Suppression of SBO and Stability Improvements of TRISTAN 1MW High Power Klystrons

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Abstract

Philips 1MW CW Klystrons have been well operated in TRISTAN for almost 7 years. Problems like degradation of gun insulation and abnormal anode emission, both caused by excess barium evaporation from cathode and by emission of electrons from hot electrodes of electron gun, have been successfully solved by the use of M-type cathode as well as of redesigned gun with decreased electrode temperatures. The electrode temperatures are, however, still yet to be optimized. Modifications should be refined much more.

Positive spikes of anode current and Side Band Oscillations (SBO) which are caused by back streaming electrons from collector and/or output gap have been studied intensively. Much improvements have been made so far by taking a good combination of modified drift tubes, anode shape, number of cavities and redesigned output transitions.

I. INTRODUCTION

Initial problems encountered in operation of 1MW klystron YK1303 have been solved almost successfully owing to KEK-Philips joint efforts. Among these problems, intrinsic ones were all related to the electron gun structure. The phenomena were caused by unwanted electrons which emitted from incorrect places and were never focused nor simulated properly. These electrons are shown schematically in Fig.1, with numbers ①, ② and ③. Electron emission from wehnelt(①) as well as partial interception is usually inevitable. If it's limited in safe region, say below 2-3 mA, no troubles can happen in tube behavior. After a prolonged operation, however, excess barium deposited on top of the wehnelt cylinder, which increases the anode current due to thermo-field emission. Insulation between anode and wehnelt turns worse and HV becomes inapplicable due to heavy electron loading.

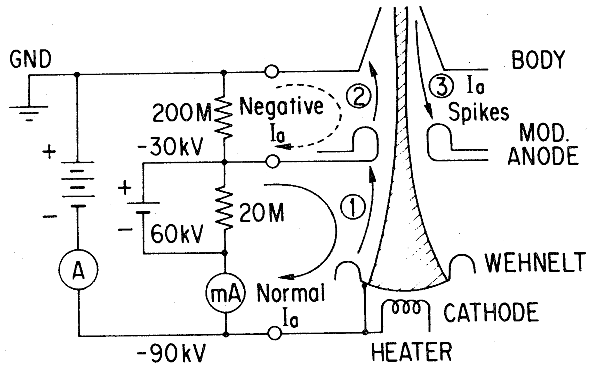


Fig. 1. Gun structure and potential level of each electrode.

Furthermore, if the anode tip is thermally isolated, it is heated up by the abnormal wehnelt current to the temperature high enough for the anode emission (②) to be triggered, which will cause the decrease and even negative going of the anode current [1]. Back streaming electrons (③) which induce the anode current spikes and/or instabilities of SBO are not directly related to the Ba evaporation. In some klystrons, however, the stable range decreases with time. They become unstable even under matched conditions after about 3,000h of operation [2]. The time dependent effect can be well explained by increase of secondary electrons caused by unwanted electron emission of ① and ② as well as by deposit of Ba on drift tube surfaces.

In order to cope with these instabilities, several remedies have been resorted to as follows: **1]** Reinforced oil cooling of each electrode; **2]** Decreasing of electrode temperature, main feature of which is backlining of anode and wehnelt with copper (② in Fig. 2); **3]** Special vacuum pretreatment of cathode and gun subassembly before installation; **4]** Lowering the cathode temperature and reduction of Ba evaporation by the use of Os-Ru coated M-type cathode (① in Fig. 2).

Much improvements have been found in tubes that above measures were taken for. The anode current has become small and very stable. No instabilities like negative going of Ia have happened any more. Only the phenomena of Ia spikes and SBO have been left unsolved even in the newly designed tubes having the gun with the lowered electrode temperatures. On top of that, after prolonged period of operation, new type of problems have become actualized of late, which need further improvements and more refinements of modifications on our tube.

II. HOT OR COLD GUN ELECTRODES?

During the last cycle of TRISTAN operation, one tube (V21) was troubled. On flat top, it showed all of a sudden a severe degradation of insulation between electrodes. A crowbar fired. High voltage could not be applied any more due to high anode current accompanying a gas burst. High potting seemed ineffective as the cold emission increased sharply only above 22kV. The filament time accumulated was about 14,300h.

