# DESIGN OF INJECTION PULSED MAGNETS FOR SESAME RING

S.Varnasseri*, G.Vignola, M.Shehab, SESAME, c/o UNESCO Amman Office, P.O. Box 2270

*Abstract*

In this paper the SESAME† storage ring injection pulsed magnet system is described. The injection process in the SESAME storage ring requires septum and kicker magnets. In this paper we discuss the geometrical and magnetic field requirements for septum and kicker magnets and present the results obtained from magnetic field analysis and also the optimization of titanium coating for the injection kicker chambers. The final specification for thin septum and injection kickers are also presented.

## INTRODUCTION

In SESAME the electrons are injected from a 20 MeV microtron into an 800 MeV booster synchrotron, with a repetition rate of 1 Hz. The 800 MeV beam is transported through the transfer line to the main storage ring and after accumulation, accelerated to 2.5 GeV [1]. The injection process for the storage ring is accomplished with a four kickers scheme. The design will be identical for the four kickers: window frame with ferrite yoke and with a maximum strength of 3.9 mrad at the injection energy. The coating thickness over the ceramic chamber is optimized to 2µm in order to decrease the field attenuation and thermal stresses at the designed pulse duration. The injection thin septum is a C-type direct driven with laminated iron in air.

## KICKER MAGNET

Four kicker magnets are required for the injection process into the SESAME storage ring. The magnets have identical specifications and are expected to produce identical magnetic field shape. Therefore they have the same electrical, mechanical and magnetic design. Each kicker magnet must produce a maximum field of 0.035 T in order to make a transverse horizontal bump of 20 mm. The overall half period of sine wave current pulse is 3µs, but the possibility of smaller period to 1.5µs 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. Fig.1 shows the layout of injection kickers in the storage ring. The kicker's strengths for a 20 mm bump are given in Tab. 1, for the linear (without considering sextupoles) and nonlinear (with sextupoles) cases.

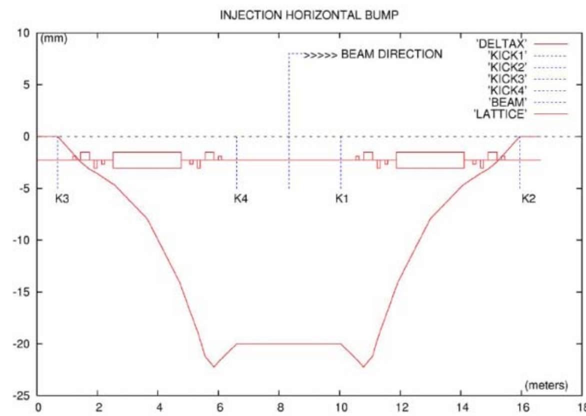


Figure 1: SESAME injection horizontal bump scheme.

A maximum kick of 3.46 mrad is required for kicker K2 and K3, therefore we took as maximum kicker strength design a value of 3.5 mrad. 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 to the beam. The vacuum chamber is made of ceramic with 2µm inner Ti coating.

Table 1: Injection Kicker's Strength for 20 mm Bump.

| 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 static analysis of the magnetic field in 2D shows a maximum field of 0.3T which is far less than the saturation field of the ferrite at 0.46 T. Fig.2 shows the vertical magnetic field $B_y$ distribution of the magnet.

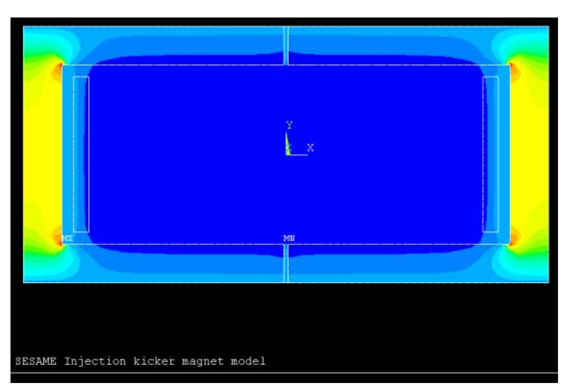


Figure 2: Magnetic field density By of the kicker.

