Ferrite Tuned Cavity as Possible Source of Bunched Beam Instability

M. Popovic
*Fermi National Accelerator Laboratory**
P.O. Box 500
Batavia, Illinois 60510

Abstract

This paper presents results from a systematic study of the frequency response of a Fermilab Booster RF cavity. Measurements were carried out on a spare test cavity as well as on a cavity used in normal Booster operation. Measurements on the latter cavity were performed under no-beam conditions. An attempt has been made to relate "parasitic" (non fundamental) frequency modes with beam instabilities.

Introduction

The proton beam in the Fermilab Booster Synchrotron is accelerated in $33.0ms$ from $200MeV$ to $8GeV$ using 15 ferrite-tuned cavities. In this time interval the RF changes from $30.10MHz$ to $52.813MHz$.

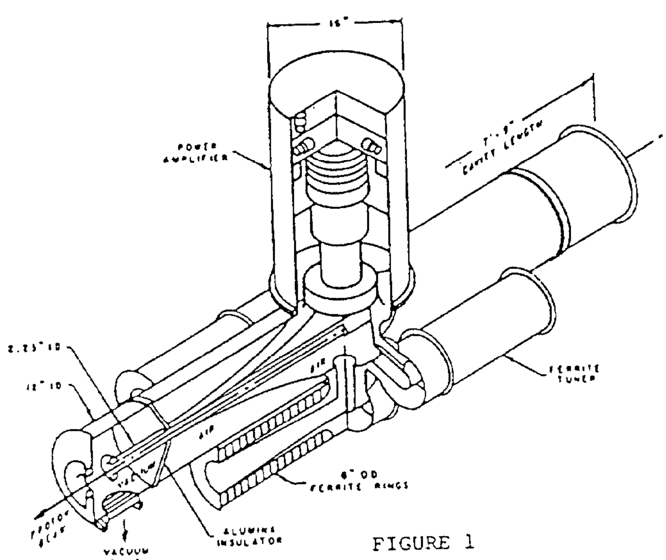

Figure 1. *A cut-away drawing of a booster cavity with a power amplifier and three ferrite tuners mounted on it.*

The cavity (see Figure 1.) contains a drift tube whose electrical length is 140 degrees and an accelerating gap at each end. The drift tube is a tapered copper structure with a 2-1/4" i.d. beam pipe in the center. An alumina insulator, with permittivity $\epsilon = 9$, near each end of the drift tube provides a vacuum-tight rf window. Only the beam pipe inside the drift tube and the accelerator gaps at the ends of the cavity are under vacuum. The central part of the cavity and the tuners are at atmospheric pressure.

Three tuners are attached to each cavity. The tuners are coaxial transmission line structures with shorted ends. The center conductor of each tuner is connected to the center of the drift tube in the accelerating cavity, and the tuners form part of the resonating structure. There are 28 toroidal ferrite cores, with permeability $\mu = 7.5$, mounted in the rf field between the inner and outer conductor of the tuner. A ten-turn bias winding passes through the center conductor of each tuner and links the ferrite cores. The reactance of the tuners and, consequently, the resonant frequency of the cavity structure is controlled by varying the current through the bias winding. The current in the tuners of each cavity is software controlled and follows the frequency change necessary to accelerate beam in the Booster. Differences between an individual cavity and the rf drive frequency is corrected by a feedback loop on each cavity which minimizes the phase difference between the rf drive and the fields in the cavity [1].

During acceleration particles in the Booster have to pass a transition point where the momentum spread reaches high values. Fast pulsed quadrupoles are used to form the so-called γ_t jump. As can be seen in Figure 2. longitudinal emittance measurements show a sharp increase right after transition [2].

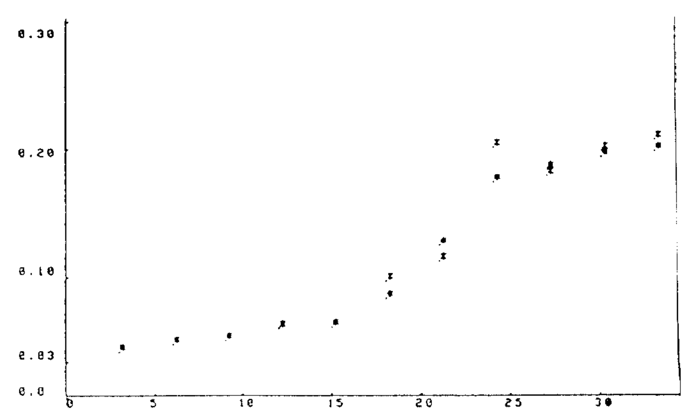

Figure 2. *Longitudinal Emittance as function of time. The transition jump is at 18.7 ms.*

*Operated by the Universities Research Association under contract with the U. S. Department of Energy

In the Figures 3 and 4 the RF signal which is the sum of the voltages coming from upstream gap monitors located in each RF cavity was measured before and after transition. The signal used for beam analysis comes from a 2 GHz bandwidth resistive wall current monitor. A total of 2.56μs worth of the beam per injected pulse is analyzed. This portion of the beam is digitized in 5120 points and displayed. The bunch parameters used in longitudinal emittance calculations are derived from a sample of 55 consecutive bunches.

