BEAM DYNAMICS WITH MANY UNDULATORS ON SUPER-ACO*

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Abstract

Up to now, 4 undulators have been installed on Super-ACO. The linear and non linear effects introduced by the first 3 insertions have been studied. The experimental results on optics and dynamic aperture are presented and compared to simulations and magnetic measurements.

Introduction

The two undulators SU7 and SU3 are located in zero dispersion sections and the third undulator SU6 is in a non zero dispersion section.

When an undulator is inserted, the fourth order symmetry is destroyed, a β-function beat is introduced, the vertical focusing effect leads to a vertical tune shift , and the non linear part of the field excites fourth order resonances which react on dynamic aperture. We have shown that the simulations with the BETA code can predict the beam gas lifetime and Touschek lifetime reduction when undulators are closed.

Optics

Definition of an Undulator

A regular undulator is introduced in the BETA structure using the following parameters : its length L, its period λ and its integrated field $\int B^2 dl$. The field is supposed to be sinusoidal [1] :

$$B_s = -\frac{k}{k_z} B_0 \sin(ks)\ \mathrm{ch}(k_z x)\ \mathrm{sh}(k_z z)$$

$$B_x = \frac{k_x}{k_z} B_0 \cos(ks)\ \mathrm{sh}(k_x x)\ \mathrm{sh}(k_z z)$$

$$B_z = B_0 \cos(ks)\ \mathrm{ch}(k_x x)\ \mathrm{ch}(k_z z)$$

The parameter k_x is used to express the x-dependence of the real field because of the finite width of the poles in the x-direction $\left(k_x^2 + k_z^2 = (2\pi/\lambda)^2\right)$.

Optical Functions

The insertion of an undulator modifies the β-functions. The beat depends on the undulator strength and location. For SU7 it is 70 % (Figure 1), for SU6 it is 40 % because it is weaker, when SU6 and SU7 are both closed, the beat is 65 % and is further reduced to 60 % when SU3 is closed, because of its symmetrical location in the ring.

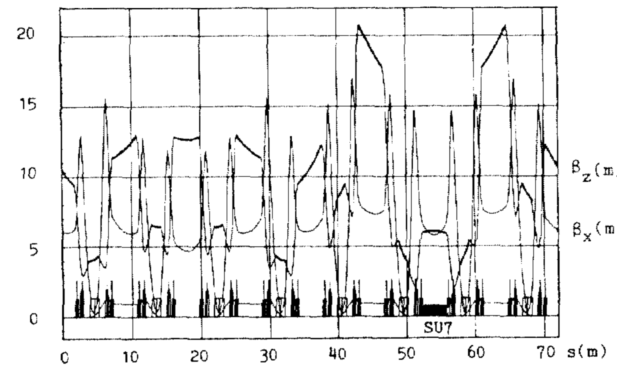

Fig. 1 : Optical functions with SU7 closed.

Tune Variation

In the following table, we summarize the undulators characteristics, the tune shift predicted by the thin lens model and the experimental ones, which are globally compensated by the quadrupole families Q_1 and Q_2.

		SU6	SU7: 2 regular undulators	SU7: Dispersive section	SU3
Strength K		2.2	6.0		6.0
Length L (m)		1.20	2.70	0.50	3.0
$\int B^2 dl$ (T^2.m)		0.065	0.30	0.091	0.3
λ (cm)		7.8	12.8	-	12.8
$\Delta\nu_x$	Thin lens model	0	0	0	0
$\Delta\nu_z$		$0.73\ 10^{-2}$	$3.3\ 10^{-2}$	$1\ 10^{-2}$	$3.3\ 10^{-2}$
$\Delta\nu_x$	Experimental	$7\ 10^{-4}$	0	$-1\ 10^{-2}$	$-0.7\ 10^{-2}$
$\Delta\nu_z$		$0.3\ 10^{-2}$	$3\ 10^{-2}$	$2\ 10^{-2}$	$4.6\ 10^{-2}$

The difference between predicted and experimental values shows that each undulator introduces an additional focusing, which can be compared to magnetic measurements :

$\int \frac{\partial B_z}{\partial x} dl$	SU6	SU7: 2 regular undulators	SU7: Dispersive section	SU3
Magnetic Measure-ments	160 G	-25 G	120 G	260 G
Experiments	144 G	0	335 G	470 G

Globally, the agreement is quite good.

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Dynamic Aperture and Beam Lifetime

Due to the undulator magnetic field, the dynamic aperture with one or many insertions is reduced.

As a consequence of the vertical aperture reduction for large horizontal amplitudes, the injection rate is reduced from 5 A/h with undulators open, to 2.5 A/h with undulators closed.

