IEEE Transactions on Nuclear Science, Vol. NS-26, No. 3, June 1979

THE DAMPER FOR THE TRANSVERSE INSTABILITIES OF THE SPS

R. Bossart, L. Burnod, J. Gareyte, B. de Raad, V. Rossi*)

Summary

For beam intensities above 10^{12} protons per pulse in the SPS, collective transverse beam instabilities develop with frequencies between 15 kHz and 3 MHz because of the resistive wall effect of the vacuum chamber1). An active feedback system2) with an electrostatic deflector has been installed in the SPS for damping the resistive wall instabilities in both the vertical and horizontal planes.

Measurements have been made to determine the threshold and growth rate of these instabilities. As a novel application, the damper can be used also for the excitation of small coherent betatron oscillations. A phase-locked loop tracks the beam oscillations and provides a continuous display of the betatron wavenumber Q during the cycle.

Layout of the damper

The feedback system consists of a beam position monitor, an amplifier chain and an electrostatic deflector (fig. 1). The monitor provides the beam position signal Δ from two electrostatic pick-up electrodes and senses beam oscillations as small as 0.01 mm at 10^{13} ppp. The amplifier chain amplifies the electrode signals by a factor of 2-4 x 10^5, and the deflector reduces the beam oscillation by a few percent at every beam revolution. The electrostatic deflector consists of a pair of parallel plates 1410 mm long. Beam monitor and deflector must be distant an odd number of betatron quarter wavelengths apart. The betatron phase angle between monitor and deflector can be adjusted by combining the signals of two monitors. The difference signal of the beam monitor is delayed by the time the beam takes for one revolution from beam monitor to deflector.

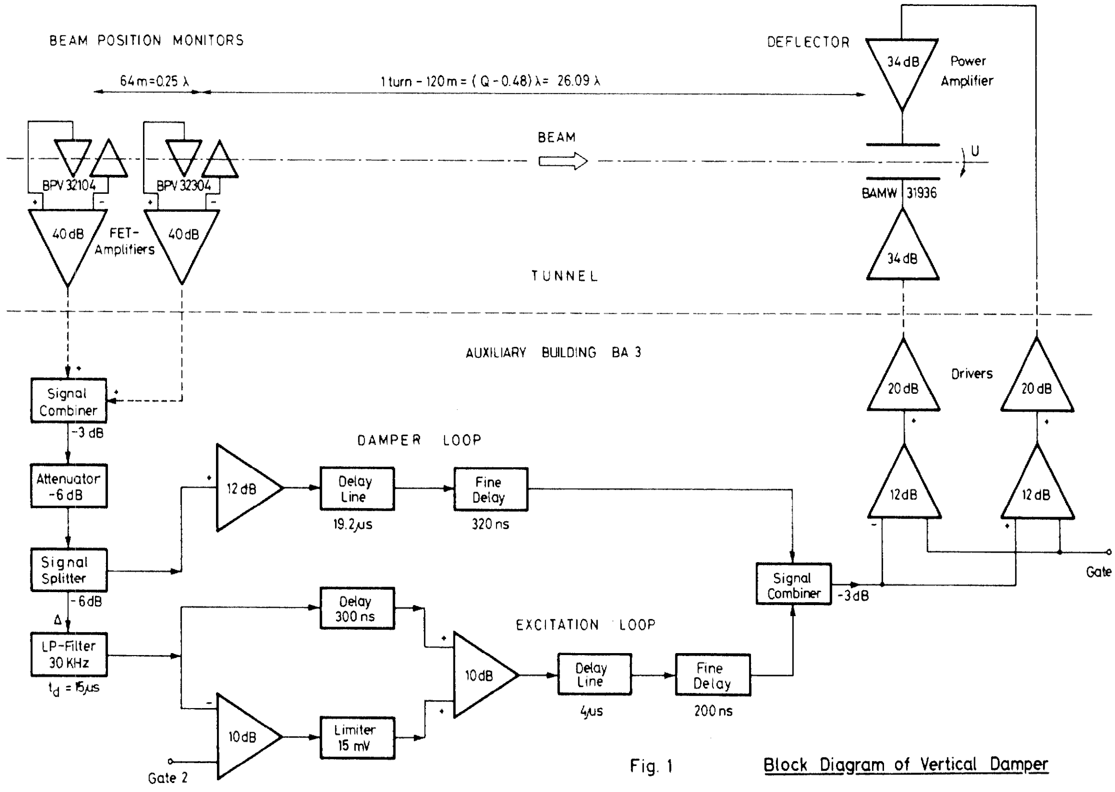

Fig. 1 Block Diagram of Vertical Damper

The damper gain is expressed as the ratio of the deflection angle and beam position to be corrected. Since the growth rate of the resistive wall instability increases with beam intensity, the damper gain must be proportional to beam intensity. The difference signal of the beam position monitor is proportional to beam position and beam intensity and thus provides the necessary increase in damper gain versus beam intensity. The damper of the SPS has a gain of 1.5 μrad/mm in the vertical plane and 1 μrad/mm in the horizontal plane for beams of 2 x 10^{13} ppp at 10 GeV/c. The power amplifiers provide a maximum deflection voltage of 2000 V between electrodes in the frequency range 3 kHz - 1 MHz.

