THE LOW-LEVEL RF SYSTEM FOR TRISTAN MAIN RING

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Abstract

This paper describes the low-level RF system for running the 16 one MW CW klystrons and the 64 nine-cell APS cavities operating at 508.6 MHz in the initial phase of TRISTAN.

Introduction

The TRISTAN Main Ring is an e^--e^+ colliding beam accelerator of 3018 m circumference. Two e^- and two e^+ bunches are injected from the Accumulation Ring at 7 GeV. After intensity accumulation the energy is ramped up to 25 GeV in two minutes. The stored current is about 2 mA/beam with a life time of close to one hour at present.

System and Parameters

One acceleration unit consists of one 1 MW CW klystron, two APS cavity units and associated waveguide circuits. Each APS unit is composed of two 9-cell cavities.[1,2] The sixteen acceleration units have been operating since the commissioning. These units are located in the four RF stations along the ring, two 5-unit stations and two 3-unit stations. Twenty more units are scheduled to be installed by this fall in other stations in order to boost the beam energy up to 28 GeV. A master oscillator located in the central control room generates a reference RF signal, which is distributed to each RF station by the phase stabilized reference lines.[3] At each station low-level components are located in the local control room adjacent to the klystron hall. Most of the components are made in a modular format of the NIM type, convenient for modification and maintenance.

Fig. 1 shows a block diagram of the RF system for one acceleration unit. Each unit can be operated independently by the computer-controlled CAMAC system, either remotely or locally. The RF parameters at the present stage are given in Table 1.

Table 1 RF Parameters at the Present Stage

RF frequency	508.58	MHz
Harmonic number	5120	
Machine circumference	3018	m
Number of bunches	2	/beam
Current per beam	2	mA
Injection energy	7	GeV
Storage energy	25	GeV
Number of klystrons	16	
Power per klystron	800	kW
Number of 9-cell cavities	64	
Total shunt impedance	3565	MΩ
at 25GeV		
Total cavity voltage	210	MV
Synchrotron radiation loss per turn	140	MV
Parasitic mode loss per turn	3.3	MV
Total RF power	13	MW
Fundamental mode cavity dissipation	12.4	MW
Synchrotron radiation loss	0.56	MW
Power loss to parasitic modes	0.02	MW
Synchrotron frequency	7.9	kHz
Synchronous phase angle	47	deg
Natural bunch length	12	mm

Voltage Pattern Generation

The overall cavity voltage Vc is raised in such a pattern that it can compensate the synchrotron radiation loss at any beam energy and can avoid

