INITIAL OPERATION OF THE RF SYSTEM FOR TRISTAN AR

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ABSTRACT

The RF system for the TRISTAN AR is illustrated in its present state of operation and development. Some of the characteristics, problems and achievements of the system during the first 7 months of operation are described.

INTRODUCTION

The TRISTAN Accumulation Ring (AR) is a storage accelerator of 377 m in circumference. It 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. The design current is 30 mA per beam of single or two bunches. On November 18, 1983 the AR accelerated the first electron beam to 4.2 GeV by a single 12-cell DAW (type A) cavity. After improvements of the RF system and the addition of two more cavities, the energy reached the design level of 6 GeV on July 4, 1984.

SYSTEM AND PARAMETERS

Fig. 1 shows a block diagram of the present RF system. The RF power feeding to the cavities is, as shown in the figure, unbalanced at present due to the limited number of available cavities. A balanced feeding method, in which one of the four equally divided powers is wasted in a dummy load, is abandoned from the view point of the RF power economy. The RF system is housed in the West Hall. The fourth cavity will be installed in the West tunnel by the end of September to complete the RF system at the West Hall. The East Hall now used for testing of klystrons and superconducting cavities is reserved for future expansion of the RF system.

The RF parameters at the present stage and the machine parameters relevant to the RF system are given in Table 1.

Table 1

RF Parameters at the Present Stage

RF Frequency	508.58 MHz
Harmonic number	640
Machine circumference	377.26 m
Injection energy	2.5 GeV
Energy achieved	6.0 GeV
Maximum circulating current at 2.5 GeV	66 mA for single bunch 90 mA for multi bunch
Cavities	two 12-cell DAW (type A) and one 9-cell DAW (type B)
Shunt impedance	27 MΩ/m for type A 22 MΩ/m for type B
Unloaded Q	62,000 for type A 33,000 for type B
Cavity coupling factor	1.7 for type A 1.4 for type B
Total length of structure	9.7 m
Total shunt impedance	247 MΩ
Number of klystron	1
Available klystron power (CW)	320 kW
Momentum compaction factor	0.0129
Synchrotron frequency	8 ∿ 45 kHz
Natural bunch length (σ_z)	7 ∿ 22 mm

CAVITIES

Three DAW cavities have been installed in the West tunnel; two 12-cell type A and one 9-cell type B[1]. The type A has been designed to maximize the shunt impedance. Though its mode overlapping and numerous higher order modes have been considered to be the problems, in the beam studies up to the present, transverse instabilities clearly attributed to the cavities have not yet been found[2]. The type B has been designed to avoid the mode overlap problem at the expense of shunt im-

