PHASE STABILIZATION OF RF REFERENCE LINE FOR TRISTAN AR

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ABSTRACT

The phase stabilization technique of the RF reference line which will be used in TRISTAN AR is described. The phase stabilization[1] is achieved by the phase feedback system which applies a modulated reflection method[2]. In this system, a phase between the input and the output signal is locked by minimizing an amplitude of the modulation in a composite signal which consists of a modulated reflection from the end of line and a sample of the input RF signal. The system has been tested between two RF stations. The result indicates that the phase error between RF stations can be held within ± 1 degree under practical operating conditions.

INTRODUCTION

In the RF system of TRISTAN AR, the reference signal is a sine-wave of nominal frequency 508.58 MHz, and distributed from the master oscillator placed at the AR west RF station. There are two reference lines. One is for AR east RF station through a cable of about 300 m long, and another is for central control room to make injection timing signals through a cable of about 370 m long. If there is a large variation of temperature around the transmission cable or a change of the RF frequency during accelerator operation, the phase of the signal at each station is changed and the acceleration becomes inefficient and unstable. So it is needed to stabilize a phase between two RF stations.

The phase stabilized cable (Dainichi-nippon, type SFZE50) are used for the reference lines. Its nominal phase-temperature coefficient is below 3 ppm/°C, so a phase variation of 300 m cable is 0.65 degrees/°C for temperature change, 0.42 degrees/KHz for frequency change. The cables are in the AR tunnel which is air-conditioned during accelerator operation, so the phase variation caused by environmental temperature change is small. However, when the RF frequency is changed, a large phase variation appears and therefore is needed a phase stabilization.

PHASE STABILIZATION FEEDBACK LOOP

Modulated reflection method

The block diagram of the feedback system is shown in Fig. 1. The RF signal transmits from right to left,
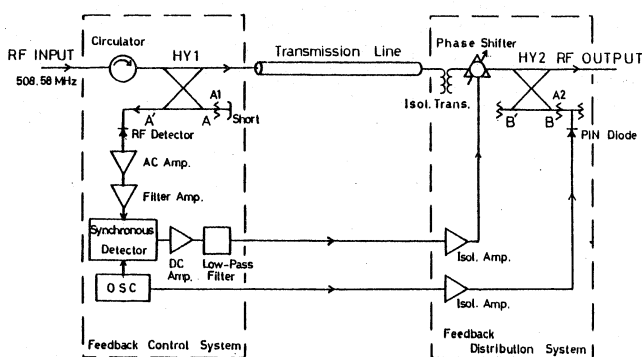
and at the port A' of the hybrid HY1 a carrier and a subcarrier are summed up, where the carrier is a reference signal reflected at the port A of the hybrid HY1 and the subcarrier is a signal reflected at the port B of the hybrid HY2. The reflected signal is amplitude modulated at the frequency ω_m. Writing the carrier amplitude Ec and the subcarrier amplitude Esc $(1+m \cos \omega_m t)$, one obtains the resultant amplitude Er at port A';

$$Er^2 = Ec^2 + Esc^2 + 1/2 \, m^2 \, Esc^2 - 2 \, Ec \, Esc \, \cos\phi$$
$$+ (2 \, m \, Esc^2 - 2 \, m \, Ec \, Esc \, \cos \phi)\cos\omega_m t$$
$$+ 1/2 \, m^2 \, Esc^2 \, \cos 2\omega_m t$$

where m is the index of modulation and ϕ is a phase angle between carrier and subcarrier. If one picks up an amplitude modulation at frequency ω_m in the resultant signal and controls a phase shifter so as to make a null modulation amplitude, then the coefficient of $\cos\omega_m t$ is zero. Namely a phase between carrier and subcarrier is locked to an angle ϕ_0 given by

