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A Feedback for Longitudinal Instabilities in the SLC Damping Rings

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I. INTRODUCTION

Longitudinal coupled bunch instabilities which are being observed in the SLC Damping Rings present a serious limitation to the ultimate luminosity of the colliding beams. It has been observed at intensities above 1×10^{10} particles per bunch with growth rates of the order of 10^4 per second. At lower intensities we were able to control the growth by detuning the RF cavity through temperature or voltage changes. As the SLC operating intensity approaches the design value above 5×10^{10}, a more fundamental cure is definitely needed. In this report we sum up the studies done so far in characterizing and simulating this instability and the proposed remedies.

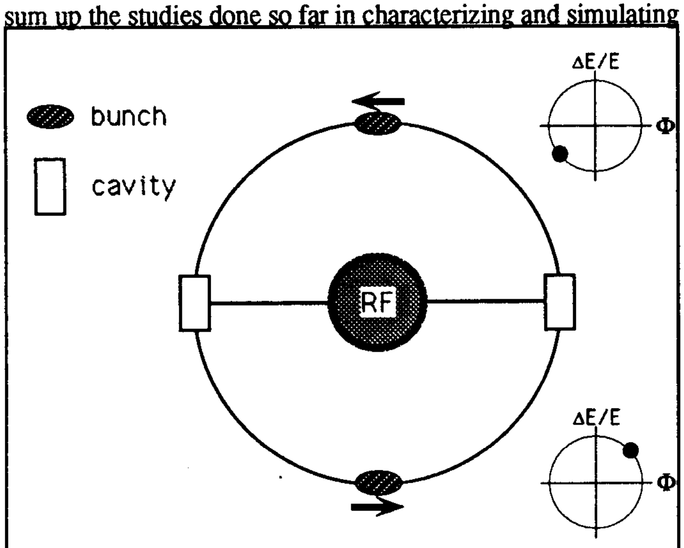

Figure 1. Damping Ring layout and π-mode

Momentum compaction (α)	0.01814	
Revolution frequency	8.5	MHz
Energy	1.21	GeV
Particles per bunch	5 & 5	10**10

Table 1. Damping Ring Parameters

Harmonic number	84	
Unloaded Q	24000	
Coupling factor (β)	2.5	
Synchronous angle	39.2	degree
Cavity detuning angle	68.3	degree
Shunt impedance	17.5	MΩ
Generator power/cavity	25.0	kW

Table 2. RF Parameters

Tables 1 and 2 sum up the relevant machine and RF parameters of the Damping Rings. The longitudinal coupled bunch instability arises in the Damping Rings due to the coupling between the normal modes of the 2 bunch system and the cavity parasitic modes. A schematic of the Damping Ring is shown in Figure 1. The 2 cavities diametrically across from each other are powered by a single RF source which decouples any RF manipulation from the normal mode in which the 2 bunches execute synchrotron oscillations with opposite phases. If the latter mode,

