Characteristics and Anode Current Stabilization of TRISTAN 1.2MW CW Klystrons

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Abstract

Some of 1.2MW klystrons (E3786) delivered for TRISTAN have good characteristics. They work as high efficiency tubes under all operational condition and show saturation at the same drive power. We obtain these characteristics by tuning the 1st cavity and 2nd cavity precisely.

Meanwhile, some of klystrons had a problem of fast self-recovery breakdown between anode electrode and body with negative spikes in the anode current. We tried to suppress the phenomenon. However we didn't obtain good results by most of the countermeasures. As a new approach we are trying to solve the problem by coating chromium oxide on anode electrode, introducing M-type cathode and enlarging anode ceramic.

I. INTRODUCTION

1.2MW CW klystrons (E3786) delivered by Toshiba Corp. work with high efficiency (65-67%) and high gain (53-58dB). Center frequency and band width of the klystrons are 508.58MHz and 0.7MHz respectively. Reliance of this klystrons is very good except anode current instability on some of the klystrons. Then E3786 klystrons are very useful to control RF power.

One-fifths of klystrons delivered for TRISTAN have characteristics of lesser collector dissipation on all operation. The saturation points of output power for every anode voltage at the same cathode voltage are nearly the same drive power as shown in Fig. 1 (Type 1). On the other hand, the other klystrons show more collector dissipation on the way of increasing the anode voltage as shown in Fig. 2 (Type 2). The saturation points shift to the lower drive power as the anode voltage is increased.

We investigated the difference of two type of klystrons. Then we like to make good use of the results on new klystrons. We summarize it in the next section.

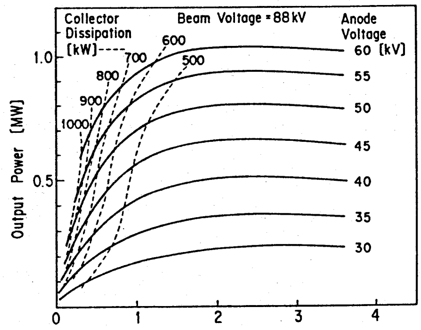


Fig. 1 Characteristic of less Collector Dissipation (Type 1)

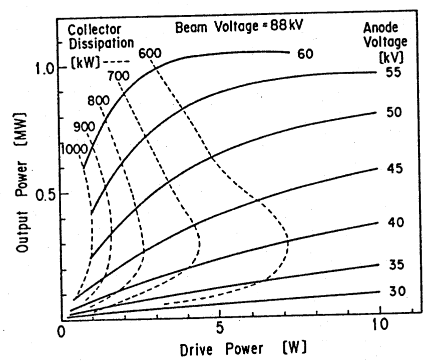
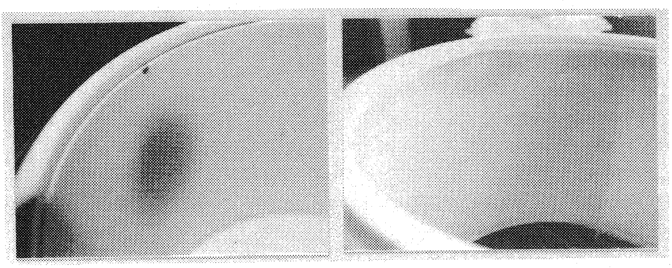


Fig. 2 Characteristic of more Collector Dissipation (Type 2)

Meanwhile, another some klystrons did not work well because of amplitude modulation (AM). This phenomenon is caused by momentary electrical breakdown between the anode electrode that is at negative high voltage and the body at earth level. At the moment of breakdown, the anode potential gets near to the body one. Then the beam current in the klystron increases and the output power increases. And the anode current decreases for a moment at the same time. Therefore, we call this phenomenon "negative anode spike". We observed contamination on inner wall of the insulation ceramic between anode and body when klystrons were opened as shown in Fig. 3. We observed discharge marks on the outside of the anode and on the inner corona ring sometimes.



(a) (b)

Fig. 3 Contamination of the Anode Ceramics

Fig. 4 shows the relation between discharge marks and contamination on the ceramic. We suspected such contamination was caused by sputtering at the moment of breakdown or glow discharging in vacuum then negative anode spike was due to electrical breakdown along the contaminated ceramic [1]. Then we took four countermeasures to suppress negative anode spike. One is reinforcing the inner corona ring on the body to relax the local electric field at the brazed point of the ceramic. A second is making grooves inside the ceramic to enlarge the breakdown path and ensure the non contaminated zones on the ceramic surface. The third is nickel coating on body side of the anode to suppress the discharge between anode and body and to suppress sputtering onto the ceramic by making use of small sputtering yield of nickel [2]. The fourth is the use of metal coated cathode (M-type) to reduce the temperature of the anode and to suppress the deposit of barium onto the anode in order to suppress the field emission from anode to body. In result we expect M-type cathode suppresses the breakdown between anode and body. However we realized after long observation time these countermeasures except M-type cathode did not work as expected.

