Technical Note

Amman, April 10, 2007
Note: **I-3**

Injection Kicker Magnet Design for SESAME Storage Ring

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I. Introduction

In SESAME electrons are transported from the 800 MeV Booster to the Storage ring and will be accumulated at 2.5 GeV. The injection process for the storage ring accomplished with a four kickers scheme with maximum strength of 3.5 mrad. The design of four kickers will be identical window frame with the ferrite yoke and with the maximum strength of 3.9 mrad at injection energy. The coating thickness over the ceramic chamber is optimized to 2 μm in order to decrease the field attenuation and thermal stresses at the designed pulse duration. The report on the general electromagnetic design of kicker magnets are given.
In principle injection into SESAME storage ring can be done successfully with high efficiency 90%, nevertheless a 100% efficiency can be achieved in many ways. As the oscillation amplitude of the injected beam is concerning, injection with angle or with different tune could be best cases for small oscillation amplitude. A kicker pulse duration of 1-1.5μs is preferable [1,2].

II. Kicker Specification

Four kicker magnets are required for injection process into the SESAME storage ring. The magnets have identical specifications and are expected to produce identical magnetic fields. Therefore they have the same electrical, mechanical and magnetic design. Each kicker magnet is to produce a maximum field of 0.031T in order to make a transverse horizontal kick of 3.5 mrad. The overall half period of sine wave current pulse is 3 μs, but the possibility of smaller period to 1.5 μs half sine wave or decay type pulse waveform also has been considered in the design of kicker magnet. The latter mainly depends on the possibility of having a suitable pulsed power supply. Figure.1 shows the layout of injection kickers in the storage ring.

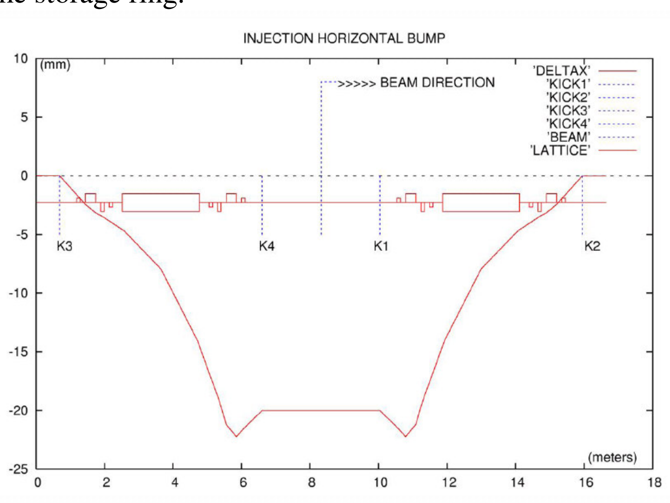

Figure.1 SESAME injection horizontal bump scheme

The kickers strengths for a 20 mm bump are given in table.1 for the linear(without sextupole) and nonlinear (with sextupole) cases. The maximum kick required for kicker K3 is 3.46 mrad is the base for the design of identical kicker with strength of 3.5 mrad.

Table.1 Nominal injection kicker strength for the storage ring

Strength (mrad)	K1	K2	K3	K4
Without sextupole	-3.16	-3.39	-3.39	-3.16
With sextupole	-3.09	-3.46	-3.46	-3.09

The magnets are of a ferrite window-frame design with a single plate conductor on each side. The conductivity of the ferrite yoke is interrupted by putting two copper plates 1mm thick in the center of the top and bottom of the window frame. This copper plate does not influence the magnetic field created by conductors but increases the reluctance of the magnetic path, and thus decrease the flux which couples the beam. The vacuum chamber is made of ceramic with 2μm Ti coating. The optimization of the coating thickness has been carried out and will be presented in section III and IV. Fig.2 shows the magnetic field density of x and y coordinates.

