Summary

Inherent to the Zero Gradient Synchrotron (ZGS) are spontaneous intensity dependent beam size growths that can lead to precipitous beam losses. Vertical losses can occur at intensities $>5 \times 10^{11}$ protons/pulse. Horizontal beam losses can occur at intensities $>10^{12}$ protons/pulse. This paper discusses the factors affecting the beam size growth, the characteristics of the signals observed, and the equipment developed to control these losses; in particular, the $(1-V_x)$ horizontal damper and the wideband vertical damper. Because of the space limit for the paper, the discussion will be limited primarily to the $(1-V_x)$ horizontal damper.

System Discussion

Early in our experience, beam size observations made with nondestructive beam-viewing systems led to the fact that there were spontaneous horizontal (radial) beam size growths in the ZGS. Those that occurred early in the cycle occasionally led to large beam losses. Furthermore, beam growths during targeting contributed to nonuniform spill and in some cases, to beam losses. It was clear that for higher intensity and improved high energy physics operation, a damper for these radial beam growths would have to be constructed. Close analysis of the radial position signals as obtained from induction electrodes showed a clear coherent oscillation at the frequency of $(1-V_x) F_{RF}/8$ during the time of the beam size growths. This simple observation led to a prototype radial damper. This system utilized equipment that had been initially designed to measure the tunes in the ZGS. Additional study of the relationships of beam behavior that impart coherent oscillations of this type lead to a conceptually simple radial damper. If a radial difference signal were obtained, delayed by $90^\circ$ and reapplied to the circulating beam, effective damping could occur. The initial tests with the simple system mentioned earlier showed that consistent radial damping could be obtained in this fashion. With the early system, the $90^\circ$ phase shift was obtained by open-loop phase shifting, utilizing a delay curve obtained from tune data. The final system, and the one to be discussed, utilizes a fixed phase shifting technique, and results in a simple system for the operators to adjust. Figure 1 shows this system in a block diagram form. The radial position signal is obtained from the induction electrodes through $40 \mathrm{~J} \mathrm{D}$ attenuators that prevent overdriving the differential amplifier (RCA 3040) that follows. The differential amplifier has $40 \mathrm{~dB}$ of fixed gain and a bandwidth of 10 kHz to 15 MHz. The output of the amplifier effectively represents the radial position of the beam. This signal is applied to a special phase-equalizing filter.

Performance

This scheme has been utilized with a power amplifier of smaller capacity and has clearly provided adequate damping of the radial growths. Since the phasing is always appropriate, only simple gain adjustments are required on the part of the operator. This dramatically simplifies the tuning requirements on the damping system if changes occur in the tune of the ZGS during acceleration. Figure 2 shows an example of an undamped beam with subsequent beam size growths of $>150\%$. Energizing the damper (Fig. 3) completely eliminates this growth and stabilizes the beam at a virtually constant size. The improvements obtained by eliminating these growths are clear in terms of operating efficiency and, in some ways more importantly, the extraction efficiency of the ZGS. A properly operating radial damper may contribute to a $60\%$ increase in extracted beam efficiency. Compromise adjustments of the gain are in some cases required because overdamping of the radial beam size may lead to vertical losses. Consideration has been given to providing vertical damper-to-radial damper feedback to prevent losses of either type. Efforts are continuing, however, to improve the characteristics of both dampers so that this type of feedback is not required.

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References

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Figure 1.

Figure 2.

Figure 3.