OPERATION OF HIGH POWER RF SOURCE IN THE TRISTAN MR

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Abstract

High power CW klystrons in the TRISTAN MR have been operated since Nov. 1986. Problems which appeared after ~2000 hours klystron operation are described, including troubles with klystron power supplies. For operation with high power generation, the RF system still shows not so small a fault rate. The operation method of the klystron is also briefly discussed.

Introduction

The TRISAN Main Colliding Ring (MR) designed to attain higher beam energy, requires high power RF sources to compensate the synchrotron radiation loss of the beams. At the latest physics run, from May to July of 1987, ~15 MW RF power in total has been generated by twenty 1 MW klystrons in CW mode for driving 80 nine

cell cavities to storage e^+e^- colliding beams at 26 GeV. The data taking at the 25 GeV and 26 GeV beam energy has been successfully achieved at the above period, though several troubles of this system still happened and interrupted the data taking. A description of the actual operation of this RF system with short explanation about the klystron operation is given with emphasis on the troubles which we have encountered and on the measures to meet the troubles.

Operation of the klystron

Synchronized with the machine operation phases such as injection, acceleration and flat top phases, the cavity voltage (Vc) is controlled to follow a pattern

voltage[1] (Vpatt) which is generated not only to compensate the radiation loss but also to avoid cavity voltage relevant instabilities of the coasting beams, in accordance with the phase stabilization of the cavity field. The former Vc stabilization is essentially done by the feedback loop which is acting on the klystron RF drive power. In the actual machine operation, output power of each klystron is ranging from 10 kW to 800 kW at most corresponding to injection and flat top phases, respectively. In order to avoid too much power dissipation at the collector (Pcl) and to reduce the power consumption, the beam current of the klystron is also controlled as a function of the outpt power of the klystron. Figure-1 shows the block diagram of the

klystron power supply[2] (KPS). The modulation anode power supply equips the Cockcroft-Walton (C-W) generator with its response time of ~0.3 sec. A loop of beam current control system (see next section) is a small perturbation to the above stated Vc stabilization loop because both loops affect the output power but the beam current control has a slow response time determined by the anode power supply. The klystrons employed in the TRISTAN are supplied from Valvo works, Hamburg, Philips GmbH, (YK1303) and from Toshiba (E3786). The phase shifts of the output RF due to the change of the modulation anode voltage (Va) are ~2.6°/kV and ~1.9°/kV for YK1303 and E3786[3], respectively as shown in Fig. 2, while the same quantities due to the cathode voltage are ~11°/kV and ~15°/kV, respectively. Because of the big phase shift in the latter case and because of the slow response time of the cathode voltage (Vk) control, the d-c power which is supplied to the klystron (
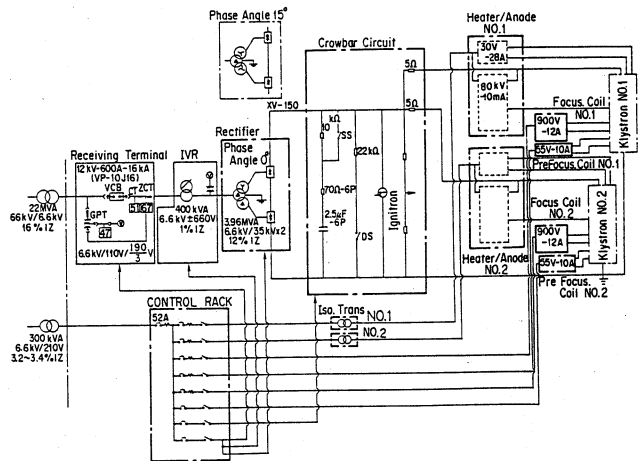

Fig. 1 Block diagram of Klystron Power Supply.
(A-type KPS for two Klystrons)

VkxIb), is controlled by Va (Ib ∝Va$^{3/2}$) to reduce the dissipation power Pcl, instead of controlling Vk. The Vk is kept to a preset value within ±1 % stability by controlling primary a-c voltage with IVR. It takes ~1 min to change the primary 6.6 kV a-c line from -10 % to +10 % which is fed to the rectifier.

The practical maximum output power of the klystron is limited to ~90 % of the maximum saturation output power in this control system because the Vc stabilization loop does not work at near and over the saturation point of the drive power. The efficiencies of the klystrons are 55 % on the average which is also lower than the optimized value (>60 %) measured at the saturation. Almost 600 kW is dissipated at the collector for 750 kW RF output for each klystron.

