THE TRANSVERSE FEEDBACK SYSTEM FOR THE TRISTAN AR

Takao IEIRI, Yoshihiko MIZUMACHI and Jean-Louis Pellegrin*
National Laboratory for High Energy Physics
Oho-machi, Tsukuba-gun, Ibaraki-ken, 305, Japan

ABSTRACT

Performance of essential components in the transverse feedback system is described. The system is composed of pickup electrodes, bunch oscillation detectors, phase shifters, power amplifiers and deflection electrodes. An effect of the system is examined with coherent betatron oscillation due to the injection kickers. Damping rate due to the system is shown as a function of feedback gain. Measured damping rate agrees with calculated one.

INTRODUCTION

A transverse feedback system has been developed for stabilizing a coherent betatron oscillation of an individual bunch. Such a system is operated for various electron storage rings[1)∼4)]; for instance, in PEP the feedback system is in operation all the time to improve injection efficiency and to reduce background noises. The system in the TRISTAN AR is applied to measurement of the tune number and beam dynamics experiments[5)] about head-tail instability.

The essential feature of the feedback system is illustrated in Fig. 1. The pickup electrode senses the transverse oscillation of a bunch as an amplitude modulation of a pulse train. The following bunch oscillation detector takes up only the amplitude modulation signal. The phase shifter adjusts phase delay of the feedback loop. The deflector reacts on the bunch to change its transverse velocity by electric and magnetic forces.

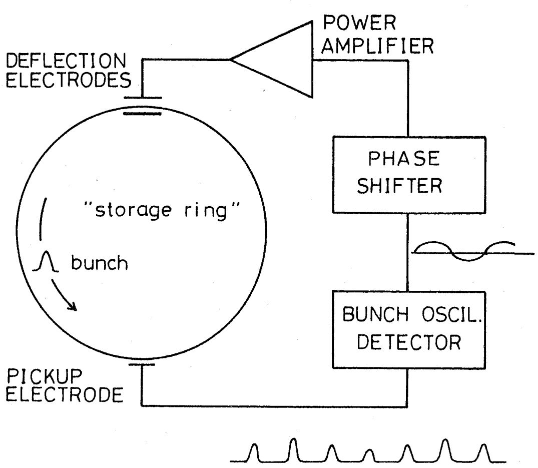

Fig. 1 Essential feature of the system.

DAMPING RATE

A bunch runs along an equilibrium orbit of a ring. If $x(t)$ is the transverse deviation of the bunch from the equilibrium orbit, the motion of the bunch will be expressed as follows:

$$x'' + 2\alpha_0 x' + (\nu\omega_0)^2 x = 0 \qquad (1)$$

where α_0 is damping rate, ν is the betatron tune and ω_0 is angular revolution frequency. The prime denotes the differentiation d/dt. If we introduce an external force into Eq. (1) derived from a displacement at the pickup electrode and amplified in the feedback loop, we will have additional damping. The damping rate α_f due to the feedback loop will be in a linear approximation[6)]

$$\alpha_f = \frac{e \cdot L \cdot c \cdot \omega_0 (\beta_m \beta_k)^{\frac{1}{2}}}{4\pi E_0} \cdot J \cdot \sin\Delta\phi \qquad (2)$$

E_0: beam energy
L: length of deflector electrode
c: light velocity
ω_0: angular revolution frequency
β_m, β_k: beta function at the pickup and the deflector
J: product of transfer function from the pickup to the deflector
$\Delta\phi$: difference in betatron phase between the pickup and the deflector

We see in Eq. (2) that the damping rate is propotional to the transfer function or feedback gain of the loop.

SYSTEM

The design and the outline of the system are described in Ref. 7 and 8. A beam deflection system is not a narrow-band type with a tuned electrode, but a wide-band one with a stripline deflector having a real impedance. A wide-band system deflects a bunch with a narrow pulse. The system has such the advantages that chamber impedance is low and deflector cooling is not needed.

Pickup electrode

Two stripline electrodes are installed in a cylindrical vacuum chamber. One is to detect horizontal oscillation and the other is for vertical one. The striplines have two characteristics; directivity and wide-band response. Owing to the directivity, one can independently pickup two bunches (electron and positron bunches) which propagate in opposite directions. Since beam induced voltage on the stripline is due to electric and magnetic fields, a pickup signal will show a more real bunch shape than that with a button electrode. However, notches in frequency response appear at the frequency of $nv/2\ell$, where $n = 0,1,2,3, \ldots$, v is the velocity of a bunch and ℓ is length of the stripline (ℓ = 30 cm). Figure 2 shows the directivity by observing one electron bunch at both ends of the stripline with a sampling scope (Tektronics, 7S12). A reflected pulse with inverse polarity appears at the upstream side after delay time of 2 ns ($2\ell/c$). No signal appears at the downstream side.