In reality two other tubes (V14 and V17) died so far very similarly. Their life times were 8,916h and 5,319h, respectively. The phenomena were well accounted for by peel off and dropping of Ba from the inner anode surface onto the wehnelt top as well as the cathode dish. When such a tube was opened, a lot of flakes and small particles of Ba were really found on these electrodes. The Ba on the annular surface of the anode less than about 100mm in diameter was completely removed out and the copper substrate was exposed. All these tubes have guns with measures to hold the electrode temperatures as low as possible to suppress primary emission. They are equipped with B-type cathodes (5:3:2 mole-ratio of impregnant).

Analyzing these effects and comparing them with results coming from data of hot-standing gun electrodes, the following hypothesis can explain the phenomena: Ba on cold surfaces is not well bonded and tends to crack and fall off when layers become too thick. Additional impact by electrons or ions may speed up this process. The adhesion of Ba on Cu is sensitive to temperature. At elevated temperatures Ba-Cuprite is formed with good bonding to Cu. About 300-400°C is the critical temperature range for this reaction to occur. From this point of view, anode temperatures in cold gun case shown in Table I are obviously too low.

Table I YK1303 Gun Temperatures[1)]

Heater Current (Cathode type)	21.5A (M)		23.0A (B)	
Gun Design	Hot	Cold	Hot	Cold
Wehnelt	>600°C	260°C	>600°C	280°C
Anode	300°C	130°C	340°C + $\alpha^{3)}$	170°C
Anode+100W[2)]	480°C	250°C	510°C + $\beta^{3)}$	280°C
Socket	80°C		80°C	

1) Data extrapolated from the other tube's experiment.
2) 100W=50kV x 2mA.
3) About zero when a "semi-cold" wehnelt is used.

Above discussions are summarized as follows: **a)** Excess Ba evaporation must be minimized. Os-Ru M-type cathode at low temperature is preferable. Further reinforcement of vacuum pretreatment before installation is necessary; **b)** Suppression of thermal emission requires temperatures of wehnelt and anode below 550°C (better <500°C); **c)** Too low temperatures, however, promote peel off of Ba deposit. Suppression of Ba blistering probably requires temperature above 300°C.

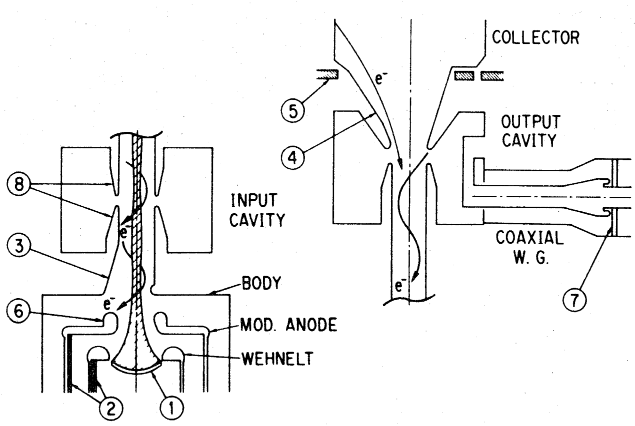


Fig. 2. Modifications against backstreaming electrons.

In order to find out the compromised solution, new combinations are to be tested in next two tubes: **i)** Cold wehnelt, hot anode and M-type cathode for new one; **ii)** Semi-cold wehnelt, hot anode and M-cathode for modified one. Hot, semi-cold and cold can be finely adjusted by removing, thinning and leaving Cu linings (② in Fig. 2). These modifications should put wehnelt and anode temperatures in narrow optimum regions of 380/400°C and 300/500°C, depending on interception, respectively. Sandblasting of inner surface of anode is also to be applied for getting higher bonding strength between Ba and Cu.

III. Os-Ru M-Type Cathode

In order to improve stability over lifetime we have introduced Os-Ru coated M-type cathode together with a special cathode pretreatment to 7 tubes in total. Decrease about 70K in cathode temperature could be allowed and reduced Ba deposition has been expected[3]. All tubes except 1 have shown good emission behavior after aging in factory for about 100h. Very recently, however, the second new problem has arisen. The sudden degrading of the emission as shown in Fig. 3 has been found in the most preceding M-cathode tube.

