# COLLECTIVE EFFECTS ON SUPER-ACO

M.P. Level, P. Marin, M. Sommer, H. Zyngier

Laboratoire pour l'Utilisation du Rayonnement Electromagnétique
91405 Orsay Cédex, FRANCE

## Abstract

Various collective effects limiting the beam performances have been investigated on Super-ACO and compared to the theory.

From bunch lengthening and transverse tune shift measurements, we deduced the vacuum chamber impedance value. On an other hand, the beam life time has been analysed in terms of Touschek effect, Rutherford and Bremsstrahlung contributions, in order to extrapolate the long term lifetime behaviour.

## Introduction

Super-ACO is a synchrotron radiation source designed for low emittance optics and several undulator insertions. The commissioning which started on March 87 is described in another paper presented at this conference [1].

We essentially report here, the measurements on the collective effects which limit the bunch intensity and determine the beam lifetime.

## Beam-environment electromagnetic interaction

### Vacuum chamber construction

Some simple precautions were taken in the design of the vacuum chamber so as to smooth out its shape and reduce its impedance.

The dimensions of the dipole chamber in the beam region, $\Delta x \times \Delta z$ = 90 mm×44 mm are close to those of the quadrupole's 120 mm×44 mm (racetrack shape). However, in the straight section (in the preundulator phase) and in the T-pieces between the dipole and the quadrupole section, the vacuum chamber is cylindrical with a diameter of 150 mm.

The 32 bellows adjacent to B.P.M.'s, are short-circuited by spring-like strips of stainless steel parallel to the beam. The 16 bellows adjacent to the dipole chambers are also short-circuited by spring-like stainless steel thin sheets inclined at 40° to the beam. The insulating circular ceramics of the current toroid monitor was RF short-circuited by a copper sheet insulated from the metallic chamber with a 35 µm thick kapton film forming a $10^3$ pF capacitance. The holes for the pumping outlets of the distributed pumps in the dipole chambers were cut parallel to the beam. For the other chamber elements, gate valves, kickers, excitation vessel and RF cavity no special precautions were taken for different reasons.

### Bunch lengthening with current. Beam energy spread

Due to the interaction of the beam with its environment, the bunch length changes with the intensity by potential well effect and turbulent motion.

Fig. 1. shows 3 sets of measurements of the bunch length versus current. $\sigma_\ell$ varies from 93 ps at low current, to 180 ps at 31 mA. A fit was made using the BBI code [2]. Below what appears to be the turbulent threshold the bunch lengthening is small and is in agreement with a broad band resonator frequency of 2.5 GHz. This part of the curve is not very sensitive to the impedance $\left|\frac{Z}{n}\right|_o$. Above the threshold at 7 mA, the data fit with $\left|\frac{Z}{n}\right|_o$ = 2.8 Ω.

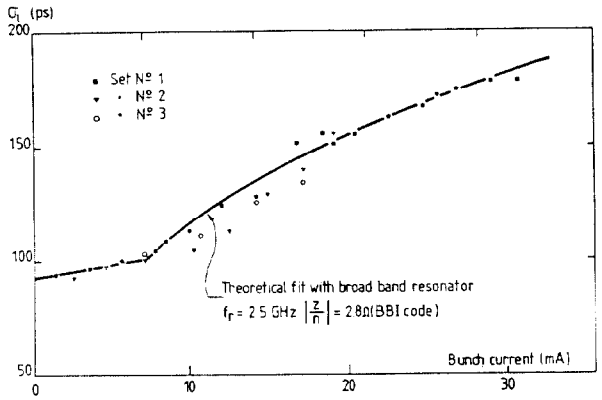


Fig. 1. BUNCH LENGTHENING WITH CURRENT

The energy dispersion increase due to the turbulent motion should reflect in the beam transverse dimension $\sigma_x$ at locations where the dispersion function $\eta$ is different from zero. We did measure the variation of $\sigma_x$ as a function of current with a CCD camera. Using the previous model, the energy dispersion as a function of current was calculated. This varies from the natural value $5.3\ 10^{-4}$ to $8.0\ 10^{-4}$ at 31 mA. Fig. 2 shows the plot of $\sigma_x^2$ versus $(\sigma_E/E)^2$ obtained. A linear fit according to the above formula gives :

$\sigma_{x\ \text{betatron}}$ = 260 microns and $\eta$ = 0.28 m

as compared to the values 230 microns and 0.32 m calculated from the optics.

Both measurements of bunch length and transverse beam dimensions call for better accuracy. Analysis of the undulator emission should provide for an independant and precise measurement of the energy dispersion.

