Quasi-Isochronous Optics for Super-ACO[1]

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Abstract

A quasi-isochronous optics experiment has been performed on Super-ACO. Experimental results are given in terms of momentum compaction factor reductions, effects of the second order term and bunch lengthening with beam current.

1. INTRODUCTION

We are studying quasi-isochronous operation on Super-ACO. Such experiments have been carried out at BESSY I, and on the UV ring of BNL [1] and resulted in a reduction of the mementum compaction α by a factor 3 and 4 respectively. Recently, on UVSOR [2], Hama et al. have succeded in obtaining a reduction of a factor 100.

When the linear momentum compaction factor α_1 approaches zero, the second order term α_2, dependent on energy, becomes dominant. The longitudinal motion, which includes α in its equations, becomes essentially non linear. Then the longitudinal phase-space shape is modified and the stable region is reduced.

In this paper, we present optics calculation for the Super-ACO quasi-isochronous operation mode, as well as preliminary experimental measurements in this mode which show the effect of the second order momentum compaction α_2 at a very low α_1, down to $\alpha_1 = 1.47 \times 10^{-4}$. Bunch length measurements versus beam current performed for the nominal point and an intermediate α_1 values of 3.6×10^{-3} are also presented.

2. CALCULATION

2.1. The Momentum Compaction Calculation

The momentum compaction factor is defined as the variation of the orbit path length, $\Delta\ell/\ell$, whith the momentum deviation, $\Delta p/p$:

$$\alpha = \frac{d\,(\Delta\ell / \ell)}{d\,(\Delta p / p)} \qquad (1)$$

The path length variation with $\Delta p/p$ in higher order is :

$$\frac{\Delta\ell}{\ell} = \alpha_1 \frac{\Delta p}{p} + \alpha_2\left(\frac{\Delta p}{p}\right)^2 + \theta(3) \qquad (2)$$

[1] Work supported by CNRS-CEA-MESR.

where α_1 and α_2 are the first and the second order momentum compaction factors, calculated respectively by the following equations :

$$\alpha_1 = \frac{1}{L_o} \int \frac{\eta_o}{\rho_o}\, ds$$
$$\alpha_2 = \frac{1}{L_o} \int \left(\frac{\eta_o'^2}{2} + \frac{\eta_1}{\rho_o}\right) ds \qquad (3)$$

where L_0, ρ_0 denote the circumference and the bending radius of the ring. η_o and η_1 are the first and the second order dispersion functions, respectively. Their analytical expressions, given in [3], show that η_o depends only on bending magnets while η_1 depends on bending magnets, edges, quadrupoles and sextupoles. So, for a fixed value of α_1, α_2 can be adjusted with sextupole strengths. Using the equations (1) and (2), α can be expressed as :

$$\alpha = \alpha_1 + 2\alpha_2\, \Delta p/p \qquad (4)$$

2.2. Quasi-Isochronous optics calculation

The lattice of Super-ACO is a fourth order symmetry expanded Chasman Green Double Bend Achromat with four families of quadrupoles, and eight straight sections alternately with (even sections) and without dispersion (odd sections). In the standard operation mode of Super-ACO, the momentum compaction value is 1.48×10^{-2}, determined by goemetrical considerations.

To lower this value of α, we used the four families of quadrupoles to render η_{x_o} negative in the odd sections in order to cancel the positive η_{x_o} contribution. During the descent path, the betatron tunes and the betatron functions are kept at constant values.

Fig. 1 shows the Super-ACO optical functions for the quasi-isochronous mode operation which corresponds to $\alpha = 1.47 \times 10^{-4}$, 100 times smaller than the standard value.

Calculated linear momentum compaction factor values as a function of the dispersion function in the odd straight sections are given in figure 2.