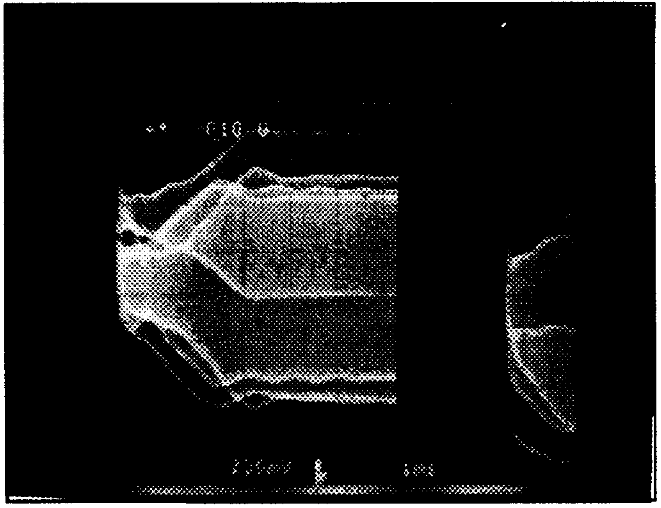

Figure 2. π-mode observed over one cycle

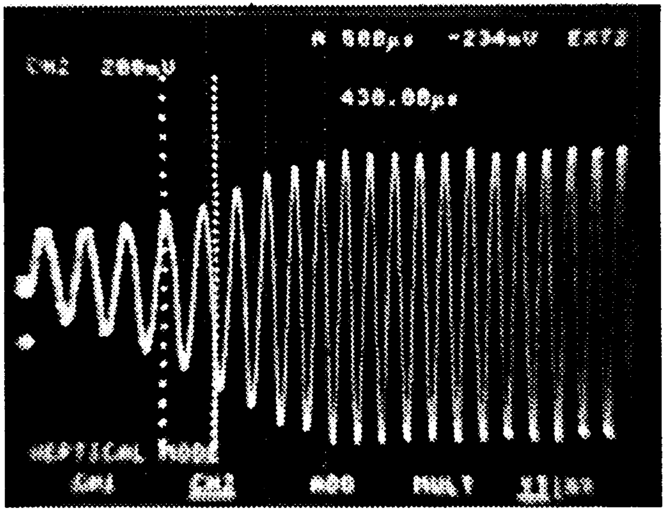

Figure 3. π-mode sampled at lower frequency

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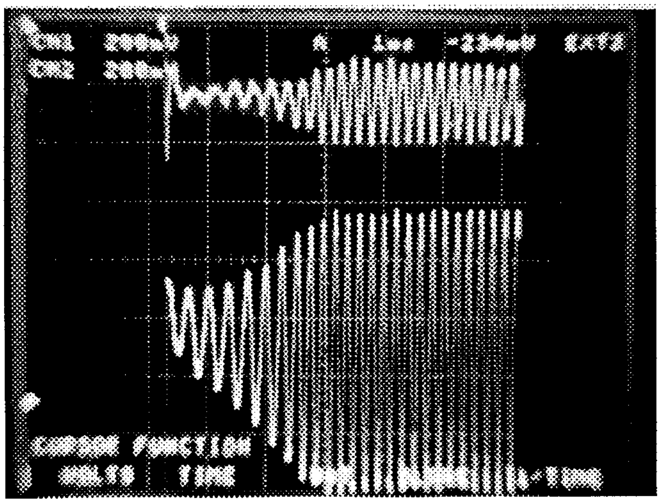