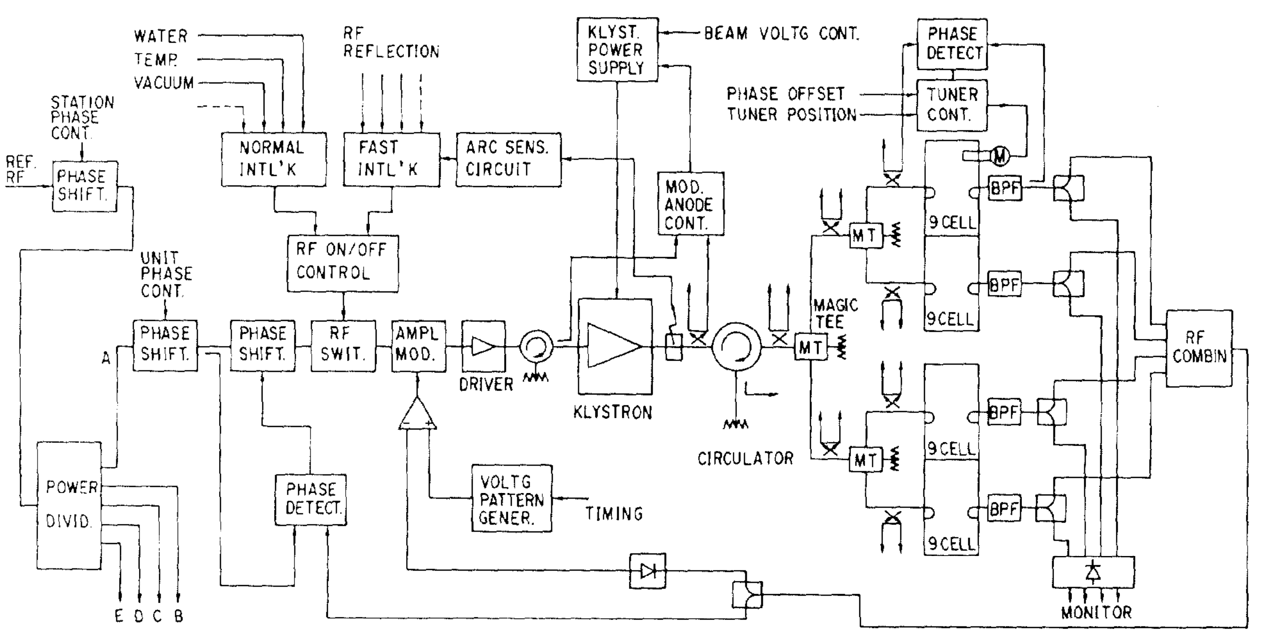

Fig. 1 Block diagram of the RF system for one acceleration unit.

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possible Vc-relevant beam instability. Fig. 2(a) shows the hardware system for Vc pattern generation. A pattern is generated by the computer in the central control room and transferred through the CAMAC serial highway to the memory module at each local RF control room. When the pattern is called, the data are taken out at every 10 ms by the strobe pulse from the timing generator. Then the data are sent to the D/A converter to make the analog pattern. As the same timing signal is used, the Vc pattern is synchronized with the guide field one.

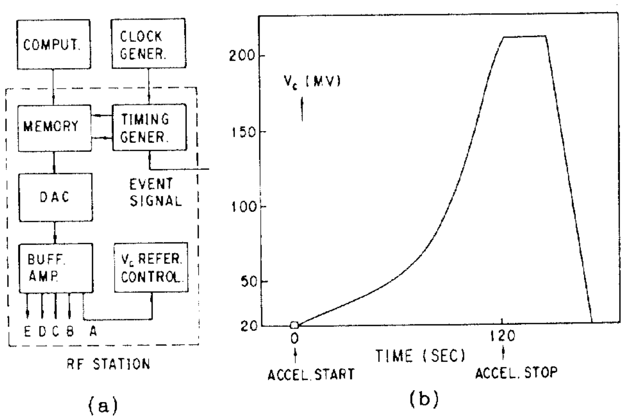

Fig. 2 (a) Hardware system for Vc pattern generation.
(b) Vc pattern used in the present operation.

An operator can easily generate and modify a pattern by touch panel operation in monitoring it on the graphic display. Fig. 2(b) is the Vc pattern used in the present operation. The time scale other than the acceleration period is not scaled. With this pattern the synchrotron frequency increases monotonically from 6 kHz at injection to 7.9 kHz at storage. The precise control of Vc pattern is not necessary at the present beam intensity.

The attainable Vc is going to be about 600 MV at the time when the 20 units of APS and 16 units of superconducting cavities are installed. It means that the Vc varies over a range of 30 dB if the injection voltage is assumed to be 20 MV. This will not be a favourable condition for the RF system. The Vc pattern can be also made by phasing the acceleration units. All units are operated in a constant voltage and are divided into two groups, in each group the units operating in the same phase. The required Vc pattern is then obtained by properly phasing the two groups. In this case, as the cavity works at a nearly constant temperature, the beam instability arising from higher order modes will get less hard to handle. This method, however, gives unbalanced beam loading between two groups. Besides, the overall Robinson damping rate becomes very small at the injection porch, because the one group gives a positive damping rate, while the other a little bit smaller negative damping rate. When the number of cavities is increased, the Vc pattern may be generated partly by common amplitude modulation and partly by phasing.

Amplitude Stabilization

A block diagram of the cavity field control loop is shown in Fig. 1 and the more detailed circuits in Fig. 3. A sample of each cavity field is sent via phase stable coaxial cable to the RF combiner to make the vector sum of the four samples. The linearly detected sum signal is compared to the reference voltage from the Vc pattern generator. The error signal is amplified and then applied to the RF modulator, which controls the RF drive power to the klystron.

The RF amplitude detector uses a schottky diode as a peak detection element. The linearization of the detector is done by putting the same type of diode into the feedback path of the buffer amplifier. To get a better linearity over a wide amplitude range, only pairs of preselected diodes with similar characteristics are allowed to use. A pair of diodes is placed inside the constant-temperature bath to reduce the temperature dependent drift. The detector works within ±1% error over a range of 35 dB from the maximum 20 dBm down to -15 dBm. The error increases to about 5% at -20 dBm. The output drift due to the temperature change of 25°C±10°C is within ±0.2% at 20 dBm and ±2% at -15 dBm.