The KPS also equips the crowbar switch to protect the klystron by suppressing the energy flow into the tube when arcing is happened inside the tube.
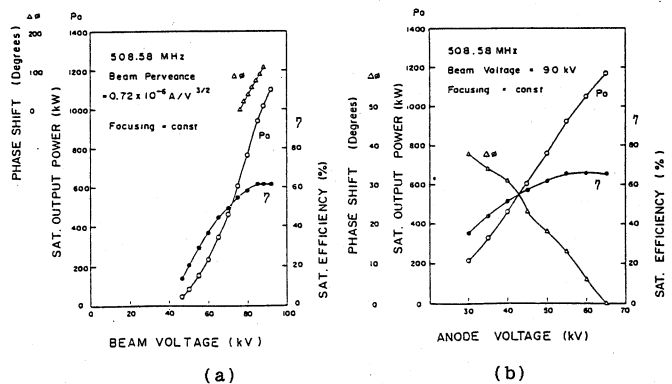

Fig. 2 (a) Beam Vol. (Cathode Vol.) dependence.
(b) Mod. Anode Vol. dependence.
(E3786 Klystron)

Klystron beam current control

The linearly detected drive power amplitude is fed into the function generator. The anode voltage (Va) controlled by this functioned signal, produces a proper beam current as shown in Fig. 3. In an alternative way,

Vc-pattern[1] signl is fed into the function generator. Generally, the former scheme (Vdrv control) is preferable for operation because the beam loading effect of

the coasting e^+e^- beams is already included via Vc-stabilization loop in the klystron beam control. The latter Vc-pattern control scheme is employed for some Valvo klystrons because the less perturbation is better for stable operation, though the power consumption is traded off; for even small beam loading, the klystron beam current is set to a value which is optimized for maximum beam loading. These Valvo tubes show rather unstable anode current spikes at higher output. Therefore the adjustment of several parameters such as beam current, focus coil current etc., are needed for stable operation. Typical operation of both schemes are shown in Fig. 4.

The functioned signal is generated as follows. For smaller input signals compared to a preset voltage, constant bias signal is generated. Above this voltage, the functioned signal is increasing linearly or quadraticly to the input signal by the preset increasing rate. This generator has also two limiter functions. One is for limiting the Va to a value somewhat below the Vk; typically $Va \leq 0.7 \times Vk$, and the other is for limitting of the collector dissipation; typically $Pcl \leq 800$ kW. A typical klystron operation curve is shown in Fig. 5. Owing to the slow response time of the anode power supply, the dissipation power could be quite larger than the max rated dissipation power for ~100 msec duration, when the drive power is interrupted by interlocks at high output power levels. In some Valvo tubes which are installed in the early stage, the KPS supplied high voltage (HV) is also occasionally interrupted by collector temperature interlock (>140°) under the above stated situation. We have just tried to search more stable operation parameters for reducing the HV trip rate at such troubles.
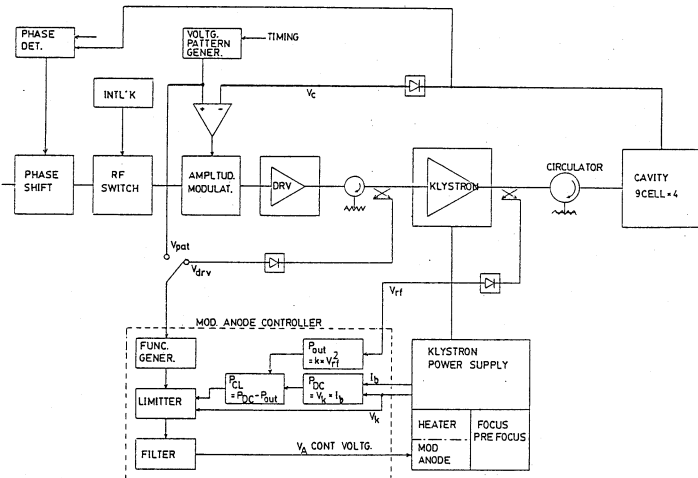
Fig. 3 Block diagram of Beam Current Control.

Operation of high power RF system

Fault rates of the klystron operation (HV trip rate) in the above stated period are summarized as

    0.14/day/klystron   for 25 GeV
    0.42/day/klystron   for 26 GeV.

