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Technical aspects of the soleil project

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The SOLEIL project is built around a 2.15 GeV positron storage ring with its own injector, i.e. a linear accelerator and a booster. The scientific community have required a large number of insertion devices optimized in the soft X-ray range and the ultra-violet, several operation modes offering a high brilliance or a usable time structure with a maximum beam lifetime. The choice of the machine energy, of positrons circulating as particles, of the magnetic lattice, and the type of radio-frequency, etc. will be discussed through a more detailed presentation of the machine. Comments will be made about the tolerances required for the beam and the implications for the building stability.

1. INTRODUCTION

The main features for new synchrotron radiation light sources based on storage ring are the number of insertion devices, the brilliance, the lifetime, the stability of the photon beams and the flexibility of the optics for the different modes of operation.

It is difficult to define a universal criterion for all kind of sources and all users [1]. In this paper, the different possible goals are discussed and two alternative configurations of the storage ring are presented assuming the same global cost.

2. STORAGE RING LATTICE

For a medium energy range machine, the main limitation of the lifetime is the Touschek effect, especially for operation with few intense bunches. The reduction of the energy acceptance ($\Delta P/P$) due to the undulator non linear fields, further increases this effect. In order to keep an acceptable lifetime, the particle density should not be too high and consequently the emittance too low.

In other respects, experience acquired on medium energy range machines shows that most of the time, undulators are used with high K values and constant gap. The effective brilliance is then the average brilliance on and off axis, taking into account the even and odd harmonics. The figure of merit depends then on the beam dimensions which scale as the square root of the emittances. All these considerations and the results of a survey including all the LURE users (150 groups of scientists) led, in a first stage, to retain for the SOLEIL storage ring design the following criteria :

- Polyvalent synchrotron radiation source in the energy range of 20 eV to 20 keV photon beams.
- Excellent lifetime with the two modes of operation, 20 hours for 300 mA in the multibunch operation, 10 hours for 6×10 mA bunches in the temporal structure operation.
- Large number of insertion devices (> 12).

- Long straight sections (> 5 m).
- Large number of beamlines installed (> 30) to replace the potentialities of both DCI and Super-ACO.
- Optimised cost by minimization of the machine length (≈ 200 m).

For the required critical wavelength $2.5 \text{ \AA}$ ($\epsilon_c = 5 \text{ keV}$) and a 1.6 T magnetic field, the machine energy is 2.15 GeV .

A modified DBA lattice allowing the implementation of two insertion devices per period was chosen. An emittance of $37 \cdot 10^{-9} \text{ m.rad}$ meets the lifetime request of the temporal structure operation. This value can be reduced to $16 \cdot 10^{-9} \text{ m.rad}$ by adjusting the dispersion function in the straight sections. This optics is suitable for the high brilliance multibunch operation mode (see Fig. 1).

Fig. 1 : Optical functions for modified DBA lattice with $\eta_x \neq 0$ in all straight sections, $\epsilon_x = 16 \cdot 10^{-9} \text{ m.rad}$.

The resulting storage ring design, 216 m long, made of 8 periods with 13 insertion devices and 35 experimental beamlines is shown Fig. 2.

Fig. 2 : Overview of SOLEIL with a typical insertion device distribution.

The capital cost for the source has been evaluated to 270 MFF. It includes : a high current Linac with 200 MeV energy followed by a quarter wavelength converter, a 400 MeV positron Linac and a booster increasing the beam energy to 2.15 GeV. The beamlines and experiments budget is 315 MFF, components recovered from Super-ACO and DCI reduce this bill by 67 MFF. Taking into account the price of buildings and infrastructures of the new laboratory, the total cost rises to 812 MFF HT (value 1993) [2].

Recently, there was a further request for more flexibility in order to provide two more modes of operation, high brilliance (10^{18} to 10^{19} phs $^{-1}$ mrad $^{-2}$ mm $^{-2}$ /0.1 % from undulator) and free electron laser.

