

THE BEAM DIAGNOSTICS FOR SESAME

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Abstract

SESAME[†] (Synchrotron-light for Experimental Science and Applications in the Middle East) is an Independent Intergovernmental Organization developed and officially established under the auspices of UNESCO. SESAME will become a major international research center in the Middle East, located in Allan, Jordan. The machine design is based on a 2.5 GeV 3rd generation Light Source with an emittance of 26 nm.rad and 12 straights for insertion devices. The conceptual design of the accelerator complex has been frozen and the engineering design is started [1]. The completion of the accelerators complex construction is scheduled for the end of 2009. In the following an overview of the electron beam diagnostic system is presented, with special emphasis on the beam position monitoring system and the synchrotron light monitor for the main storage ring.

INTRODUCTION

In SESAME the electrons are injected from a 20 MeV microtron into a 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 at 2.5 GeV. Through the path from microtron to and within storage ring both destructive and non-destructive monitoring of beam are performed, consisting of Faraday cup, florescent screen, current transformer, strip line, scraper, beam loss monitor, synchrotron light monitor and beam position monitor pick ups [2].

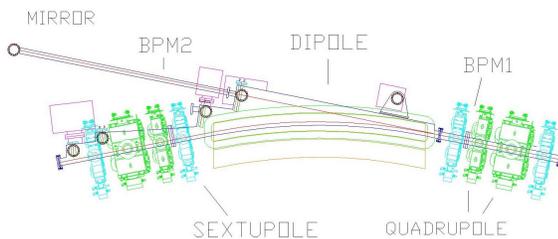


Figure 1 : Arrangements of BPM and light monitor within half cell of the storage ring SESAME.

The aim is to use the destructive monitor instruments mainly for commissioning and first day operation and non-destructive devices for the normal operation of the machine.

Fig.1 shows the half cell of the machine with the proposed diagnostic elements.

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[†] It involves at present the following Member States: Bahrain, Egypt, Iran, Israel, Jordan, Pakistan, Palestinian Authority, Turkey and United Arab Emirates.

Table 1: SESAME storage ring parameters relevant to beam diagnostics and their normal values.

Energy (GeV)	2.5
RF frequency (MHz)	499.564
Natural emittance ϵ_x/ϵ_y (nm.rad)	25.24/0.2524
Injection energy (MeV)	800
Max. Average current(mA)	400
Harmonic number	222
Revolution period(ns)	444
Bunch length (cm)	1.16
Horizontal beam size (μm) LS/SS/Dipole	794.8/789.7/232
Vertical beam size (μm) LS/SS/Dipole	28.1/16.6/71.5
Horizontal divergence(μm) LS/SS/Dipole	45.3/45.9/260.9
Vertical divergence(μm) LS/SS/Dipole	9/15.2/12.1

The tunnel air temperature for SESAME storage ring will be stabilized at $(25 \pm 1)^\circ\text{C}$. The vacuum chamber temperature gradient per the horizontal distance between the button PUs will not exceed 0.5°C . This gives a maximum of $8\mu\text{m}$ repositioning of button pick ups due to the temperature differential on the stainless steel vacuum chamber.

BEAM POSITION MONITORS [3,4,5]

Overall there are 32 BPM sets, four BPMs in each cell of the storage ring. They will be placed at the exit and entrance of each bending magnet and between sextupoles and quadrupoles, to measure the closed orbit distortion all around the ring. Fig.2 shows the SESAME optical function and 4-buttons BPM arrangements.

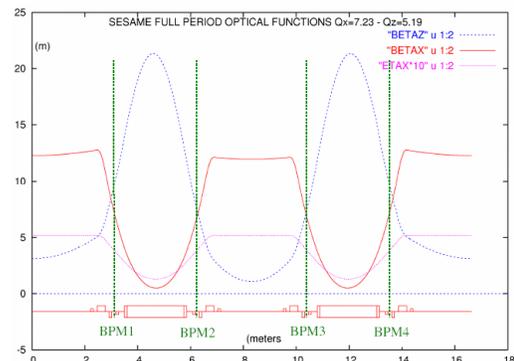


Figure 2: Optical function of SESAME and the BPM arrangements.

The ESRF type capacitive BPM buttons will be used for SESAME electron BPM head. 2D electrostatic sensitivity analysis of the BPM head has been carried out for horizontal and vertical planes and for different relative horizontal positions in the vacuum chamber. Since the vertical distance of the buttons is dictated by the vacuum chamber geometry, the horizontal distance of the buttons should be optimized in order to reconstruct accurately the transverse beam position and recover the nonlinearity of the transfer function.