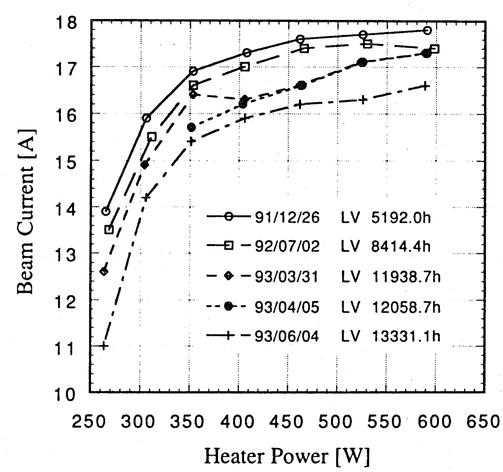


Fig. 3. Underheating data vs. time of V23.

From the beginning this tube has been operated with a decreased heater current of 21.0A (466W) very sufficiently. Until now underheating data have been taken regularly during each shutdown period. Just when new data were being collected on 93/03/31, the gas level in the tube increased and as a consequence the emission decreased. In general M-type cathodes are more sensitive to poisoning by gas than normal B-type ones. Especially the reactivation time after gas bursts is longer if an especial thermal flashing procedure is left undone as it is in our case. Anyway in order to ascertain whether the emission can be recovered or not, this tube must be aged in our test stand further and probably this flushing procedure must be tested. As there is also ample room for doubt that poisoning was caused by underheating process itself, for the next M-type tube, only change of gun perveance with time will be monitored at a fixed underheating point.

IV. Anode Spikes and SBO

The last but most serious problem left unsolved is the instability due to irregular increase in modulating anode current and Side Band Oscillation[2]. These phenomena can be attributed to back streaming electrons whose hit on anode ring causes current spikes and whose implication in a feed back mechanism involving high Q buncher cavities induces beam intervened self oscillations[3]. Many factors are involved in the instability: drive power, load mismatch, beam and geometrical perveances, focusing field, cavity Q, drift tube diameter, anode ring diameter, electrode temperatures, extent of Ba deposit on electrodes and drift tubes, etc.

Measures and modifications taken for improvement so far are as follows: **1)** M-type cathode instead of B-type in order to suppress Ba evaporation (① in Fig. 2); **2)** Cold gun to suppress unwanted emissions from wehnelt and mod. anode (②); **3)** Decrease of the 1st drift tube diameter at the transition gun-RF section, aiming to hide the mod. anode ring from back streaming electrons (③); **4)** Decrease of the collector entrance diameter in order to minimize the contribution of secondary and backscattered electrons (④). The diameter was chosen carefully not to intercept the blown up beam and was decreased in two or three steps with the additional modification of pole piece diameter (⑤); **5)** Increase in diameter and oblique shape of anode hole for the same purpose as the item 3) (⑥); **6)** 5 cavities instead of 6. Table II summarizes these modification points taken for recent 8 tubes.

Table II Modifications made on YK1303

	Tube No V....							
Modification	23	24	25	26	17A	27	14A	01A
1)M-type	O	X	O	O	O	O	O	O
2)Cold gun	O	O	O	O	O	O	O	O
3)1st drift tube	X	X	O	O	O	O	O	O
4)Step 1	O	O	X	X	X	X	X	X
Step 2 or 3	X	X	O	O	X	O	X	X
5)Anode ring	X	X	X	X	X	X	O	X
6)5 Cavities	X	X	X	X	X	X	X	O

Although the instabilities have not been completely repelled out, the extent of the region which ensures a stable operation has been made clearly wide. Interestingly, the best stability and even the highest efficiency have been obtained by a modified tube (V01A) with reduced cavity number (6→5).