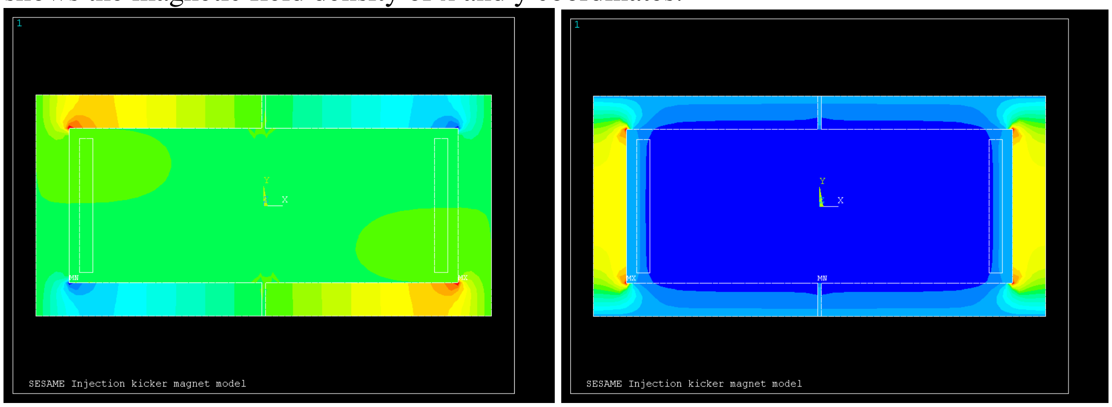

Figure.2 Magnetic field density, Bx(left) and By(right) of the kicker magnet.

The static analysis of the magnetic field in 2D carried out shows the maximum field of 0.3T which is far less than the saturation field of ferrite at 0.46 T. Fig.3 shows the 2D static electromagnetic analysis.

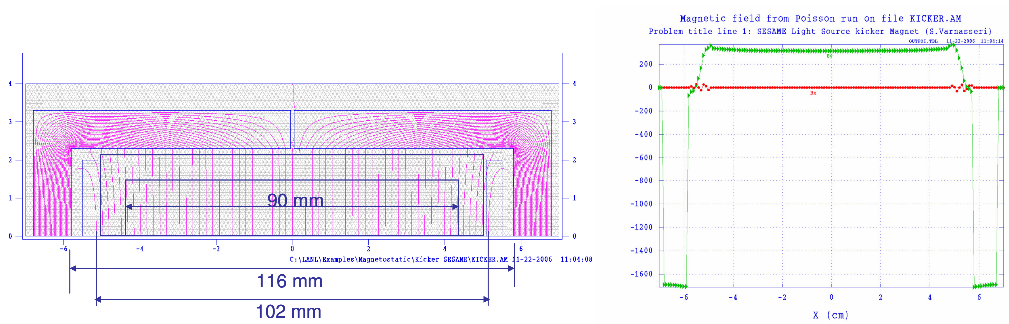

Figure.3. 2D static electromagnetic analysis of the kicker magnet and the transverse field

3D static field analysis also has been investigated in order to have a clear idea of the magnetic length of the kicker magnet (see fig.4)

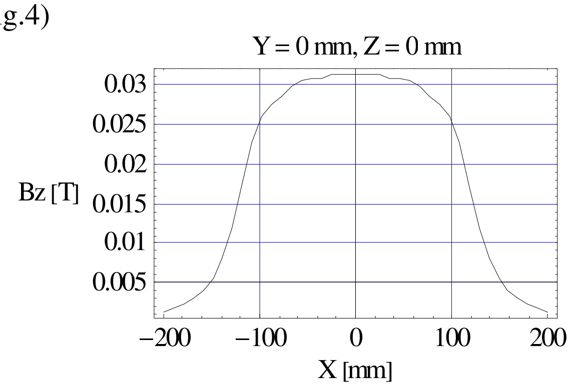

Figure. 4 Longitudinal magnetic field on axis

III. Ceramic Coating Optimization

In order to avoid strong eddy currents which would prevent the excitation field penetrating to the beam, it is necessary for pulsed magnets to use ceramic chambers. For SESAME injection kickers a thin titanium coating will cover the inner side of the ceramic chambers to minimize the impedance seen by the beam and to avoid the accumulation of charge on the ceramic. Ceramic chamber of SESAME kicker has rectangular cross section with an aperture of HxV=90x32mm^2 and a mean alumina thickness of 6mm. The magnetic length of kicker is 300mm. According to S.H.Kim calculations[3], the analysis of the penetrated field (B_{int}) through the coating of a rectangular ceramic aperture and the thermal analysis of various coating thicknesses[4] together with the effect on the injection process gives the optimal value for the coating thickness for the kicker. Figure.5 shows the field attenuation and effective pulse shift for different coating thickness of SESAME kickers. For 2µm titanium thickness the attenuation of the magnetic field is 5% and the beam will be affected by the kicker field during 5 revolution periods, while for 3µm titanium coating the attenuation of the magnetic field is 10% and the beam will see the kicker field during 6 turns. Fig.6 shows the injection efficiency for two various thicknesses. In both cases the injection with less than 1 mrad angle is possible which gives an efficiency of more than 99.7%.

