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COUPLED BUNCH INSTABILITY AND LONGITUDINAL EMITTANCE GROWTH IN THE FERMILAB BOOSTER

V. BHARADWAJ, J. CRISP, K. HARKAY, J. LACKEY, W. MERZ, S. STAHL
Fermi National Accelerator Laboratory,* Batavia, Illinois

Abstract At the present time the coupled bunch instability is the major limit to the beam brightness coming out of the Fermilab Booster. This paper describes the measurement of the longitudinal emittance growth as a function of the beam intensity and impedance of the Booster ring. Comparisons with theory will be attempted.

INTRODUCTION

The Fermilab Booster[1] is a rapid cycling (15Hz) synchrotron using 96 combined function magnets run from a resonant power supply. Table 1 list its more important parameters. The Booster is presently capable of delivering a maximum of 3.6×10^{10} protons per bunch, a limit that comes from space charge effects at injection. With the upcoming Linac upgrade[2], this space charge limit is expected to rise to 1.0×10^{11} protons per bunch. At this point it is believed that the beam brightness that can be delivered by the Booster will be limited by the longitudinal emittance blowup during acceleration. It is further believed that this emittance blowup is caused by coupled bunch instabilities induced by parasitic modes in the RF cavities.[3] The longitudinal emittance at extraction is expected to be an exponential function of intensity and impedance.[4]

RF CAVITIES

The RF system for the Fermilab Booster consists of 17 RF cavities[5] and associated high and low level drive systems. This system has to generate almost a megavolt of RF and sweep in frequency from 30 to 53 megahertz during the 33 millisecond accelerating ramp. The sinusoidal momentum program generates a maximum frequency sweep rate of 3 GHz per second at about 5 milliseconds into the cycle. Figure 1 shows the

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*Operated by the Universities Research Association under contract with the United States Department of Energy.

crossection of one of the RF cavities. One feature (not shown in Figure 1) is the mechanical operated short that is used when the cavity is turned off. This short consists of a one inch metal rod, with a few ferrite rings around it, which makes contact between the cavity shell and the inner cylinder at one end of the cavity.

In addition to resonating at the fundamental mode, these cavities are known to have significant impedances at other frequencies. Measured impedances of these parasitic resonances have been used to successfully model the longitudinal emittance blowup in the Booster.[4]

EXPERIMENTAL SETUP AND METHOD

The rapid cycling nature of the Booster makes measurements of the time and frequency structure of the beam extremely difficult. For this experiment the time and frequency structure of the beam is recorded while varying the intensity and impedance of the Booster. The impedance is changed by running with some of the RF cavities either shorted out or physically removed from the Booster.

The experimental setup consist of using a 2 GHz bandwidth resistive wall pickup to look at the beam signal. The signal is analyzed with a Tektronics DSA 602 oscilloscope. This instrument is capable of digitizing at 2 gigasamples per second and of recording up to 32K points. Its internal FFT capability enables us to analyze the frequency structure of the beam. The RF voltage, beam charge and time and FFT spectra from the longitudinal pickup are recorded for 15 different times through the acceleration cycle. For both the tune and frequency domain data, the record length is 16K points and the information is averaged over 32 beam cycles. The averaged bunch length at the base is read from the oscilloscope. In addition the complete spectra and waveforms are recorded on floppy disk using a IBM PC to read out the DSA 602 oscilloscope. Such data has been taken for 6 different intensities for each of six different longitudinal impedances. In all, approximately 30 megabytes of data were written to floppy disk.

DATA ANALYSIS AND RESULTS

The bunch length data and RF voltage for the various times in the Booster cycle are entered into a program that calculates the longitudinal emittance as described in reference 6. Figure 2 shows the longitudinal emittance as a function of time for five different intensities. Beam is injected at 2 milliseconds, transition occurs at 19 milliseconds and beam is extracted at 35 milliseconds. Figure 3 shows the longitudinal emittance as a function of time for different impedances (the unused cavities are shorted out for the data used in this plot). A 25% reduction in the impedance causes a factor of 2.5 reduction in emittance. An unexpected result of the measurements was that there is no difference in the longitudinal emittance blowup between shorting RF cavities and removing them from the Booster. This implies that at these intensities the shorts are adequate at damping the parasitic resonances in the RF cavities that cause emittance blowup. Figure 4 shows longitudinal emittance vs intensity for three difference impedance. For the 12 and 14 cavity data exponential fits describe the data well. In the 16 cavity curve we believe that Landau damping is limiting the longitudinal emittance.