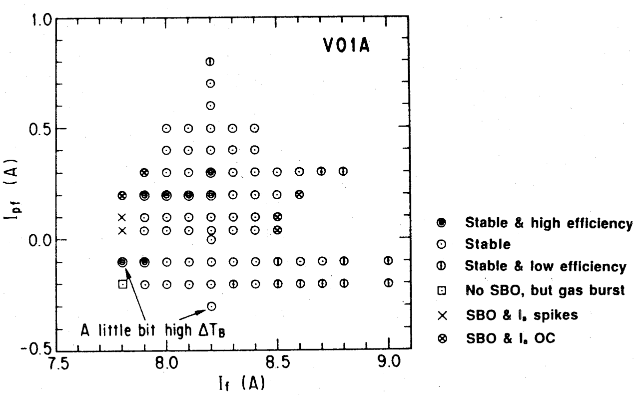


Fig. 4. A stability map vs. focusing & prefocusing currents.

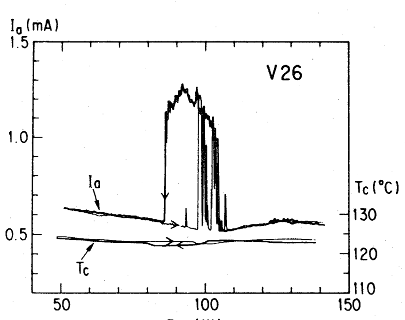
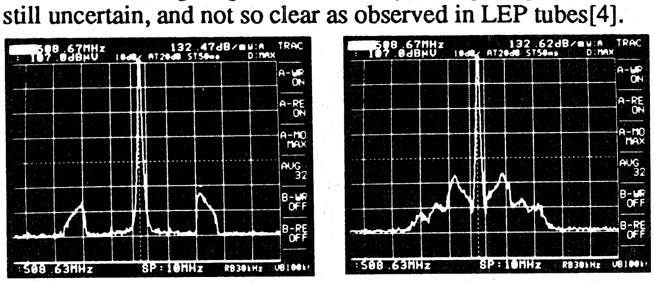


Fig. 5. Hysteresis of Ia and collector temperature Tc vs. Pd.

As an example a stability map of this tube is shown in Fig 4. Other tubes also give a similar extent of stable region. If no changes were expected of the map and the stable region should neither shift nor shrink with time, a sufficiently stable operation without instabilities would be ensured.

Effects of modifications and new findings found phenomenologically are as follows: **A)** Ia spikes and SBO almost always induce increase in Ii (ion pump current) and modulations (AM) in P_0 (output power) and Tc (collector temperature); **B)** They are observed slightly under saturation. Triggers are often necessary for their starting. In some cases 10 or even 30 minutes were needed for them to be triggered; **C)** They are very sticky phenomena with respect to P_d change, showing a kind of hysteresis as illustrated in Fig. 5; **D)** Simultaneous modification of items 3)&4) seems very effective on Ia spikes. Extent of Ia seems limited, say below 1.5mA. Anode overcurrent (O.C) is scarcely found in these tubes (V25, V26 and V27); **E)** Anode O.C. seems different from usual Ia spikes prior to which grassy fluctuations and background increase are found. O.C. happens often all of a sudden without any small symptoms while the tube is operated very calmly and stably. Conditions seem to be fulfilled in very narrow and limited region on Ipf - If stability map as experienced typically by V17A, V14A and V01A; **F)** Modification item **5)** on V14A decreased the efficiency as well as perveance as expected. More trials may be necessary which combine it with items 3)&4); **G)** Ia spikes are not always equal to SBO. In some cases only SBO can be observed with neither Ia spikes nor Ia O.C. Shown in Fig. 6(a) is an example of V26. While coincidence is found between Ia spikes and SBO, the envelope of the spectrum shows an AM pattern which is always symmetric with respect to the carrier frequency (Fig. 6(b)). The pattern is not discrete, but partly continuous and changes with operating conditions. Relations between these signal peaks and cavity tuning frequencies are still uncertain, and not so clear as observed in LEP tubes[4].



(a) (b)

Fig. 6. SBO spectrum: (a) when no instabilities were found in Ia; (b) when instabilities were found in Ia coincidentally. Span 10MHz, Horizontal 1MHz/div, Vertical 10db/div, Center frequency 508.63MHz.

IV. CONCLUSION

A stable operation without Ia spikes, Ia OC and SBO has been ensured over a wide range of focusing and load conditions for modified versions of YK1303. Unknown factor has been found about poisoning of the Os-Ru M-type cathode, though. Further improvements will be continued, including the finding of the best choice of operating temperatures of gun electrodes.

V. REFERENCES

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