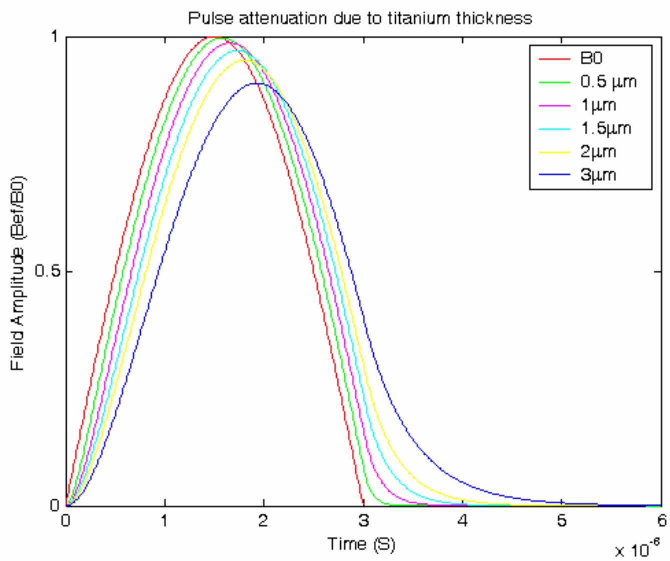

Figure.5. Injection kicker pulse attenuation for various coating thickness

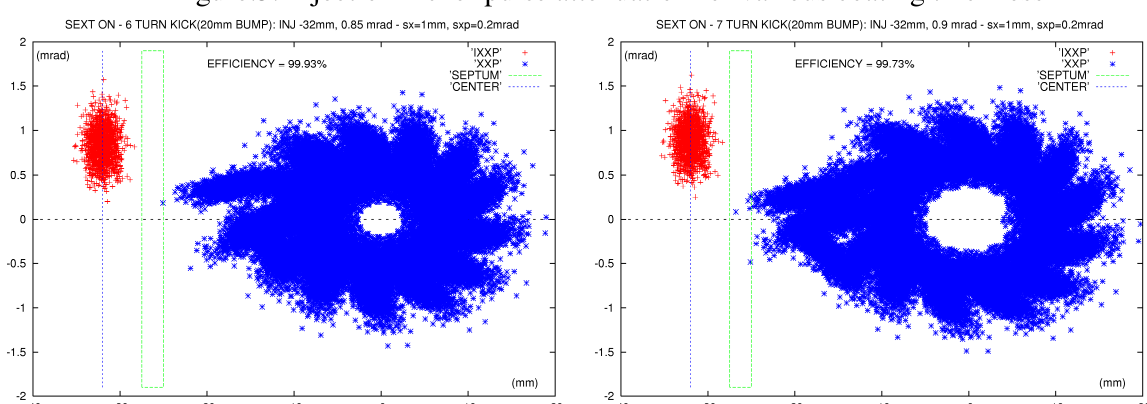

Figure.6. SESAME Injection with 2µm Ti coating thickness (left) and 3µm Ti coating thickness (right)

IV. Deposited Power

Deposited power in the titanium coating due to stored beam analysis has been carried out. The bunch length is assumed 10.7 ps at the injection energy and the nominal bunch current is 2mA. This is the worst case scenario form the point of power deposited in the titanium-ceramic structure. The coating of the chamber wall is assumed to have uniform surface resistivity with conductivity of 2×10^6 S/m [4]. Fig.7 shows the deposited power due to stored beam in titanium coating with various thicknesses.