A new storage ring configuration is currently being studied with the same DBA structure but 12 periods providing a minimum emittance of $4 \cdot 10^{-9}$ m.rad tunable to $30 \cdot 10^{-9}$ m.rad. The Fig. 3 presents the optical functions of one period for $\epsilon_x = 3.9 \cdot 10^{-9}$ m.rad.

Fig. 3 : Optical functions (1/12 of the machine) $\epsilon_x = 3.9 \cdot 10^{-9}$ m.rad.

The main parameters are : $\nu_x = 15.7$; $\nu_z = 9.7$; $\alpha = 6.8 \cdot 10^{-4}$; $\sigma_E/E = 8.6 \cdot 10^{-4}$ and the beam dimensions at the source points are given in the following Table 1.

Table 1

		σ_x (μm)	σ'_x (μrad)	σ_z (μm)	σ'_z (μrad)
Bending magnet beamlines (up to 21)	Odd	44	124	39	10
	Even	63	77	37	10
Insertion beamlines (up to 21)	Odd	386	13	37	10
	Even	142	44	74	5

The whole design (Fig. 4) consists of two superperiods with two 10 m long straight sections, one of them dedicated to free electron laser [3]. The optimisation to match the optical functions between the long straights and the arcs for the same emittance is in progress.

Fig. 4 : Overview of SOLEIL with the new storage ring configuration.

Fig. 5 shows the optical functions of one superperiod for the FEL mode with $\epsilon_x = 16 \cdot 10^{-9}$ m.rad at 1.5 GeV. The β_x and β_z values in the long straight sections have been adjusted to 6 m.

Fig. 5 : Optical functions for one superperiod, $\epsilon_x = 16 \cdot 10^{-9}$ m.rad.

Fig. 6 focuses on FEL straight section and illustrates the possibility of two colour experiments from bending magnet radiation and from an other insertion radiation.

Fig. 6 : FEL straight section.

3. LIFETIME

For the computation of the lifetime, the pressure is assumed to be 1 ntorr for 300 mA and 0.3 ntorr for 80 mA, which seems to be realistic after one year of operation.

For the Touschek lifetime we assume a (conservative) value of 1.8 % energy acceptance taking into account the possible limitation due to the insertion non linear fields. The results are given also with the energy acceptance allowed by the 3 MV RF voltage limited to a maximum value of 3.5 %. For the different modes of operation they are :

Table 2

	E = 2.15 GeV I = 300 mA			E = 2.15 GeV I = 8 × 10 mA	E = 1.5 GeV I = 4 × 5 mA
ϵ_x (nm.rad)	30	11	3.9	30	16
ϵ_E (%)	1.8	1.8	1.8	1.8	1.8
σ_l (mm)	6.6	6.6	6	6.6	5.4
τ (h)*	24	16	10	10	5.2
V (MV) for $\epsilon_E = 3.5$ %	3	3	2.2	3	1.74
σ_l (mm)	4.1	4.1	3.9	4.1	3.1
τ (h)*	30	23	18	29	20

* These calculations are given with $\kappa^2 = 0.1$ except for the case E = 1.5 GeV where $\kappa^2 = 1$.

4. TECHNICAL CHOICES

4.1. Injector

The full energy injection means no ramping and guarantees good beam position reproducibility. Furthermore high intensity instabilities which are more severe at lower energy are avoided. Although needing an extra capital and operation cost for the preinjector (≈ 40 MFF) the positron option is safer from the point of view of stability and lifetime as it is shown below.

Ion trapping in the electrons beam increases the beam size and spoils the stability and lifetime. This effect can be minimized by leaving a gap in the bunch train instead of a uniform filling and reducing coupling between vertical and horizontal emittance (κ^2). Unfortunately, for medium energy range the density per bunch increasing, the Touschek lifetime decreases. For example, $\epsilon_x = 11 \cdot 10^{-9}$ m.rad and 300 mA :

- Uniform filling	$\kappa^2 = 0.1$	$\tau = 16$ h
- 5/7 filling	$\kappa^2 = 0.01$	$\tau = 8$ h

In many cases of machines operating with electron, ion trapping effect failed to explain the observed events, another process has been proposed [4], related to the trapping of macro particles (dust of all kind) photoionized by synchrotron radiation. They are raised into the beam, then further ionized by the electrons and finally trapped in the beam potential. It results in sudden losses and/or bad lifetime.