Bunch oscillation detector

The pickup pulse is stretched by a Gaussian low pass filter with 300 MHz cut-off frequency. The pulse is put into the bunch oscillation detector circuit which is seen in Fig. 3. Bunch oscillation appears on the pulse as an amplitude modulation at the fractional betatron frequency. The degree of the modulation is typically 1 %. An amplitude of the pulse depends on beam current. The AGC loop in the circuit makes normalization of the bunch oscillation; that is, lets the modulation be independent of beam current. Its dynamic range is about 40 dB. The oscillating part of the normalized pulse is picked up by a comparator and put into a sample-and-hold circuit. A sampling pulse is derived from the input beam pulse itself. An output signal contains several harmonics of the fractional betatron frequency. Only the fundamental mode is taken out and synchrotron frequency is eliminated by a band pass filter.

* Visitor from SLAC, Stanford, CA.

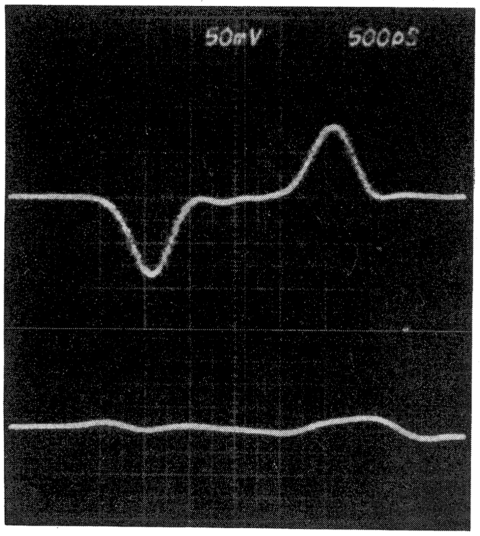

Fig. 2 A picked up electron pulse by the stiipline using a 800 MHz low pass filter.
upper: at upstream side
lower: at downstream side

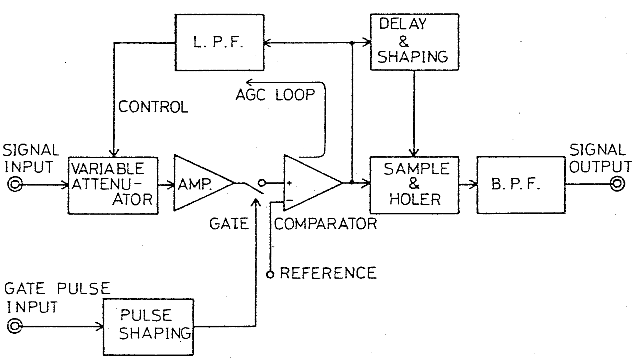

Fig. 3 Block diagram of bunch oscillation detector.

Phase shifter

The phase of the fundamental betatron oscillation (100 ∿ 400 kHz) varies according to the betatron tune. The phase of the feedback signal is adjusted by a CR phase shifter. The phase varies from 0 to ± 150°.

Power amplifier

Characteristics of a power amplifier are listed below.

frequency response	50 kHz ∿ 30 MHz
power output	200 W
gain	70 dB at 1 MHz
input/output impedance	50 Ω

The mode of the amplification is class A. The final stage of the amplifier consists of 8 transisters (2SC2652, Toshiba) connected in parallel and of a power combiner for them. The heat dissipation in the amplifier is about 1.2 kW and we need a blower for the cooling.

Deflection electrodes

Two sets of deflection electrodes are installed in the AR. Each set is composed of 4 electrodes and mounted in the vacuum chamber as shown in Fig. 4. Each electrode is a cylindrical pipe of 20 mm in diameter and 1920 mm in length. Its impedance is 50 Ω. Each deflector kicks the bunch with combined signals from horizontal and vertical ones. Horizontal or vertical deflection is done by combination of the 4 deflectors. The electrode is connected to vacuum feed-throughs[9)] at both ends. A feedthrough at the downstream side is

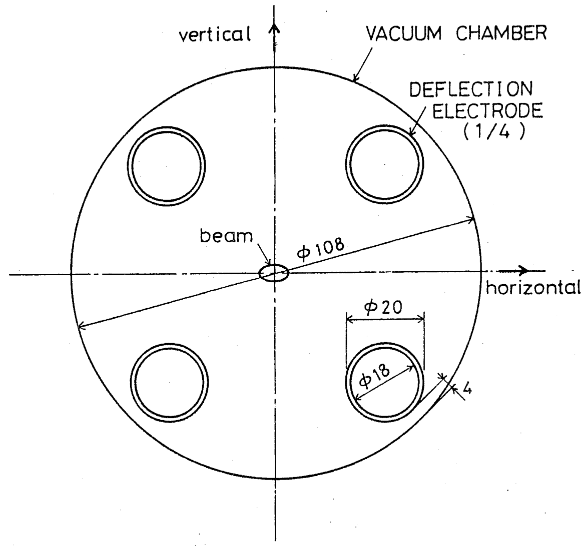

Fig. 4 Crosssectional view of deflection electrodes.

connected to the power amplifier via a coaxial cable and the other side is used for monitoring of a deflecting signal.

