COMMISSIONING OF SESAME STORAGE RING

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Abstract

SESAME light source uses a 2.5GeV storage ring designed to produce synchrotron light in the hard X-ray region. The 133.2 m circumference ring composed of 16 Double Bend Achromat cells with 16 dispersive straight sections, offers a maximum capacity of 25 beamlines. The storage ring is filled with electrons using an 800MeV injector of 1 Hz repetition rate. This article reports on the main results and first experience of storage ring commissioning and operation.

INTRODUCTION

The SESAME 8-fold storage ring lattice is a simple Double Bend Achromat (DBA) one composed of 16 mirror-image cells with 16 dispersive sections (8*4.4 m and 8*2.4 m). Each cell contains one combined-function bending magnet (BM) flanked by two focusing quadrupoles (QF), two defocusing ones (QD), two focusing sextupoles (SF) and two defocusing ones (SD) each in one family. The main defocusing is done by the -2.8T/m graded 2.25-meter long BM. Two optics are foreseen for storage ring, different mainly in vertical tune [1]. Optics 1 with working point (Q_x =7.23, Q_y =5.19) is more relaxed and makes life easier during commissioning with better beam lifetime, however optics 2 with working point (7.23, 6.19) offers smaller beam-stay-clear in straight sections, hence accommodating a smaller gap Insertion Device. Optics 2 is the one intended for machine operation. Main machine parameters at top energy are listed in Table 1, and optics 1 is shown in Fig. 1.

Table 1: Main Parameters of SESAME Storage Ring

Parameter	Symbol	Value
Circumference (m)	L	133.2
Hor. emittance (nm.rad)	ε_x	26.0
Momentum compaction factor	α	0.0083
Design RF frequency (MHz)	f_{RF}	499.654
Energy loss per turn (keV)		603
Damping times (ms)	τ_x, τ_y, τ_s	2.3, 3.8, 2.7

The BMs are powered with one power supply whereas quadrupoles are powered independently, and sextupoles are powered with 4 power supplies [2]. The RF system composes 4 ELETTRA-type cavities each is powered with a 80 kW solid-state amplifier [3].

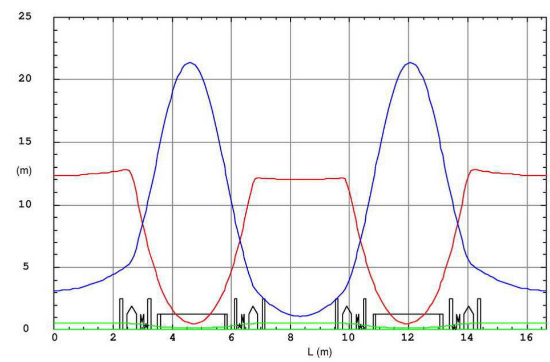

Figure 1: Optics 1 of SESAME storage ring showing betatrons β_x (red), β_y (blue) and dispersion η_x (green).

The storage ring is equipped with 3 in-air Aluminum Oxide fluorescent screens; screen 1 is located at exit of injection septum, driven by stepper motor and used to detect the injected beam at full turn too, screens 2 and 3 are driven by pneumatic systems and located at cells 5 and 10 respectively. The beam current is monitored by Fast Current Transformer (FCT) and DC one (DCCT) from Bergoz located at cell 2. The Beam Position Monitors (BPMs) are 4 BPMs per cell, two of them flanking the BM and two at beginning and end of the straight sections, however only 48 of them are equipped with Libera Brilliance+, from Instrumentation Technology, till now and used for orbit correction with 32 correctors in each plane. The visible-light diagnostic beam line is not yet installed. The injection scheme into SESAME storage ring uses a single dipole kicker installed in cell 5 [4].

COMMISSIONING EXPERIENCE

Prior to First Injection into Storage Ring

Commissioning of SESAME storage ring started in early January 2017. Before injecting into storage ring functionality and controllability of all subsystems, polarity of all magnets were verified. The storage ring magnets were cycled to the optics 2 injection set values BM = 153.83A, QF = 76A, and QD = 57.55A.

Getting Full-turn Beam on Jan 11, 2017

At the first trials the beam was getting lost at the end of cell 1, however by fine tuning injection angle, the beam passed the FCT, then by fine tuning BM the beam showed up on screen 2. The beam was guided to screen 3, then to full turn screen 1 using the vertical corrector in cells 5 and 14 respectively. The BPMs were not helpful in this phase due the still required timing optimization.