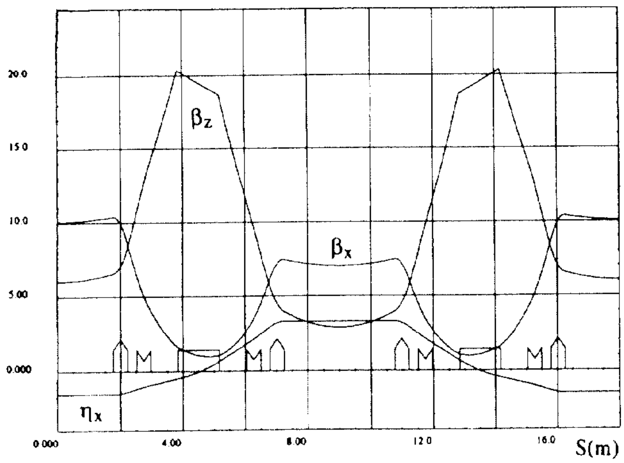

Figure 1. Optical functions for the quasi-isochronous mode operation ($\alpha = 1.47 \times 10^{-4}$).

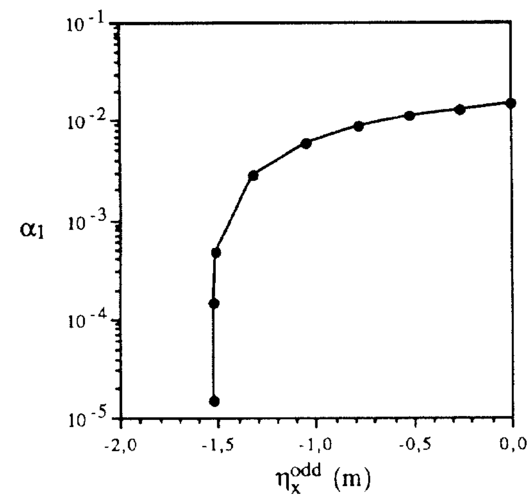

Figure 2. Calculated momentum compaction factor during the descent path.

3. MEASUREMENTS

The natural bunch length σ_{ℓ_0} and the synchrotron frequency f_s are proportional to $\sqrt{\alpha}$.

For a fixed value of the RF voltage, the measurements of σ_{ℓ_0} and f_s allow one to deduce the value of the momentum compaction. The value of α at any point of the descent path may be calculated from its initial value and the corresponding measured synchrotron frequencies using the relation :

$$\alpha\ (i) = (f_s\ (i)/f_s\ (1))^2 \alpha\ (1) \tag{5}$$

provided that RF voltage is maintained constant. f_s (1) measured at the nominal point ($\alpha(1) = 1.48 \times 10^{-2}$) is 15 kHz.

Another method to deduce α is to measure the horizontal position of the beam as a function of the RF frequency. The beam position displacement Δx is related to the momentum compaction factor as :

$$\Delta x = -\frac{\eta_x}{\alpha}\frac{\Delta f_{RF}}{f_{RF}} \tag{6}$$

where η_x is the calculated horizontal dispersion at beam position monitors.

The gradient values of quadrupoles calculated for each point of the descent path were introduced into a control program. The beam was injected at the nominal point, then α was reduced step by step by changing the quadrupole current. The experiment was performed with a single bunch at the nominal energy of 800 MeV.

4. EXPERIMENTAL RESULTS

The measured values of the synchrotron frequency during the descent path varies linearly with $\sqrt{\alpha}$, (fig. 3), while the second order term α_2 is still negligible, ($\alpha_1 \geq 3 \times 10^{-3}$). The reduction of α at this point is then a factor of 5.

In the region of α below 3×10^{-3}, the nonlinearity of f_s becomes apparent. To explain this, we reconsider the equation (2) whose physical solution in $\Delta p/p$ is :

$$\frac{\Delta p}{p} = -\frac{\alpha_1}{2\alpha_2}\left[1 - (1 - \Delta)^{1/2}\right] \tag{7}$$

where $\Delta = 4\ \dfrac{\alpha_2}{\alpha_1^2}\dfrac{\Delta f_{RF}}{f_{RF}}$.