The injection oscillations of beams of 2 x 10^{13}ppp are damped with an e-folding time of about 0.5 ms in the vertical plane and 1 ms in the horizontal plane. The blow-up of emittance by filamentation of the injection oscillation is avoided by the fast damping, and the tolerances for the injection steering are increased by the damper.

---

*) CERN, F-01631 CERN CEDEX, FRANCE

0018-9499/79/0600-3284$00.75 © 1979 IEEE

Threshold, growth rate and bandwidth of resistive wall instabilities

The vertical instability appears above an intensity of 1×10^{12} ppp and the horizontal instability above 6×10^{12} ppp for a well tuned machine with octupoles off.

The growth rate $1/\tau$ of the instability is proportional to beam intensity and has been measured indirectly by observing the e-folding time of the damped betatron oscillations for different gain settings of the damper. The betatron oscillations are excited either by injection errors or by a fast kicker magnet. The growth time τ measured at injection for a beam intensity of 10^{13} ppp amounts to:

$\tau_V = 1.0 - 1.4$ ms in the vertical plane
and $\tau_H = 1.8 - 2.5$ ms in the horizontal plane.

It is the fundamental mode of the beam oscillation at a frequency of 17 kHz which grows the fastest. Higher modes with frequencies above 100 kHz grow more slowly than the fundamental mode. In the horizontal plane growth times of $\tau_H = 10 - 20$ ms have been observed in the frequency range 1 - 3 MHz at 16×10^{12} ppp.

The growth time of the resistive wall instabilities can be calculated for the SPS according to references 3 and 4. For a beam of 10^{13} ppp at 10 GeV/c, the fundamental mode at 17 kHz has a calculated growth time of $\tau_V = 1$ ms in the vertical plane and $\tau_H = 2.1$ ms in the horizontal plane. The growth time of higher modes around 2 MHz amounts to $\tau_H = 20$ ms at 16×10^{12} ppp and 10 GeV/c. All this is in good agreement with the measurements.

The adjustment of gain and phase of the amplifier chain is important for the stability of the higher modes at the upper limit of the damper bandwidth. The stability margin of the feedback system which prevents beam losses has been measured. For beams of 12×10^{12} ppp, the tolerances of the gain and delay settings amount respectively to 10 dB and 0.6 µs in the vertical plane and 6 dB and 0.4 µs in the horizontal plane. The tolerances of gain and delay for the damper feedback loop decrease with increasing beam intensity.

Unstable modes are observed over a bandwidth which depends on the octupole fields. With all octupoles switched off, the upper limit of the unstable mode numbers increases with beam intensity, and horizontal instabilities have been observed up to 3 MHz at 16×10^{12} ppp. These very high modes lie outside the bandwidth of the damper feedback loop and can be stabilized by relatively weak zero harmonic octupoles located at maximum β_H.

Coherent excitation of vertical oscillations for Q-measurement

Small coherent oscillations of 0.1 mm amplitude can be excited by the damper by means of a positive feedback loop with an amplitude limiter (fig. 1). The beam itself acts as a bandpass filter of the closed loop adjusting its frequency of resonance according to the betatron wave number Q.

The lowpass 30 kHz filter of the excitation loop has a high selectivity and constant delay time over the frequency range 15 - 28 kHz selecting the two lowest modes of betatron oscillations for excitation. The revolution frequency 43 kHz of the beam is rejected by a bandstop filter incorporated in the lowpass filter, so that no intermodulation products between the revolution and betatron frequencies are generated in the limiter.

The positive feedback in the excitation loop excites beam oscillations, which grow from the noise of the FET-amplifier up to a stable amplitude. Above the stable amplitude, the negative feedback is stronger than the limited positive feedback, and beam oscillations are damped down to the equilibrium point, which is defined by the intersection of positive and negative feedback gain (fig. 2). The equilibrium point can be adjusted by the limiter level. For small signals below the limiter level, the gain of the positive feedback is three times larger than the gain of the negative feedback.

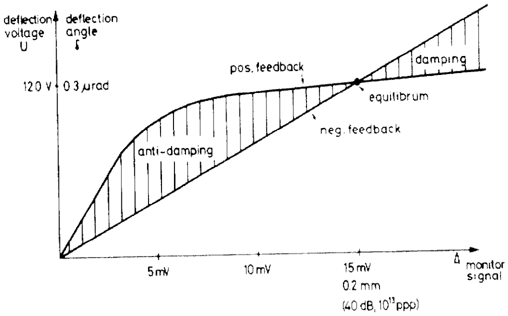

Fig. 2 Stability Diagram of Excitation Loop

The stable amplitude of oscillation depends not only on the feedback loops alone, but also on the strength of the resistive wall effect. As the damper loop is stronger than the resistive wall effect the equilibrium point of 0.2 mm for 10^{13} ppp is shifted towards smaller amplitudes. If the resistive wall effect becomes stronger during acceleration, the equilibrium point shifts to higher oscillation amplitudes.

