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DAMPING OF COHERENT TRANSVERSE OSCILLATIONS IN PETRA

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(presented by S. Pätzold)

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Summary

A narrow band bunch-by-bunch feedback system has been installed in PETRA in order to damp all modes of coherent transverse bunch oscillations. The system consists of pick up electrodes, a damping kicker and 8 parallel channels that each detect the oscillation signal of one particular bunch. The loop phase error due to machine tune shift is automatically corrected by a compensating network. At large betatron amplitudes, the damping kicker reaches its power limit. Taking this nonlinearity into account, the damping of the system was calculated and was found to bein good agreement with the measured values. During the first experimental runs with 4 bunches the feedback system was successfully used.

Introduction

In order to damp transverse coherent beam instabilities, a bunch-by-bunch feedback system was installed in the electron positron storage ring PETRA. Unwanted coherent betatron oscillations are excited by the injection kickers and possibly by particular cavity modes and the head tail effect, if the chromaticity is negative. Such a feedback system is also helpful for investigations of beam dynamics and instabilities.

The general design features of transverse feedback systems have been developed at different accelerators (1,2). The essential components of the loop are the pick up electrodes with the detector electronic, the phase shifter, and the damping kicker driven by a power pulser. The loop is closed using the beam as a signal path.

PETRA is designed to store a maximum number of 8 bunches. Since each bunch is considered as an independent oscillator, the system consists of 8 parallel narrow band channels that each detect and influence the transverse oscillations of one particular bunch. Two identical systems have been installed in order to damp both the horizontal and the vertical bunch motions (3).

Betatron Oscillation Detector

The bunch signal sensed by the pick up electrode contains a large number of harmonics of the revolution frequency. If the bunch's center of mass oscillates transversely, each harmonic of the signal is amplitude modulated by the betatron frequency. Therefore it is sufficient to select one of the harmonics by a narrow band detector and to separate the betatron oscillations by use of an amplitude demodulator. Because of desired high detector sensivity and low technical expense we choose the harmonic number n = 3840, i.e. a frequency of 500 MHz. The revolution frequency of PETRA is f_r = 130.12 kHz, and assuming the fractional part of the machine tune to be less than ΔQ = .35 we get the required bandwidth of the detector

$$\Delta f = \pm \Delta Q \cdot f_r = \pm 45 \text{ kHz}.$$

In order to combine the high input frequency and the narrow bandwidth we apply the superheterodyne technique as sketched in fig.1. The signal sensed by the pick up electrodes passes a 500 MHz filter before it is converted to 30 MHz. This signal is fed into a narrow band IF-amplifier containing a filter with the required bandwidth. An AM-demodulator finally detects the betatron oscillation signal.

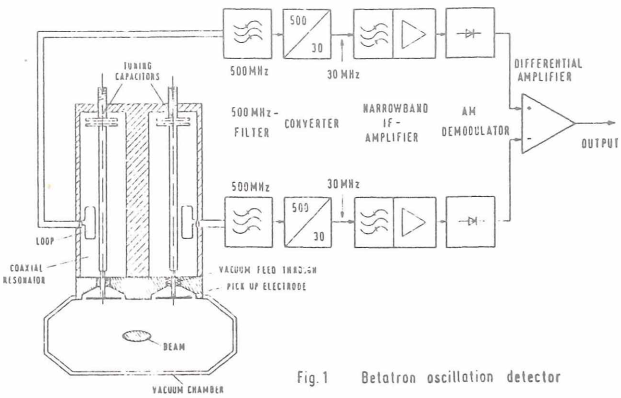

Fig. 1 Betatron oscillation detector

Using two identical pick ups with detector electronics, and a differential amplifier connected to the demodulator outputs, the betatron oscillation detector becomes sensitive in one of the two transverse planes of oscillation.
The pick up electrodes are of the same type as used for the PETRA position monitor system (4), but a resonant transformer was added to increase sensitivity. The transformer consists of a shortened half wavelength coaxial resonator with two capacitive loads at both ends. One capacitor is the pick up electrode, the second one is tuneable in order to adjust the desired resonant frequency. The signal is coupled out by a small inductive loop at the resonator's current maximum. Two resonant transformers are combined in a common case mounted outside the vacuum chamber.
With well adjusted loop coupling and resonant frequency, the gain improvement is

$$g = \frac{1}{2} \sqrt{R_s / R} = + 15 \text{ dB}$$

where R_s is the shunt impedance of the resonator and R the converter input resistance.

Damping Kicker

The damping force is produced by an air coil kicker magnet with four windings mounted in a cylindrical vacuum tank. It is driven by zero crossing current pulses with constant peak amplitudes, triggered synchronously with the bunch repetition rate (5). The bunch normally passes the kicker unaffected at zero crossing time. Shifting the trigger time with respect to the bunch by use of a time delay modulator, the beam is deflected transversely by a kicker strength which, for small amplitudes, is proportional to the modulation voltage. The kicker driver operates with the high repetition rate of 1.04 MHz. In order to avoid unreasonably high power consumption and technical expense we had to limit the peak strength of the kicker. Therefore at larger betatron amplitudes the driver reaches its power limit, and above this limit the beam deflection is independent of the signal amplitude in the loop. This saturation of kicker strength is the main nonlinearity in the feedback loop one has to take into account. An unstable beam is therefore damped only below a critical amplitude. This critical amplitude, which is nearly independent of the loop gain, is the main parameter of the nonlinear feedback system and is given by

$$x_{crit.} = \varepsilon \cdot \frac{\beta_0 \cdot \tau}{E}$$

where β_0 is the betafunction at the kicker, τ the growth time of the instability, E the beam energy and ε a numerically calculated factor (6). The PETRA damping kicker has a maximum strength of 2 Gm corresponding to [illegible] = 4.7 GeV/sec. This value is sufficient up to a PETRA energy of 19 GeV, if