The FFT data that was recorded is very rich in detail. Great care and effort will have to be used in analyzing that data. Figure 5 shows an FFT spectra just before beam is extracted. The relative amplitude of all 84 coupled bunch modes are seen. These amplitudes vary with time, intensity and impedance. Modes 16 and 36 have been correlated with specific unwanted resonances in the RF cavities.

CONCLUSIONS

A large amount of longitudinal emittance data for the Fermilab Booster has been taken. The RF cavities have been demonstrated to be the major cause of longitudinal emittance blowup. The experimental method described above is general in nature and can be used to look at longitudinal emittances under a variety of conditions. For example this method will be equally effective in looking at the possible effects of various longitudinal damping schemes. Careful analysis of the FFT will identify the parasitic mode contributing to longitudinal emittance growth. From this information a decisions can be made on the best options for improving Booster performance.

REFERENCES

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4. S.A. Bogacz, "Longitudinal Emittance Blow-Up Due to Coherent Motion of Coupled Bunches", FN-517, Fermi National Accelerator Laboratory, June, 1989.
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TABLE I

Injection method	multiturn H^- injection
Injection energy	200 MeV (kinetic)
Extraction energy	8.0 GeV (kinetic)
Circumference	474.2 meters
Harmonic number	84
Horizontal, vertical tune	6.85
Transition gamma	5.4
RF frequency	30.3 - 52.8 MHz
# of RF cavities	17
Total RF voltage	950 kV (maximum)
Transverse aperture	~ 20 π mm-mrad
Longitudinal dp/p	+/- 0.6% (extraction)

