The 6th Symp. on Accelerator Science and Technology, 1987, Tokyo, Japan (© Ionics, Tokyo, 1987)

INSTABILITIES DUE TO MULTIPACTORING, MODULATION AND ANODE EMISSION FOUND FOR TRISTAN HIGH POWER CW KLYSTRONS

M. Yoshida, S. Isagawa, Yo .Takeuchi, M. Ono,
M. Sato, K. Takata and H .Baba
National Laboratory for high Energy Physics (KEK)
Oho-machi, Tsukuba-gun, Ibaraki-ken 305, Japan

ABSTRACT

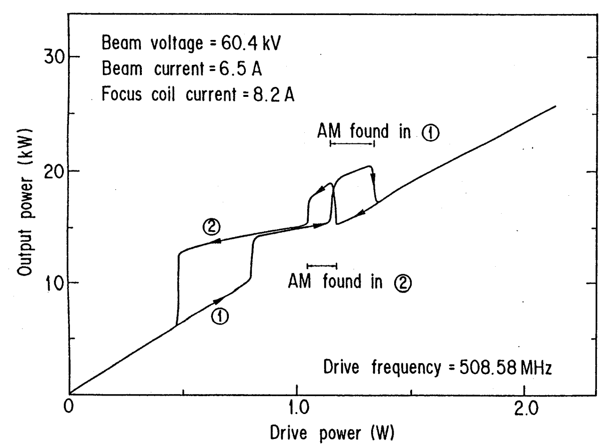
Not all the klystrons delivered for TRISTAN work completely well. Hysteresis and amplitude modulation (AM) of output power occur in a 800kW (T13) and a 1.2MW (T16A) klystron E3786 made by Toshiba corp.. On the other hand, instabilities of anode current occur in 1MW klystrons YK1303 made by Valvo corp.. These phenomena are well explained by the effect of barium layer sputtered on a drift gap and on an anode, respectively.

INTRODUCTION

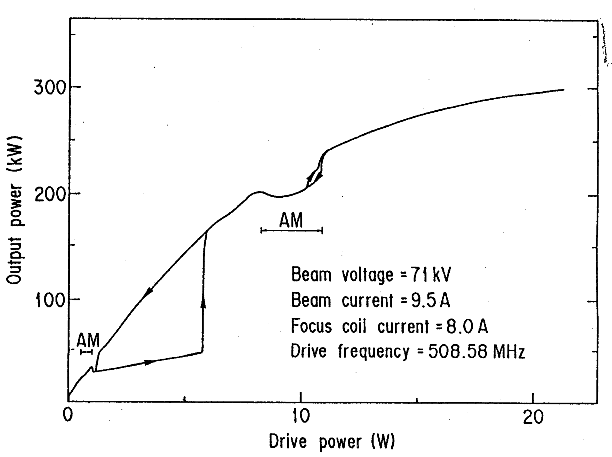
Because of the hysteresis occurred in T13 which was installed in a TRISTAN accumulation ring, the beam injection to main ring failed. While AM, accidentally started in T16A, interrupted aging of accelerating cavities through the increase of reflection power which interlocked the system. Upon investigation, the hysteresis and AM were found in both klystrons.

Instabilities of YK1303 consist of increase or decrease of anode current. It induces anode overcurrent or beam overcurrent in the klystron power supply control system. Voltage applied to klystron is switched off automatically. The decrease of anode current is found in two of 13 klystrons. While the increase of anode current is found in most klystrons including two.

We describe these phenomena in details and discuss about their origin and the way of coping.



(a) E3786 T13



(b) E3786 T16A

Fig. 1 Hysteresis of klystron

PHENOMENA OF INSTABILITIES

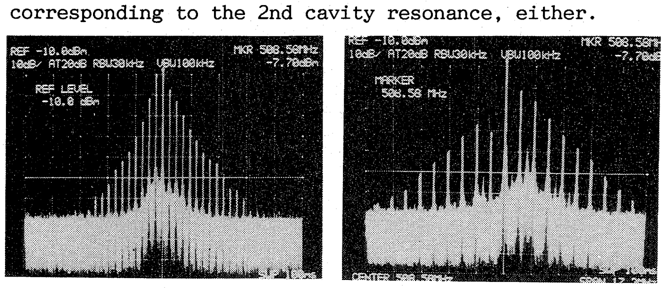
E3786 T13,T16A

The phenomena of hysteresis and AM are shown in Fig. 1 and Fig. 2. AM in lower part always appears in the same drive and output power levels under the same conditions. In T13 it occurs at output power of 25-35kW on condition that beam voltage (Vk) is 70kV, beam current (Ib) is 9.8A and focus coil current (If) is 8.0A. On the other hand, in T16A, it occurs at both 30-35kW and 200-220kW levels on condition of Vk=70kV, Ib=9.5A, and If=8.0A. Upper AM at 200-220kW disappeared after high power aging at RF power 800kW.