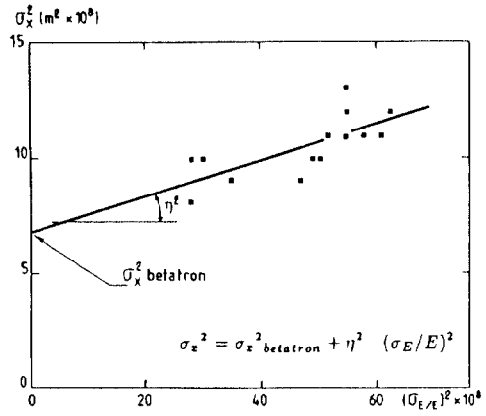


Fig. 2. HORIZONTAL BEAM SIZE VERSUS BEAM ENERGY DISPERSION

## Transverse instability. Mode measurements

The maximum intensity stored in a single bunch is 31 mA. Above this value, a vertical instability stops the injection. An increase of the chromaticity reduces the amplitude of the instability but the current limitation remains the same. Above 25 mA, the vertical profile evolves. The tails of the distribution become important leaving the core dimension unchanged.

The transverse mode coupling theory [3] predicts an instability when two modes merge.

Fig. 3 shows the mode frequency plot for various values of the chromaticity.

- For $\xi_z = 0$. Below 20 mA, only the m = 0 dipole mode is present. Between 0 and 31 mA the tune variation is 3.7 $10^{-3}$ a value slightly larger than the measured synchrotron tune 3.4 $10^{-3}$.

- For $\xi_z = 1$. The two modes m = 0 and m = - 1 are clearly distinguishable and their frequencies are getting closer as the intensity is increased.

- For $\xi_z = 2$. The modes converge more slowly in accordance with the observed instability damping.

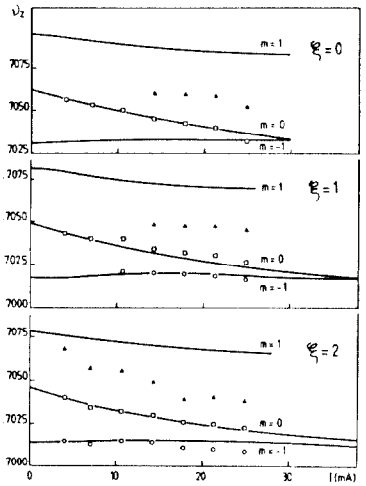


Fig. 3. TRANSVERSE MODE FREQUENCY VARIATION WITH BUNCH CURRENT

MOSES code [4] (solid lines) has been used to simulate the behaviour of the tune shifts with intensity, taking into account the bunch lengthening and the synchrotron frequency variation.

The value of the impedance : $Z_T = 0{,}3$ M Ω/m was determined by fitting the mode m = 0 at $\xi = 0$. The relationship between longitudinal and transversal impedances : $Z_T = \frac{2R}{b^2}\frac{Z}{n}$, strictly valid for a round pipe, yields an equivalent vacuum chamber radius b = 1.5 cm. This is not too far from the average half height of the Super-ACO vacuum chamber, 2 cm.

Fig. 3. shows a good agreement of MOSES calculations with the measurements, for the modes m = 0 and m = 1, as well as for the instability thresholds, for the different chromaticities :

- in fact, for the case $\xi = 1$, although the modes frequencies are not strictly equal for 30 mA, the motion is unstable with a rise time of 3 ms.

- for $\xi = 2$, the motion is stable for higher currents. The present limitation of the injection at 31 mA might be due to the dynamic acceptance reduction by the high sextupole field values. Further experiments with better sextupolar optimisation are foreseen. As already been observed (DCI, EPA [5]), the mode + 1 is not correctly accounted for by these calculations.

However we conclude that for bunches, a few centimeters long, the broad band resonator model is still a good approximation to calculate bunch lengthening and mode coupling instability threshold.

## Lifetime

The beam lifetime is limited both by single intrabeam scattering (Touschek effect) and by collision losses on the gas.

### Beam Gas lifetime

During the beam conditioning of the vacuum chamber, the current per bunch is small enough so as to neglect the Touschek effect. In these conditions the beam gas lifetime evolution can be studied.

The plot of Log $I^+\tau^+$ versus Log $[\int I^+ dt]$ shows a linear dependance. In the region covered experimentally $I^+\tau^+$ is proportional to the reciprocal of the outgassing rate λ, assuming that the static pressure is negligible. One finds :

$$I^+\tau^+_{gas} = \alpha[\int I^+ dt]^{0{,}73}$$

At the dose of 8 A×h, a lifetime of 4 hours is obtained for a total current of 100 mA distributed over 24 bunches. When operating with the distributed pumping, the lifetime increased by 20 % to reach 5 hours. Subtracting a small Touschek lifetime contribution yields a net beam-gas lifetime of 6 hours.