Following comments are in order. In one particular klystron power supply to which two tubes are connected, the troubles of crowbar work are happened so frequently. A large portion of the trip rate is due to
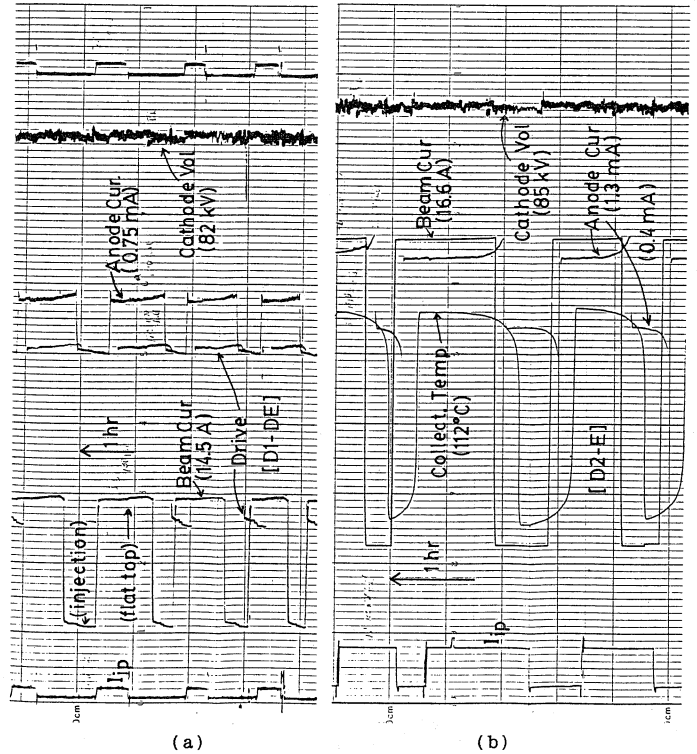
Fig. 4 Typical Operation of Klystron.
   (a) Vdrv control : E3786.
   (b) Vpatt control : YK1303.
Beam current is changing as a function of beam loading for (a), while beam current is almost constant for (b) at injection or flat top phases.

this KPS ; 67 % and 62 % of the trip rate are observed for 25 GeV and 26 GeV, respectively.

Twenty klystrons are used with mean input powers of 550 kW and 750 kW to four 9 cell cavities, at each runs. Almost half of the trip rate except the above stated KPS is due to crowbar work no matter how it is triggered; true crowbar work or mis- triggering by the noise. The remainings are due to anode over current (o. c.), and collector temperature interlock of some Valvo tube. In the followings, rather common troubles among the KPS's and klstrons are described.

(1) Crowbar work. At crowbar work, large short circuited currents flow in a-c 6.6 kV line and in d-c high voltage side. Voltage drop of 6.6 kV line for 20 msec duration (a vacuum circuit breaker switches off the line within one cycle of 50 Hz) affects other operating klystrons at such points as the output power drop besides the phase shift of the RF output, because the cathode voltage also drop for that duration.

Effects of crowbar work on the transformer of the KPS is another severe problem, because the large current produces an excess stress at the coils. Except the one above stated KPS, the crowbar work rates per HV-on-time of the KPS are ranging from 1/34 to 1/292 per hour, with a mean rate of 1/90 per hour for almost 1400 hours of klystron operation. It seems that the crowbar work of the above KPS (with fault rate of ~1/9.6 per hour) is due to mis- triggering noises, because we have neither observed a large d-c current nor gas burst at the klystrons.

(2) Anode O. C. As already stated, some Valvo klystrons show unstable andode current spikes at higher output power, as shown in Fig. 6. The difficulties to find out the operation parameters for stable operation at the higher output power in accordance with the stable operation at no drive power, are major reason to limit the max output power in the actual tube operation. It is now tried to dull the monitor signal which is used for interlocks because the fluctuation of anode voltage are small enough in our C-W generator

even at the occurrence of that current spikes.

Some Tohiba tubes show another type anode o. c. at the transient period just after HV is switched on, where the anode voltage is almost equal to cathode voltage because the electrodes are short circuited by condensors of the C-W generator. When we resume operation of a klystron which is interrupted by the interlocks, several times successions of switch on/reset are required until HV on is succeeded. Once HV can be applied, the tube shows stable operation for wide range of output power.

