New Developments on SOLEIL[1]

M.-P. Level, G. Flynn, C. Herbeaux, A. Nadji, H. Zyngier
LURE, Centre Universitaire de Paris Sud, Bât. 209 D, 91405 Orsay Cedex, France

Abstract

This report presents the new philosophy and optics adopted for the SOLEIL project. Studies concerning high intensity multibunch stability thermal behaviour of the vacuum chamber and stability, constraints on civil engeneering are described.

1. INTRODUCTION

Based on the results of an inquiry sent to all LURE users and also various considerations about lifetime, brilliance versus utilisation, a first version of SOLEIL was designed. The 216 m long storage ring contained 8 periods and was equipped with 36 beamlines and 13 insertion devices [1].

Taking into account new discussions with the scientific community and accelerator experts, a new philosophy has been adopted which leads to a new configuration of the storage ring open to future possibilities.

- The emittance is in the range of 4 10^{-9} m.rad, tunable up to 30 10^{-9} m.rad in order to allow respectively :

. very high brilliance : 10^{18} to 10^{19} phs^{-1} mrad^{-2} mm^{-2}/ 0.1 % BP, from undulators,

. large lifetime in the temporal structure operation mode with a few intense bunches.

- Two long straight sections (≈ 10 m) for FEL operation or other insertion devices to be defined later.

2. BEAM PARAMETERS

2.1. Lattice

Two (modified DBA) optics are currently being analyzed with the same circumference ≈ 320 m [2].

- 12 periods (2 superperiods) with 2 insertions per period and 2 light ports per bending magnet (0 and 4°).

ε_x = [4 10^{-9} m.rad → 30 10^{-9} m.rad.] 42 beam lines and 21 insertions are possible.

- 16 periods (2 superperiods) with 1 insertion per period and one light port per bending magnet (0° or 3°).

ε_x = [2 10^{-9} m.rad → 30 10^{-9} m.rad]. 30 beam lines and 14 insertion devices are possible.

Fig. 1 presents the general layout of SOLEIL with 12 periods and 2 superperiods. The main parameters are given in Table 1, and the beam dimensions at the source points in table 2 for ε_x = 4 10^{-9} m.rad and κ^2 = 0.1.

Table 1.

Circumference	C = 320 m
Energy	2.15 GeV
Tunes ν_x, ν_z	17.4, 8.2
Emittance (m. rad)	ε_x = 4 10^{-9} ; 30 10^{-9}
Momentum compaction	α = 6.8 10^{-4} ; 1.03 10^{-3}
Damping times	τ_x = 11.2 10^{-3} s ; τ_s = 5.6 10^{-3} s
Energy dispersion	σ_E/E = 8.6 10^{-4}
Energy loss per turn	U_0 = 450 keV

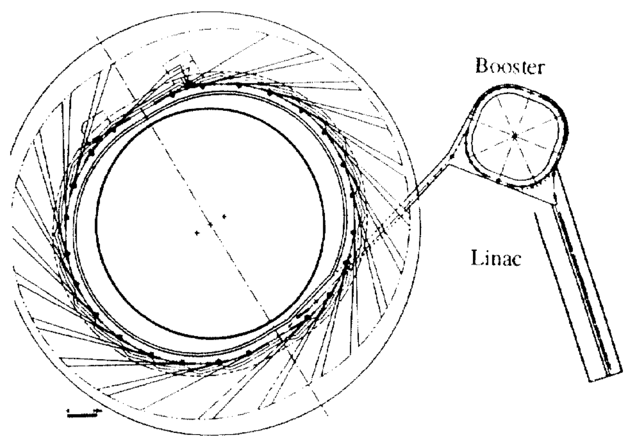

Figure 1.

Table 2.

		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

2.2 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 also given with the energy acceptance allowed by the 3 MV RF voltage limited to a maximum value of 3.5 %.

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For the different modes of operation they are :

Table 3.

	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_ε (%)	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 ε_ε = 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 $\kappa^2 = 1$.

3. LONGITUDINAL MULTIBUNCH INSTABILITIES

Storage rings operating in the energy range of SOLEIL with large numbers of bunches typically suffer from longitudinal multibunch instabilities provoked by accelerating cavity higher-order modes (HOM's) above a relatively low threshold current. These instabilities do not usually lead to beam loss but result in phase-energy oscillations which are transformed into horizontal oscillations in all sections having a non-zero dispersion function η_x. The observed horizontal beam size is thus increased and the effective brilliance reduced in all such sections.

Such oscillations would be unacceptable in SOLEIL because the project calls for the placement of user insertions in all available straight sections, including those having $\eta_x \neq 0$ with the achromatic optics. In addition the low emittance mode optics require that η_x be non-zero in all sections [2]. This mode of operation would thus be of little interest if longitudinal oscillations were present.

For these reasons a detailed analysis of longitudinal multibunch instability in SOLEIL was undertaken [3]. Calculations were performed for three possible accelerating cavities using both the program ZAP and simplified forms of the Sacherer-Zotter formalism for the 12 period lattice with two long straight sections. The results are presented in table 4. The three cavities chosen were the 5-cell LEP normal conducting cavity (also in use at the ESRF), the SLAC PEP-II cavity with HOM dampers and the Cornell B-factory superconducting "monomode" cavity. This type of calculation is complicated by the statistical nature of the distribution of higher order cavity modes due to manufacturing tolerances (as well as temperature and pressure variations, etc.), however the importance of this effect varies for the three cavities studied.