The vertical aperture reduction for small horizontal amplitudes makes the beam lifetime decrease. We adjusted $(k_x/k_z)^2$ to have a vertical aperture reduction in agreement with the measured beam gas lifetime variation ($\tau \alpha h^2$). So $(k_x/k_z)^2$ was reduced to -0.05 for SU6, and the strong value -0.5 is required for SU7 and SU3.

For various cases, the dynamic aperture is given on figure 2.

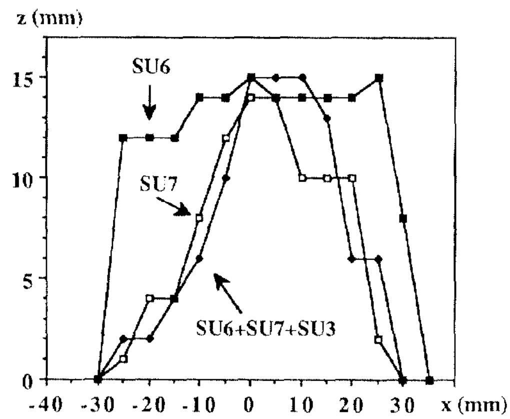

Fig. 2 : Dynamic aperture at the working point ($\nu_x = 4.72$ - $\nu_z = 1.70$).

In the following table, we present the Iτ values (product of the beam intensity and lifetime) measured at the working point for a 100 mA stored current in 24 bunches.

Undulators closed	h (cm)	Predicted Variation	Iτ (mA.h)	Experimental variation
No	1.5	-	1010	-
SU6	1.5	0	1040	0
SU7	1.2	-36 %	730	-28 %
SU6 and SU7	1.0	-55 %	690	-32 %
SU6, SU7 and SU3	1.0	-55 %	660	-35 %

Non Linear Resonance Effect

Using the hamiltonian formalism, it can be shown that fourth order non linear resonances are excited by the undulator field [2] :

$$4\nu_x = 19$$
$$4\nu_z = 7$$
$$2\nu_x + 2\nu_z = 13$$
$$2\nu_x - 2\nu_z = 6$$

These resonances can be identified in $(X, \dot{X})$ and $(Z, \dot{Z})$ diagrams, or (E_x, E_z) diagram for coupling resonances (Figures 3 and 4).

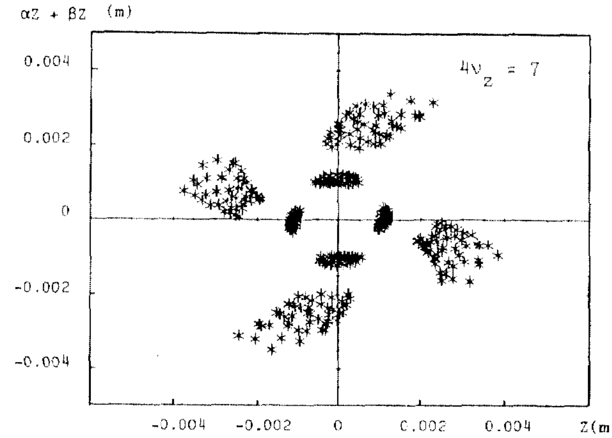

Fig. 3 : $(Z, \dot{Z})$ diagram for $\nu_x = 4.70$ and $\nu_z = 1.75$ (x_0 = -10 mm, z_0 = 1 and 2 mm).

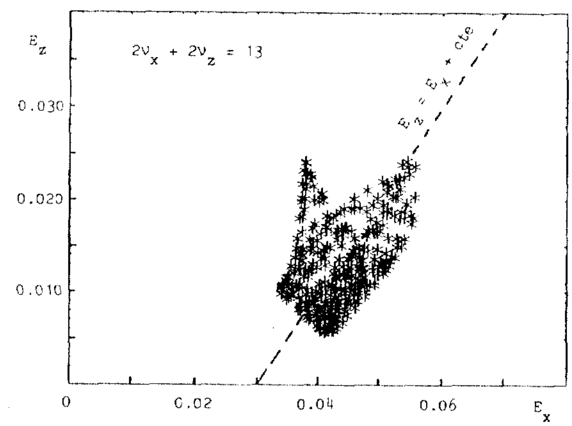

Fig. 4 : (E_x, E_z) diagram for $\nu_x = 4.73$ and $\nu_z = 1.78$ (x_0 = -15 mm, z_0 = 8 mm).

During experiments we have tested the effect of these resonances. A beam was stored (I = 100 mA), and keeping $\nu_x = 4.72$, we scanned ν_z from 1.70 to 1.78. The main results are summarized on figure 5 for various cases.

