© 1985 IEEE. Personal use of this material is permitted. However, permission to reprint/republish this material for advertising or promotional purposes or for creating new collective works for resale or redistribution to servers or lists, or to reuse any copyrighted component of this work in other works must be obtained from the IEEE.

THE LONGITUDINAL FEEDBACK SYSTEM IN TRISTAN AR

H. HAYANO and E. EZURA
National Laboratory for High Energy Physics
Oho-machi, Tsukuba-gun, Ibaraki-ken, 305, Japan

Abstract

Longitudinal dipole instability which had been the problem during the running in of the TRISTAN Accumulation Ring (AR) and the first year of operation has been damped by the feedback system. The dipole oscillation is detected by comparing the phase of the RF component (508.6 MHz) in the bunch signal with the phase of the RF reference signal. The detected oscillation is, after being adjusted in amplitude and phase, fed back into the RF phase shifter at the input stage of the klystron. The damping rate with and without feedback has been measured. The feedback system provides a sufficient damping rate in the synchrotron frequency range of 20 to 40 kHz.

Introduction

AR is a storage accelerator which accumulates electrons (or positrons) supplied by the 2.5 GeV linac and accelerates them to at least 6 GeV for injection into the Main Ring. It is now routinely operated in the single bunch mode for the calibration of lead glass counters to be used in the TRISTAN detectors, VENUS and TOPAZ. In the present operation the current of 20 to 25 mA is accelerated and stored at 5 GeV.

Since commissioning of AR, several types of beam instabilities have been observed in both transverse and longitudinal planes. One of the troublesome instability is a longitudinal dipole oscillation. It has been verified that the cavity control system is innocent of this instability. Inductive detuning of the cavities has cured the instability only in relatively low currents. In order to damp the instability, a feedback system has been developed. At a stage of full installation of the cavities in AR, the synchrotron frequency of the beam will vary from about 20 kHz at the injection porch to about 50 kHz at the 8 GeV flat top. The feedback system, therefore, is required to consists of wide band components to ensure effective damping over this frequency region. The RF cavities in AR, however, have narrow half-bandwidths of 11 to 20 kHz and we must use these as feedback cavities.

System Description

Fig. 1 shows a block diagram of the feedback system, which is incorporated into the RF system[1]. A button electrode of the position monitor is used to pick up a bunch signal, which is fed to a series of band-pass filters to extract only the harmonic at the RF frequency. The phase of the RF component of the beam thus obtained is compared with the RF reference phase. The phase difference is filtered by a high-pass and a low-pass circuit to obtain a component of synchrotron oscillation. This signal is adjusted in phase by a LF phase shifter and amplified by a LF variable-gain amplifier. It is then fed into an RF phase shifter in the drive signal path to the klystron.

The total phase shift of the loop increases with frequency mainly due to the narrow bandwidth of the cavities. It is therefore desirable to control the phase shift so as to give the highest damping rate at any synchrotron frequency. As the LF phase shifter now available is, however, not remotely controllable, the amount of phase shift is set at a fixed value. This value makes the total phase shift of -180 degrees at the frequency of 30 kHz, which is around the center of the synchrotron frequency range. To make the feedback system more effective over a wider frequency range, a new LF phase shifter is being made, which is able to control the phase shift in accordance with synchrotron frequency.

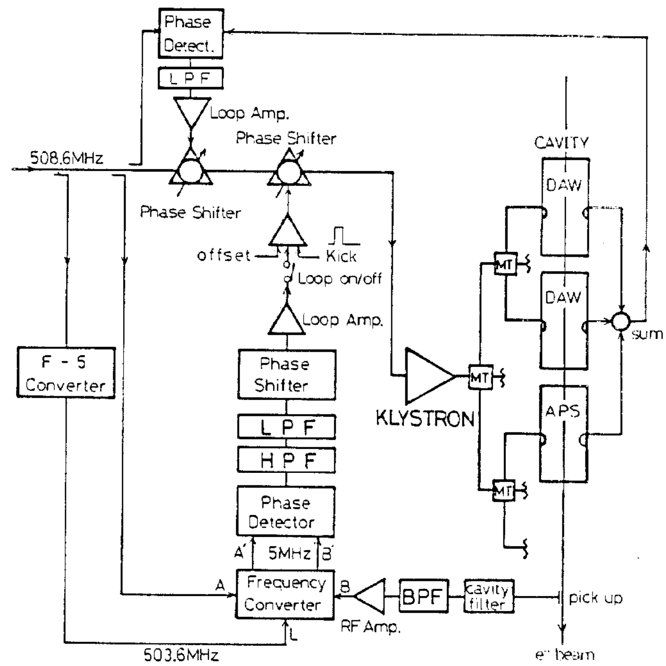

Fig. 1 Block diagram of the longitudinal feedback system. The klystron phase-lock loop is also shown and it works in the frequency range below 1 kHz.

