to guarantee uniform conductivity along this piece. Also, beam induced fields tend to erode this coating at the ends of the ceramic chamber.

This kicker design is entirely metallic and its cross section conforms to the shape of the beam chamber which, in the case of SPEAR 3, is approximately elliptical, with a major diameter of 42 mm and a minor diameter of 16 mm. Because of this shape, the beam impedance is dominated by the top and bottom walls. The continuous path for the image current on these walls is responsible for the low kicker beam impedance. The two kicker striplines are on the side walls. A gap separates them from the rest of the chamber at the upstream end as well as the top and bottom. The kicker is powered by a bipolar pulse; positive current goes in one strip while negative current goes into the other. The downstream end of the kicker, where the striplines meet at the continuation of the vacuum chamber, is ground.

The other type of beam impedance to avoid is a higher order mode (HOM) resonance. MAFIA calculations have predicted a possible resonance at ~ 4.2 GHz. Our colleagues from LBL will measure the strength of these modes for us. Provisions will be made to damp any strong modes.

3.2 Field Strength and Uniformity

The goal for a low beam impedance competes with that for a strong uniform kicker magnetic field. The larger the image current paths, the lower the beam impedance; the larger the gap, the greater the strength and uniformity of the kicker field. A 1 cm wide image current path separated by 1.8 cm from the striplines, is an acceptable compromise between the the two goals. This geometry results in a loss factor of $.1$ V/pC and a stripline impedance of $76\ \Omega$.

The maximum strength of the required field is set so that the kicker can inject at 3.3 GeV. (Even though the SPEAR

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3 design energy is 3 GeV, all components are designed for the higher energy to provide possible future flexibility.) These field strengths are 20 mT in K1 and K3, and 22 mT in K2.

In order to decrease the required current needed to obtain this field, the half width of the kicker was decreased from 42 to 30 mm. This width exceeds that of the septum adjacent to K2 and there is sufficient room for a smooth transition between 42 and 30 mm. Because of the aspect ratio of the chamber, this change in width is not crucial to the beam impedance. The calculated field varies $\pm 6\%$ over the transverse dimension.

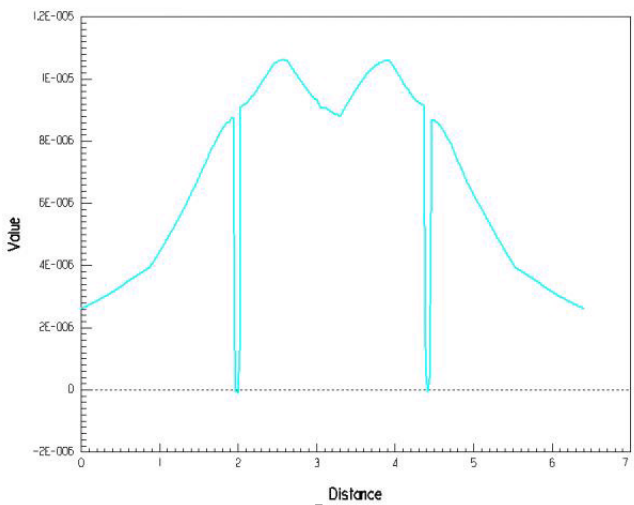

Figure 1: Magnetic field (per Ampere) profile calculated by MAXWELL.

3.3 *Construction*

The prototype kicker is copper inside of a cylindrical stainless steel vacuum chamber. Copper was chosen for its good thermal and electrical conductivity. The cross section of the striplines is C-shaped to match the vacuum chamber profile. This shape minimizes the sag of the long striplines. Stainless steel water tubing welded to the striplines provides additional strength for the striplines as well as cooling. The water tubes enter and exit the kicker at the downstream (grounded) end of the kicker. The image current paths are also copper in the prototype kicker. Water tubing is welded to these strips for cooling.

The top and bottom image current strips and the side striplines are constrained transversely but not longitudinally to allow for thermal expansion. The image current strips slide in a channel connected to the upstream vacuum chamber flange; RF spring fingers guarantee good electrical contact between the two. The striplines are transversely constrained by the assembly that attaches to the vacuum feedthroughs. A welded bellows attached to this assembly allows longitudinal expansion.

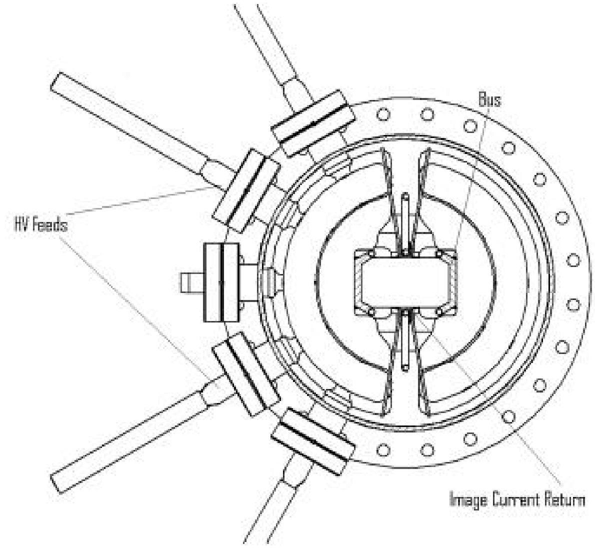

Figure 2: Cross-sectional view of the upstream end of the kicker. The feedthroughs, striplines, image current strips and field shaping fins are visible.

The image current strips also have large metallic fins welded along their length that extend out to the wall of the external cylinder. These fins shape the pulsed field lines to force them to go inside of the beampipe. The prototype image current strips are made from copper, but the softness of the copper makes it difficult to hold the desired tolerances over the length of the finished strip. We are considering making the final strips from stainless steel and copper plating their inside walls.

