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THE FERMILAB TRANSVERSE INSTABILITY ACTIVE DAMPING SYSTEM

E. Higgins, Q. Kerns, H. Miller, B. Prichard,
R. Stiening and G. Tool
Fermi National Accelerator Laboratory*
Batavia, Illinois

ABSTRACT

A system for controlling vertical single bunch instability is described. The vertical position of each of the 1,113 bunches in the Fermilab Main Ring is digitized and stored in a memory. After an interval determined by counting RF cycles, the memory is read. The delayed position signal is sent to a distributed amplifier. A transmission line serves as a beam deflector.

Coherent vertical instability occurs in the Fermilab 500-GeV accelerator at an intensity of 10^{12} protons. Coherent radial instability occurs at an intensity of 5×10^{12} protons. Beam dampers with a limited bandwidth have been in use for one year.[1] These dampers have a bandwidth sufficient to affect the coherent motion of approximately 15 of the 1,113 bunches in the machine. In terms of the usual definition:

$$f_c = f_{REV}\,(M-\nu_y) \tag{1.}$$

where f_{REV} = 47 kHz (revolution frequency) and ν_y = 19.4 (vertical time), these beam dampers suppress modes as high as M = 100.

Experiments[1] have shown that a wide distribution of wake field ranges is responsible for the instability. Below an intensity of 10^{13} the short range wake fields are not sufficiently strong to cause individual bunches to be unstable through the "head-to-tail" mechanism. Above 10^{13} (this threshold is not well defined -- it has varied with time from 8×10^{12} to above the peak intensity 1.4×10^{13}) the bunches become individually vertically instable. The low frequency vertical beam damper is inadequate for controlling single bunch instability. At injection the chromaticity is controllable through correction sextupoles. These sextupoles are adequate for suppressing head-to-tail effect from the injection level (8.89 GeV/c) up to 50 GeV/c. Beyond 50 GeV/c the chromaticity of the machine is negative and head-to-tail instability occurs.

The main consequence of the single bunch vertical instability at high energy is to cause large beam losses in the extraction channel which has a vertical aperture much smaller than that of the accelerator. The instability does not progress to the point where beam losses occur inside the accelerator. Our initial diagnosis of the extraction loss problem was made by placing a scintillator near the extraction channel. An oscilloscope, triggered at the revolution frequency[2] was used to view the losses. In Figure 1 we show a typical case. Most bunches show only the normal loss associated with the extraction septum. A few bunches have blown up and account for a substantial part of the losses in the extraction system. A simultaneous observation of a fast vertical position signal showed that the bunches which caused the large loss had blown up during acceleration.

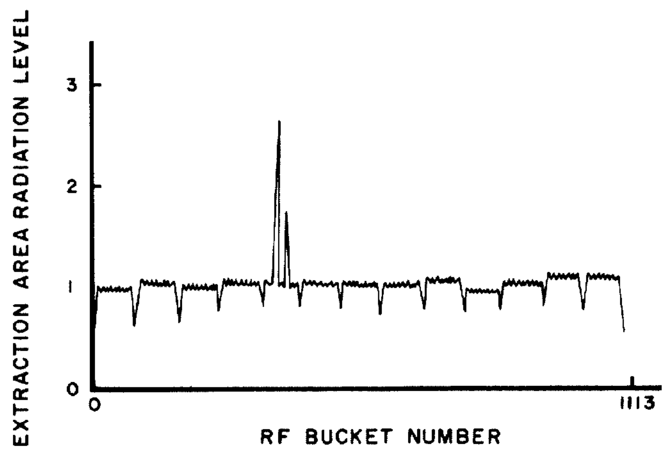

Fig. 1. A radiation monitor near the extraction channel is observed on an oscilloscope triggered at the revolution frequency. The gaps occur between each of the 13 batches injected by the booster synchrotron. A few bunches have blown up and show large losses.