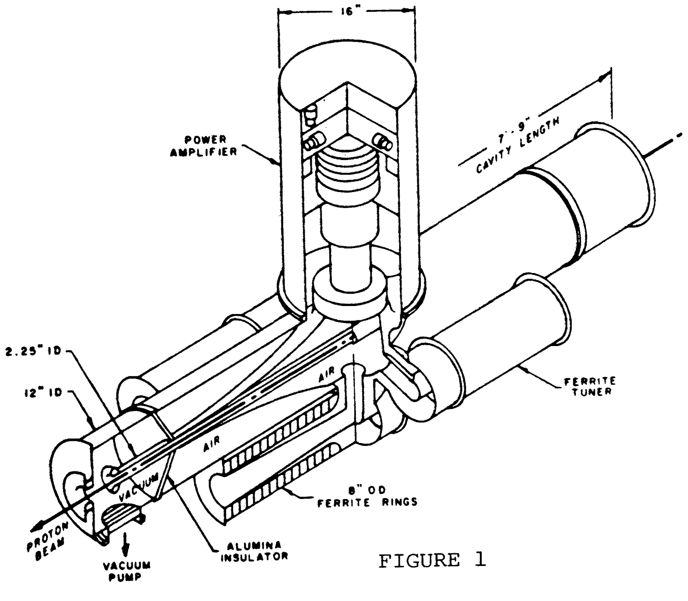

FIGURE 1

FIGURE 2 : EMITTANCE vs TIME & INTENSITY

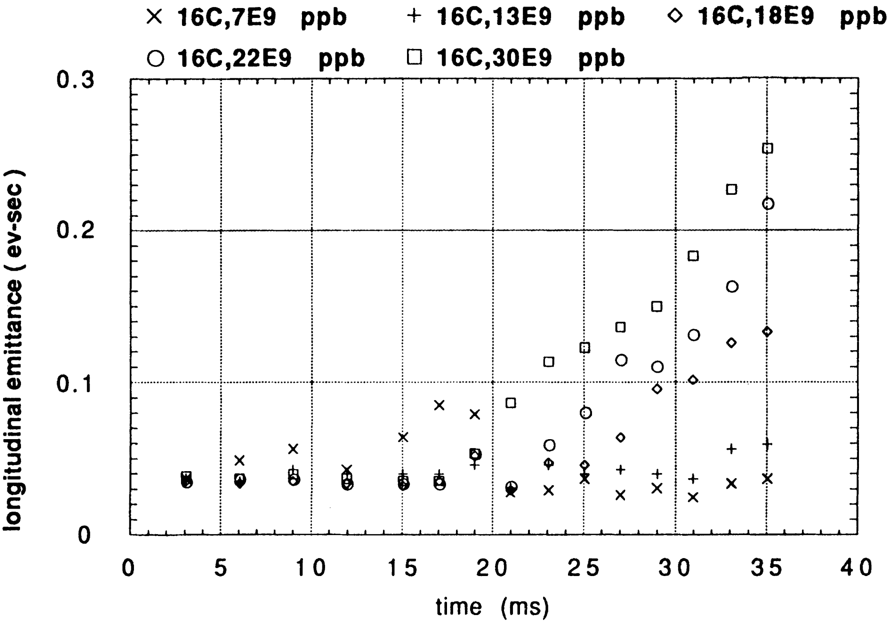

FIGURE 3 :
EMITTANCE vs TIME & IMPEDANCE

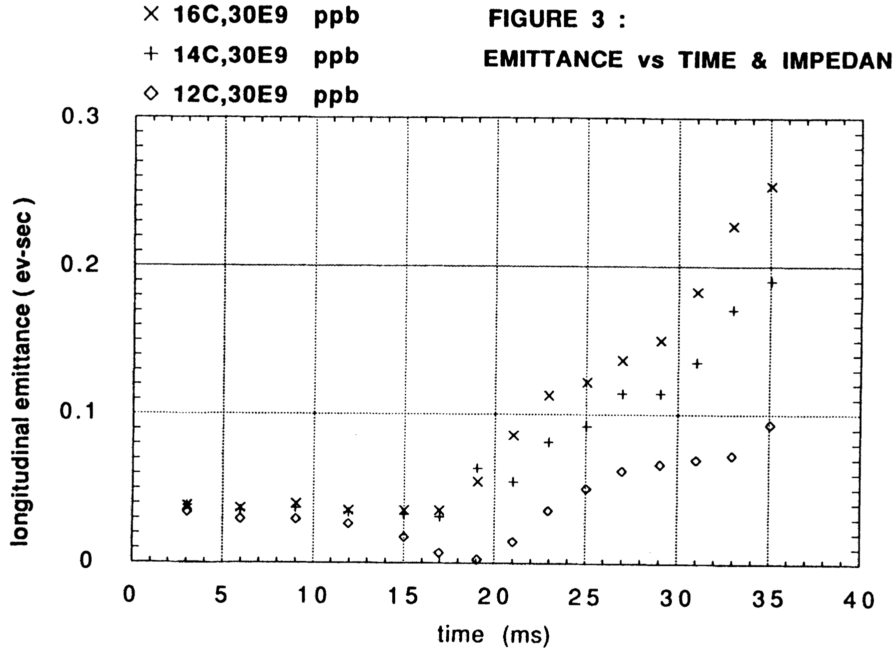

FIGURE 4

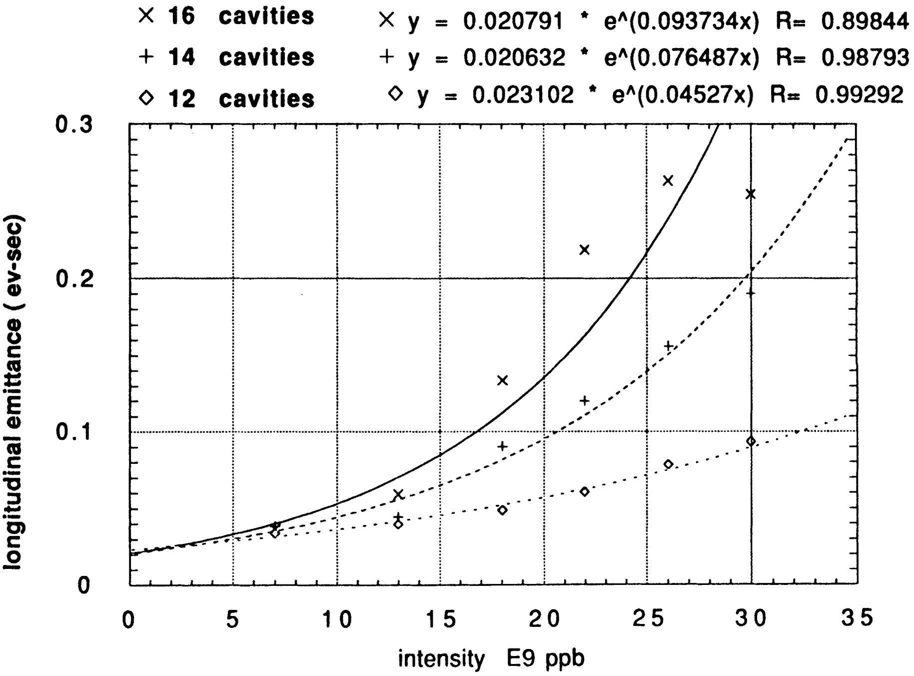

FIGURE 5