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CONTROL OF THE RF VOLTAGE FOR TRISTAN MR

K. Akai, T. Takashima, E. Ezura, K. Ebihara, H. Hayano and M. Suetake

National Laboratory for High Energy Physics
Oho-machi, Tsukuba-gun, Ibaraki-ken, 305, Japan

ABSTRACT

The control system of the RF accelarating voltage in TRISTAN Main Ring is developed. It consists of the voltage pattern management system and the feedback control system.

INTRODUCTION

In the present operation of TRISTAN Main Ring, the RF system consists of twenty 1 MW CW klystrons, each of which feeding four 9-cell APS structures[1]. The total cavity voltage Vc is 20 MV at the beam injection and is raised up to 250 MV to accelerate the beam to 26 GeV. The low level RF control systems are located in the local control rooms close to the klystron halls along the ring[2].

VOLTAGE PATTERN MANAGEMENT SYSTEM

The total cavity voltage Vc is expected to be provided in such a way that not only it can compensate the synchrotron radiation of the beam but also it can avoid possible Vc-relevant beam instability. From this point of view, the accelerating Vc pattern must be such that it does not cause a large change in the synchrotron frequency of the beam. When the machine is in RF aging operation, another Vc pattern is desirable such that the aging can be performed efficiently at any power level from a few kW to nearly 1 MW. So it is desirable that the Vc pattern can be easily generated and changed.

In usual operation, not all the klystron units are in the same conditions. It is necessary that the total cavity voltage Vc is distributed to each klystron unit according to its ability.

The RF control system of the accelerating voltage in TRISTAN main ring is developed to satisfy these requirements. The block diagram of the system is shown in Fig.1. It is composed of software program complex in the central control room (CCR) and hardware system in the local RF control rooms.

The accelerating voltage pattern can be easily generated using the pattern generation software by touch panel operation in monitoring it on the graphic display. An operator can draw appropriate pattern curve with the help of spline interpolation. If desired, the pattern can be made such that the synchrotron frequency is kept constant during the acceleration. Fig.2 shows the voltage pattern for the last machine operation.

The pattern generation software also has a function to distribute the total Vc to each klystron unit. Since all cavities are adjusted in phase each other, the Vc is distributed as scalar sum of the voltage for each klystron unit. The control voltage for k-th klystron unit corresponding to the distributed RF voltage, Vcont(k), is determined by two types of parameters. One is pattern data to be loaded to the CAMAC memory module, Vpat, which is set to be 0(V) at the beam injection and 10(V) at the flat top energy. The other consists of two parameters, Vbias and Vgain, which give the RF voltage at injection and flat top energy. The relation between these parameters is

$$\mathrm{Vcont}(k) = \mathrm{Vbias}(k) + \mathrm{Vgain}(k) \times \mathrm{Vpat}/10$$