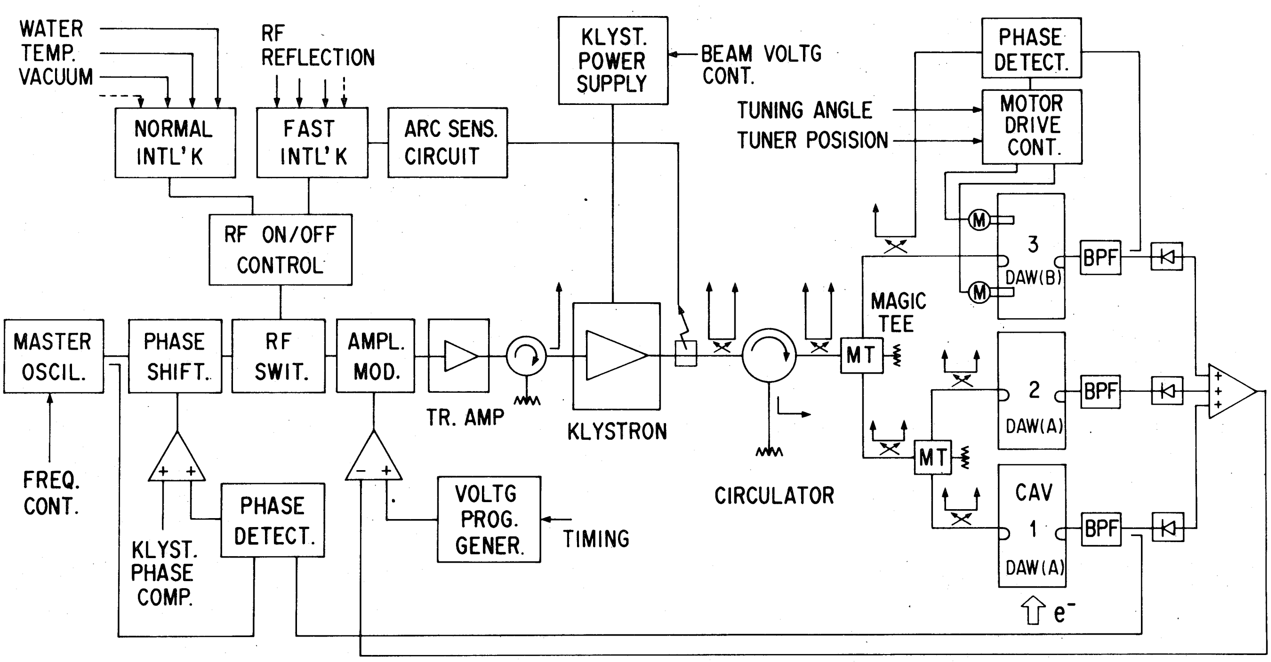


Fig. 1 Block diagram of the present RF system.

pedance. The first APS type cavity was completed in August and is ready to be installed in the West tunnel as the fourth cavity[3]. These cavities of different types are being tested in the AR to get the practical design data for the Main Ring cavities.

The maximum CW power supplied to each cavity by the end of the last run was about 100 kW. In the usual machine operation, the pressure in the cavities, being in the order of 10^{-8} torr for a low RF power level and no beam, was increased to the order of 10^{-7} torr. One of the causes of the pressure rise is obviously the insufficient processing of the cavities. In early August, the type B cavity was processed to a CW power level of 200 kW. It resulted in the remarkable reduction of the pressure rise appearing with the increase of power level. By the start of the next run, the type A cavities will also be processed to a higher power level.

The ceramic window of the power coupler to cavity is of a cylindrical type, being capable of transmitting up to 250 kW of CW power. Two out of six windows have failed so far. One had cracks and the other exhibited an abnormal temperature rise even at a low power level. Cracking occured soon after the processing of the first cavity started. The incident power level was about 10 kW, and the abrupt rises of cavity pressure and window temperature were recorded at the occurrence of cracking. The cause of the failure is attributed rather to inexperience of cavity processing and the insufficient interlock system, than to a fault of the window itself. On the other hand, the latter of the failed windows evidently has its own problems. At relatively low power levels, a glow discharge was observed around the window, through a hole at the bend of the waveguide. The glow discharge started at the power level of about 20 kW, and at the same time the temperature of the window, measured on the outer surface of the coupler, began to rise steeply. At the prsent stage of investigation the quality of the ceramic material is most suspicious.

KLYSTRON AND CIRCULATOR

The energy of AR is at present limited by the RF output power of the klystron. The maximum CW power of the present klystron is 320 kW. In usual operation of internal target mode[4], the energy at the flat top is 5 GeV, which is achieved with the three cavities supplied with the RF power of around 150 kW. The limitations of the RF power of the klystron mainly come from the power handling capability of the window. The investigation and development of the window are being made on the geometrical configuration, the dielectric material and the coating.

A 1 MW circulator has been installed between the klystron and the cavities, though it was not planned at the early design stage[5]. The circulator is effective in the following ways.

(1) It makes the klystron see a matched load regardless of a beam loading condition of the cavities, and eases the maixmum power transfer from the klystron to the cavities.

(2) It keeps the klystron free from a reflected power from the cvities, which might lead the klystron to unstable operation.

(3) It avoids beam instability which might arise from the coupling of the circulating beam with the klystron.

The circulator has operated with no problem up to the power level of 320 kW, over which it has not been tested for lack of a power source.

LOW LEVEL RF SYSTEM

Field in each cavity is controlled by the three feedback loops; the amplitude control, the phase lock and the tuning control loops. On the whole these loops are working well as expected and have no serious problem. However, several improvements are to be made for upgrading the operational performance. For example, a circuit producing the feedback signals of the loops is to be improved. In the amplitude control loop, as shown in Fig. 1, a scalar sum of the rectified levels of three cavities is used as the feedback signal. In the phase lock loop, the feedback signal is the pickup of the cavity No.1. It is obviously desirable to take a vector sum of the three cavity pickups, and to use it in the phase loop and its rectified signal in the amplitude loop, as the feedback signals.

