

Chapter 18. Passive Damper and Active Feedback

18.1 RF Cavity Passive Spurious Mode Damping

J. Griffin

With the large beam intensity increases proposed, spurious resonant modes in the rf cavities (and elsewhere in the lattice), present increased sources of longitudinal instability. The existing rf cavities have higher order mode dampers attached to vacuum seal cooling fans. These dampers are effective at two predominant offending cavity modes: 128 and 225 MHz. Originally there were additional iris-coupled mode dampers containing frequency selective ferrite (Indiana General Q2), at each end wall. The iris ports may still be in place, but possibly covered with copper due to water leaks in the ferrite cooling plates backing the lossy ferrite. Improved ferrite cooling could be implemented if measurements indicate that the iris dampers can contribute to stability.

The cavity revisions proposed in Ch. 15 will probably change the offending cavity mode frequencies so that they will have to be remeasured, along with any additional modes that appear to have potential for causing beam instability.

There is an additional feature of the upgraded cavity design that may be turned to advantage in the area of spurious mode damping. In Ch. 15 it is proposed to couple 50 - 70 kW additional rf power out of each cavity, to be dissipated in matched water-cooled terminations. The additional power dissipation is primarily for the purpose of establishing an adequate margin of stability against the Robinson beam loading instability. However, if rf power output coupling devices (inductive loops or possibly capacitances), are selectively located and properly configured they may effectively be used to also damp spurious cavity modes.

The effectiveness of reinstating iris coupled damping, the location of new spurious modes, or the location of damping power output coupling devices should be studied to the extent possible using cavity modeling programs such as enhanced versions of MAFIA.

18.2. Longitudinal Feedback and Damping

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Before discussing longitudinal feedback in the Main Injector, it is necessary to understand the different responses of the modified (see Section 15.5) and the new rf systems (see Section 15.9) to transient beam loading. Both the modification of the existing MI rf system and the design of an entirely new system aim to increase beam stability by lowering the rf cavity shunt impedance, R_s , by increasing the power dissipated in the cavity. Modifying the existing system would lower R_s by reducing Q by

connecting a 150 kW rf load to the cavity. The new system would lower R_s by reducing the cavity's characteristic impedance, Z_o , while leaving Q unchanged. In the steady state beam-loading limit, the two approaches give essentially the same results. However, transient beam loading effects are quite different in the two options. Consider the case of a single high intensity bunch passing through an rf cavity. The voltage induced in the cavity after the passage of the bunch is proportional to the R_s/Q of the cavity. In the modified system, R_s/Q remains unchanged since R_s was lowered by changing Q . In the new system R_s/Q is lowered by a factor of four (R_s decreased by lowering Z_o , Q remains unchanged.) This means that transient induced voltages (on time scales short compared to $2Q/\omega$) will be four times smaller with the new rf system.

As previously mentioned in Ch. 15, the cavity tuning feedback system will not be able to change the cavity tuning angle on the time scale of a 1.6 μ s Booster batch. Therefore, there will be a shift in the phase of the total rf cavity voltage with respect to the beam as the Booster batch transverses the cavities. For the modified version of the present cavities, assuming narrow proton bunches of 3×10^{11} per bunch, the beam induced voltage in a single rf cavity after the passage of 84 bunches $\approx 84\omega\Delta q R_s/Q = 140$ kV. At injection, the maximum cavity voltage is limited to 110 kV due to sparking in the tuners. Under these conditions the total phase shift θ observed would be $\theta = \arctan(140 \text{ kV}/110 \text{ kV}) \approx 52^\circ$ and beam will be lost from the machine as the trailing bunches try to gain energy by moving to a new synchronous phase angle, ϕ_s . Beam loss will occur since the last bunch loses 140 keV/turn while it can only gain 110 keV/turn from the rf voltage. For the completely new rf system, the transient induced voltages will be lower by a factor of four ($140 \text{ kV}/4 = 35 \text{ kV}$) due to the lower R_s/Q . The new system is also designed to run at a higher voltage at injection. If the new cavities were operated at 150 kV at injection, this would result in a total phase shift of $\theta = \arctan(35 \text{ kV}/150 \text{ kV}) = 13^\circ$. This 13° phase shift corresponds to that presently observed in the MI at injection.

The above example illustrates the important difference between a modified and a new rf system. If the present MI system is modified, a fast feedback loop around each individual rf cavity will be absolutely necessary for beam stability in the face of transient beam loading effects. The new rf system, without any fast feedback, would give performance comparable to the present MI.

A fast feedback loop around each rf station would be designed as a direct feedback loop in the tunnel around each rf cavity. A fraction of the detected cavity gap voltage would be summed with the cavity drive signal to reduce both amplitude and phase excursions.

The damping of longitudinal coupled-bunch motion will be required in PD2. If the present rf cavities are modified for use in the new machine, the three existing higher order mode (HOM) passive dampers will have to be redesigned to provide more coupling to the HOMs and allow for greater HOM power dissipation. Likewise, effective HOM dampers must be included in any new rf cavity design. Even if all the HOMs of the accelerating cavities are successfully damped, other resonant structures in the ring might have sufficiently high impedances to excite coupled-bunch instabilities. In this case an

active longitudinal damper will be required. Since the amount of power that will be required for damping coupled-bunch oscillations is unknown, a modular active damping system is proposed. Each module would consist of a $50\ \Omega$ broadband rf cavity driven by a commercially available 10 kW solid state amplifier. Each cavity/amplifier module will generate peak gap voltages up to 1 kV over the frequency range of 100 kHz to 250 MHz. The drive to the amplifier will be derived from the existing resistive wall monitor signal. Initially, one module will be inserted in the ring for testing and damping studies. During commissioning, as the machine intensity is raised to its design value, additional modules could be inserted, if needed, to provide increased damping.