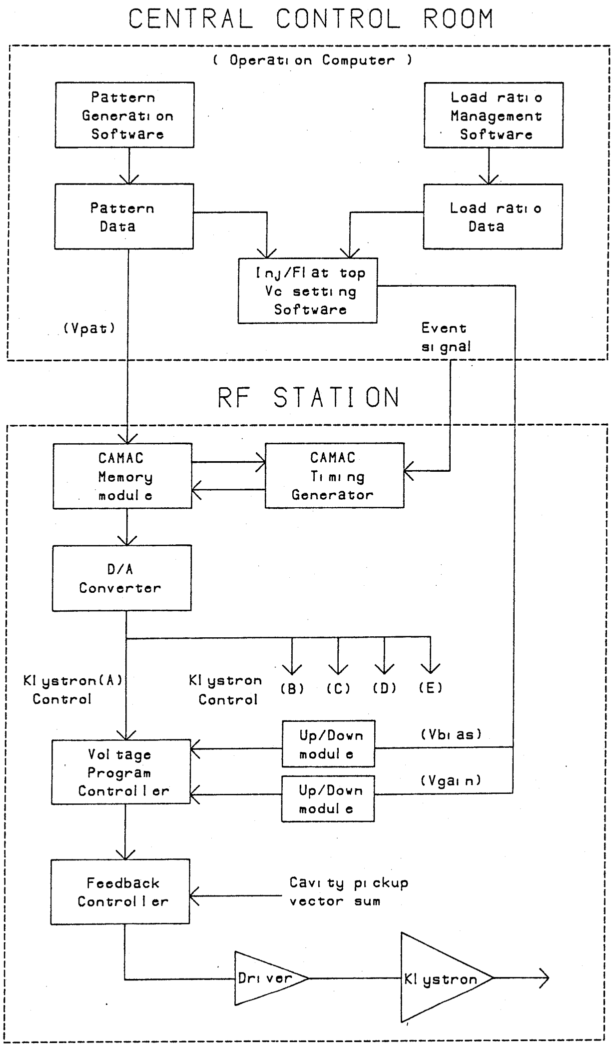

Fig.1 The RF control system for management of the accelerating voltage pattern

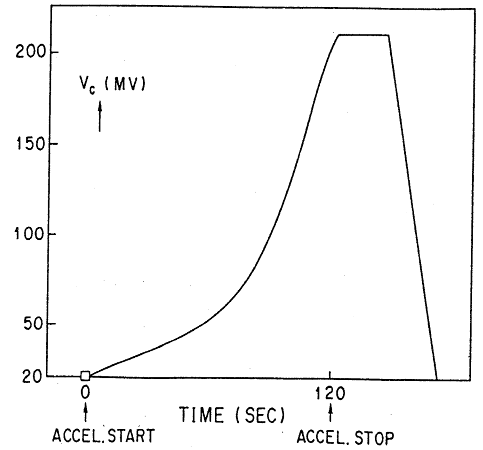

Fig. 2 The total Vc pattern for the last machine operation made by the pattern generation software

Information of conditions of klystrons is stored as load ratio data. According to the conditions of each klystron unit, the operator can set the load ratio data of each klystron by the load ratio setting software. Vbias(k) and Vgain(k) are determined proportional to the load ratio of each klystron, and as a result the Vcont(k) is proportional to the load ratio.

The voltage pattern Vpat is transformed to the memory module in each local RF control room through the CAMAC serial highway. When the pattern is started by the triggered pulse from the event signal, the memory module put out the data to D/A converter. The Vbias and Vgain are send to up/down modules for each klystron control unit, which transform the data into analog voltage data to the voltage program controller.

VOLTAGE-PHASE PATTERN SYSTEM

In the present operation the total Vc is controlled only by changing the klystron output power, while the phase between the cavities is kept in phase. When the additional 24 APS cavities and the 16 superconducting cavities are installed, the attainable Vc is going to be about 600 MV. Assuming that the injection Vc is not changed drastically, the klystron output power might be changed about 30 dB. Such a wide dynamic range of the klystron power may cause unfavorable conditions; cavity temperature changes with the klystron power, which makes higher mode handling difficult, and the klystron collector is in sevear condition.

One possible solution is to control the phase between cavities as well as the klystron power. The voltage-phase pattern operation system is developed. All cavities are devided into two groups. The phase between two groups is set out of phase at the injection and is made gradually in phase when the beam is accelerated. This method allows us not to reduce the klystron output to a very low power level at the injection, which means the dynamic range of the power is decreased.

It must be reminded, however, too much phase angle at the injection might bring about beam instability because the one group gives negative Robinson damping rate and the total damping rate becomes very small. We have tested whether this method cause any serious influence on the beam. The relation between the relative phase (A) of the two groups and the total Vc is

$$\cos(A)=\{(V_C/V)^2-N_1{}^2-N_2{}^2\}/2N_1N_2 \qquad (2)$$

where, N_1 is number of klystrons in group 1,
N_2 is number of klystrons in group 2,
V_C is the total RF voltage (vector sum) and
V is the voltage of one klystron.

The experiment was carried out at injection energy. Both N_1 and N_2 are 8. In order to examine the effect of the phasing on the beam, the total voltage Vc (vector sum) is kept at 20 MV during the test. V and A are changed in such a way that they satisfy Eq.(2). The beam current just after three times of injection from the accumulator ring (AR) is observed. The sysnchrotron frequency (f_s) is measured to confirm that the Vc is unchanged. The result is

V (MV)	A (deg)	f_s (kHz)	beam current (mA)
1.39	0	6.2	1.28 (3 inj.)
4.17	150	6.2	0.97 (3 inj.)
6.94	160	6.2	1.05 (3 inj.).