* s.varnasseri@unesco.org.jo

† Synchrotron-light for Experimental Science and Application in the Middle East is an International Organization founded by UNESCO according to the model of CERN. Jordan is the host State and has granted special privileges to SESAME. It involves at the present the following Member States: Bahrain, Cyprus, Egypt, Israel, Jordan, Pakistan, Palestinian Authority and Turkey. Iran is in the process of finalizing its formal membership.

### *Ceramic Coating Optimization*

In order to avoid strong eddy currents which would prevent the excitation field penetrating the chamber, it is necessary for pulsed magnets to use ceramic chambers. For SESAME's 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. The ceramic chamber of the kickers has a rectangular cross section with an aperture of HxV=90x32mm$^2$ and a mean alumina thickness of 6 mm. The magnetic length of the kicker is 300 mm. According to S.H.Kim calculations[2,3], the analysis of the penetrated field ($B_{int}$) through the coating of a rectangular ceramic aperture and the thermal analysis of various coating thicknesses together with the effect on the injection process gives the optimal value for the coating thickness for the ceramic chamber. Fig. 3 shows the field attenuation and the effective pulse shift for different coating thickness of the storage ring 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. 4 shows the injection efficiency for 3 μm coating thickness.

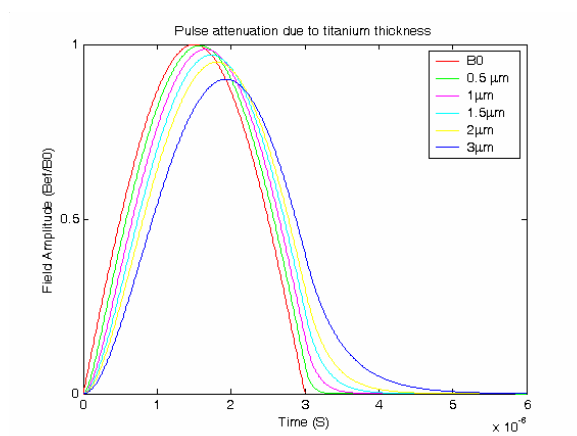


Figure 3: Injection kicker pulse attenuation for various coating thickness

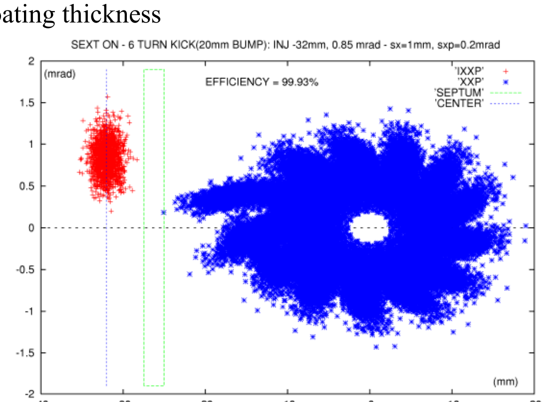


Figure 4: SESAME Injection with 3μm Ti coating thickness.

In both cases the injection with less than 1 mrad angle offset is possible which gives an efficiency of more than 99.7%.

### *Deposited Power and Thermal Analysis*

Deposited power in the titanium coating due to stored beam 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 from the point of view of the power deposited in the titanium-ceramic structure. The coating of the chamber wall is assumed to have uniform surface resistivity with conductivity of $2\times10^6$ S/m.

Thermal analysis for various titanium thicknesses have been carried out. 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. Thermal 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. 5), 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 Tab. 2.

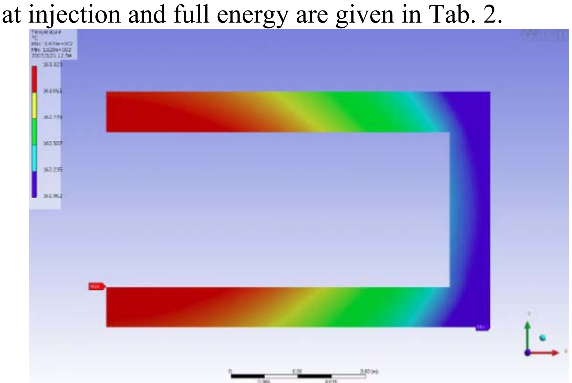

Figure 5: Temperature distribution for 1μm titanium layer thickness.