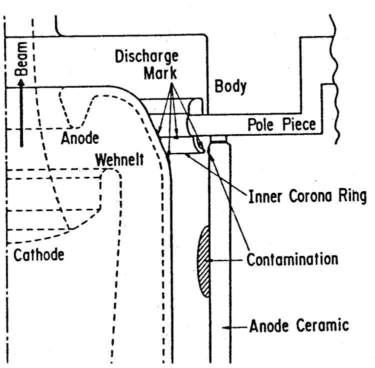


Fig. 4 Schematic Drawing of Relation of Discharge Marks and Contamination

Now we are trying to take two countermeasures. One is chromium oxide coating on the anode as the same reason as nickel coating. The other is enlarging the diameter of anode ceramic to suppress the breakdown between anode and body. We describe these countermeasures and M-type cathode in section III.

II. CHARACTERISTICS OF E3786

Klystrons in Fig. 1 and Fig. 2 have special frequency characteristics respectively. Difference of the two is the gain vs. frequency. Tuning of the resonant frequencies of 1st and 2nd cavity affects the gain vs. frequency. Therefore we measured resonant frequencies of the cavities by the white noise method [3] as follows. We terminated the input cavity with 50 Ω and picked up the output signal from a wave guide (WR1500) to N type connector transition. Then we applied High Voltage to the klystron in a condition that beam voltage is 47kV and beam current is around 0.3A. Then we measured output signal of the N type connector by spectrum analyzer. We used the averaging function of the spectrum analyzer because of that the signal was too small to be measured.

Table 1

Resonant Frequencies of 1st and 2nd Cavities of E3786

		Resonant Frequency [MHz]	
	S/N	1st cavity	2nd cavity
Type 1	T32A	508	508.6
(Fig. 1)	T33A	507	508.5
	T51	507	508.8
Type 2	T45	508	509.0
(Fig. 2)	T28	507	509.0
	T26	507	509.3
Design Value		507	509.5

Table 1 summarizes the result. We measured other cavities (3rd, 4th and 5th) except output one. There were little differences of resonant frequencies, but they didn't affect the characteristics. There are no characteristic differences between type 1 and type 2 for 1st cavity, but for 2nd cavity. Resonant frequencies of 2nd cavities of type 1 and type 2 are near 508.6MHz and 509MHz respectively. We simulated characteristics of the klystron with measured frequencies by klystron simulation code FCI [4]. Results are very similar to Fig. 1, Fig. 2 and the frequency characteristics.

Design value of 2nd cavity is 509.5MHz because of extending the band width. But band width of type 1 is sufficient for TRISTAN. The gain of type 1 is higher than type 2, but we didn't observe self-oscillation in type 1. Although klystrons of type 1 are very useful for us as they save energy and are easy to be controlled, it is too difficult to tune the 2nd cavity accurately in the present production.

III. STABILIZATION OF ANODE CURRENT

A. Chromium Oxide Coating on Anode Electrode

We coated chromium oxide on the outside of anode by sputtering. The target is chromium(Cr). We intended to coat the anode with Cr_2O_3, but Cr was coated on it first by the trouble of sputtering. Then the anode was coated with chromium oxide after that. The chromium oxide we used is not strictly Cr_2O_3 but CrO_x. Thickness of Cr + CrO_x layer is 200-500Å. After a gold brazing process of the anode, we coated chromium oxide that was different from Ni coating [1]. Then we assembled the anode into klystron after a silver brazing process and heated it to a temperature of 550 °C in vacuum. Therefore change of CrO_x coating is less than Ni coating.

Chromium oxide coating on the copper electrode showed no deterioration and no bad effects on the insulation between electrodes or vacuum in the tube. Chromium oxide has higher melting point than pure copper and Ni. We expect that the coating suppresses to sputter copper onto the ceramic. However, it is not clear whether we can suppress the negative anode spikes completely. We will continue further investigations on the behavior of this modified version (S/N T32B) of the klystron. Then we intend to test another chromium oxide coating by vacuum evaporation in the next modified tube (S/N T29A). We coated the anode with Cr_2O_3 after silver brazing process, which was different from T32B.

B. M-type Cathode

We used iridium coated M-type dispenser cathodes were made by Toshiba Corp. for four modified klystrons. Working temperature of M-type cathode is lower than that of S-type as shown in Fig. 5. Then the less evaporation of barium (Ba) is expected in iridium coated M-type. That is why the life of M-type cathode is said to be long [5]. Barium on electrodes is bad for insulation of klystron electrodes. Lower temperature and less evaporation of Ba are very good for insulation of them. Therefore we expected that M-type cathode can help suppressing the breakdown between anode and body. However we had to age the klystrons for above 1000 hours with rather higher heater power to get regular characteristics as shown in Fig. 5. In aging period, the M-type cathode behaves as the S-type, and evaporation of Ba seems even more. We tested many choices of preparations but have not obtained good result so far. We assume it is due to gas poisoning.