Getting the Beam for Multi Turns

Three main issues were noticed on the full turn beam, the horizontal beam size was increasing considerably with s-direction, beam phase advance was far from the theoretical one, and kicker polarity was reversed as indicated by beam response to injection angle and kicker. Simulations showed that beam size increment was a result of optical mismatch between storage ring and booster-ring transfer line TL2 coming mainly from the ring side, and that the existing phase advance corresponds to Q_x above half-integer. The normal horizontal focusing was recovered by reducing QF strength by ~ 1.6 %, and Q_x was brought to below half-integer and to less than 0.25 specifically by reducing strengths of both QF and QD in parallel after kicker polarity was corrected. After this optimization the beam did tens then hundreds of turns on Jan 25, by more fine tuning of vertical correctors, kicker parameters, and quadrupole strengths. By turning sextupoles on and setting them to the values SF = 15.8 A and SD = 25.9 A, which correspond to theoretical $\xi_{x,\,y} = 0$, and doing more fine tuning for quadrupoles, around 4000 turns were obtained as shown in Fig. 2.

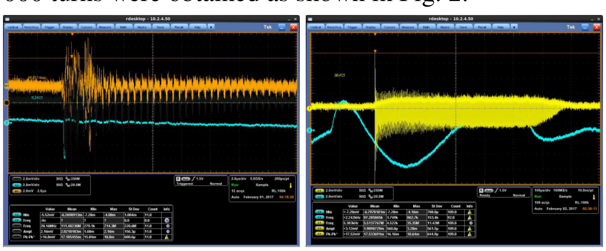

Figure 2: Ring FCT signals showing tens of beam turns with sextupoles OFF (left) and thousands of turns with sextupoles ON (right).

Tune Measurement

The measurement of Q_x was straight forward using the high amplitude oscillations of injected beam while Q_y measurement was trickily done by injecting the beam with vertical angle due to the power limitation on beam shaker at that time. Integer parts of tunes were defined by number of distorted orbit peaks. The first result showed $Q_x = 7.12$ whereas $5.7 < Q_y < 6.0$ which were brought then to theoretical values (7.23, 6.17), as seen in Fig. 3, for - 0.13 %, - 0.6 % and 9 % deviations in BM, QF and QD respectively from the theoretical set values.

Using Optics 1 and Getting a Stored Beam

At the beginning it was not possible to store the beam at optics 2. Moreover better injection efficiency and higher number of turns were being obtained by going down in quadrupole strengths. So we decided to go to optics 1 first where beam shaker was used in Q_y measurement after increasing its power to 50 W. Optics 1 was obtained for the set values BM = 152.45 A, QF = 67.1 A and QD = 16.8 A.

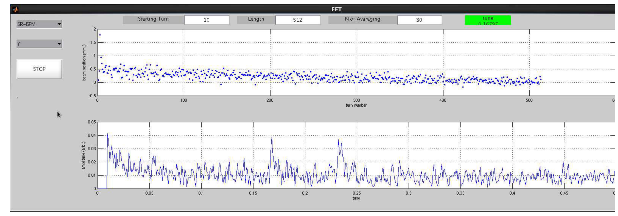

Figure 3: Measured ring tunes $Q_x = 7.23$, $Q_y = 6.17$.

The RF system has then been operated with one cavity set to 300kV, and scanned in frequency and phase with respect to injected beam for better beam capture. Increasing the RF frequency by 20 – 40 kHz gave longer period of RF - beam interaction as shown by BPMs turn-by-turn data, but no real beam capture was indicated by BPMs. After trying many magnetic fine tunings without big change, the beam was successfully stored on Feb 9, as shown by FCT signal in Fig. 4, by using some horizontal correctors.

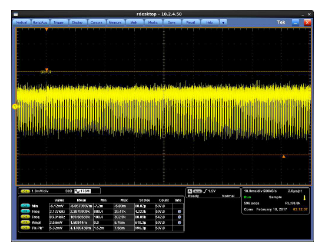

Figure 4: The first beam stored in SESAME storage ring.

Beam Accumulation

It was not possible to accumulate on the working point (7.23, 5.18) in spite of varying many machine parameters, but with Q_x fractional part > 0.3 accumulation was successfully done on Feb 13. This limitation comes from the 1.2 µs injection kicker pulse which found to be longer than the specified one (< 0.9 µs). The working point (7.45, 5.21) was adopted for showing higher accumulation rate and more stable beam. The maximum accumulation rate obtained, with 1 Hz repetition rate, is 0.2 mA/s which indicates a poor injection efficiency < 10% from booster to storage ring. This issue is under investigation but preliminary results showed that most of beam losses happen during extraction from booster. The first accumulation of 3 then 5.6 mA increased average pressure to 510^{-9} and 110^{-8} mbar respectively.