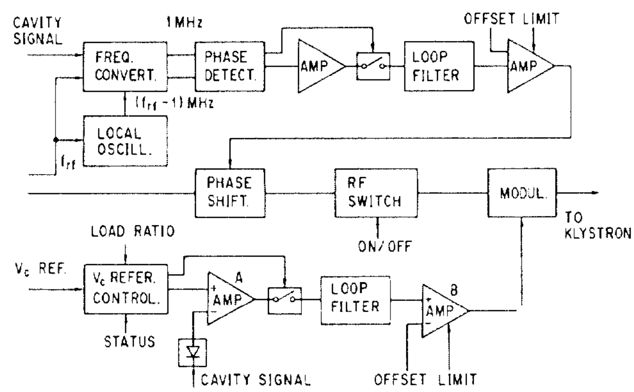

Fig. 3 Cavity field control circuits.

The RF modulator uses PIN diodes as the modulation element and has a modulation range of 50 dB. The PIN diode has in itself a nonlinear response between the RF output voltage and a control voltage. To linearize the overall response, an antilog ratio amplifier is used in the control circuit. Since the modulator is in the phase control loop, it must have a small phase shift. The phase shift is reduced to below 10 deg over the modulation range by properly attaching capacitors to the circuit.

The start sequence of the amplitude loop is as follows. The RF switch is turned on, but the loop is still open. The offset voltage applied to the amp B (Fig. 3) makes the modulator pass a small RF signal to the klystron, which amplifies it to 5 - 10 kW and delivers to the untuned cavities. The tuning system works to bring the cavities to resonance. The tuner controller (Fig. 4) sends the cavity tune status to the Vc reference controller. The reference voltage is then applied to the amp A and the amplitude loop is closed. The offset voltage is still on, but its effect is reduced to 1/(loop gain) and is negligible.

The loop gain of the amplitude loop is between 30 dB and 45 dB depending on the RF level (see the last section) and the open loop unity-gain frequency is between 80 Hz and 300 Hz. The loop reduces the cavity voltage variation within ±1%. However, ripples of 100 Hz and 300 Hz are still seen on the cavity voltage. They will be reduced by gain and bandwidth improvements, though they do not seem harmful to the beam.

Phase Stabilization

The phase feedback loop has been designed to maintain a phase stability of the cavity fields within ±1 deg at any power level. The vector sum of the four cavity samples is used for the phase comparison with the reference signal. The phase comparison is done after the input signals are down converted by mixers to an intermediate frequency of 1 MHz. The local oscillator provides the frequency converter with a frequency exactly 1 MHz below the acceleration frequency. Then the phase detector always works at 1 MHz even if the acceleration frequency is shifted, as is often the case at the machine study. The IF inputs to the phase detector are limited in amplitude and fed into the exclusive OR gate, whose output has the duty factor linearly related to the phase of the two IF inputs. To prevent misoperation the phase detector provides no output if either input level falls below the preset value. The phase detection system works within ±1 deg error for input power levels between 0 dBm and -35 dBm. The frequency converter is responsible for the upper limit of the level, while noises set the lower limit. The dynamic range of the frequency converter is to be improved.

An electronic phase shifter module with ±180 deg phase range is used as a control element in the phase loop. Two modules are cascaded to compensate for a large phase change the klystron exhibits when its beam voltage is varied between 60 kV and 90 kV. The choice of a phase control loop bandwidth depends on the maximum ripple frequency of the klystron phase and on the range of the synchrotron frequency. The 3 dB bandwidth is chosen to be 800 Hz so that the loop can damp the 600 Hz ripple but can be insensitive to the minimum synchrotron frequency of 6 kHz. The loop gain of the phase control loop is 40 dB.

Cavity Tuning Control

The motion of the tuner compensates thermal detuning and reactive beam loading of the cavity. The 9-cell APS cavity has 9 movable tuners, one at each accelerating cell. Their relative positions are fixed after being adjusted to make a uniform field distribution in the cavity. The cavity can be tuned over the range of 1.6 MHz by the common motion of the 9 tuners driven by one stepping motor.