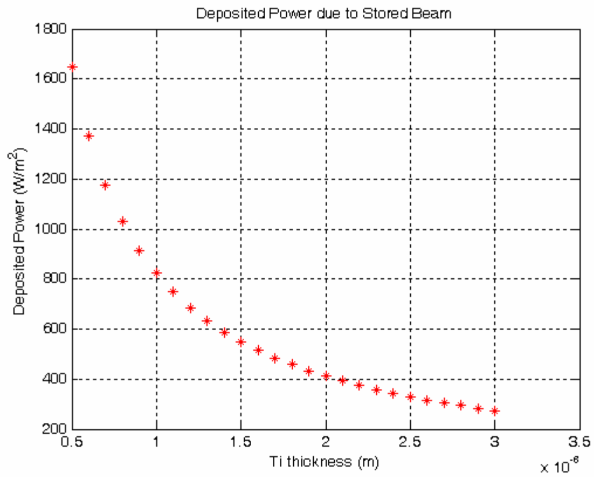

Figure.7. Deposited power in titanium coating at injection energy

V. Thermal Analysis

Thermal analysis for various titanium thicknesses have been carried out in [5]. There were three different heating loads associated with the different titanium layer thickness value. Very thin part of the kicker was modeled to assure that symmetry is a valid assumption along the center of the kicker. This means that the heat transfer in the longitudinal direction is zero. Free convection heat transfer from the outer walls of the ceramics was assumed. The stagnant air convection heat transfer coefficient has been taken as 5 W/m^2 at 25^0 C room temperature. The ANSYS analysis shows that the maximum temperature for the 1 µm titanium thickness is 163^0 C on the middle of the kicker inner surface (fig.8), for the second case of 2 µm titanium thickness the maximum temperature was 92^0 C. The various chamber temperature at different heating loads at injection and full energy are given in table2.

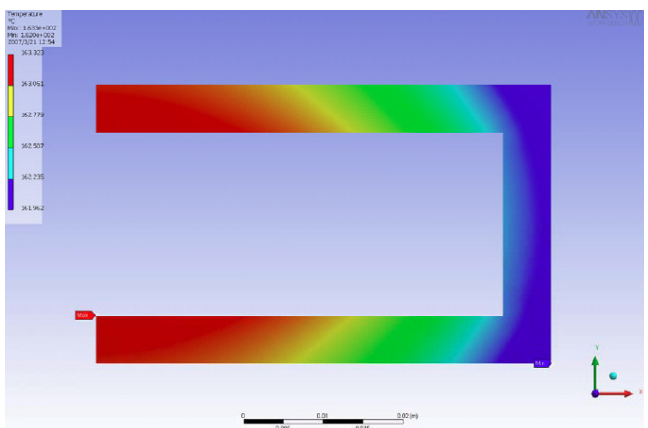

Figure.8. Temperature distribution for 1µm titanium layer thickness

Table.2 Various temperature at different heating loads

Coating Thickness (µm)	Temp. at 800GeV(^{o}C)	Temp. at 2.5GeV(^{o}C)	Power Density Deposited at 800MeV (W/m^2)	Power Density Deposited at 2.5GeV(W/m^2)
1	163	64.5	820	235
2	92	43.5	400	110
3	70	37.6	275	75

VI. Kicker parameters

Overall injection kicker parameters are given in table.3. The magnet has single coil conductor without any water cooling assembly and is kept outside vacuum.

Table.3 Injection kicker various parameters

Deflection Angle (mrad)/ Max	3.5 / 3.9
Magnetic Field (T)	0.031
Magnetic Length (cm)	30
Pulse duration (µS)	3 (1.5-2)
Magnet Material	Ferrite Yoke / Ceramic Chamber
Aperture Dimension (mm2)	46×116
Conductor Dimension (mm^2)	4×40
Magnet Resistance (mΩ)	0.1
Magnet Inductance (µH)	0.90
Current (A)	1160

VI. Conclusion

The electromagnetic specifications and general mechanical dimensions of kicker magnets have been presented and optimum titanium coating thickness has been found to be 2µm. The usage of shorter pulsed is a matter of power supply and using 1.5-2 µs pulse does not have major effect on the current kicker design, but on the PS specifications. The titanium maximum temperature rises to 92^0C at injection energy. This high temperature will be cooled down if we apply a forced convection to the kicker during injection time.

VII. References

[1] G. Vignola, "SESAME Tech committee talks" Dec. 2006, Amman

[2] M.Attal, "800 MeV Injection" SESAME Tech Notes, I-2, June 2006

[3] S.H.Kim "Calculation of pulsed kicker magnetic field attenuation inside beam chambers", APS, US ,Jan. 2001

[4] R. Nagaoka et al. "Recent Studies of Geometric and Resistive-wall Impedance at SOLEIL", EPAC06, Edinburgh

[5] M.Shehab, "FEA Thermal Analysis for SESAME kickers" Internal Reports. March 2007