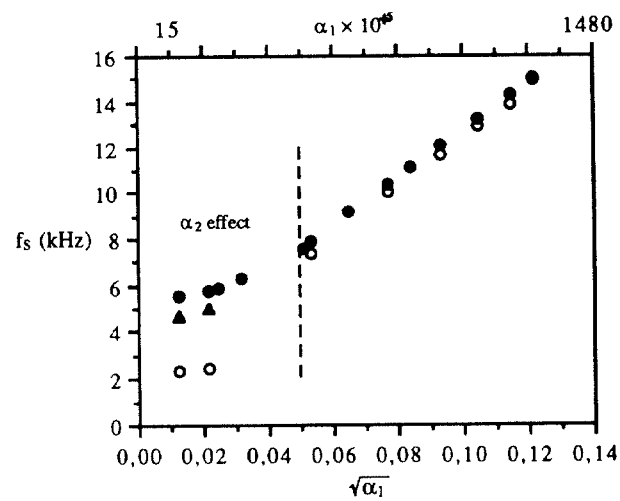

Figure 3. Measured synchrotron frequency as a function of the momentum compaction with different sets of sextupole strenghts.

The synchrotron frequency becomes nonlinear in Δ and depends on α_2 :

$$f_s = f_{s_o} (1 - \Delta)^{1/4} \quad (8)$$

where f_{s_o} corresponds to the case $\alpha_2 = 0$.

This is why different experiments with different sets of sextupole strengths gave different f_s values for the same α_1. Note that the experiment is made difficult by poor lifetime, various instabilities and large closed orbit shifts which occur towards at the end of the descent. One sextupole configuration was especially favorable to reduce α_2 close to zero, leading to low values of f_s (2.3 kHz) with a beam current of 0.1 mA.

5. BUNCH LENGTHENING WITH BEAM CURRENT

The bunch length was measured for two different values of α at beam currents up to 10 mA per bunch. Fig. 4 shows the measured values compared to the predictions of the turbulent bunch theory (code BBI). The impedance value of 6.3 Ω fits the bunch length measurements up to 80 mA at $\alpha = 1.48 \times 10^{-2}$. We observe that for $\alpha = 3.6 \times 10^{-3}$, the threshold is below 0.3 mA and for 4 mA and above there is no change in bunch length.

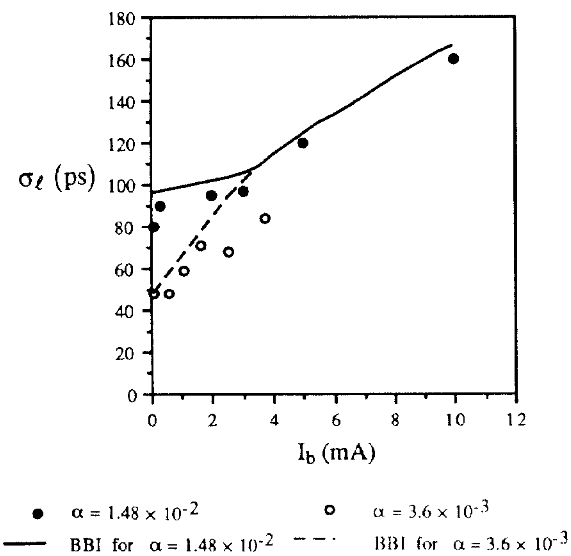

Figure 4.

6. CONCLUSION

In future experiments, we shall vary the RF frequency to control closed orbit and the sextupole strenghts to act on α_2 in order to get the smallest possible bunch length.

7. REFERENCES

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[3] J.P. Delahaye and J. Jäger, Particle Accelerators, 18 (1986) 183.

8. ACKNOWLEDGEMENTS

It is a pleasure to acknowledge the contributions from the storage rings technical staff.