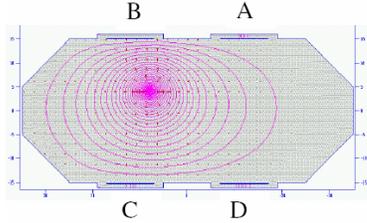


Figure 3: Cross section of the SESAME vacuum chamber, pick up buttons with a non-centered beam.

Figure 3 shows the vacuum chamber cross section and the BPM Pick up's. The electrical beam position in the horizontal/ vertical plane is given by:

$$X = \frac{(Q_A + Q_D) - (Q_B + Q_C)}{(Q_A + Q_B + Q_C + Q_D)} \quad (1)$$

$$Y = \frac{(Q_A + Q_B) - (Q_C + Q_D)}{(Q_A + Q_B + Q_C + Q_D)} \quad (2)$$

Where Q_A , Q_B , Q_C and Q_D are the induced charges on button pick ups. The position sensitivities in each plane are given by the derivatives of electrical position with respect to x and y , in other words S_x and S_y respectively.

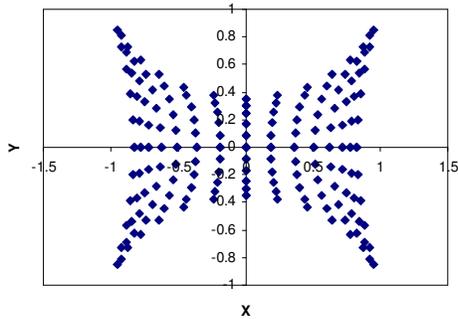


Figure 4: Position map with 30 mm H distance. distance between dots is 2mm.

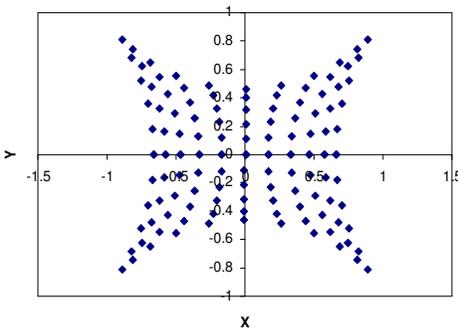


Figure 5: Position map with 24 mm H distance. distance between dots is 2mm.

Figures 4 and 5 show the horizontal and vertical position map for 30mm and 24mm as the horizontal distance between the buttons. The results have shown a better response and resolution for 24mm as the horizontal distance.

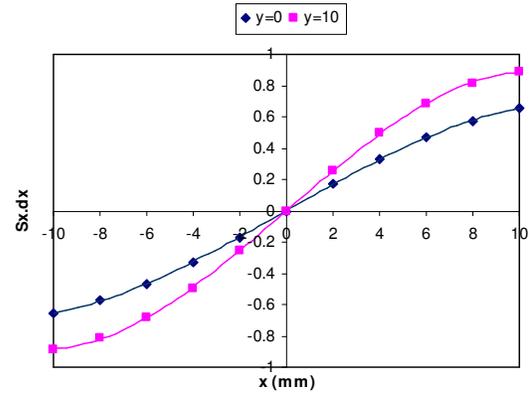


Figure 6: bpm sensitivity curves for x direction.

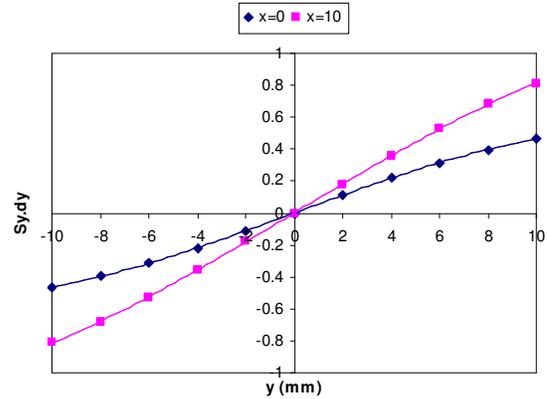


Figure 7: bpm sensitivity curves for y direction.

Figures 6,7 show the sensitivity curves for x -direction and y -direction where the horizontal distance between PUs is 24 mm. The coefficients of the polynomial fitted to the calculated points in x and y direction are as follows:

$$x = 11.73X + 2.63X^3 - 19.66XY^3 + 12.35X^5 + 26.24X^3Y^2 - 2.03XY^4 - 13.77X^7 - 38.02X^5Y^2 + 32.07X^9 \quad (3)$$

$$y = 17.64Y - 21.17X^2Y + 9.89Y^3 + 16.76X^4Y - 25.29X^2Y^3 + 48.57Y^5 - 14.91X^4Y^3 - 48.55Y^7 + 33.94Y^9 \quad (4)$$

The sensitivity at the center of the beam pipe is 8.5% per mm for the x -direction and 5.6% per mm for the y -direction.