Component Description

A series of RF band-pass filters consists of a coaxicial cavity filter and a LC band-pass filter. The cavity filter has a Q value of 1400, an insertion loss of 6.8 dB and a phase-temperature coefficient of 0.5 deg/°C at 508.6 MHz. The LC band-pass filter has a rather wide bandwidth of 20 MHz and its insertion loss is 2.9 dB. This filter is used to eliminate higher frequency components which pass through the cavity filter.

The phase detection system is composed of a local oscillator which generates the frequency of 503.6 MHz, a frequency converter producing an intermediate frequency of 5 MHz and a phase detector operateing at this frequency. The detection system introduces errors smaller than ±1 degree over a power range of 45 dB. This dynamic range well covers the present beam current range of 0.5 mA to 30 mA. A frequency bandwidth of the phase detection system is over 150 kHz and a long term stability is within ±1 degree.

The high-pass and the low-pass filter has a cutoff frequency of 1.5 kHz and 50 kHz respectively. The LF phase shifter is of an RC filter type, so the controllable phase range is 180 degrees and the phase shift increases with frequency. The RF phase shifter is the electronic one using voltage variable capacitance diodes as control elements. The phase shifter has a linear response of phase versus control voltage over a

0018-9499/85/1000-2156$01.00© 1985 IEEE

range of 360 degrees. The bandwidth of the phase shifter is more than 1 MHz.

At present the klystron supplies the RF power to the three cavities, two DAW (type A)[2] with 12 cells and one APS[3] with 9 cells. The half-bandwidth of the DAW cavity is 11 kHz, and that of the APS cavity is 20 kHz.

Damping Rate with No Feedback

The damping rate of longitudinal dipole oscillation has been measured in the absence of feedback. The oscillation was excited by a small phase perturbation in the cavity field, which was produced by a pulsed control voltage given to the RF phase shifter. The oscillation was detected by a beam position monitor placed at the position with a large dispersion. The output signal from the monitor was displayed on an oscilloscope, and the damping rate was obtained from an envelope of a decaying oscillation.

The measurement was done at the beam energy of 2.55 GeV and the cavity voltage of 1.8 MV. The synchrotron frequency is 24.4 kHz in this case. The damping rate was measured as a function of tuning angle of the cavities. The tuning angle was controlled by an offset voltage given to the cavity tuning system. Fig. 2 shows the measured damping rates versus cavity tuning angle for the beam intensity of 1.5, 5, 10 and 20 mA.

The damping rate in the absence of feedback is the sum of the radiation damping rate and the so-called Robinson damping rate. The Robinson damping rate[4] α_d for a fundamental mode of cavity is given by,

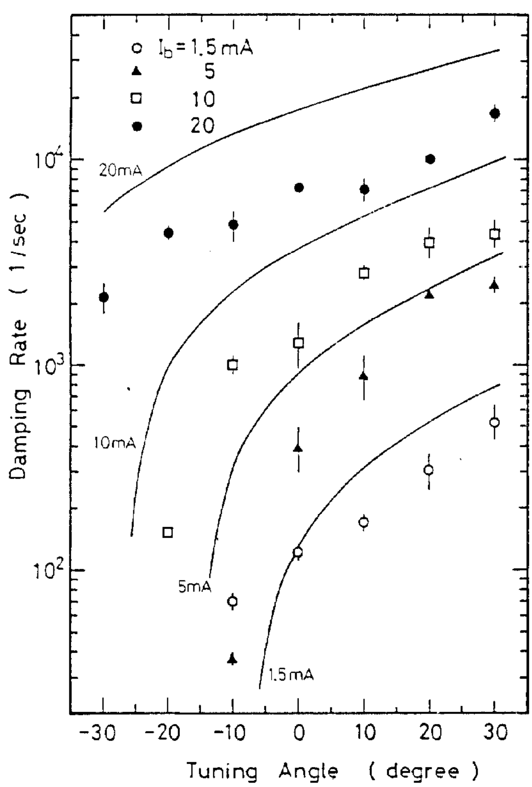

Fig. 2 Measured longitudinal damping rates with no feedback as a function of tuning angle of cavities and beam currents. Solid curves represent calculated damping rates.