It seems that when the two group is out of phase the accumulated current is a little bit smaller than that of in phase. However, since the machine study had not been done enough at the time of the experiment, this smaller accumulated current can not be attributed only to the phasing. The result is rather considered to show the possibility of the phase-voltage pattern operation. The whole system will be tested in the next machine cycle.

CAVITY VOLTAGE CONTROL SYSTEM

One acceleration unit consists of one klystron and four 9-cell cavities. Fig. 3 shows a block diagram of the cavity voltage control system. All the components except for high power equipments are located in the local control room and are implemented in a modular format of the NIM type. Among the control components, the following three modules are playing important roles in the system; a voltage program controller (VPC), a feedback controller (FC) and an RF amplitude modulator (RAM).

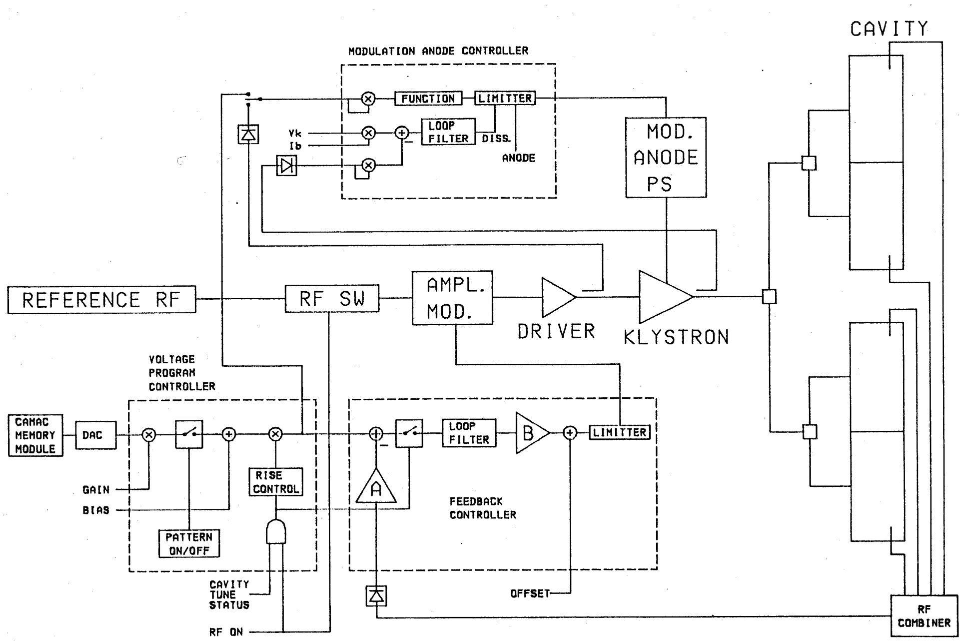

Fig. 3 Block diagram of the cavity voltage control system

The main roles of the VPC are to switch on and off a pattern voltage, to make a reference by adding a bias voltage to the pattern voltage, to control a rise and a fall time of the reference voltage, and to control the RF ON/OFF sequence. The reference voltage, or the output voltage of the VPC is given by Eq.(1). This configuration enables us to change the voltages at the injection and at the flat top without disturbing each other. For example, when the injection voltage, or Vbias is changed, the Vgain is also changed in the software so as to keep the flat top voltage unchanged. The pattern voltage is sometimes switched off and only the bias voltage is used when the cavities are conditioned and when the klystrons are adjusted.

The FBC consists of, as shown in Fig.3, the amp A, the adder A, the analog switch, the loop filter, the amp B, the adder B and the limiter. The vector sum of the four cavity-pickup signals is linearly detected and fed into the amp A. The gain of the amp A is so adjusted that we can easily get the acceleration voltage/klystron by multiplying the output voltage of the amp A by $2x10^6$. We chose this multiplying factor because the maximum accelerating voltage/klystron is about 14 MV and the amp A works within +10 V. The limiter works not to supply an excessive drive power to the klystron when the gain of the klystron is much reduced by improper anode voltage control. The output of the FBC is fed into the RAM to control the amplitude of the RF signal. The RAM uses PIN diode as the modulation element and has a modulation range of 50 dB. The antilog amplifier is used in the control circuit of the RAM to linearize the overall response between the RF output voltage and the control voltage.