$$\cos\phi_0 = Esc \, / \, Ec \quad .$$

If $Esc \ll Ec$, ϕ_0 will be about 90 degrees. Fig. 2 shows the vector diagrams of the relation between Ec, Esc, and Er.
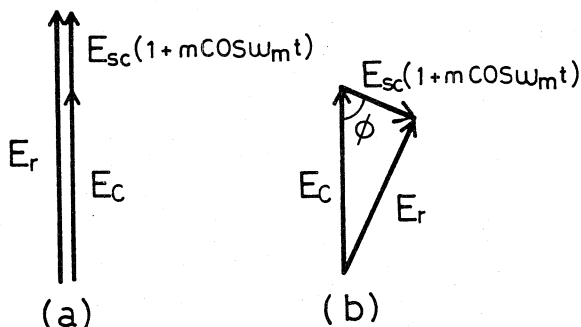

Fig. 2 Vector diagrams of a resultant signal.
(a) crrier and subcarrier in phase
(b) carrier and subcarrier $(180-\phi)$ out of phase

Feedback system

The system description of the modulated reflection method is as follows. The RF reference signal of + 30 dBm level is isolated by a circulator, and enters a 3 dB hybrid HY1. A portion of the signal is reflected at the short termination of port A and is used as a carrier signal. The main signal travels through the reference transmission line, a feedback phase shifter, and enters another 3 dB hybrid HY2 in the another RF station where a half of the signal is used as a reference signal of this RF station. The other half of the signal is attenuated by 3 dB (A2) and amplitude modulated by a PIN diode modulator. A portion of the modulated signal is then reflected and returns back to HY1 as a subcarrier through A2, HY2, the feedback phase shifter, and the transmission line. At the port A' of HY1, these carrier and subcarrier signals are summed up, and then rectified by an RF detector. The output of the detector is amplified by a following AC amplifier and a tuned amplifier which amplifies only a signal at the modulation frequency. The followoing synchronous detector converts the input signal to a dc

Fig. 1 Block diagram of the feedback system
for the RF phase stabilization.

error signal, using a sample-hold circuit gated by the same oscillator that modulates the reflection signal. The dc error signal, after being amplified by a dc amplifier and filtered by an RC low-pass filter, is fed to the feedback phase shifter.

The main source of error in this feedback loop is a reflection from the phase shifter. The reflection loss of the phase shifter varies from 17 dB to 47 dB depending on a dc control voltage. In order to reduce the effect of reflection, the phase shifter is placed at the end of the transmission line.

TEST RESULTS OF THE FEEDBACK SYSTEM

The feedback system was tested between the west and east RF stations. To check the performance of the system the output signal was sent back to the west station through another independent feedback system as shown in Fig. 3. This enables us to measure a phase
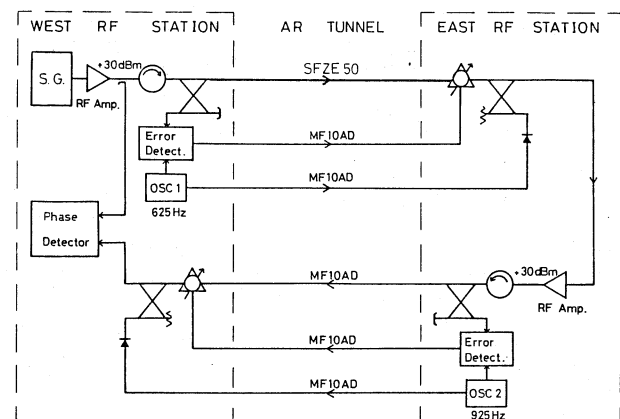
Fig. 3 Block diagram of the feedback test
at AR using two feedback systems.

variation of a returned signal relative to the phase of the transmitted one and to evaluate the overall performance of the two series systems. Two systems were made exactly the same except for the coaxial cables used. One is the phase stabilized cable described above and the other is a cable with attenuation of 45 dB/km at 508.58 MHz and phase-temperature coefficient of 18 ppm/°C.