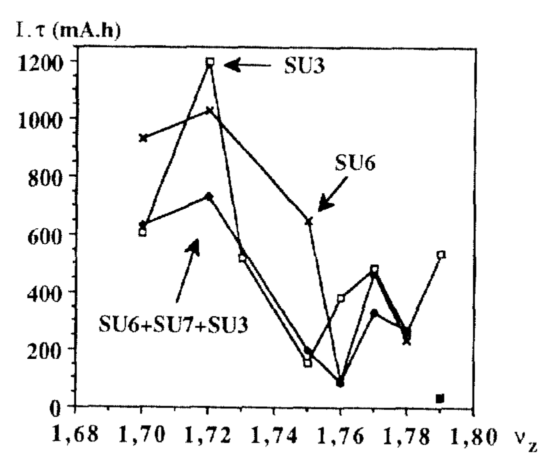

Fig. 5 : Variation of the beam lifetime with ν_z : ❑, x, ◆ for $\nu_x = 4.72$, and ■ for $\nu_x = 4.737$.

In all cases, $4\nu_z = 7$ ($\nu_z = 1.75$) and $2\nu_x + 2\nu_z = 13$ ($\nu_z = 1.78$) resonances are dangerous, and two other fourth order resonances $\nu_x + 3\nu_z = 10$ ($\nu_z = 1.76$) and $3\nu_x + \nu_z = 16$ ($\nu_z = 1.79$) are the most dangerous. Since these are not predicted by theory, this suggests that the analytical field model is not fully satisfactory.

Chromaticity

To complete the study of each undulator, the chromaticity was measured with undulators open and closed, to evaluate the sextupolar residual field due to the x-dependence of the finite value $\int B_z dl$. The experimental variations are :

Undulator closed	$\Delta\xi_x$	$\Delta\xi_z$
SU7	0	0
SU6	0.7	-1.5
SU3	0.2	0.4

As they are located in zero dispersion section, SU3 and SU7 do not introduce chromaticity. The small variation produced by SU3 is due to the change in optics. The chromaticity variation due to SU6 is equivalent to a sextupolar strength $K = 0.5\ m^{-2}$. As shown on figure 6, this evaluation agrees with the magnetic measurements in the region where the beam is stored ($-20 < x < 20$ mm).

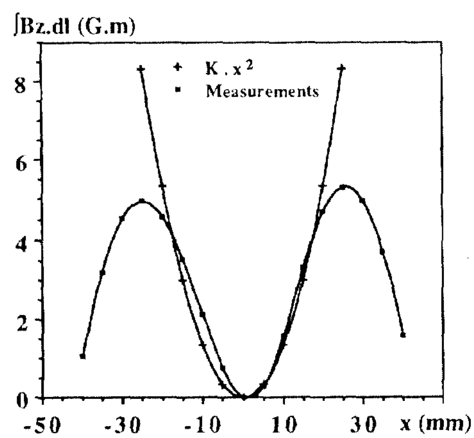

Fig. 6 : Variation of $\int B_z dl$ with the horizontal position x.

Touschek Lifetime

A direct measurement of the Touschek lifetime was performed using two unequal bunches with respective intensities 5 and 22 mA. The Touschek lifetime was found 160 mA.h with undulators open and 85 mA.h with SU6 and SU7 closed.

The dynamic aperture reduction due to SU6 and SU7 can not explain such a drastic reduction of the energy acceptance. So we have tested the transverse stability of a particle which receives an energy kick $\Delta p/p$ after a collision with an other particle in the same bunch. The simulations showed that when the kick is located in a dispersive section, the maximum stable value $\Delta p/p$ is less than the RF acceptance when the two undulators are closed. Then the Touschek lifetime is reduced.

For various initial betatron amplitude, we obtained :

	Undulators open		SU6 and SU7 closed		
x_0 (mm)	($\Delta p/p$)	($I\tau$) (mA.h)	($\Delta p/p$)	$I\tau$ (mA.h)	Variation
1	1.6 %	184	1.5 %	150	-19 %
3	1.6 %	184	1.3 %	104	-44 %
5	1.6 %	184	0.6 %	16	-91 %

We note that the measured lifetime reduction corresponds to an amplitude of about 3 mm, which is compatible with the horizontal beam size in dispersive sections ($\sigma_x = 800\ \mu m$).

Conclusions

The insertion of an undulator remains a strong perturbation even if linear effects are globally corrected.

Simulations with the BETA code have predicted the dynamic aperture reduction, the effect of most of the resonances and the energy acceptance reduction. Most measurements made on the beam agree with magnetic measurements. Meanwhile, the sinusoidal field model is not fully satisfactory. Presently, the choice of a working point far away from resonances provides good beam lifetime and injection rate with 3 undulators closed.

References

[1] L. Farvacque, J.L. Laclare, A. Ropert. "BETA user's guide", ESRF-COMP, 87-01.

[2] P. Certain-Brunelle. "Study of Super-ACO dynamic aperture", Anneaux RT/88-06.

Acknowledgments

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