A master oscillator used now is a commercially available signal generator of a synthesizer type. In the machine study in which a closed orbit was shifted to change the damping constants, the frequency was slowly changed by ± 60 kHz, corresponding to the orbit shift of ± 7 mm. A considerable beam loss was observed whenever the frequency crossed 508.600 MHz. This is explained from the characteristics of the master oscillator. In order to keep the particles inside the bucket at a change of RF frequency, the master oscillator must have a property of amplitude and phase continuity at frequency switching. However, the present oscillator maintains the continuity only when the frequency switching is made within the digit of 100 kHz. A new master oscillator having the phase continuous switching region of 508.580 ± 0.2 MHz is being developed.

The control and the signal monitoring for the RF system is governed by a minicomputer. CAMAC is used as the interface between the computer and the devices. Fig. 2 shows a simplified block diagram of the control system. A number of commands, such as switching on or off equipment, setting analog value and resetting interlocks are done through the touch panel at the central control room. At the early operation stage, the RF system was manually controlled at the West Hall.

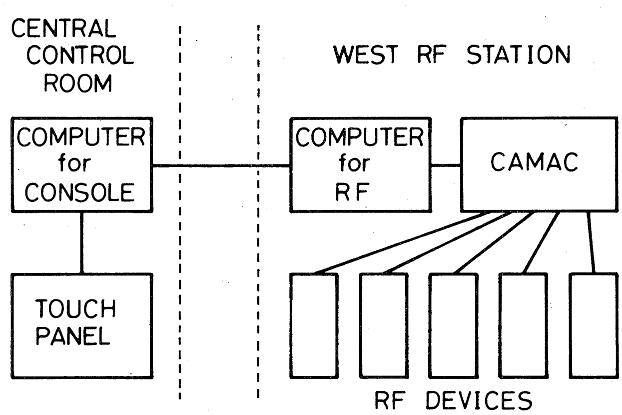


Fig. 2 Block diagram of RF remote control system.

PHASING OF THREE CAVITIES

For effective and stable acceleration, the phases of the three cavities, seen by the beam, must be adjusted to be approximately the same. The phasing error arises from the following three factors; a cavity setting error, a cavity tuning error and a difference of path length from the klystron to each cavity. The cavities have been set in position within the error of ± 1 degree.

Accuracy of cavity tuning depends on the error of the phase detector and on the adjustment of the cable length from the cavity to the phase detector. The error of the phase detector has been measured to be less than ± 1 degree for the input range of - 35 to 10 dBm. The cable lengths have been adjusted in such a way that the phase detector indicates a zero phase when the cavity resonates. Resonance of the cavity was detected with a frequency modulation method, by which the resonance can be detected within the error of ± 0.2 degrees.

After the tuning adjustment was finished, path lengths from the klystron to the three cavities were adjusted in the following way. The phase of each cavity, relative to the phase of the input signal of the cavity No.2, was measured by using a network analyzer. To remove the error due to the use of different cables, only one cable was used, throughout the measurement, to connect the pickup port of each cavity to the port of the network analizer. Then, to compensate the measured phase unbalance among the three cavities, the spacers were inserted in the waveguide circuits. This process, phase measurement and spacer insertion, was repeated until the phases of the three cavities converged to an approximately the same value. Overall phasing accuracy of the three cavities is estimated to be better than ± 2 degrees.

PHASING OF TWO STATIONS

A phasing of the West and East RF stations was tried when the beam test of the superconducting cavity was made at the East hall. The beam was accelerated by three normal cavities and one superconducting cavity. The phase shifter in the West Hall was adjusted in such a way as to obtain a maximum of synchrotron frequency of the stored beam. Synchrotron motion was excited by modulating the amplitude of the RF signal in this frequency. The result of measurement is shown in Fig. 3.

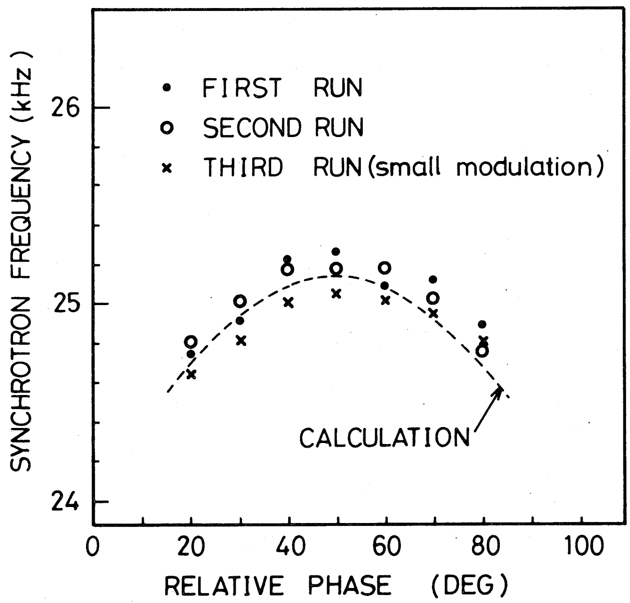


Fig. 3 Measured synchrotron frequency as a function of phase difference between two RF stations.