KLYSTRON ANODE CONTROL

The RF power from the klystron varies from about 5 kW at injection to about 800 kW at storage. The cathode of the klystron is kept at a constant voltage somewhere between 80 kV and 90 kV. Then, if the beam current of the klystron is also kept constant, the collector dissipation becomes very large at the injection period where the RF power is only about 5 kW. To protect the collector from overheating and to save the power consumption, the beam must be controlled in a suitable way.

The modulation anode controller (MAC) shown in Fig.3 is used for this purpose. The amplitude of the RF drive power is linearly detected and fed into the MAC, which makes by a function generator an appropriate control voltage for the power supply. The alternative input to the MAC is the output of the VPC. It is free from fluctuations caused by feedback action, but it does not include a beam loading effect which is included in the detected signal. The VPC output is therefore favourably used in relatively low beam-intensity operation.

The function generator produces the input-output relation like the one shown in Fig.4. For a small drive power the modulation-anode voltage is kept low to reduce the collector dissipation. It increases linealy after the drive power exceeds about 50 % of its maximum. The RF output power at the turn-up point is around 10 % of the maximum. Input-output characteristics of klystrons differ from klystron to klystron. Each klystron therefore has its own anode voltage function which is obtained by the adjustment of the DC levels, the turn-up point and the slope as shown in Fig.4.

The MAC has two limiter functions to protect klystrons; one is for keeping the modulation-anode voltage somewhat below the collector voltage, and the other is for limiting the collector dissipation to a preset value. The limiter for collector dissipation works as follows. An analog operational amplifier receaves a cathode voltage Vk, a beam current Ib and a linearly detected RF output Vrf, and perform the operation $Pcol=Vb*Ib-kVrf^2$ where Pcol is the collector dissipation. When a Pcol exceeds a preset value, the anode voltage is lowered till the Pcol decreases to the preset value.

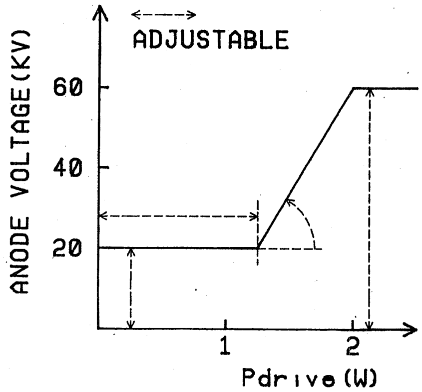

Fig. 4 Anode voltage versus drive power

RF ON/OFF SEQUENCE AND FEEDBACK PROPERTIES

A start sequence of the cavity voltage control loops is shown in Fig.5. The detailed start procedere is described elsewhere[2]. The output power of the klystron after RF switch on but feedback loop off is controlled to be several kW by the offset voltage of the FBC (Fig.3). On receiving the cavity-tuned signal, the VPC turn on the feedback loop and makes the reference voltage rise from 0 to a set value at a rise time of 3 sec or 10 sec. This ramp of the reference voltage is necessary, because the cavity tuner takes a little time to compensate the resonant frequency change caused by the increase of the input power. At the end of operation, the output of the VPC is decreased to 0 and then the RF switch is turned off. This procedure prevents the cavity from emitting a large power at RF switch off.

The loop filter in the FBC is used to adjust the loop properties. A time constant of the filter is variable between 5 ms and 50 ms, corresponding to the cutoff frequency of 30 to 3 Hz. The filter time constant and the amp B gain have been adjusted to make the feedback loop stable. At the present operation, the filter time constant is 50 ms, the amp B gain is 100 and the closed loop cutoff frequency is about 100 Hz. The loop gain varies with the RF power, since the gain of the klystron depends on the beam current. The loop gain is about 30 dB at the RF power of 5 kW and increases with the power level to about 45 dB at 800 kW.

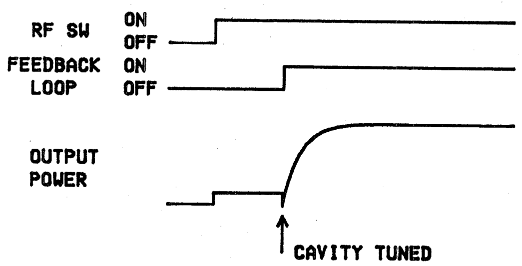

Fig. 5 Start sequence of the voltage control system

ACKNOWLEDGEMENTS

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