Touschek lifetime

A direct measurement was performed using one weak and one strong populated bunches. Both experience the same beam gas lifetime. Their difference in lifetime is due to the Touschek effect.

Close to the minimum coupling $K^2 = 2.3\ 10^{-2}$, a lifetime of 6.4 hours is obtained at the nominal bunch current of 20 mA.

On another hand, a single bunch experiment using beam scrapers, allows one to measure simultaneously Touschek, Rutherford and Bremsstrahlung beam gas lifetimes as well as the dynamic outgassing rate.

One can write :

$$\frac{1}{\tau} = \frac{b}{h^2}\ (P_o + \lambda I) \quad + \quad aI \quad + \quad c\ (P_o + \lambda I)$$

Ruth. Touschek Brems.

where $P_o$ is the static pressure and h the scrapers' half-aperture.

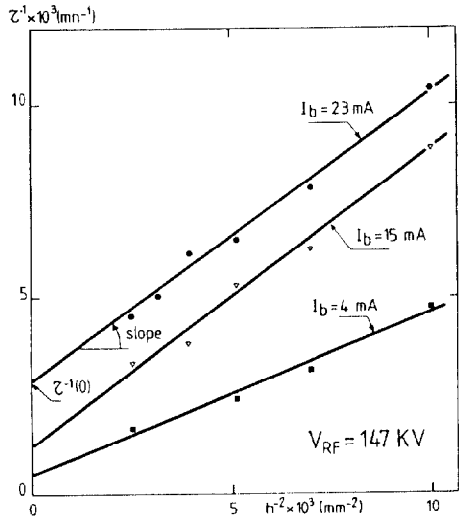


Fig. 4. LIFETIME VARIATION WITH VACUUM CHAMBER APERTURE

Fig. 4. shows the curves $\tau^{-1}$ versus $h^{-2}$ taken at three different currents. The data have been analysed with least square fits. The slope, $b\ (P_o + \lambda I)$ and the intercept of the ordinate $(a + c\lambda)I + cP_o$ have been plotted against current.

The values obtained from the data are :

$bP_o = 0.39\ mm^2.min^{-1}$

$b\lambda = 1.8\ 10^{-2}\ min^{-1}\ mA^{-1}$

$cP_o = -\ 2.2\ 10^{-4}\ min^{-1}$

$a+c\lambda = 1.2\ 10^{-4}\ min^{-1}\ mA^{-1}$

The negative value deduced for $cP_o$ reflects the very long Bremsstrahlung lifetime for the static pressure and the limited accuracy of the results for this particular evaluation. Finally $c\lambda$ being 8 % of the value of a, is neglected and :

$$\tau_{Touschek} = 140\ mA \times I^{-1}$$

For a current of 20 mA, the Touschek lifetime is 7 hours, in agreement with the direct measurement. The computed value, for the optics and the RF voltage used, is 8.4 hours.

At the beginning of the year, four octants were opened for new installations, especially an undulator 3.2 m long with a 30 mm vacuum chamber height. After a new bake out and conditioning for 2 A×h the average outgassing rate has almost recovered yielding a 5 hours beam gas lifetime for a current of 100 mA.

## Conclusions

The broad band resonator model was found to describe satisfactorily the beam behaviour in longitudinal as well as in transverse planes. The rather small impedance obtained has been reached at a reasonable cost. Beside reducing the vacuum chamber impedance and using transverse feedback, an increase of the chromaticity might be suitable to raise the instability threshold. This requires a better optimisation of the dynamic aperture.

Touschek lifetime has been found in fair agreement with calculation. The linear dependance of Log $\frac{\Delta P}{\Delta I}$ versus Log $\int Idt$, together with the computed Touschek lifetime allows one to predict long term beam lifetime.

## References

[1] E.M. Sommer et al. This conference : "Commissioning of Super-ACO". SA-88/23.

[2] M. Gygi Hanney et al. Program BBI. "Bunched Beam Instabilities in High Energy Storage Rings" CERN/LEP TM/83-2.

[3] B. Zotter. "Limitations of bunch-current in LEP by transverse mode coupling". IEEE Trans NS 30- p.2519, 1983.

[4] Y. H. Chin. "User's guide for new MOSES". CERN/LEPTH/88.

[5] D. Brandt et al. "Transverse mode measurements with positrons in EPA". CERN/PS/LRI/87-35.

## Acknowledgements

One of the authors, M.P. Level, would like to thank Y. H. Chin for sending the new program MOSES, B. Zotter and D. Brandt for many fruitful discussions.