Observation of a Short Bunch Train Longitudinal Instability in the Fermilab Main Ring

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Abstract

Longitudinal coupled-bunch instability has been addressed in many papers. Most of them assume that all bunches are distributed equal-distant from each other. Here we present a different case where a train of 13 bunches is followed by a big gap of 1100 empty buckets in the Fermilab Main Ring. No residual wake fields are left after one revolution for a higher order mode of the RF cavity with Q in the few hundreds. The head bunch of the train cannot feel the wake field left by the previous turn, and classic closed loop instability is not possible, though destructive coherent oscillation are observed in later bunches. However, it has been observed that the beam can still be unstable if the beam intensity is high enough (e.g. 1E10 per bunch). In this paper we will present some experimental observations along with computer simulation results. They agree with each other quite well. A feedback loop is possible to eliminate these coherent oscillations.

I. INTRODUCTION

This paper is concerned with the subject of longitudinal beam instability observed in the Fermilab Main Ring. During the present collider run, a high intensity proton beam is needed in the Tevatron to provide a high luminosity, described by the equation

$$L=N(p)\,N(pbar)\,f\,n\,/A \qquad (1)$$

Here A is the transverse area, N(p), N(pbar) are numbers of protons and antiprotons in one bunch, f is revolution frequency, n is number of proton(antiproton) bunches in the whole ring.

In order to get a high intensity beam, a technique called coalescing[1] is used to get as much charge in a single bunch as possible from 11 to 15 individual bunches in the Main Ring. This coalescing charge efficiency is strongly dependent on longitudinal emmitance. It can also be poorer if there is coherent oscillation before coalescing. Based on observations, it is found that the beam is not stable at the coalescing energy of 150 Gev. This instability is caused by a high order mode in the RF cavities.

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When a beam passes through a cavity, a voltage is induced (see fig. 1), given by[2]

$$V=q\,\omega\,R\,/\,Q \qquad (2)$$

Here q is bunch charge, ω, R, and Q are resonant frequency, impedance and Q values respectively.

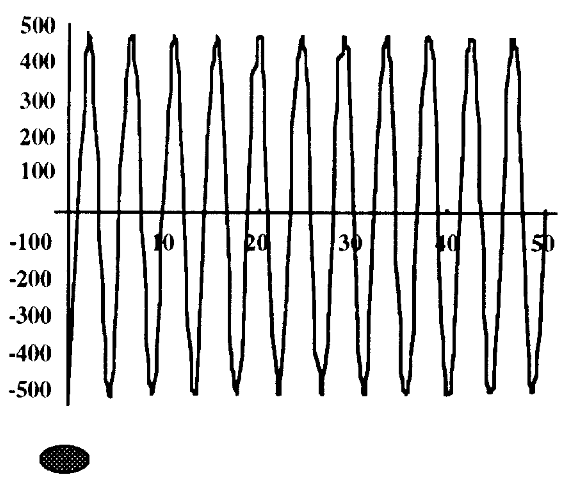

Figure 1 Beam loading voltage(V) as a function of time(nsec) by a bunch with 1E10 particle

This voltage acts as another external RF voltage. Since we only have 13 consecutive bunches in the ring, the coupled bunch mechanism is different from traditional predictions[3]. The Q of the offending higher order mode is not high enough to let the wake field propagate for one revolution period. The fill time $t=2Q\,/\,\omega_{rf} = 2\ \mu sec$ is a factor of 10 smaller than the revolution period. This is an open loop type of instability[4]. We don't expect any beam oscillations in the front bunches and progressively larger oscillations in the tail bunches. Here we describe the experiment set up, data taking and simulation results.

II. EXPERIMENT SET-UP

In order to record the whole process of beam growth, the proton beam is stored at flattop with an energy of 150 Gev for 10 seconds. During this period, dipole oscillations can be seen quite easily. With higher intensity the situation gets worse. To make analysis easier, a Tektronix RTD720 digitizer is used to record resistive wall signals turn by turn. The analog bandwidth is 500 MHz and the digitizing rate is 2 Gsamples/sec. Typically the bunch length is about 4 nsec, so there are 8 samples per bunch. The program LabView on a Macintosh is used to read out data stored in the digitizer through GPIB. Some analysis (such as FFT) can also be performed by that program. The time scale is adjusted by a trigger box so that it can take data for any cycle and for any number of turns per trace. This way short and long range phenomenon can be studied.