Figure 3. shows that before transition, the bunches are equally spaced and follow exactly the RF frequency change.

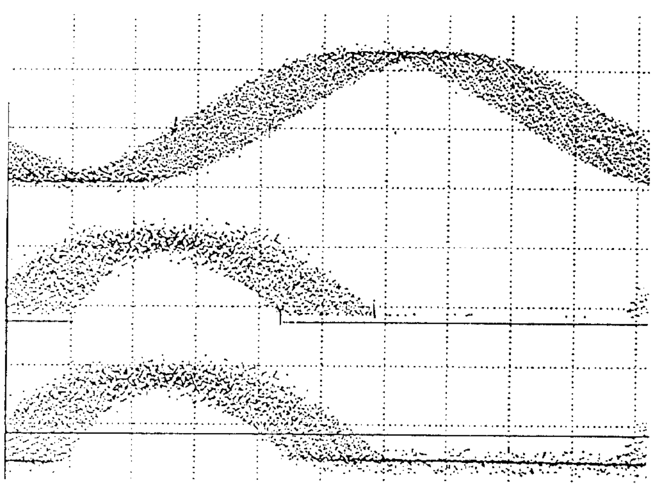

Figure 3. *RF signal, (overlap of RF periods) and overlap of the proton bunches at 9.0 ms after injection*

After transition bunches do not remain equidistant, but engage in relative motion with respect to each other as documented in Figure 4.

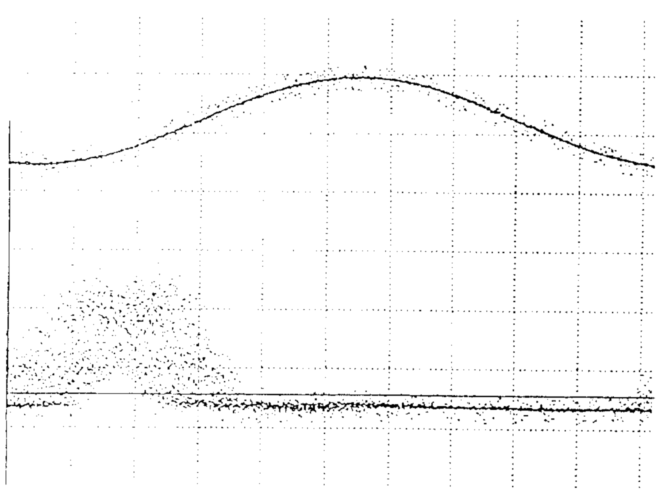

Figure 4. *RF signal, (overlap of RF periods) and overlap of the proton bunches at 33.0 ms after injection*

Cavity Measurements

The measurement of the frequency response of the test cavity was done using two antenna-type probes. The signal from the RF signal generator was applied at one accelerating gap through this probe. The receiving antenna was mounted at the second accelerating gap and connected to a spectrum analyzer. As the RF signal was swept from 25 to 325 MHz, the resonant frequencies of the cavity appeared as peaks in the amplitude of the signals received by the second probe and sent to the spectrum analyzer, Figure 5.

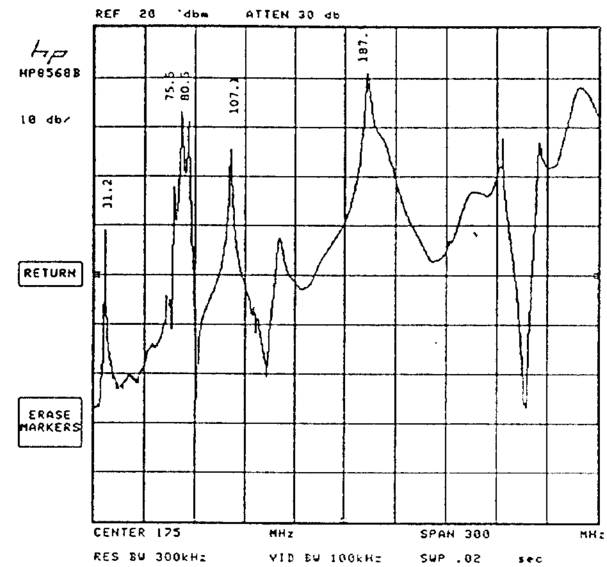

Figure 5. *Resonant frequencies in the case that cavity is tuned to have 31.2 MHz as fundamental resonant frequency*

During the RF sweep, the ferrite bias current was kept constant. The resonant frequencies as function of fundamental resonant frequency are presented in Figure 6.