A block diagram of the tuning control system is shown in Fig. 4. All of the control elements including the stepping motor drivers are located at the local control room on the ground. The cavity signal and the forward signal of the directional coupler are sent via phase stable coaxial cables 60 to 90 m long. The band-pass filter with ±10 MHz bandwidth is inserted in the signal path to cut off unwanted beam-induced frequency components. The phase detection system is the same as the one described in the preceding section. The output of the phase detector is converted by the V/F converter to a corresponding frequency. It is then formed into an adequate pulse train, which drives the stepping motor. In this way the tuning speed is proportional to the phase deviation. In present operation 5 deg phase offset is added to the phase detector output to inductively detune the cavity for enhancing Robinson damping.

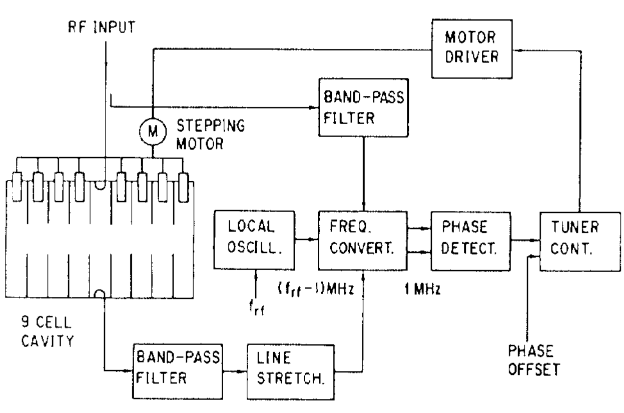

Fig. 4 Block diagram of the tuning control system.

The cavity tuning is varied over 1.6 MHz by tuner motion of 40 mm. Since the tuners are moved 0.4 μm by every pulse, the average frequency resolution is 16 Hz. With the cavity 3 dB bandwidth being taken as 34 kHz, the phase resolution is 0.04 deg around the resonance. The maximum tuning speed is 16 kHz/sec.

Klystron Beam-Current Control

As described above the cavity voltage Vc is controlled by varying the RF input power to the klystron. If the DC input power is kept constant, the collector dissipation becomes very large when a small RF power is needed. To reduce the power consumption and to protect the collector from overheating, we use the system in which the klystron beam-current is controlled by a required RF power. Fig. 5 shows a block diagram of the system. The RF amplitude of the klystron input is linearly detected and fed into the function converter. It generates a suitable function for the modulation-anode voltage to give a beam current just enough for producing a necessary RF power. The alternative input to the function converter is the Vc pattern. It is free from fluctuations caused by feedback action, but does not include beam loading information. At present operation most of the system use the detected signal, and some use the Vc pattern for testing. The system has two limiter functions; one is for keeping the modulation-anode voltage somewhat below the cathode voltage, and the other is for limiting the collector dissipation to a preset value.

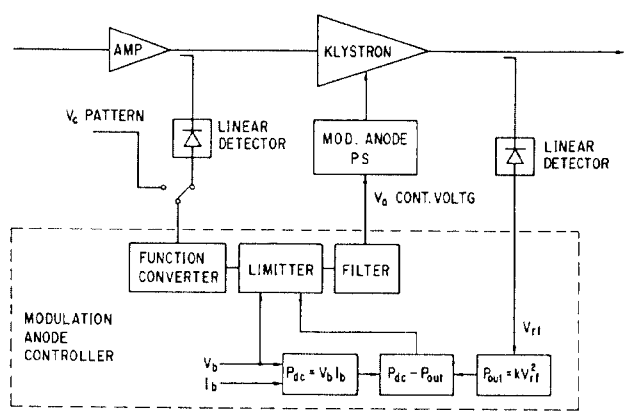

Fig. 5 Block diagram of the klystron beam-current control system.

Though this system is essentially an open loop one, it acts as a perturbation source to the Vc feedback loop. The response speed of the system, therefore, must be much slower than that of the Vc loop. This requirement is automatically met because we use an inherently slow speed Cockcroft-Walton generator as the modulation-anode power supply. The response speed of the system is about 0.3 sec. Another effect of the system on the Vc feedback loop is to make the loop gain depend on the RF power level. The RF power level determines the klystron beam current, which determines the klystron gain and consequently the loop gain of the Vc feedback loop. The loop gain varies by about 15 dB over the RF power range between 5 kW and 800 kW.

References

[1] K. Akai, et al., Proc. of the 13th International conference on high energy accelerators, Novosibirsk, 1986.
[2] T. Higo, presented at this conference.
[3] H. Hayano, presented at this conference.