$$\alpha_d = \frac{1}{\tau_d} = \frac{V_{br}\omega_s}{V_c \sin\phi} \cdot \frac{-\xi\eta}{[1+(\xi+\eta)^2][1+(\xi-\eta)^2]} \tag{1}$$

$$\xi = -\tan\psi = (\omega-\omega_0)T_f = \frac{V_{br}\sin\phi}{V_c}$$

$$\eta = \omega_s T_f$$

$$V_{br} = \frac{I_0 R_a}{(1+\beta)} \quad .$$

In AR RF system, the tuning control system works to compensate automatically for the reactive component of the beam current. This means that, in usual operation, the beam always sees the inductively detuned cavity, while the incident RF wave sees the tuned cavity. This detuning makes the current dependence of the damping rate through the term ξ, in addition to the dependence by the current proportional term V_{br} in eq.(1). The tuning angle taken as the abscissa in Fig. 2 is the externally given angle and does not include the beam-induced detuning mentioned above. The solid lines in Fig. 2 shows the calculated values obtained by the sum of the Robinson damping rate from eq.(1) and the radiation damping rate estimated to be 48. The calculated damping rates are larger than the measured ones, and the difference is approximately proportional to the square of beam current. An assumption of higher mode impedances which give an antidamping rate proportional to beam current can not explain the difference.

Damping Rate with Feedback

Prior to the measurement of damping rate, the effectiveness of the feedback system was checked. At first, the loop was kept open and the cavities were capacitively detuned by 20 degrees to cause Robinson instability. The beam began to oscillate coherently and the amplitude of oscillation grew until it was saturated due to a nonlinear damping effect. Fig. 3(a) is the spectrum of the cavity field, in which the side-bands of the dipole oscillation appears clearly. Then the loop was closed with an appropriate loop gain. The oscillation was damped away as shown in the spectrum in Fig. 3(b).

The damping rate in the presence of the feedback was measured in the same manner as described in the previous section, under the condition of the beam energy 2.55 GeV, the beam current 5 mA, and the cavity voltage 1.8 MV. The tuning angle of the cavities was chosen as -20 degrees, which gives Robinson antidamping. Fig. 4 shows the measured damping rate as a function of the loop gain. The measured data is the sum of the damping rate provided by the feedback, the radiation damping rate and the Robinson antidamping rate. The damping rate by the feedback is expected to be proportional to the loop gain. The fall at the smaller loop gain is the contribution of the Robinson antidamping.

The next step was to measure the frequency bandwidth of the feedback system. For the sake of easiness of measurement, the synchrotron frequency was varied by changing the cavity voltage at the fixed beam energy of 2.55 GeV, instead of changing the beam energy. To vary the synchrotron frequency from 22 kHz to 40 kHz, the cavity voltage was required to change from 1.5 MV to 4.5 MV. The tuning angle was set to -20 degrees. The phase shift of the loop was adjusted so as to give the best phase relation at 30 kHz. The measured damping rate is shown in Fig. 5 as a function of the synchrotron frequency. One of the factors causing the frequency dependence of the measured data is an adequate phase relation of the loop in the frequency region far from 30 kHz.

The damping rate can be made larger by increasing the loop gain as shown in Fig. 4. The loop gain, however, limited at present to a certain value, over which the system becomes unstable due to the large frequency-phase lag characteristics of the loop.