It becomes clear that the range of drive power in which hysteresis and AM take place is varied by changing focus coil current. The lower the focus coil current, the smaller the hysteresis and AM, and *vice versa*.

Dependence of the power of T13 on the beam and anode voltage (beam current) is shown in Fig. 3 and Fig. 4, respectively. In these figures, drive frequency(f_0) is varied from 508.04MHz to 508.58MHz. There is no AM but only hysteresis at 508.04MHz which is a resonant frequency of the 2nd cavity of T13. At 508.58MHz, AM occurs at the beginning of hysteresis. Two figures indicate that the power levels above which hysteresis begin almost depend on the anode voltage.

Dependence on the drive frequency is shown in Fig. 5, where no AM are found between 507.88MHz and 508.38MHz . Below 507.88MHz, hysteresis is attended with AM and its extent is enhanced as the frequency is decreased. There is no AM in T16A near 509.40MHz corresponding to the 2nd cavity resonance, either.



(a) E3786 T13 (b) E3786 T16A

Fig. 2 Amplitude modulation of klystron as seen on spectrum analyzer, (a) span=20MHz (Vk=60.9kV, Ib=6.8A, If=8.0A, f_0=508.58MHz), (b) span=17.3MHz (Vk=73.3kV, Ib=9.7A, If=7.0A, f_0=508.58MHz).

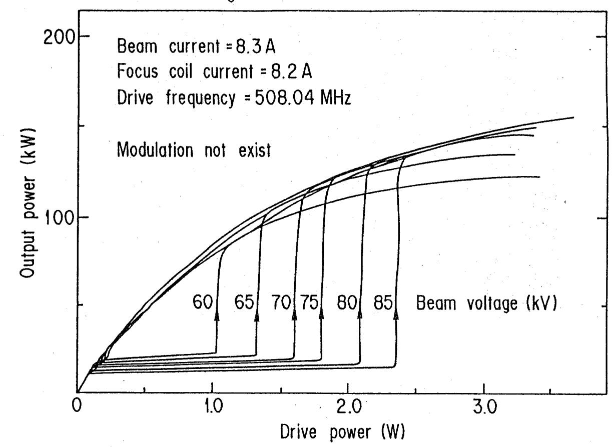


Fig. 3 Dependence of hysteresis on beam voltage of E3786 T13.

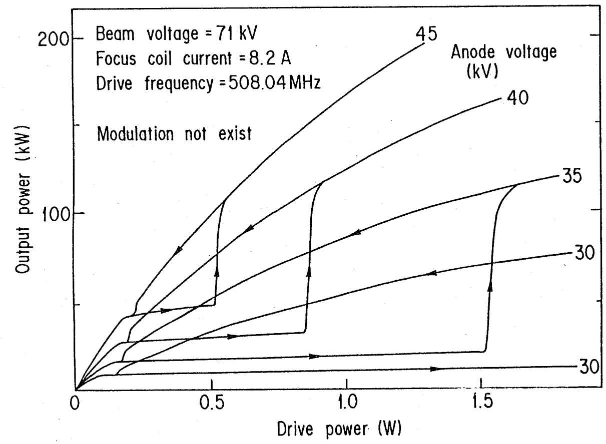


Fig. 4 Dependence of hysteresis on anode voltage of E3786 T13.

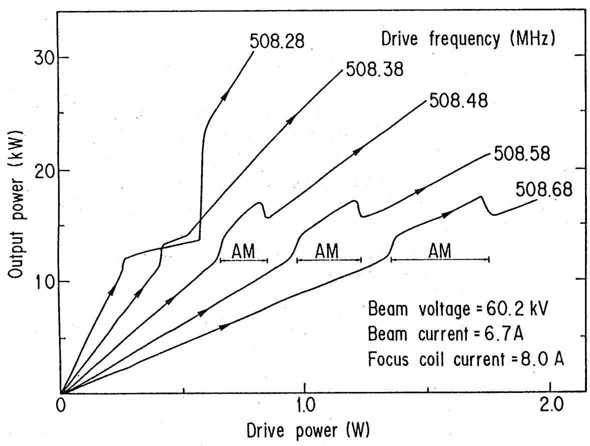


Fig. 5 Dependence of amplitude modulation and hysteresis on drive frequency of E3786 T13.