Figure 4. Observed 0 and π-modes

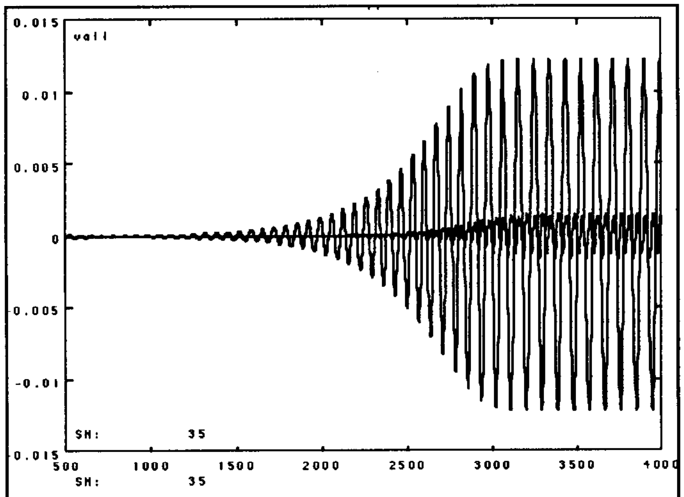

Figure 5. Simulated growth of 0 and π-modes

henceforth called the π-mode, falls within the resonance peak of some higher odd harmonic of the cavity, a resonant growth can result. Such instability was demonstrated in Figure 2, which displays a Damping Ring position monitor located at a high dispersion point picking up the growing amplitude in the energy oscillations throughout the cycle. Figure 3 shows a more clear pattern of this growth using a lower sampling frequency. Such signals from individual bunches can be added or subtracted to manifest the two normal modes, namely the zero mode and the π-mode. These are shown in Figure 4. It is seen that as the growth in the π-mode progresses, there is an accompanying growth in the zero mode. Very similar phenomenon has been observed in the simulation program as shown in Figure 5 where the growth in the π-mode appears to influence the otherwise damped zero mode. In the latter case this is understood to be caused by the nonlinearity in the RF potential probed by the large amplitude oscillation, which deforms the limiting phase space contour and puts some growth into the zero mode, which in turn reaches a limiting value due to Robinson damping. It can not be determined presently whether the observed zero mode growth shares the same origin as the one in simulation. Calculation based on the RF cavity geometry was done with URMEL to look for the offending parasitic modes. Table 3 gives a partial list of the possibly existing odd harmonic modes which could drive the π-mode. Note that in calculating the respective growth rates, the frequencies of these modes have been shifted to the proper synchrotron sideband as indicated in the second column so as to give the worst possible growth. They are thus more benign in reality than is indicated in the table.

Mode no.	Δ freq.	R MΩ	Q	τ (rise time) μs
83	0	2.0	30000	17.4
127	0.4	2.64	30000	9.11
177	0.1	0.53	29000	23.1
209	0.3	0.82	27600	12.8
221	0.4	1.7	61800	8.22

Table 3. Odd parasitc modes calculated by URMEL

II. STUDY OF POSSIBLE SOLUTIONS

Several solutions have been studied in addressing the π-mode problem. Due to the special RF configuration in the Damping Ring, we can not contain the π-mode with any feedback based on RF manipulations using the direct π-mode signal. We give a brief account of these studies below, followed by a description of the passive damping cavity being designed and expected to be in service for the second 1991 SLC run.

Single bunch damping

A feedback mechanism has been experimented where the signal of a single bunch is picked up and used in the RF feedback which affects both bunches in the same way. This effectively damps the bunch being monitored and antidamps the other. The damped bunch is the one to be immediately extracted. This method was effective in controlling the final amplitude of the extracted bunch when the growth is mild in the first place.

Tune splitting

The idea of tune splitting is to superimpose the RF with an odd harmonic waveform so as to modify the RF potential differentially for the 2 bunches. The resulting tune splitting would then disrupt the coherence of the π-mode. Study based on computer simulation indicates that in order to control a π-mode

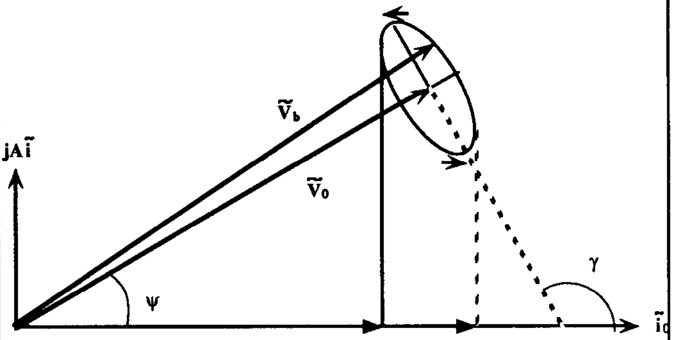

Figure 6. Concept of passive damping

with growth time of 81 μsec (mode number 83), a 15 kV RF modulation with mode number 85 is needed.

Active damping cavity

A feedback scheme using an extra odd harmonic cavity has also been studied. This cavity would couple exclusively to the π-mode and thus effectively damp it. It is found that a maximum gap voltage of 8 kV running at 253rd harmonic is needed to damp the 83rd harmonic π-mode with a growth time of 81 μsec.