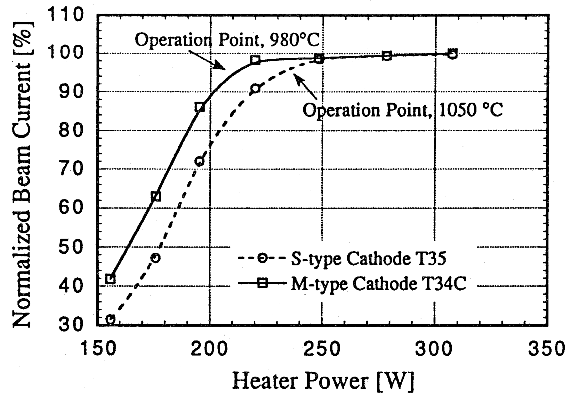


Fig. 5 Miram Plot for M-type and S-type Cathodes

Until now, however, there are no M-type cathode klystrons which showed negative anode spikes. We will continue further investigation on the behavior of these klystrons. And we must find a good answer to shorten the aging period of this M-type cathode.

C. Reconstruction of Anode Insulation Ceramic

The big contamination in Fig. 3 (a) consists of copper compounds and the small one of iron compounds. The latter was observed on the place near inner corona ring, on ceramic side of which a discharge mark was found as shown in Fig. 4. We observed big contamination very often, but almost always small ones except only one case of Fig. 3 (b). We now suspect that the origin of negative spikes is not the big contamination but the small one. Two reasons can be considered which support this view. One is that even the tube (T34B) installed with grooved ceramic could not suppress the anode current spike phenomena. In this case the anode could not be connected with the body electrically through the sputtered contamination layer by virtue of grooves. The other is the fact that the big contamination of copper compounds was not always observed on ceramics of opened troubled tubes. On the contrary, the small one was found even on the ceramic with grooves. Therefore, another possible explanation which accounts for negative anode spikes is as follows. In Fig. 4, field emitted electrons usually flow in vacuum from the anode to the body. However, in some cases, they drift by chance to the ceramic as the inner corona ring is very near to the anode ceramic. The more electrons the ceramic gets, negatively the higher the potential of the ceramic with respect to the body becomes, as the electrons can not move along the high insulation ceramic. When breakdown occurs between the charged-up part of the anode ceramic and the inner corona ring, the potential difference between the anode and the body is relaxed by electric charge flows. At this time the decrease of anode current can be observed. This conjectured mechanism well explains small contamination near the inner corona ring, although the tube T29 in Fig. 3 (b) is an exception. Therefore at this stage we don't have 100% conviction about the above explanation of the mechanism.

Then we adopted enlarging the anode ceramic as shown in Fig. 6 to suppress the breakdown and contamination of the ceramic. Distance between anode and inner corona ring is taken long sufficiently to relax the local electric field at the inner corona ring and to suppress breakdown and sputtering. Distance between inner corona ring and anode ceramic is also taken long to suppress the breakdown between inner corona ring and anode ceramic. The first klystron modified as Fig. 6 (T29A) is to be delivered in August. We expect this new klystron will work well without negative anode spikes.

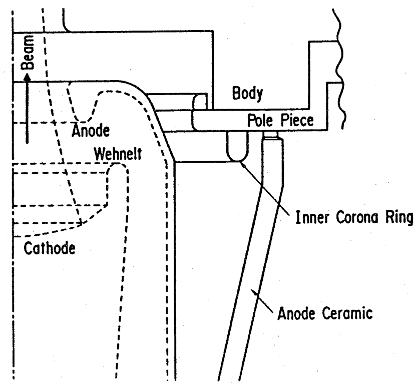


Fig. 6 Schematic Drawing of Modified Anode Insulation

IV. CONCLUSION

Characteristic of E3786 klystron is determined by tuning of 1st and 2nd cavity, especially 2nd cavity. Therefore we can produce a good characteristic klystron having a low collector dissipation and a same saturation point for all conditions by finely tuning its 2nd cavity. However it is difficult to tune the resonant frequency accurately in the present production. If we surely like to get the good characteristic klystron, the 2nd cavity must be equipped with the tuner that enables tuning after production.

We didn't solve the problem of negative anode spike until now. But we expect to obtain the good result by three countermeasures. Chromium oxide coating on anode, M-type cathode and reconstruction of anode insulation ceramic must be highly effective to suppress the negative anode spikes that induce pulse AM in the klystron output and interrupt the TRISTAN operation. We especially place our hope on reconstruction of the anode insulation ceramic. We will continue further investigations on the behavior of these modified versions of klystron. And we must make the mechanism of negative anode spikes more clear.

V. REFERENCES

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