For both types of tube, spot knocking (s. k.) (applying HV between electrodes) is tried to diminish the anode o. c. However almost no improvement is observed at Valvo tubes, and only short term improvement at Toshiba tubes; the tubes forget the s. k. effect after some tube operation.

(3) Disease found in the latest run. After ~2000 hours tube operation, several Valvo tubes show relatively long term (~1 hour) anode current instabilities. A monotonous increase of the anode current is one symptom and the decrease of it even to a large negative value is another symptom. Both symptoms are enhanced at higher output powers.

In the negative going symptom, the negative anode current generates the voltage across a 16 MΩ resistor which has been installed for improving the response time of the anode p. s. If this voltage becomes larger than the voltage generated by the anode p. s., beam current can not be controlled by the anode p. s. The uncontrolled anode voltage generates more beam current, and the increasing beam current generates more negative anode current; positive feedback loop are formed. An over beam current (>20 A) interrupts the operation. A negative anode current alone never trips the HV.

For both symptoms, heater powers are reduced to a value where no such symptoms are observed for at least 1 physics run period (~1 hour); a rated current of 23 A is reduced to around 21 A. In one of the positive going symptom tubes, the decreasing of the gun perveance was continued for more than a week when the heater power is reduced. Furthermore, if HV is interrupted for >30 min, the gun perveance of this tube is re-

AC-Couple
200 msec/div
0.1 mA/div
←0
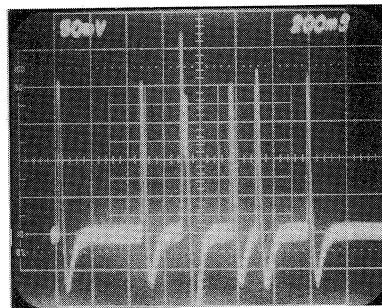
Fig. 6 Anode current spikes.
(d-c anode current = 1. 2 mA).

covered again to the almost normal one without doing anything (just cooling down). In the actual operation, the decreasing of the gun perveance is daily compensated by increasing of the anode voltage to maintain the beam current. When we resume the operation after some interruptions, a special care are necessary to reduce anode voltage, otherwise the stable operation can not be achieved due to the severe anode current spikes causing by too much beam current.

The reducing of the heater power does not simply mean the reducing of the gun perveance. The perveance is not so much reduced as expected from the reduced heater power. Heating induced by the beam current may happen inside the tube.

Impossibility to operate the tube at high beam current is another reason to limit the available max output power. At least ~650 kW output power is kept in the above period. The s. k. alone is not adequate to cure these symptoms. A cooling around the socket is another possibility to cure the disease. Forced cooling of the insulation oil is now planned to test.

Conclusion

Stable and reliable RF sources are required for such a big project. During the summer shut down period (1987), the normal conductiong cavities fill up the straight sections of the MR. Twenty six klystrons will be installed for driving 104 nine cell cavities in total. If the trouble of one specific KPS will be fixed, the expected fault rate may be ~4 /day in the next machine time. For reducing these fault rates, further efforts are needed.

Acknowledgement

We wish to thank all the other members of the TRISTAN project, and those of the industries. Without their efforts, this system was never constructed.

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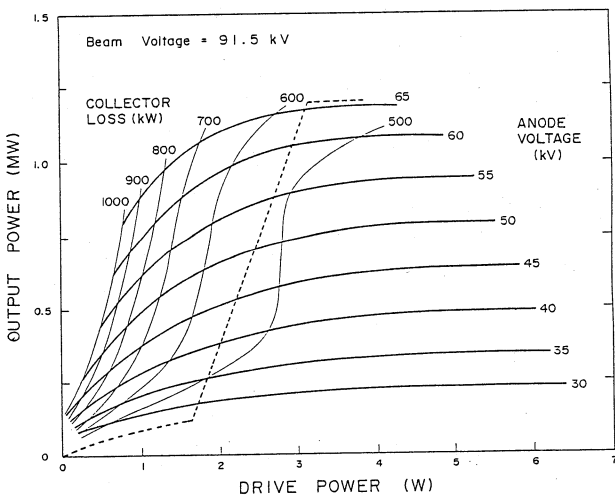
Fig. 5 Characteristics of Klystron Operation.
Solid curve show constant collector dissipation.
Dotted curve show typical operation points.
(E3786).