III. DATA ANALYSIS

Looking at fig. 4, there is a dipole oscillation for later bunches while the front bunches are stationary. The oscillation amplitude varies from bunch to bunch. Typically 2 nsec of oscillation amplitude can be observed, which is close to 1 sigma of the beam. By examining the oscillation closely, a pattern of phase between them is found. A line can be drawn to match oscillation peaks of different bunches. The phase slope is about 70 degrees/bunch for such a line. By doing FFT of this data, beam spectrum is available(see fig. 5). Note that there are modulation sidebands around each RF frequency harmonic line. The frequency is $\Delta\omega$=11 MHz. Thus the driving frequency is determined by $\omega o = i^*\omega_{rf} \pm \Delta\omega$. Here ω_{rf}=53.104 MHz at 150 Gev. To determine the value of i and sign, a more direct measurement is employed. Since the RF cavity is a dominant factor in terms of impedance at such high frequencies, a survey of all possible modes was performed by using a stretched wire method(see fig. 2).

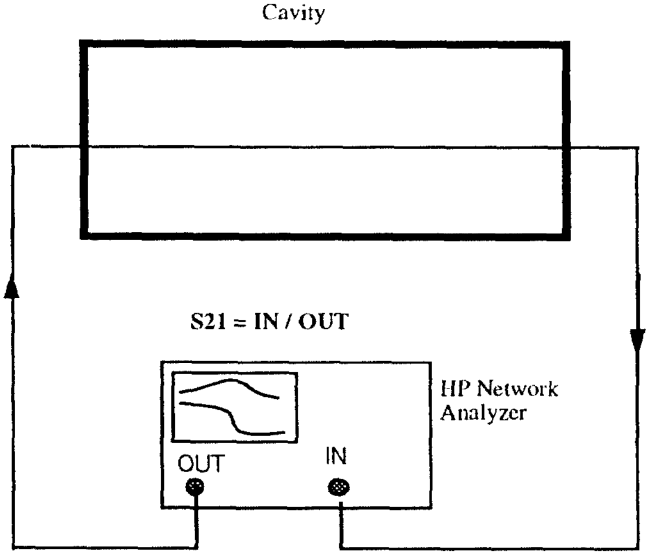

Figure 2 Setup of S21 measurement

This is performed by using a HP8751A network analyzer and a wire is pulled through the cavity center. The two ports of the network analyzer are connected to either wire end, which are impedance matched to 50Ω using matching resistors[5].

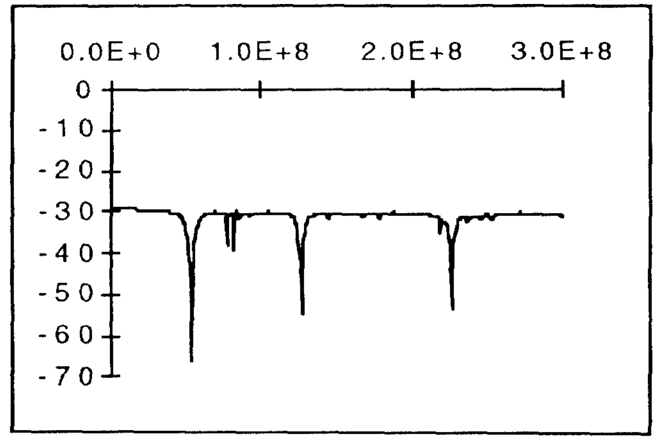

Figure 3 Measured S21(dB) vs. frequency(Hz)

There are three deep notches in S21 (see fig. 3). The first one is the fundamental RF mode. The other two are high order modes. One of them is approximately 225 MHz. This is the mode causing the beam instability. Its frequency corresponds for i=4 and has R/Q=1500 and Q=1000 for a filling time of 2 μsec. This decay time is relatively short compared to revolution period of 21 μsec. It explains why the later bunches oscillate with a much bigger amplitude while the front one are still stable.(see fig. 4). While these tail bunches feel a stronger wake field produced by all proceeding bunches, the front bunches see little wake field after one turn. The same behavior can also be seen from our simulation results (see fig.6).