In the case of the LEP cavity, the worst case instability threshold, assuming that a cavity HOM falls exactly on a beam resonance is very low, only about 10 mA. However, the narrowness of these undamped HOM's implies that the probability of this condition being met is also rather low. On the other hand, this cavity consisting of 5 coupled cells, the number of possibly dangerous modes is large. A rough estimate of the total probability of falling below the threshold current can be made in the following manner. We assume that individual HOM's are distributed at random within each of the four measured multiplets [4]. The order of magnitude of the width of the dangerous zone of each HOM, Δf_r , is given by $\Delta f_r / Q$. We may equally well associate this width with each beam mode. In this case, the probability, p, of an HOM falling within the dangerous zone of the beam spectrum is given by the ratio of the total width of this zone to the width the multiplet or : $p = \Delta f_r / f_0$. A typical value of Δf_r (30 kHz), then leads to a probability of about 3 % per mode. Using the binomial distribution, we may then estimate the total probability for all 20 known modes at about 46 %, an unacceptably high value.

In the case of the SLAC cavity [5], the worst case threshold is high (270 mA), but still below the 300 mA nominal current. Moreover, the HOM widening produced by damping greatly reduces the effect of statistical variations. Results are presented in table 4 for a single HOM of which the resonant frequency was picked at random six times following a Gaussian distribution with a sigma of 100 kHz. The results show very little dispersion and imply a high probability of an instability at 300 mA with this cavity.

Finally the Cornell cavity leads to a stability limit far surpassing the nominal current. It has therefore been decided to adopt this superconducting cavity for the SOLEIL project and a collaboration has been established with Cornell on its continuing development. The reader is referred to the numerous papers published by Cornell on this cavity and its associated systems (see, for example [6]).

Table 4

Cavity	Number Needed	Worst case stability threshold (mA)	Results of statistical analysis
LEP-normal conducting 5-cell	1	10.93	$P(I_s<300$ mA, 1 HOM$)$ = 3 % $P(I_s<300$ mA, 20 HOM$)$ = 46 %
SLAC: PEP-II	4	270.6	6 trials $\langle I_s \rangle$ = 280.00 mA σ = 4.82 mA
Cornell CESR-III	2	11 511	not applicable

4. VACUUM CHAMBER

Though the nominal value of the beam current is 0.3 A for SOLEIL, all the absorbers are designed to support the heat load of a 0.5 A beam. In this case W = 32.6 kW.rad^{-1} and the radiated power per dipole reaches 8.5 kW for the 12 period configuration. Power radiated in the upstream insertion device must be added to this value.

Calculations of power densities and 3D thermal analysis [7] have been made for two different distributions of OFHC copper absorbers : distributed and lumped. This study has shown that the most appropriate configuration for the dipole, is a lumped absorber (crotch) placed at the downstream extremity of the vacuum chamber. The irradiated surface is inclined to reduce the power density by reducing the angle of incidence of photons. A maximum power density of 27 W/mm^2 is applied on the absorbers and a maximum temperature of 300 °C has been calculated by thermal simulation. Optimization of the geometry and of the thermal exchanges has to be made in order to decrease this value. On the other hand, OFHC copper can be associated with GlidCop which has a high yield strength even at elevated temperatures. The solution of a crotch associated with a lumped pump has also the advantage that the photodesorption takes place in an antechamber and not in the chamber where the particles circulate. For quadrupole and straight section vacuum chambers, power densities are low enough to keep distributed absorbers.

5. ORBIT STABILITY

The user photon beam stability requirements 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 have been converted to the following civil engineering criteria :

Table 5.

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 → 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".

As for the foundations, taking into account environmental and equipment noise sources, the best solution to meet the requirements has been found to be a slab laying on a two meter thick artificial substrate. The slab is 1 meter thick with a honeycomb 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 supports. Temperature control is mandatory (machine ± 0.2 °C, experiments ± 1 °C) and closed orbit feedback must be implemented in order to combat the lattice amplification factor ($A_x = 60$, $A_z = 30$). It consists of real time global feedback based on an harmonic method using machine Beam Position Monitors (BPM) and local feedback for insertion devices based on photon detectors or BPM's for both position and angle stability. Presently development work is under way on DCI and Super-ACO [8]. An HLS system as developped at the ESRF will be installed on both the storage ring and the beamlines.

6. CONCLUSION

The final choice of the structure and emittance will be made after dynamic aperture optimization, β value matching for FEL operation and insertion β optimization for undulator photon emission.

The solution proposed elsewhere of replacing some bending magnets by superconducting ones thus avoiding the installation of wigglers in straight sections will also be considered and can influence the choice of the structure (it leads to an emittance increase of ≈ 1.7 for 4 magnets).

The project planning extends over 8 years (the commissioning of the source starts 3 years after ground breaking) with a total of 20 beam lines equipped from 10 insertion devices.

6. REFERENCES

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