SSC--14

DE90 014106

Overlap Knock-Out Resonances in the SSC

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March, 1985

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Introduction

The appearance of 'overlap-knock-out resonances' was first observed in the ISR.[1] These resonances caused severe enlargement of the vertical beam dimensions and a significant reduction in the luminosity. Somewhat later[2] these resonances were also observed with bunched beams of different energies in each ring, and under resonant conditions reduced the beam lifetime to a few seconds with a beam-beam tune shift of less than 10^{-5}.

For the case of the SSC where the energies of the beams may under certain circumstances be unequal, these resonances may appear and cause beam loss.

Resonance Condition

The longitudinal frequencies in a circulating bunched beam are nf_{rev} where f_{rev} is the revolution frequency.

The overlap resonance condition occurs when the longitudinal frequency components of one beam become equal (overlap) with the transverse betatron frequencies of the other beam i.e. the resonance condition is[2]

$$(n + Nq_1)f_1 = nf_2 \qquad (1)$$

where N = 1,2, for dipole quadrupole etc.

f_1 refers to the revolution frequency of the low energy beam

f_2 refers to the revolution frequency of the high energy beam

n is the harmonic number of the bunch spectra

and

$$f_1 = \frac{\beta_1 c}{2\pi R} \qquad f_2 = \frac{\beta_2 c}{2\pi R}$$

Hence (1) is

$$(n + Nq_1)\ \beta_1 = n\beta_2$$

For N = 1 then

$$(n + q_1)\ (1 - \frac{1}{2\gamma_1^2}) = n\ (1 - \frac{1}{2\gamma_2^2})$$

or

$$q_1\ (1 - \frac{1}{2\gamma_1^2}) = n\ (\frac{1}{2\gamma_1^2} - \frac{1}{2\gamma_2^2})$$

For $\gamma_2 >> \gamma_1$ the resonance condition is simply

$$q_1 \approx \frac{n}{2\gamma_1^2} \qquad (2)$$

Equation (2) tells you the harmonic number in the bunch longitudinal frequency spectrum which will cause 'overlap' at a given tune and energy of the low energy beam. As the order of the overlap knock-out resonance is increased the required harmonic content is decreased.

It would be very difficult to ensure that all orders of resonances are not excited in a machine like SSC when operated with short bunches at unequal energies. It may be apparent that these resonances are totally avoided when the revolution frequencies of each beam are equal (by locking the RF systems) even if the energies are different. The consequences of accomplishing this is described in the next section.

Phase Locked RFs for Each Beam

The RF system of each beam may be made equal thereby avoiding the resonance condition i.e.

$$f_1 = f_{10}\left(1 + \alpha_1\left(\frac{\Delta P}{P_1}\right)\right) = f_2 = f_{20}\left(1 + \alpha_2\left(\frac{\Delta P}{P}\right)_2\right) \qquad (3)$$

where f_{10} and f_{20} are the revolution frequencies at the centre of the accelerator. For $\alpha_1 = \alpha_2 = \alpha$ and ignoring higher order terms gives

$$\alpha\left(\left(\frac{\Delta P}{P}\right)_1 - \left(\frac{\Delta P}{P}\right)_2\right) = \frac{1}{2\gamma_{10}^2} \qquad (4)$$

Further assume that

$$\left(\frac{\Delta P}{P}\right)_1 = -\left(\frac{\Delta P}{P}\right)_2 = \frac{\Delta P}{P}$$

so that the minimum amount of momentum aperture is wasted, then

$$\left(\frac{\Delta P}{P}\right)_{\text{each beam}} = \pm \frac{1}{4\alpha\gamma_{10}^2} \approx \pm \frac{1}{4}\left(\frac{\nu_x}{\gamma_1}\right)^2$$

The corresponding orbit shift is

$$\Delta R = \alpha R \frac{\Delta P}{P} = \frac{R}{4\gamma_1^2} \quad .$$

For the 6 SSC test lattices (ref. SSC Aperture Workshop Summary, Nov., 1984, SSC-TR-2001), we have, for $\gamma_1 = 10^3$,

B (tesla)	phase/cell	ν_x	$2\pi R$	$(\Delta P/P)$ each beam	ΔR
6.5	60°	66	100Km	$\pm 1.1\times10^{-3}$	±4mm
	90°	99	100Km	±2.5	±4mm
5.0	60°	75	115Km	±1.4	±4.6mm
	90°	113	115Km	±3.2	±4.6mm
3.0	60°	97	160Km	±2.4	±6.4mm
	90°	146	160Km	±5.3	±6.4mm

These values of $\Delta P/P$ and ΔR appear unacceptable in terms of wasted aperture!

Conclusions

The problem of overlap knock-out resonances in the SSC could be avoided by phase locking the RF systems of both rings. Unfortunately this will require the beams to be displaced in momentum by around $\frac{\Delta P}{P} \simeq 1\text{-}5 \times 10^{-3}$. This value seems unacceptably high. It therefore appears that unequal beam energies in the SSC should be avoided if possible.

References

1. J.-P. Gourber, H. G. Hereward, and S. Myers; IEEE Trans. Nucl. Sci. Vol. NS-24, 1405-1407, 1977.

2. S. Myers, IEEE Trans. Nucl. Sci. Vol. NS-26 No. 3 June 1979.

Acknowledgement

I thank the staff of the SSC and in particular A. Chao for the several discussions and their hospitality during my stay at Lawrence Berkeley Laboratory.