The input RF level of this feedback system is + 30 dBm and the output RF level is about + 1 dBm. The level of the carrier is + 2 dBm and that of the sub-carrier with modulation index of 0.23 is - 36 dBm. In order to avoid a possible interaction with a beam, the sufficiently low modulation frequency compared to a synchrotron frequency was used. And to avoid a coupling of two feedback systems, the modulation frequency was chosen to be 625 Hz for the transmission feedback system and 925 Hz for the return feedback system. The feedback loop gain was about 90, and the time constant of the RC low-pass filter of each system was 825 sec.

Examples of the test results are shown in Fig. 4. They are the recorder outputs of the phase monitor which measures the phase difference between the transmitted and the returned signal at the west RF station. Fig. 4(a) shows the result with no feedback; a large phase variation mostly comes from the environmental temperature change. This variation was greatly reducd by closing the feedback loop as shown in Fig. 4(b). The system was tested for 24 hours and proven to keep the phase variation within ± 1 degree during the period. Fig. 4(c) shows the response of the system to the frequency change by ± 100 KHz. The feedback system reduced the phase variation, caused by frequency change, within ± 1 degree, while it was over ± 80 degrees without feedback.

The feedback system described above provides a sufficient phase stabilization and is useful for AR RF reference line. However, at present, only the west RF station is working and no cavity is installed in the east tunnel. So the feedback system will be tested in the presence of a circulating beam in this autumn, when the east RF station will begin to work.
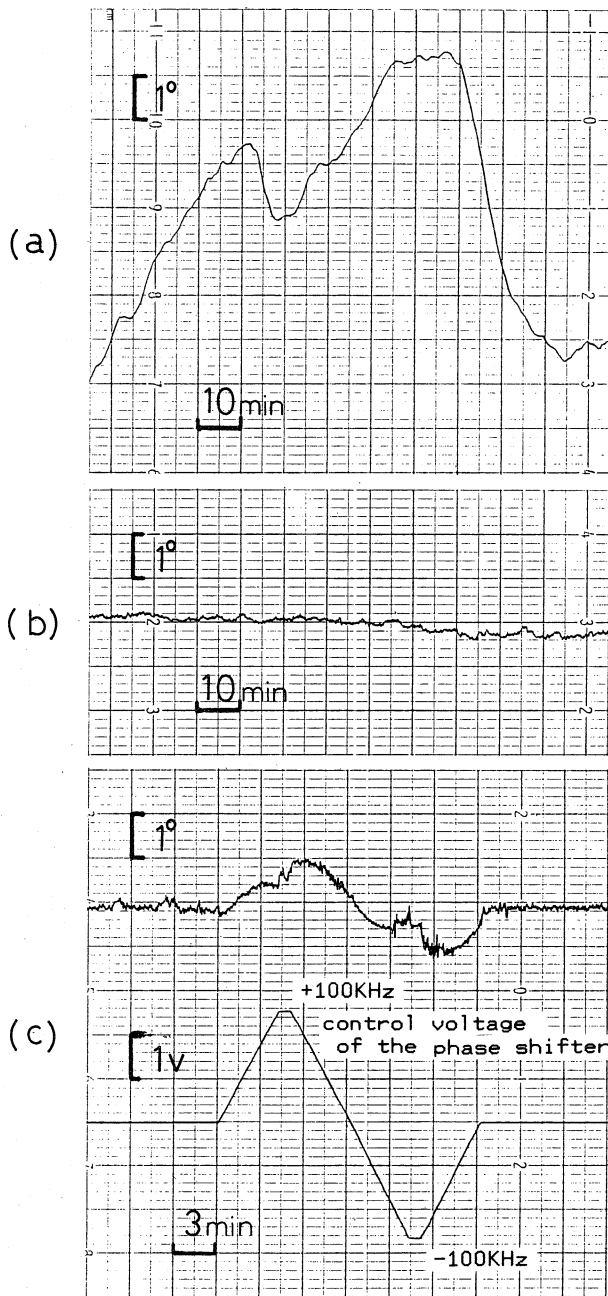
Fig. 4 The phase variation.
  (a) with no feedback
  (b) with feedback
  (c) with gradual ± 100 KHz frequency change

REFERENCES

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