$$\tau \geq 0.5 \text{ ms and } \beta_0 = 20 \text{ m.}$$

Phase Adjustment and Correction

In order to adjust the phase delay in the loop, an electronic phase shifter is used operating at the low betatron frequency. Because of the narrow band technique with the unavoidable signal delay in the loop, a fixed phase adjustment is only correct at a definite tune Q_0 of the machine. Changing the tune Q we obtain a phase error of

$$\phi = 2 \pi m (Q_0 - Q)$$

where m is the number of revolutions between pick up a signal and reaction on the beam. This effect gives a significant reduction of the usable Q-range. Therefore it is necessary to compensate the negative slope of phase versus betatron frequency by an additional network with a positive slope. Unfortunately any active or passive element has a characteristic with negative slope. Therefore we use an allpass filter with an electronically reversed phase shift $\psi(\omega)$. Using the relation

$$\cos(\omega t - \psi) = \cos\psi \cos\omega t + \sin\psi \sin\omega t$$

we first separate the cosinusoidal and the sinusoidal part of the allpass output signal by use of sample and hold technique. After separation we subtract the signals electronically and obtain the desired phase shift

$$\cos(\omega t + \psi) = \cos\psi \cos\omega t - \sin\psi \sin\omega.$$

With the compensation network the phase error in the loop is less than ± 20° in a Q-range from .15 to .30.

The System Design

The pick up electrodes and the damping kicker are mounted near the middle of the arc between two interaction regions where the 8 bunches of both beams pass with alternating direction at time intervals of 960 nsec. Because of its wide bandwidth of 6 MHz, the converter output signal generated by one bunch vanishes before the next bunch passes the pick up station. Therefore it is easy to distribute the 8 bunch signals per revolution with fast IF-switches to the inputs of 8 identical narrow band channels (fig.2).
Each channel consists of the detector electronic, the phase shifter and the compensating network.
The damping kicker produces 8 zero crossing pulses per revolution that act on the 8 bunches. These pulses are individually modulated by the signals sampled in turn at the outputs of the 8 channels. With this arrangement each bunch is stabilized by its own feedback loop. In addition, by opening the loop, the system allows the external excitation and observation of transverse bunch oscillations. This mode of operation is always used for tune measurements.

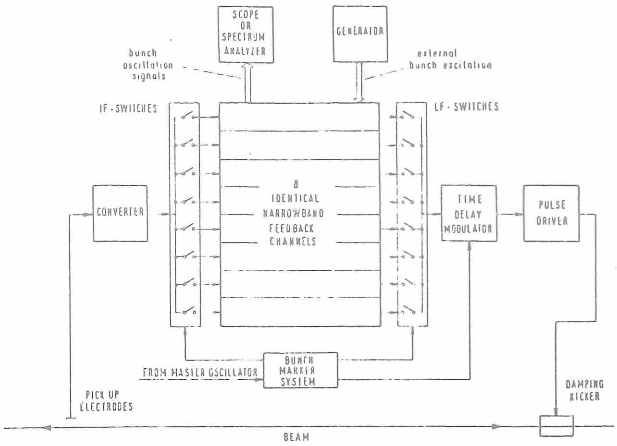

Fig.2 Arrangement of the 8channel feedback system

Operational Experiences

Shortly after the first beam in PETRA had been stored, the transverse feedback system was tested by damping the horizontal bunch oscillations excited by the injection kickers at 5 GeV (fig.3).

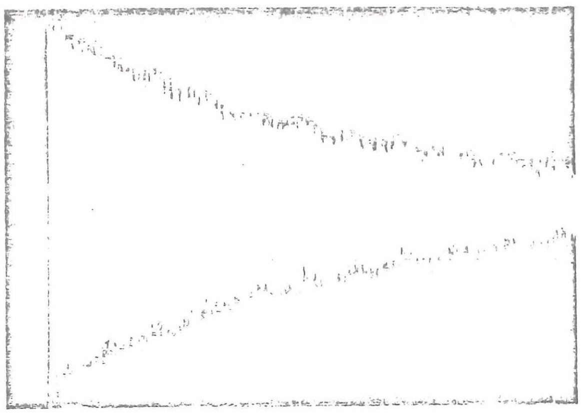

Fig. 3a: Coherent horizontal bunch oscillations without feedback (time base: 10 ms/div)

The measured damping time with feedback of τ = 0.42 ms is in agreement with the calculated value of 0.395 ms. The kicker strength during these first tests was 0.7 Gm.
Another test consisted in setting the storage ring to the negative chromaticity ξ = - 4.5. Without feedback, the maximum bunch current was limited to 0.3 mA due to head tail effect. With feedback we could store more than 6 mA. As an operational routine during experimental runs with four bunches, the system was always used for reducing the particle losses during injection.

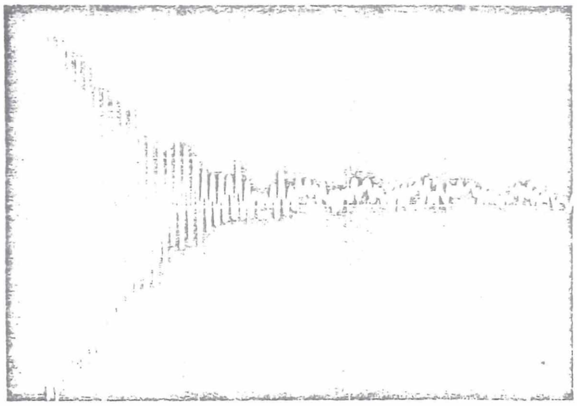

Fig.3b: Bunch oscillations with feedback. The time base is expanded by a factor 50 (0.2 ms/div)

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