The calculated synchrotron frequency is also shown in dotted line; a position of the maximum is fitted to that of the measured. A rather small modulation factor is preferred to get reproducible data and good phasing. Another phasing method was tried for comparison. The phase between the two stations was adjusted so that the beam was accelerated to the highest possible energy. The obtained phases by both methods agreed within 10 degrees. The phasing accuracy can be improved by refining the measurement technique.

LONGITUDINAL DIPOLE OSCILLATIONS

Since comissioning of the AR, several types of beam instabilities have been observed in both transverse and longitudinal planes. One of the often observed instabilities is a vertical one appearing at the beam current of around 3.7 mA, which is considered to be a coupled mode type, originated from the impedance of the vacuum chamber components, especially of the bellows.

Another troublesome instability is a longitudinal dipole oscillation. It has been verified that the cavity control system is not responsible for this instability. The cutoff frequencies of both the phase and amplitude loops are chosen to be about 4 kHz, to avoid the coupling with the beam of which synchrotron frequency is over 8 kHz as given in Table 1. To suppress the instability, which is likely to come from parasitic resonances, the cavities have been inductively detuned by 10 to 30 degrees. This cures the instability in relatively low currents, but the damping rate in this method is not large enough to cope with the antidamping rate increasing with current. Obviously, the high Q nature of the DAW cavities works adversely in this case. In usual operation, the ratio of the bandwidth of the cavity fundamental to synchrotron frequency is smaller than 1, while for effective damping this ratio must be in the range of 2 to 7.

In order to damp the dipole oscillations, a feedback system shown in Fig. 4 has been developed. A button electrode picks up a bunch signal, which is fed

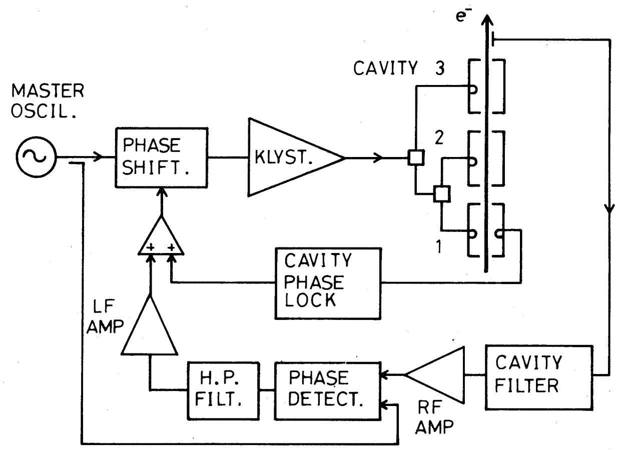
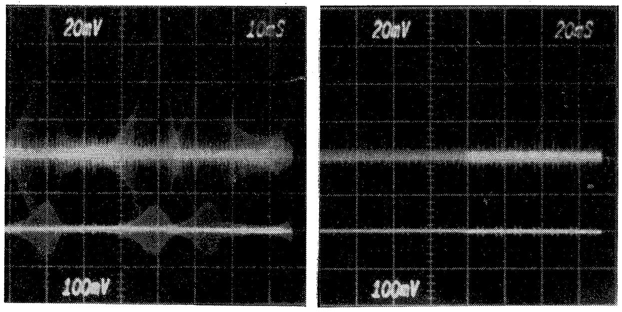


Fig. 4 Block diagram of the feedback system for damping longitudinal dipole oscillations.

to a cavity filter to extract only the harmonic at the RF frequency, the phase of which is compared with the RF reference phase. The phase difference is filtered by a high-pass circuit to extract a f_s component, which is amplified and fed into the phase shifter in the drive signal path. The system works reliably in a certain range of synchrotron frequency, though further improvements are needed before using it in daily operation. Fig. 5 shows an example of dipole oscillations observed at the output of the phase detector; (a) without feedback and (b) with feedback.



(a) without feedback (b) with feedback

Fig. 5 Longitudinal dipole oscillations observed at the output of the phase detector shown in Fig. 4.

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