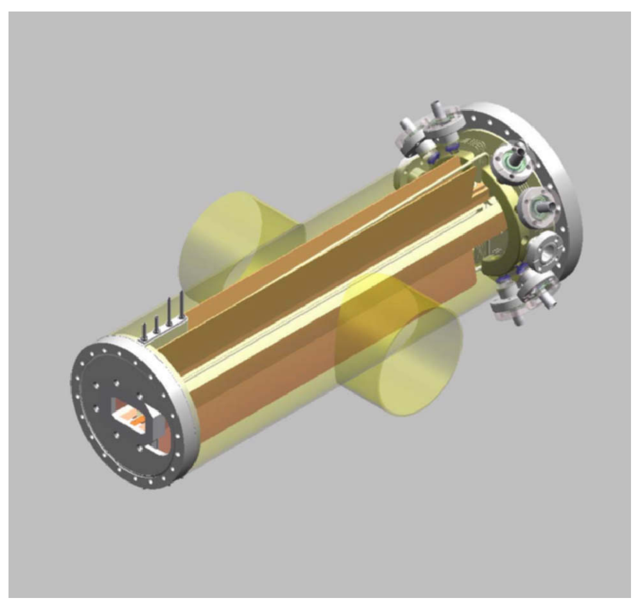

Figure 3: Assembly drawing of kicker. Note that enclosing stainless steel cylinder is transparent in this drawing.

4 KICKER PULSER DESIGN

The kicker pulser [3] is a design derived from technology that has been developed by a SLAC/LLNL collaboration for the NLC. The pulser uses individual IGBT assemblies each of which quickly discharges its individual storage capacitor through a transformer into the transmission line load. The individual assemblies are stacked in series to increase the total load voltage and, if necessary, can be stacked in parallel to increase the current.

As noted above, each kicker needs a bipolar pulse; a positive pulse for one stripline and a negative pulse for the other. These matched pulses are obtained by running the two transmission lines through the Finemet core in the IGBT stack in opposite directions.

Multiple $22\ \Omega$ transmission lines are run in parallel to reduce the transmission line impedance to the value needed to obtain the desired kicker currents, 2.4 kA for K1 and K3 and 2.6 kA for K2. In order to obtain identical pulse risetimes from the three kickers, the total cable impedances for K1 and K3 are double that for K2. This is the ratio of the kicker inductances, which is set by the ratio of the kicker lengths. The pulse length, ~ 780 ns, the SPEAR 3 revolution period, sets the time duration that each switch is on. The cable lengths are set so that the reflections from the cable-stripline mismatch do not arrive at the pulser until after it is turned off.

5 RESIDUAL KICKER OSCILLATIONS

SPEAR 3 is intended to ultimately run in “top-off” mode, in which beam is incrementally added to the stored beam so that the total current is kept nearly constant. One goal of such operation would be to make a perfectly closed bump that would allow the injection process to be transparent to the synchrotron light users. From the standpoint of the injection kicker system, this requires all magnets and pulsers to be matched.

This also places a requirement on the transverse uniformity of the kicker field strength. The working plan for the SPEAR 3 fill pattern is to fill $\frac{3}{4}$ of the ring uniformly, followed by a gap. It is not technically feasible to develop a kicker with rise times less than the 2 ns bunch spacing, so that along the bunch fill the various bunches will sample the kicker waveform at different amplitudes. This is not important for K1 and K3, since, for a closed bump, the beams will always pass through the center of the kicker.

This is not true for K2. In that magnet, as the pulser waveform increases, the beam is kicked further out from the center of the magnet. The strength of the K2 kick on the beam is then a product of the instantaneous strength of the pulse and the field gain at the transverse location of the bunch in K2. Transverse non-uniformity of the kicker gain will cause a mismatched bump and residual oscillations around the ring.

But the kicker nonlinearities are not the only problem. Since the SPEAR 3 injection bump spans two complete standard lattice cells, the nonlinear contributions of these cells must also be calculated. Each of these cells has four sextupoles, each of whose kick depends on the offset of the beam from the axis.

Tracking, using the MAD accelerator code, was carried out to calculate the maximum residual oscillation amplitude of any bunch in the ring during injection. The result was an oscillation amplitude, with respect to a $\beta = 10$ m, of 1.4 mm. This oscillation amplitude caused by the sextupoles removes the requirement for perfect uniformity of the kicker field.

The sextupole effect can be minimized, if one is willing to individually power the sextupole magnets within the kicker bump. Each cell has two SF and two SD magnets, symmetrically placed within the cell. The beam cannot be stored with these magnets off, but one can keep the first order chromatic effects of the cell invariant by rearranging the strengths of the sextupoles within the two cells. The kicker bump is not symmetric, so by shifting as much possible field, within the magnet design limits, to the magnets at which the bump is smallest, this oscillation amplitude can be reduced by about 25%. The amplitude can be further reduced if one is able to decrease the chromatic correction in those two cells. There are now no plans to individually power these sextupoles.

6 STATUS

A prototype version of the 1.2 m kicker has been built and is being tested. The kicker is very satisfactory from a mechanical standpoint. As noted above, the image current paths may be changed from copper to copper-plated stainless steel in order to strengthen them. The first pulser has been built and run, at reduced power, into both a resistive load and the prototype magnet. The field strength plots on axis match the calculations. Subsequent tests will map out the transverse field profile. Minor work still needs to be done to improve the pulse rise and fall times. The beam impedance of the magnet will next be measured by our colleagues at LBNL. After that, full power tests will be performed with the pulser and magnet.

7 ACKNOWLEDGEMENTS

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8 REFERENCES

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