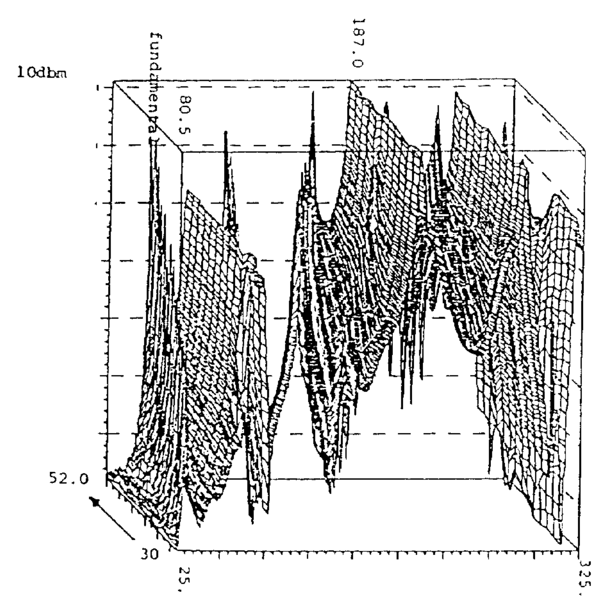

Figure 6. *Resonant frequencies as function of the fundamental resonant frequency*

For the second set of measurements the operational cavity was used and the RF signal was the one used in normal operations. The tuner bias current followed the programmed curve used when accelerating beam. The frequency response of the cavity was monitored using the upstream cavity gap monitor and the dumping loop as pickup. Figure 7. is contour plot of RF frequencies as functions of time during the Booster accelerating period.

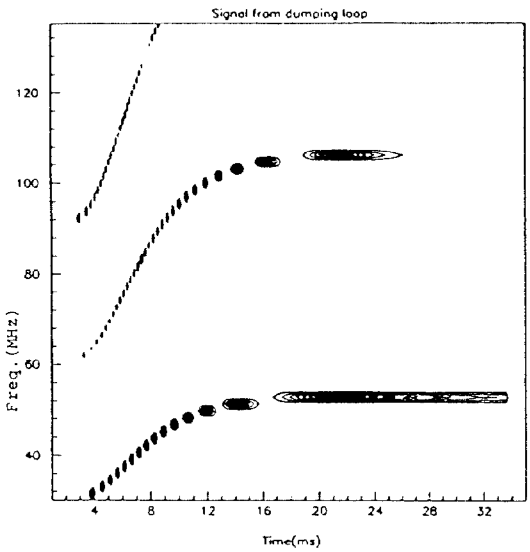

Figure 7. *Resonant frequencies as functions of time*

Figure 8. is a lego plot of the amplitude of the RF signal as function of the frequency and the time. The signal is monitored using the dumping loop as a pickup.

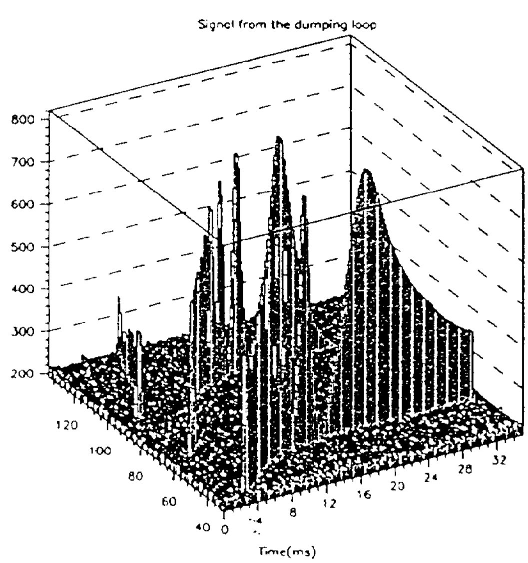

Figure 8. *RF signal as function of time and frequency*

Conclusion

As conclusion we can say that existing Booster cavities contain a very rich frequency structure. For future studies there is a plan to filter higher harmonics coming from the low level RF system and study RF spectra with the beam present. The special attention will be paid to RF signals which exhibit no change in frequency during whole accelerating cycle. There is a plan to weakly couple two cavities in atempt to dump 80 MHz mode. The measurements (see Figure 6.) and a numerical modeling[3] have shown that this mode has constant frequency as function of the bias current in the tunners.

References

[1] Design Report, *National Accelerator Laboratory (1968)*

[2] V. Bharadwaj and M. Popovic, *"A Longitudinal Emittance Measurement Program for the Fermilab Booster", FERMILAB-TM-1709*

[3] M. Popovic, *"Modeling a Ferrite-Tuned RF Cavity", FERMILAB-TM-1710*