Furthermore, beam losses or lifetime accidents are observed from various synchrotron radiation sources operating with electrons when insertion device gaps are changed*. No observation of this kind was so far reported from machines operating with positron beams.

Presently, ALS (Berkeley) and ELETTRA (Trieste), are in commissioning process and we expect results about electron beam behaviour in the above conditions, especially in single or few bunch operation mode.

4.2. Cavity option

Coherent multibunch instabilities driven by the higher order modes (HOM) of the cavities are one of the intensity limitations for the storage ring synchrotron radiation sources. The longitudinal and transverse stability for multibunch operation is especially important for SOLEIL and all the projects which have non zero dispersion in the straight sections equipped with insertion devices. With the pessimistic assumption that the parasitic frequency of the cavity is exactly on the synchrotron dipole side band, the threshold of the longitudinal oscillation is approximately given by :

$$I_{TH} \approx \frac{4\pi (E_0/e) v_s}{\tau_E \alpha} \times \frac{1}{\omega_r R_s}$$

where E_0 is the particle energy, v_s the synchrotron tune, α the momentum compaction factor, τ_E the damping time, ω_r and R_s respectively the cavity HOM frequency and its shunt impedance.

For low or medium energy range machine and rather low periodicity, the higher order modes are severe. Studies have been performed with different kinds of cavities and it turns out that a "monomode" cavity will be a worthwhile option for SOLEIL.

The solution of superconducting CORNELL cavity [5] (500 MHz) is considered and LURE participates in the development studies. The parameters are chosen as follows :

$$U_0 = 450 \text{ keV with insertions}$$

* Note that at the ESRF the phenomenon has been explained by the migration of magnetic particles out of the beam path during the dynamic change of the magnetic field and not related to the electron or positron behavior.

$$I_{\text{Beam}} = 500 \text{ mA}$$

$$V_{\text{RF}} = 3 \text{ MV}$$

$$P_{\text{Beam}} = 225 \text{ kW}$$

$$2 \text{ cavities fed by 4 klystrons (75 kW).}$$

4.3. Stability requirements

The user requirements for the photon beam stability are the following :

- 1 μm over 1 hour (instantaneous),
- 10 μm over 1 day (short term),
- 100 μm over long term (between alignments).

These constraints are converted in following civil engineering criteria :

Table 3

Criterium	Stress	Maximum displacement
Static	500 kg load	6 μm upright the load 2 μm - 2 m from the load
	80 kg moving mass	1 μm and 0.3 respectively
Dynamic	Vibrations : 0.1 $\rightarrow$ 70 Hz	1 μm peak to peak

A study has been performed by the SETEC company. The results are applicable to the reference site : "L'Orme des Merisiers" on the "Plateau de Saclay".

With regard to the foundations, two solutions have been considered, taking into account the cultural and technical noises. One slab laying on two meter thick artificial substrat meets the previous requirements and seems better than the second solution "jacketed piles" which is too sensitive to horizontal stresses. The slab is 1 meter thick with honey comb pattern for the experimental hall and 1.20 meter thick for the machine and its shielding. The metallic structure of the hall and the two slabs are independent.

In order to meet the beam stability requirements, girders are used as quadrupole multiplets support. Temperature control is mandatory (machine ± 0.2 $^{\circ}\text{C}$, experiments ± 1 $^{\circ}\text{C}$) and closed orbit feedback has to be implemented to combat the lattice amplification factor ($A_x = 60$, $A_z \approx 30$). It consists of a harmonic global feedback using Beam Position Monitor (BPM) of the machine and a local feedback for insertion devices based on photon detectors or BPM. HLS system as developped at ESRF has to be installed on both the storage ring and the beamlines.

5. CONCLUSION

The study of the flexible version of SOLEIL looks very promising but is not yet completed. More optimisation is required on optics studies. An alternative solution replacing four bending magnets by superconducting dipoles is also under consideration, being more attractive than the implementation of wigglers.

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