Passive damping cavity

This method takes advantage of the finite filling time of any cavity which gives rise to either growth or damping of the normal modes of the circulating bunches, as manifested by Robinson damping of longitudinal oscillations by RF cavities. The damping mechanism is depicted in the phasor diagram of Figure 6[1], where it is shown that due to the finite filling time in the cavity, a phase oscillation in the bunches would induce an oscillation in both amplitude and phase of the induced voltage, which in turn leads to dissipation of the stored oscillation energy. The same concept applies to an odd harmonic cavity coupled to the π-mode. It has been worked out in [1] that the resulting damping rate is given by*

$$\frac{1}{\tau_d} = \frac{N_{pc}}{N_h} \cdot \frac{V_{br}\,\omega_s}{V_c \sin\phi} \cdot \frac{-\,\xi\,\eta}{[1+(\xi+\eta)^2]\,[1+(\xi-\eta)^2]}$$

where

$$\xi = -\tan\psi = (n\,\omega_0 - \omega_r)T_f\ , \quad \eta = \omega_s T_f$$

and

N_{pc} : harmonic number of passive cavity
N_h : harmonic number of main cavity
V_{br} : beam induced voltage
V_c : peak RF voltage
ϕ : synchronous angle
ω_s : synchrotron frequency
ψ : cavity tuning angle
T_f : $2\,Q_0/\omega_0(1+\beta)$
ω_0 : revolution frequency
ω_r : cavity resonant frequency
β : cavity coupling factor

Thus with an odd harmonic cavity in the Damping Ring passively coupled to the π-mode, one can expect to see some dissipation of the energy stored in the π-mode. Extensive tracking simulations and URMEL calculations have been devoted to characterizing the parameters of such a cavity in order to overcome the π-mode growth of the order of 100 μsec while conforming to other physical restrictions in the machine. Table 4 shows the damping time of passive cavities with various specifications in the Damping Ring environment. These correspond to various physical designs of the cavity. Table 5 shows the result of an URMEL study of the dependence of longitudinal impedance on the cavity diameter. We also studied the potential transverse instability that might be caused by this addition. The evidence suggests that with an extra tuner in the cavity we can safely steer the operation point clear of transverse resonances. A prototype design of this cavity is completed (see Figure 7) which incorporates the features dictated by the studies described above. It relies on two tuners to stay clear of any transverse resonances with the beam.

Mode no.	R MΩ	τ (damping time) μs
43	3	33.8
85	3	17.9
127	0.3	94.0
169	0.3	68.6
253	0.3	46.1
337	0.3	36.8
421	0.3	29.7
505	0.3	27.3
673	0.3	23.9
841	0.3	22.3

Table 4. Damping times for various passive cavities

Diameter (in)	R (MΩ)	τ (damping time) μs
0.59	4.8	12.6
1.0	3.9	14.5
2.0	2.1	22.0

Table 5. URMEL results of impedance vs. cavity size

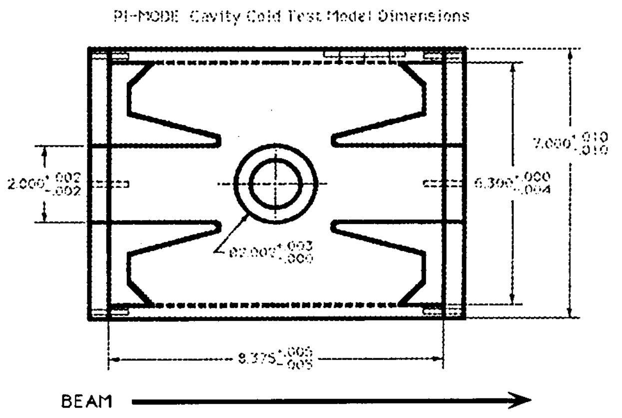

Figure 7. Side view of the passive damping cavity showing end caps and 2 tuners

III. CONCLUSION

The longitudinal coupled bunch instability in the SLC Damping Rings has been thoroughly studied, as well as many possible cures thereof. We have decided to pursue the passive damping cavities based on power considerations. Extensive evaluation and design studies have been done to make sure this will live up to its expectation without causing adverse side effects. We expect to commission this cavity in December 1991.

REFERENCE

[1]. P.B. Wilson, SLAC-PUB 2884, 1982
P.B. Wilson, Proc. 9th Int. Conf. on High Energy Accelerators, p.60

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