Table 2: Various Temperatures at Different Heating Loads

| Coating Thickness (μm) | Temp. at 0.8 GeV(°C) | Temp. at 2.5GeV(°C) | W/m$^2$ at 0.8 GeV | W/m$^2$ at 2.5 GeV |
|---|---|---|---|---|
| 1 | 163 | 64.5 | 820 | 235 |
| 2 | 92 | 43.5 | 400 | 110 |
| 3 | 70 | 37.6 | 275 | 75 |

## KICKER SPECIFICATION

The optimum titanium coating thickness has been found to be 2μm. The titanium maximum temperature rises to 92$^0$C at injection energy. This high temperature will be cooled down if we apply a forced convection to the kicker during the injection time. Overall injection kicker parameters are given in Tab. 3. The magnet has a single coil conductor without any water cooling assembly and is kept outside vacuum.

Table 3: Injection Kicker Parameters

| | |
|---|---|
| Deflection angle (mrad)/max | 3.5/3.9 |
| Magnetic field (T) | 0.031 |
| Magnetic length (cm) | 30 |
| Pulse duration (μs) | 3 |
| Magnet material | Ferrite yoke/ ceramic chamber |
| Aperture dimension ($mm^2$) | 46*116 |
| Conductor dimension ($mm^2$) | 4*40 |
| Magnet resistance (mΩ) | 0.1 |
| Magnet inductance (μH) | 0.90 |
| Current (A) | 1250 |

## INJECTION SEPTUM MAGNET

The injection process from booster to storage ring takes place in the horizontal plane. The microtron and booster are installed inside the main ring, so the injected beam comes from the inner side of the straight section. The injection scheme (four kickers closed orbit bump) foresees the septum with two kickers in a long straight section, while the other two kickers will be positioned in the two adjacent short straights. The septum magnet is direct driven C magnet (laminated iron) in air. A 9 mm vacuum pipe is used for the incoming beam. The thin septum magnet is required to bend the beam 9 degrees. There is also a C-type thick septum with bending angle of 15 degrees just before the thin septum. Fig. 6 shows the cross section at the injection point to the storage ring.

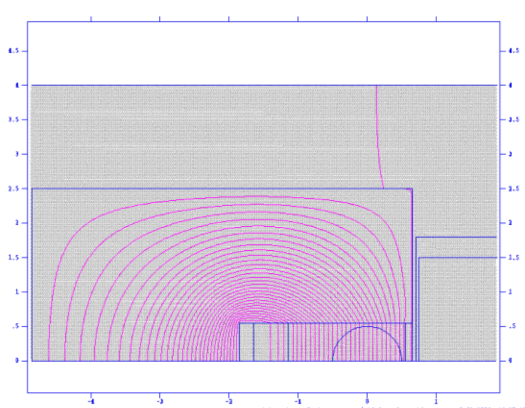

Figure 6: Septum magnet downstream cross section.

The injection point is defined to be at the downstream end of the thin septum, at this point the injected beam is parallel and 32 mm from the ideal central orbit. The C-type magnet arc length is 50 cm and the radius is 3.183m. The thin coil is 2.5 mm at the upstream end and smoothly decrease to 1 mm at the septum downstream end. The magnet gap is 10 mm and the coils are kept outside vacuum. The overall half sine waveform is 250μs and the repetition rate is 1Hz. The main parameters of the injection septum magnet are given in Tab. 4.

Table 4: Septum Magnet Parameter List

| | |
|---|---|
| Deflection angle (degree) | 9 |
| Field Strength (T)@ 800MeV | 0.84 |
| Magnetic length (m) | 0.5 |
| Septum thickness (mm) | 2.5 |
| Magnet Aperture ($mm^2$) | 10x25 |
| Pulse length (μs) | 250 |
| Copper resistance (mΩ) | 0.98 |
| Inductance (μH) | 1.57 |
| Current (A) | 6690 |
| Voltage (V) | 198 |

## CONCLUSIONS

The injection process from the booster in the storage ring takes place in the horizontal plane unlike the original BESSY I storage ring. The injection scheme is based on four 30 cm long kickers and 50 cm thin septum. The kicker ceramic coating is optimized to 2μm and the pulse duration is 3μs.

## REFERENCES

[1] G.Vignola et al. "SESAME status" EPAC06, Scotland

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

[3] S.Varnasseri et al. "Injection kicker magnet design for SESAME storage ring" SESAME Tech. note I-3, April. 2007.