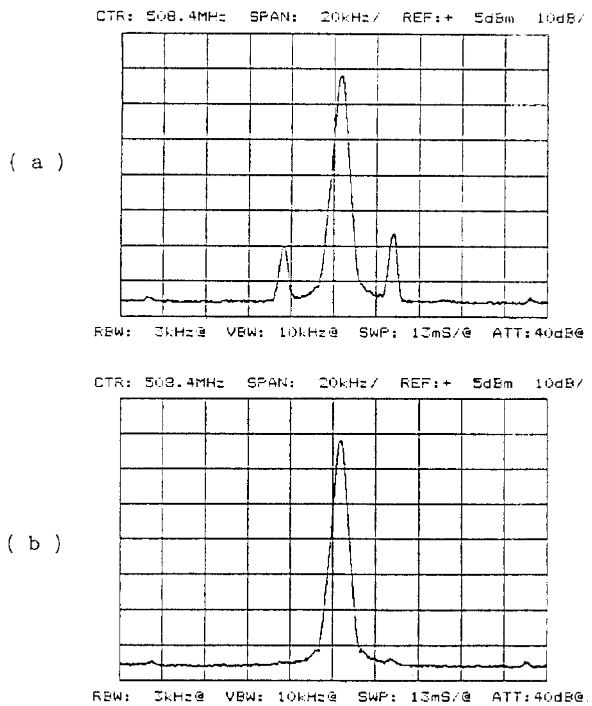

Fig. 3 Spectrum analyzer scans of the signal from a cavity pick-up with an intentional Robinson instability.
(a) without feedback
(b) with feedback

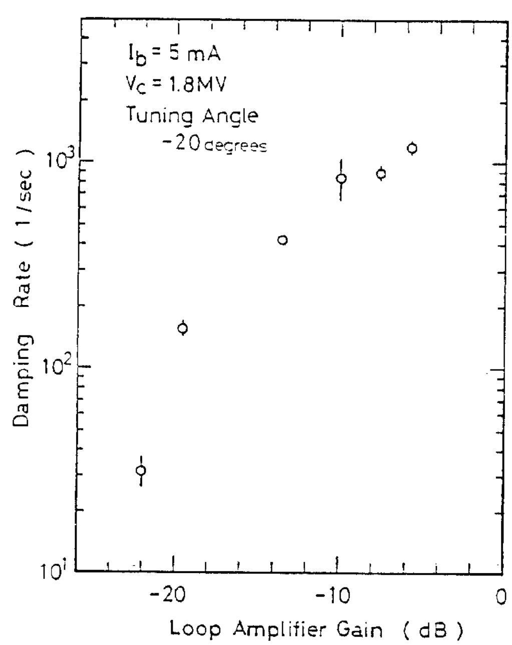

Fig. 4 Damping rate vs. loop amplifier gain with feedback.

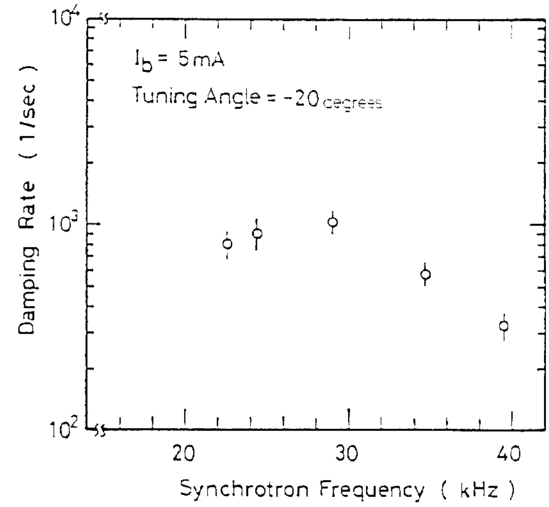

Fig. 5 Damping rate vs. synchrotron frequency with feedback.

Conclusion

Longitudinal dipole instability in AR has been damped by the feedback system which provides the damping rate of 10^3 in the synchrotron frequency range of 20 kHz to 40 kHz. Futher improvements are necessary to increase the damping rate and to widen the operational bandwidth.

Acknowledgement

The authors would like to acknowledge T. Higo, T. Kageyama, and M. Akemoto for their collaboration in the damping rate measurements.

References

[1] E. Ezura et. al., "Initial Operation of the RF System for TRISTAN AR", Proc. 5th Symposium on Accelerator and Technology (KEK, 1984), p.117.
[2] S. Noguchi et. al., "12-Cell DAW Structures in the TRISTAN Accumulation Ring", Proc. 5th Symposium on Accelerator and Technology (KEK, 1984), p.111.
[3] T. Higo et. al., Proc. of this conference.
[4] P. B. Wilson, Proc. 9th Int. Conf. on High Energy Accelerators (Stanford Linear Accelerator Center, 1974), p.60.