The deflecting signal is a pulse of 200 ns in width, whose envelope is oscillation with the fundamental betatron frequency as shown in Fig. 5. Peak current or voltage of the pulse is ± 2 A or ± 100 V at maximum power. The current and voltage give a bunch magnetic and electric deflecting forces at the center of the chamber. The two transverse forces are equal, therefore the deflecting force f is

$$f = 2ecB \tag{3}$$

where e is electric charge and B is magnetic field at the center.

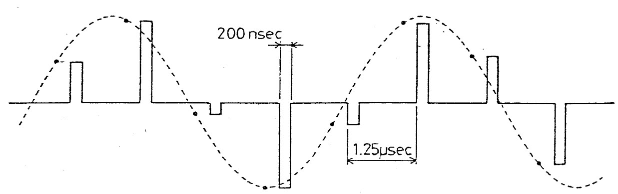

Fig. 5 Deflecting signal. The broken line shows the betatron oscillation.

The higher order mode loss of a model deflector with 30 cm in length is 0.04 V/PC at σ = 2.4 cm. Power loss of a bunch with 35 mA current is 60 W. The VSWR of the deflector is less than 1.2.

OPERATION

Coherent betatron oscillations are excited by the injection kicker and damped due to radiation damping process. The effect of the feedback system is tested at the injection of 2.5 GeV. The output signals of the bunch oscillation detector in Fig. 6 show the damping of coherent oscillations with and without the feedback system. The horizontal oscillation is well damped by adjusting feedback gain and phase. Maximum damping rate is $2 \times 10^{4}\ \mathrm{sec}^{-1}$ or damping in 40 turns. The vertical oscillation is not damped by the vertical feedback only, but can be damped with the aid of the horizontal feedback, because the horizontal oscillation is mixed into the vertical plane at the injection.

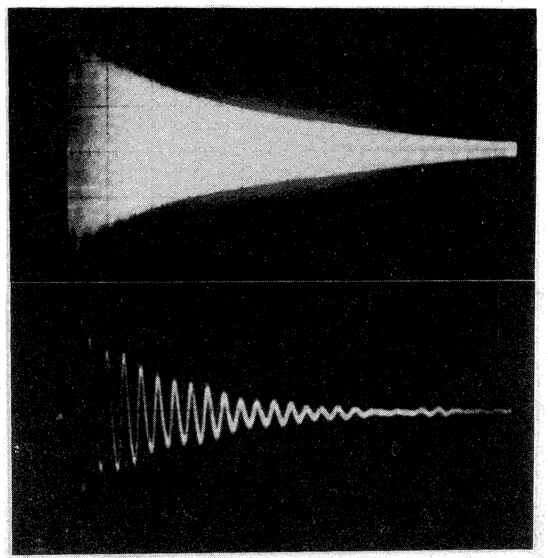

Fig. 6 Coherent horizontal betatron oscillation at the injection. Beam current is 1 mA and chromaticity is + 3.
upper: without feedback, 2 mS/div, τ_d = 10 mS
lower: with feedback, 20 μS/div, τ_d = 80 μS

The damping rate (α) is measured as a function of the feedback gain (G) under the condition that beam current is 2 ∿ 4 mA and chromaticity is + 3. If G is high enough, α is propotional to G as shown in Fig. 7. This relation is calculated from Eq. (2). When G is relatively low, the difference between the measured and the calculated values is noticeable. The damping mechanism due to finite chromaticity (see Ref. 5) in addition to the radiation damping can explain the difference.

We wish to thank Mr. M. Tejima for making software to operate the system.

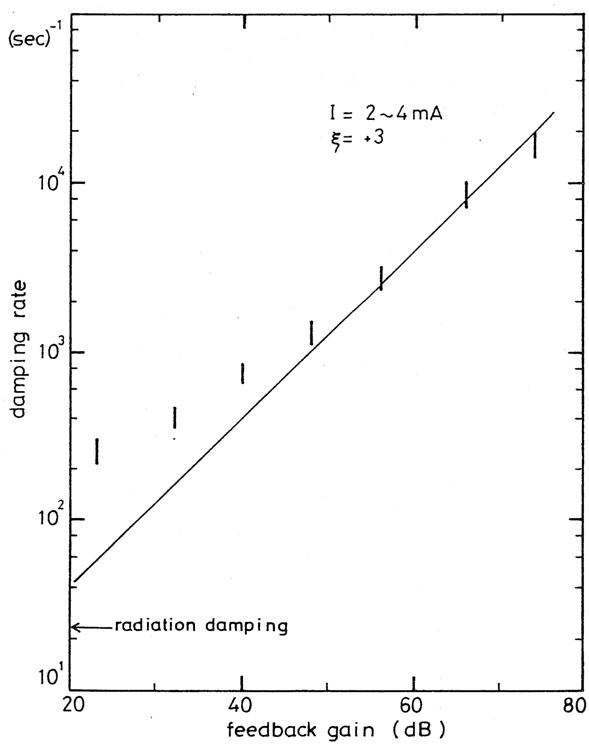

Fig. 7 Damping rate vs feedback gain. The solid line line shows the calculated value using eq. (2).

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