YK1303

The anode current decreased to negative value on hot days when the max. room temperature in a klystron gallery was 40 °C. Fig. 6 illustrate the mechanisum of beam overcurrent. Normally the anode current flows from anode to Wehnelt which is in cathode potential. In this abnormal case, however, the current flows from body to anode and into R_0,R_1 and R_2. More current flows as the anode voltage, that is, the beam current grows. As a result of positive feedback, anode voltage power supply falls into uncontrolable state and interrupts the system. These behaviors are shown in Fig. 7. The anode current decreases to negative value very slowly.

The positive spikes of anode current are shown in Fig. 8. Rise time of these spikes are about 20msec. Although most of their heights are smaller than 3mA, some of them exceed the interlock level of totally 7mA.

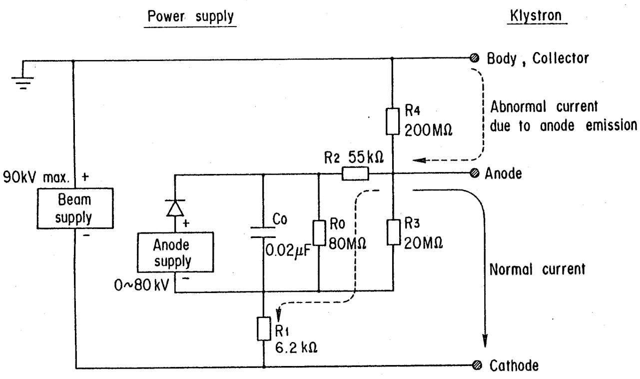


Fig. 6 Schematic circuit of klystron power supply.

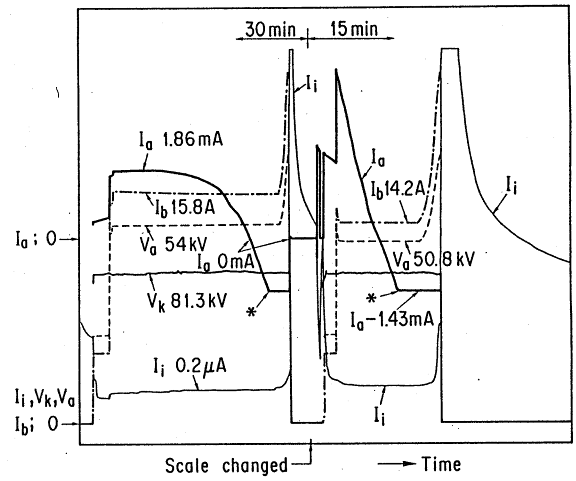


Fig. 7 Beam overcurrent due to anode emission of YK1303 V07 (* limit of anode current monitor).

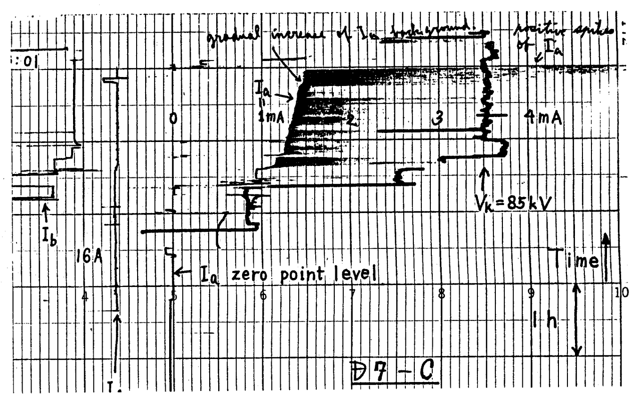


Fig. 8 Anode overcurrent of YK1303 V03.

CAUSE OF INSTABILITIES

E3786

The modulation and hysteresis depend on the focus coil current, especially on a magnetic field near the 2nd cavity. Besides if the drive frequency is adjusted to the resonant frequency of the 2nd cavity, the modulation is not found. On the other hand calculation by a klystron simulation program JDISK[1] shows that gap voltage of the 2nd cavity is about 3.0-3.5kV at the power level of AM. The gap length of the 2nd cavity is 24mm, which gives fd value of 1246MHz·cm. It is no wonder multipactoring occurs in 2nd cavity gap[2]. In addition to that, geometrical treatment to suppress the multipactoring has not been done on the 2nd gap of T13, 16A and T19. In conclusion, the modulation and hysteresis are due to multipactoring of the 2nd cavity gap. The reason why the multipactoring occurs later is as follows. The barium sputtered on the cavity gap from cathode is oxidized gradually, so that the secondary electron emission ratio changes to about 4.8 from 0.83[3]. It needs time for multipactoring to begin.