SYNCHROTRON LIGHT MONITOR

[6,7]

The 2.5GeV electron beam emitting synchrotron light in the 1.455T dipole magnet. It consists of visible light spectrum from 300 nm to 700 nm with a vertical opening angle of 2.3-3.1 mrad. The electron beam sizes in the horizontal and vertical planes are $\sigma_x = 232\mu\text{m}$ and $\sigma_y = 71.5\mu\text{m}$ respectively for 1% emittance coupling.

Electrons moving in the storage ring radiate energy in discrete quanta or photons, each with energy equal to

hf. In case of a beam of particles the total continues energy per second radiated, is proportional to the number of particles that pass the observer per second. In this case the angular distribution of total power in (Watts/mrad²) is given by:

$$\frac{dP}{d\Omega} = 5.42E^4 .B.I_b \frac{1}{(1+\gamma^2\psi^2)^{5/2}} \left[1 + \frac{5\gamma^2\psi^2}{7(1+\gamma^2\psi^2)} \right] \quad (5)$$

where E, B and I_b expressed in GeV, Tesla and Ampere respectively. ψ is the observation angle in the vertical plane. Therefore in case of observation on off-axis radiation direction, the peak power density is given by:

$$\frac{dP}{d\Omega} = 5.42E^4 .B.I_b \quad W/mrad^2 \quad (6)$$

Integration over vertical angle gives the linear power density:

$$\frac{dP}{d\theta} = 4.22E^3 .B.I_b \quad W/mrad \text{ Horizontal} \quad (7)$$

At SESAME ring, the source point is aligned at 6.5° port of dipole magnet. The first mirror is positioned in a distance of 4.2m from source point. This gives the peak power density and linear power density on the 45 degree positioned mirror as 87 W/mrad² and 27.2 W per Horizontal mrad respectively.

Imaging resolution

The visible light wavelength of 500 nm will be used, however shorter wavelength will improve the resolution, but on the other hand the cost of optical elements also will be increased. The resolution of synchrotron light monitor is limited by several fundamental effects. These effects are different in vertical and horizontal plane in some cases.

Table 2: parameters list at 2.5 GeV

Vertical opening angle of light, $\lambda=500$ nm	2.75 mrad FWHM
Slit angular aperture	1mrad horizontal, 7 mrad vertical
Visible light power	2.9 mW (300nm-700nm)
Depth of field error	21.49 μ m
Diffraction error	105 μ m
Curvature error	2.87 μ m
Distance from source point to first mirror	4.2 m
Lattice function values at source point	$\beta_x=1$ m , $\beta_y=19.74$ m , $\eta_x=0.154$ m
Bending radius at beam point	5.7296m
Peak power density on the mirror	4.95 W/mm ²
Linear power density on the mirror	6.5 W/mm

The main effect comes from diffraction error and in a less effective factor comes from depth of field error and curvature error. For a simple vertical slit the diffraction resolution is given by:

$$\Delta_{diff} \approx 0.21 \frac{\lambda}{\theta} \quad (8)$$

Where λ is the visible light wavelength and θ is the half acceptance angle, This error has a value of 105 μ m.

Depth of field error is very dependent on the acceptance angle and length of the source as given by:

$$\Delta_{df} \approx 0.5L\theta \quad (9)$$

where L is the length of source and θ is the half acceptance angle. With a half acceptance of 1 mrad, this error will be 21.49 μ m. The less effective error comes from the curvature of electron beam as given by(10). It has the value of 2.87 μ m.

$$\Delta_{cur} \approx 0.5R\theta^2 \quad (10)$$

where R is the bending radius at the source point. For a particular wavelength the best resolution is obtained by minimizing the sum of squares of the errors. Overview of the light monitor and related optical parameters are given in table(2). With 1 mrad half angle aperture, we will reach a resolution not less than 130 μ m. The thermal peak power on the first mirror reaches 4.95 W/mm² and a sufficient cooling will be arranged to prevent any deformation on the mirror surface.

Transmission outside the ring

The light is reflected out from the first mirror that is positioned 45° vertically and 4.2m far from the source point into the 1m tube under atmospheric conditions. The second plane mirror brings the visible light into a horizontal (normal to gravity) plane, and into the other side of the SR ring through the 80cm thick concrete shielding wall. All the optical components and tables will be in the other side of shielding wall.

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