In order to suppress this instability we have constructed a beam damper capable of acting on individual bunches. A block diagram of this device is shown in Figure 2. A bunch-by-bunch intensity independent beam position voltage is derived from a pair of strip transmission line signals. This position voltage is digitized at the bunch rate (∿ 53 MHz) and is stored in a memory as a 5-bit word. After 1,076 RF cycles† have taken place, this word is converted to an analog signal. It is amplified by a high power (5 kW) distributed amplifier whose output feeds a pair of transmission lines which deflect the beam. The detector and the deflector are located 19.75 x 2π apart in vertical betatron phase. We operate the damper gain at 2×10^{-5} radians/cm. This value results in a time for damping to ½ amplitude of ≈ 15 revolutions at 8.89 GeV/c. In Figure 3 we show a vertical betatron oscillation which has been excited at 8.89 GeV/c by a kicker magnet for the two cases damper on and damper off.

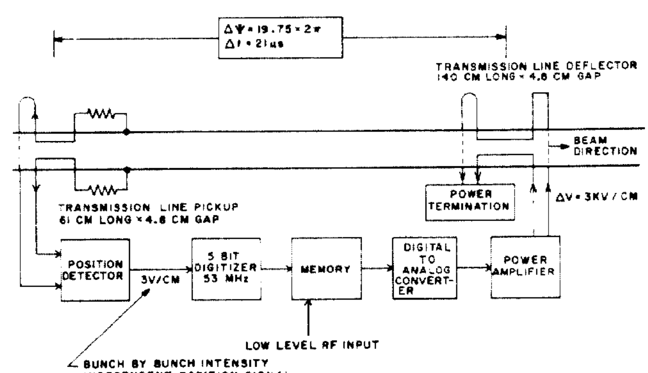

Fig. 2. Block diagram of the digital feedback vertical damper.

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†The detector and deflector are near to each other. The number 1,076 takes into account a variety of cable and amplifier delays.

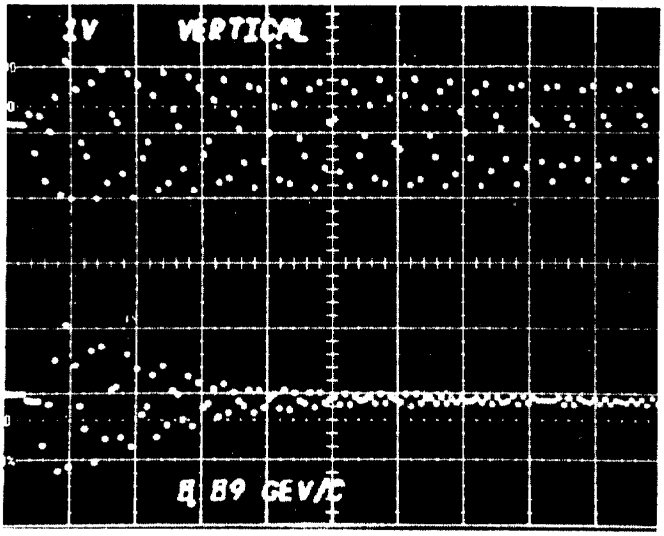

Fig. 3. The traces show a vertical betatron oscillation which has been induced at 8.89 GeV/c with a kicker magnet. The dots show the beam position on successive revolutions. In the upper trace the damper is off; in the lower it is on. The damping rate is consistent with the measured gains.

An interesting question about a device of this sort is the number of bits required to represent the feedback signal. In normal operation it is represented by a 5-bit word where each state corresponds to a 0.05 cm vertical position error. We made the experiment of removing the less significant bits from the feedback while maintaining the same loop gain. With only one active bit the damper was able to suppress catastrophic instabilities. However, when bits were removed, a steady beam growth occurred which resulted in large extraction losses and some injection losses. With the full 5 bits, there was no observable difference between hard wire and digital feedback.

In addition to working as a damper we have used this device for other purposes. The digital memory unit can be set to reverse the sign of the feedback on selected bunches. In studying longitudinal instabilities excited by an RF cavity parasitic resonance at 7/3 the RF frequency, we were able to increase the exciting frequency component in the beam current by removing every third bunch with the damper. It has also been used to remove from the injected beam those bunches which would strike the extraction system during the rise and fall of certain pulsed extraction devices.

REFERENCES

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2. E. F. Higgins, A 53 MHz Randomly Triggered Synchronous Predetermined Scaler for Accelerator Diagnostics, Fermilab; 1975 Particle Accelerator Conference, Washington, D. C.