YK1303

The spike-shaped anode overcurrent is well understood by field emission to a modulation anode from a Wehnelt cylinder on which barium is sputtered. High temperature of the Wehnelt during operation promotes the emission. We can not, however, explain why the phenomenon is not continuous.

As for the anode current decreasing, we think as follows. Barium migrates to anode surface, originally from cathode, and anode is heated up by radiation from hot cathode. Because of its insufficient heat conduction, it becomes hot gradually and emit more electrons to body.

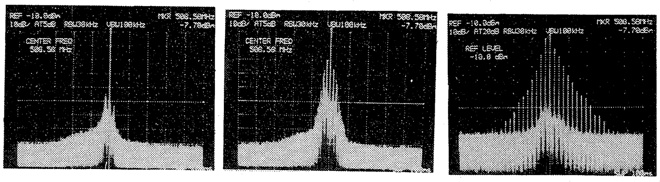
HOW TO COPE WITH INSTABILITIES

E3786

The condition on which multipactoring dose not occur in T13 and T16A may be obtained by changing the focus coil current. But at 5.0-9.0A, there is no such condition.

If the surface of 2nd cavity gap could be changed, multipactoring would be suppressed. We tried to change the surface by hitting parts of electron beam to the cavity gap. After 63 hour's hit under the conditions of the focus coil current 2.5-3.0A and DC input power 47kW, both AM and hysteresis in T13 incidentally disappeared. However, a little later, the modulation gradually reappeared as shown in Fig. 9. But this hitting have surely an effect on AM and hysterisis. In fact, there is no AM and hysteresis now for the focus coil current of 7.0A and 8.0A and the anode voltage of 30kV and 40kV , respectively. The smaller focus coil current and the larger anode voltage seem to be better to expel both AM and hysteresis.

If the resonance frequency of 2nd cavity is tuned to the drive frequency, AM may disappear, but hysteresis may not. But the latter can be suppressed small by decreasing the focus coil current. Further studies are now being continued to remove the instabilities, so that these klystrons may return in active service.



(a) (b) (c)

Fig. 9 Amplitude Modulation as seen on spectrum analyzer after 63 hours aging of E3786 T13 span=20MHz (Vk=60.1kV, Ib=6.7A, If=8.0A, f_0=508.58MHz). (a) 30 seconds later, (b) 2 minutes later, (c) 20 minutes later.

YK1303

Anode emission

We tried to remove barium from anode by electron bombardment procedure. High voltage (1.8kV or 40.0kV) was applied between cathode as negative and anode as positive for 95 minutes in total with a heater on. The current was kept below 63mA or 1.95mA, respectively. The situation, however, was not improved. There seems two reasons for them. One is that the energy put on anode by electron is too small to sputter out or evaporate barium which has so high melting point as 990 °C. Two is that the electrons from cathode do not efficiently hit the anode surface opposing to the body.

Since the anode emission depends on the temperature, it may be better to cool the anode. So we tried to reduce the heater power. Then the anode emission could be suppressed, but at the expense of the emission of main beam, that is the maximum available output power.

Anode overcurrent

Insulation voltage proved to be not so bad in cold sate. For the time being, we have no effective means to suppress this anode overcurrent. We can, however, continue the operation of these tubes by making anode current monitor less sensitive.

CONCLUSION

Instabilities of E3786 and Yk1303 may be caused by barium or barium oxide layer which accumulated during operation on 2nd cavity and anode surface, respectively. At present no specific remedy is found to remove the instabilities these klystrons.

Geometrical modification should be introduced to make a crown (anti-multipactoring) structure on the 2nd cavity gap just as on the other gaps in Toshiba case. In Valvo case, heat conduction of anode material should be increased so that the anode temperature may become lower during RF operation. Design improvement have been already made on new klystrons of both makers in this line.

ACKNOWLEDGMENT

We would like to thank Professor Y. Kimura and Professor J. Tanaka for their advice and encouragement, and also Messrs. Y. Kawakami and K. Ohya of Toshiba corp. and Messrs. H. Bohlen and W. Matziol for their suggestion.

REFERENCES

1) H. Yonezawa, Y. Okazaki, A One-dimensional Disk Model Simulation for Klystron Design, SLAC-TN-84-5 (1984).
2) A. J. Hatch, Suppression of Multipactoring in Particle Accelerators, Nucl. Instr. Meth. , 41 (1966) 261.
3) H. Bruining et al. , Secondary electron emission of metals, Physica, Haag 5, 17.

Field calculation by JDISK was performed with Hitachi M-280.