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OBSERVATIONS AND CURE OF HEAD-TAIL EFFECT IN THE ARGONNE RAPID CYCLING SYNCHROTRON*

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Summary

Radial head-tail effects have been observed in the 500-MeV Rapid Cycling Synchrotron (RCS). The threshold intensity of accelerated beam to induce the instability was 4×10^{11} protons/pulse, and the mode numbers observed were m = 1 and m = 2. Detailed study showed that the radial chromaticity of the lattice at this particular time in the acceleration cycle was positive. This is consistent with theoretical predictions for a machine operating below the transition γ. In order to prevent the onset of this instability, a set of programmable sextupole magnets has been introduced that can be programmed to vary the chromaticity at any point during the acceleration period. With these sextupoles, the machine intensity has passed 2×10^{12} protons/pulse.

Introduction

The RCS operates at a repetition rate of 30 Hz, and its guide field varies from 2.8 kG to 10.0 kG in 16.7 ms, with a half sine wave dB/dt. At the time of commissioning, the accelerator was equipped with a set of dc sextupole magnets that allowed the adjustment of the chromaticities within a limited guide field range. This limitation forced the setting of the currents close to the proper settings for the injection chromaticities in order to maximize capture. This, in turn, allowed beam instabilities, i.e., the head-tail effect, to occur later in the acceleration cycle.

This paper describes a detailed study of the head-tail effect observed in the RCS and the cures implemented to prevent the onset of the instabilities.

Experimental Studies

Available Aperture Search

The RCS was tuned to operate at an intensity of 8×10^{11} protons/pulse, which is the intensity level just below the beam loss due to the instability. The sextupole current settings were at nominal operating dc levels. A steering frequency function generator was inserted in the RCS RF Master Oscillator (MO). With this MO pulser, the accelerating beam could be moved radially inward or outward at any time of the accelerator clock. A fast beam position signal,[1] which gives a null difference signal when the beam is being accelerated in the central orbit, was used to define the central orbit.

While the beam was steered to various radial positions, the MO frequency was recorded in order to convert the frequency into the radial position. The inner limit or outer limit was defined by an onset of a beam loss due to steering into the aperture limits.

The results of this study are shown in Fig. 1. With 8×10^{11} protons/pulse, the available aperture suddenly disappears near 15 ms of the accelerator clock. After this time, the aperture reappears. The same experiment was repeated with an accelerator intensity of 4×10^{11} protons/pulse, and the observed phenomenon disappears, as indicated in Fig. 1.

A conclusion one can draw from this observation is that at higher intensities, the beam size increases around 14-15 ms of the accelerator clock.

Fast Position Signal Studies

The single bunch turn-to-turn position was investigated using the fast difference signal. There was no abnormal bunch behavior throughout the entire acceleration period on the vertical signal. However, the radial difference signal showed a head-tail, turn-to-turn bunch oscillation around 15 ms of the accelerator clock.

Figure 2 shows the radial difference signal. The oscilloscope was triggered every two turns. The mode numbers of the head-tail oscillation shown in the figure are both m = 1 and m = 2. As expected from the aperture studies, such bunch oscillations were not observed at beam intensities below 4×10^{11} protons/pulse.

Chromaticities

Investigation of the chromaticities under the above condition showed that the vertical chromaticities were all negative throughout the acceleration period. The horizontal chromaticities were negative up to 14 ms, became slightly positive between 14-16 ms, and then again became negative.

The head-tail instability due to the positive chromaticity is expected for this machine because the RCS operates below the transition energy. The theoretical description can be found elsewhere.[2]

Cure

In order to adjust the chromaticities of the guide lattice to any required value at any time during the acceleration period, a set of two programmable power supplies was designed and built. The details of the power supplies and the function generators are described elsewhere in these proceedings.[3]

With the new flexibility of the sextupole adjustments, it is no longer necessary to compromise the injection and acceleration chromaticities. After having installed the new hardware, the RCS intensity has increased to 2×10^{12} protons/pulse and also, the extraction because of the smaller beam size at full energy efficiency has improved.

References

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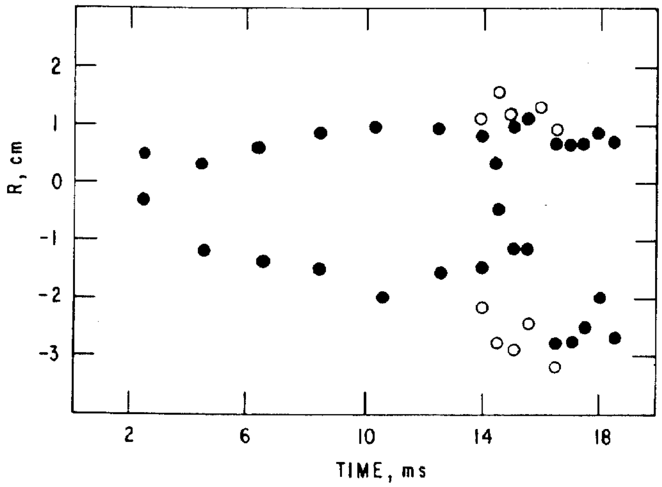

Fig. 1. Available Aperture as a Function of the Accelerator Clock

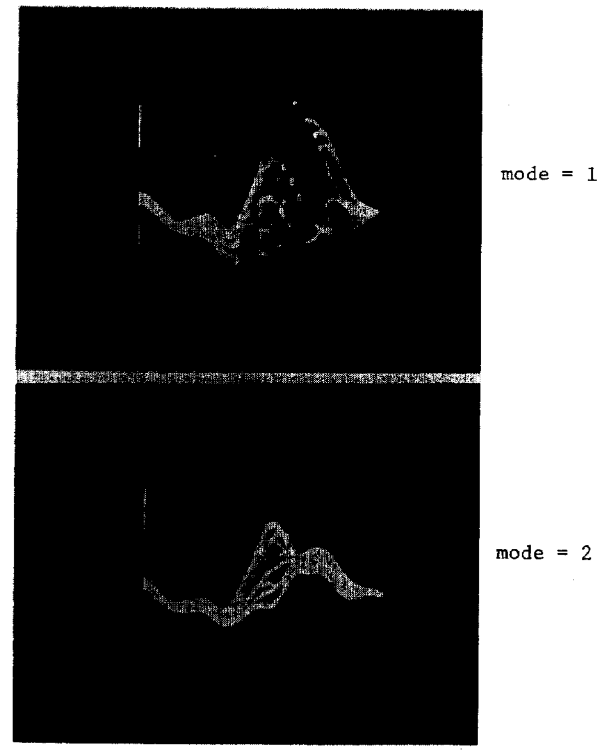

Fig. 2. Radial Difference Signal of Beam Bunch, Two Revolutions per Trace