The excitation can be switched on and off during the flat bottom of the accelerator cycle by the gate 2 in the positive feedback loop (photo 1). The rise and fall time of oscillation is about 2 ms. The amplitude of the oscillation remains constant at 0.1 mm during the whole acceleration cycle up to 380 GeV/c, except at transition when the oscillation is strongly damped by the increased Q-spread (photo 2).

The betatron frequency f is tracked by a phase locked loop whose output provides a direct voltage u proportional to the betatron frequency f and enables Q tracking during the accelerator cycle (photo 3) with a transfer ratio u/f = 1V/850 Hz, Q/u = 0.02/V.

The coherent excitation of small beam oscillations of 0.1 mm causes no noticeable blow-up of the beam emittance, even when excitation is on during the whole acceleration cycle. The beam dimensions have been observed on the ionisation beam scanner (IBS) and have not shown any blow-up with excitation.

Acknowledgments

We would like to acknowledge the important contributions of R. Stiening in the commissioning of the SPS damper and the helpful assistance of J.P. Papis and H. Rossi in its implementation.

References

1. E. Courant, A. Sessler, Transverse coherent resistive instabilities of azimuthal bunched beams in particle accelerators, Rev.Sci.Instru., 37, N11, 1579 (1966).

2. R. Stiening, E.J.N. Wilson, Transverse collective instability in the NAL 500 GeV accelerator, Proc. 9th Int.Conf. on High Energy Accelerators, Stanford, 329 (1974).

3. F. Sacherer, Transverse bunched beam instability theory, Proc. 9th Int.Conf. on High Energy Accelerators, Stanford, 347 (1974).

4. D. Boussard, E. Brouzet, R. Cappi, J. Gareyte, Collective effects at very high intensity in the CERN-PS. This Conference.

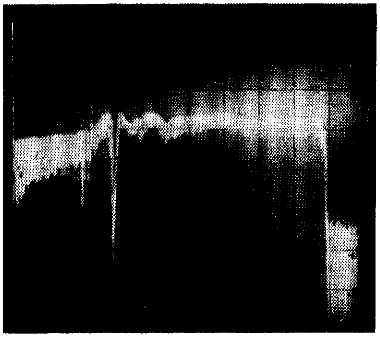

Photo 2 Excitation during whole accelerator cycle.
Amplitude tracking of excitation loop at 18.5 ± 1.5 kHz
Rms amplitude 10 dB/div versus time 500 ms/div
Log ref: -10 dBm $\hat{=}$ 2 mm
Trigger at first injection
Note injection oscillations at $t_1 = 0$, $t_2 = 1.2$ s.
Osicillation disappears at transition $t_3 = 1.4$ s and above 380 GeV $t_4 = 4.5$ s.

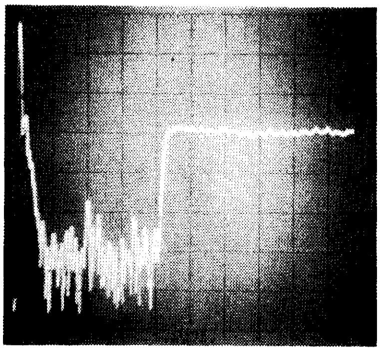

Photo 1 Vertical beam oscillations Δ323 damped at injection and excited 20 ms afterwards.
Amplitude tracking with spectrum analyser set to 18.5 ± 1.5 kHz with video filter.
Rms amplitude 10 dB/div versus time 5 ms/div
Log ref. = -10 dBm $\hat{=}$ 2 mm
Trigger: at injection
Beam intensity 1. batch: $1.2 \cdot 10^{13}$ ppp

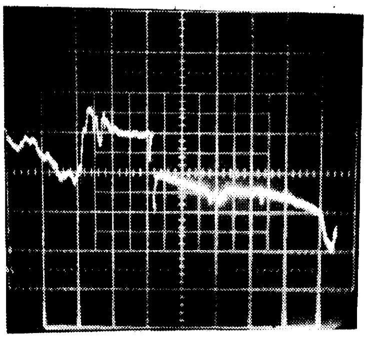

Photo 3 Q-tracking during accelerator cycle.
Q_V (output PLL) 0.02/div. versus time 0.5 s/div
Trigger at first injection, $Q_V = 26.57$ at injection.

0-1.2 s	: flat bottom
1.2 s	: second batch injected
1.26-4.8 s	: acceleration to 400 GeV
1.55 s	: transition
2.2 s	: 100 GeV
3.1 s	: fast ejection at 220 GeV
4.5 s	: Q-tracking locked out at 380 GeV