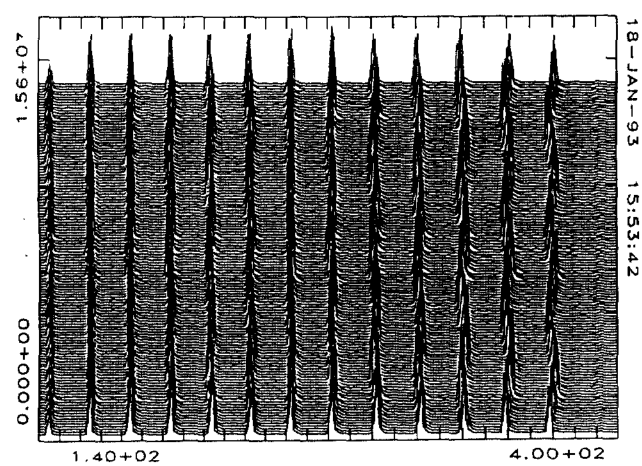

Figure 4 Measured beam motions

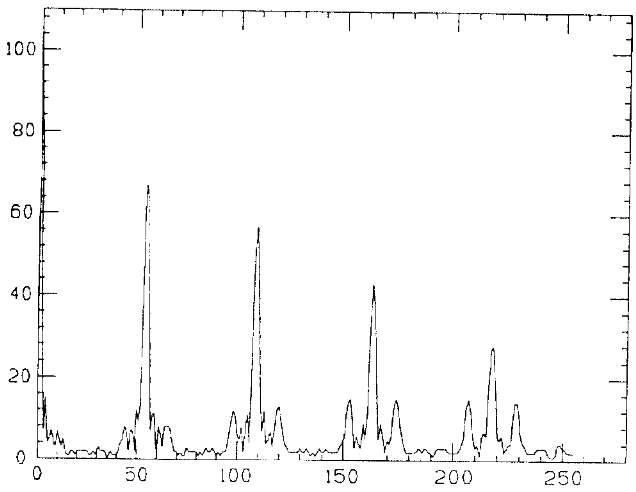

Figure 5 Beam spectrum by FFT

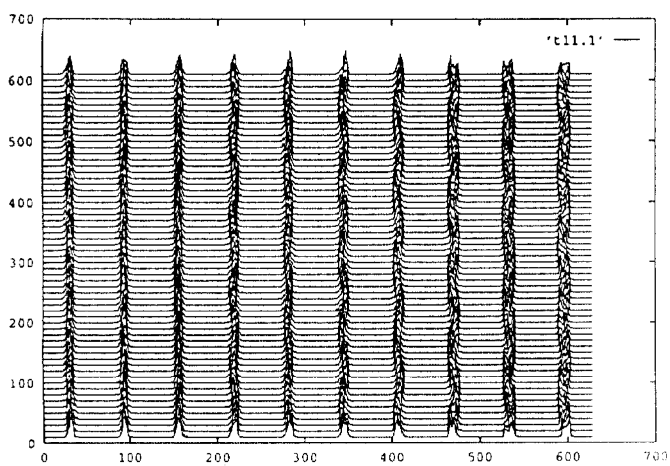

Figure 6 Simulated beam motions

IV. FUTURE WORK

We have studied the short batch coupled bunch phenomenon in the Fermilab Main Ring. A model exists which provides a good description of observed phenomenon. A feedback system must be designed to damp this beam oscillation. We are in the process designing such a system. Beam signals from a current monitor are picked up as a source for this feedback loop. They are amplified and filtered to get the correct component. Then an RF cavity probe delivers this signal into the same higher order mode impedance to nullfy the wake field. Another possibility is to make a bunch by bunch feedback system such as done by CERN[6].

V. REFERENCES

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