Closed Orbit Correction

Beam accumulation was possible without horizontal orbit correction while it was not the case for vertical orbit where strong correctors are needed. This problem was mitigated by shifting some BMs vertically. Orbit correction was done via SVD method using theoretical then measured response matrix. By doing beam based alignment and tuning RF frequency it was possible to

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correct x-orbit to 0.3mm and y-orbit to 0.17 mm rms, as shown in Fig. 5.

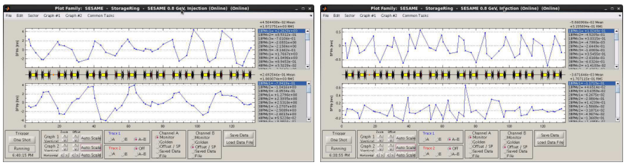

Figure 5: Uncorrected (left) and corrected (right) closed orbit.

Ramping Energy to 2.5 GeV

The initial magnetic ramping curves deduced from magnetic measurements were modified in steps of 100 MeV to keep working point far from resonances. The RF voltage was ramped in parallel from 400 kV up to 1.25 MV in the 4 cavities which are still under conditioning. The vertical orbit distortion was dramatically increasing during ramping, moreover it was strongly increasing the gas pressure in some cells of the ring mainly cell 11, so vertical orbit correction was mandatory during ramping. On the other hand horizontal orbit correction is not necessary. Orbit was corrected to x = 0.18 mm and y = 0.15 mm rms values at top energy. The beam and beam lifetime behaviour in one of the accumulation and ramping cycles of the machine is shown in Fig. 6. The corresponding RF voltage at 2.5 GeV is 1.25 MeV.

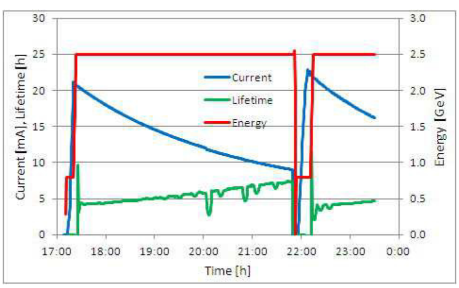

Figure 6: Machine filling and ramping cycle showing beam current and lifetime behaviour versus time.

Optical Characterization

Some optical characterizations have been done for the storage ring at injection and top energies. Chromaticities were deduced at 800 MeV by measuring tunes versus RF frequency using the formula $\xi_{x,\,y} = -\,\alpha\ .\ \Delta Q_{x,y}\,/(\Delta f_{RF}\ /\ f_{RF})$. Table 2 lists $\xi_{x,\,y}$ for different sextupole strengths.

Central RF frequency in the ring was obtained by measuring tunes versus RF frequency for different set values of SF and SD sextupoles. Figure 7 shows that central RF frequency is 499.675 MHz, i.e. 21 kHz higher than theoretical one, which corresponds to 5.6 mm deviation from design orbit. On the other hand the RF frequency that brought the mean value of horizontal correctors recently to almost zero is 499.683 MHz. This could be due to difference in tunnel temperature.

Table 2: Chromaticities at Different Sextupole Currents

SF current (A)	SD current (A)	ζ_x	ζ_y
16.79	26.9	-1.01	0.253
17.79	26.9	1.18	-0.174
18.79	27.9	2.68	0.427
18.79	28.9	2.08	1.17

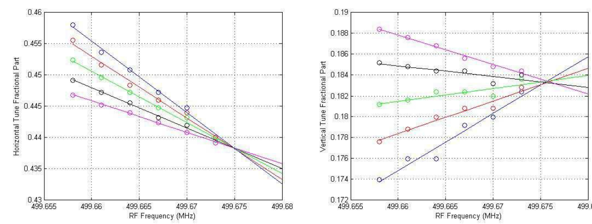

Figure 7: Chromaticity curves showing central RF frequency in the storage ring at 800 MeV.

Betatron functions at quadrupoles and dispersion function at BPMs are measured at 2.5 GeV as shown by Fig. 8.

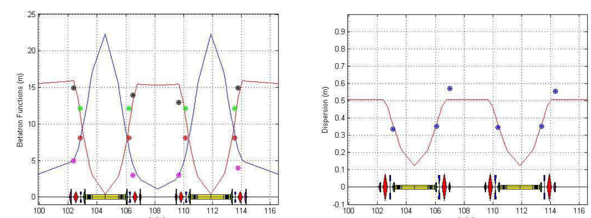

Figure 8: (Left) measured β_x (black) and (green), β_y (pink) and (red) at QF and QD respectively compared to theoretical ones in red and blue. (Right) measured dispersion (blue) compared to the theoretical one (red).

CONCLUSION

Commissioning of SESAME storage ring went smoothly taking into account that commissioning time was around 40 h per week. The machine was not far from the theory however a correct model needs to be built.

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