Upgrading of High Power Klystron YK1303

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Abstract

As is often the case with high efficiency klystrons, 1MW /508.58MHz cw klystron YK1303 tends to show instabilities like irregular anode current and spurious rf output below saturation due to back streaming electrons. It also sometimes shows the high voltage breakdown caused by excess Ba evaporation on to the gun electrodes and cracking or flaking of its deposited layer. A description is given of the recent performance of YK1303 after several countermeasures have been taken against these unwanted phenomena. They include suppression of back streaming electrons, tuning and Q of intermediate cavities, 5- instead of 6-cavity design, drift tube and anode shaping, reduction of Ba-evaporation and improvement of Ba-bonding, etc.

1. INTRODUCTION

The 1MW high power klystron type YK1303 has been well operated in TRISTAN for almost 8 years. The top runner has exceeded 32,000 h in its filament time already. Continued joint activities of KEK and Philips, Hamburg, have been in progress for further improving tube performance and life. Recent modification steps are related to observed problems [1] with a) high voltage breakdown, b) irregular anode current and c) spurious rf output.

2. HIGH VOLTAGE BREAKDOWN

2.1 *The problem*

There have been several cases of untimely termination of tube life after only 5,000 to 15,000 hours of operation due to high voltage breakdown in the gun. Disassembly of failed tubes showed that barium, which was evaporated from the cathode and deposited on the wehnelt and anode, did not bond firmly to the anode. The deposited layers had cracked and Ba-flakes had moved around due to gravitational and electrical forces. Ba-flaking was obviously responsible for high voltage breakdown.

2.2 *Action*

A) Reduction of Ba-evaporation

An Os-Ru coated M-type cathode together with a special cathode pretreatment was introduced to 9 tubes in total to improve stability over lifetime. Decrease about 70K in cathode temperature could be allowed and reduced Ba-evaporation has been expected as shown in Table I. All tubes except 1 (V27) have shown good emission behavior after aging in factory for about 100h. In general, however, M-type cathodes are more susceptive to poisoning by gas than normal B-type ones. As we reported elsewhere [1], one tube showed a gradual and a sudden decrease in emission.

Table I Comparison of cathode-types (Operational parameters)

	B-type	Os-Ru M-type
Heater power	100 percent	83 percent
Cathode temperature	1040°C	975°C
Ba-evaporation rate	100 percent	approximately 25 percent

Emission was partly recovered, however, by aging operation in a test field in KEK without a special thermal flushing procedure. Aging in current up and down mode is also being tried now.

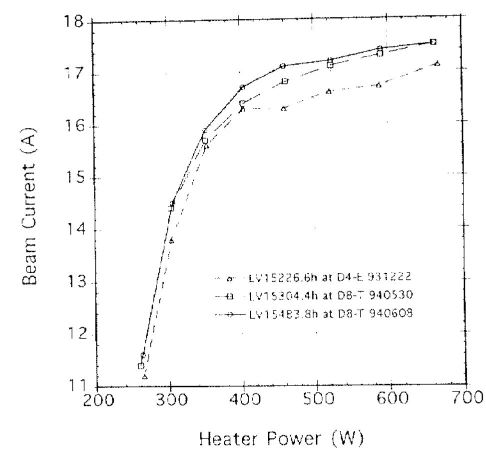

Figure 1. Underheating data vs. time of V23.

B) Improvement of Ba-bonding

Comparisons between bonding of Ba-deposits on anodes that were operated at different temperatures suggested that substrate temperature significantly affects the quality of bonding. Hot anodes (> 400°C) had good bonding, loose flakes, however, were seen on cold anodes (< 300°C). This observation agrees with statements [2] about the formation of a Ba-Cu compound at temperatures above 300°C with good bonding properties to Cu.

Consequently the anode temperature was raised to an operational value of > 400°C taking into account additional heating due to beam interception. On the other hand an upper limit to anode temperature must be observed in order to avoid thermal emission above 500°C.

An additional way of improving Ba-adhesion to the anode is by suitable surface treatment. Surface areas that are directly exposed to Ba-deposition have therefore been selectively roughened in recent tubes.

It is anticipated that the described failure mechanism has essentially been eliminated by measures *A)* and *B)*. Observation for several years will be necessary, however, to complete the field test and have a result of it successfully.

3. IRREGULAR ANODE CURRENT AND SPURIOUS RF OUTPUT

3.1 The problem

In the reference [1], observations of irregular anode current and spurious rf output (double side band oscillations) have been reported. Consensus on these effects is that they are caused by back streaming electrons. Since both effects usually occur simultaneously they are suggested to be closely related and likely manifestations of the same electron feedback mechanism.

The source of back streaming electrons is seen in secondary emission from the collector or the intermediate drift tube and/or rejected electrons from the gap of the klystron. Both may be responsible as is shown by the results of corresponding counter measures. An analysis of the feedback mechanism becomes rather difficult due to multitude of parameters affecting it, such as tuning of intermediate cavities, beam focusing, drive level, rf load conditions and even operating life time. The latter suggests an additional technological component, which may be Ba deposition affecting secondary electron emission or residual gas pressure affecting beam geometry. Actions have been directed at suppressing back streaming electrons and to a smaller extent, at interfering with the internal electron feedback mechanism.

3.2 Actions

A) Secondary electrons from the collector

To reduce the escape rate of secondary (or reflected) electrons from the collector, the radial dimensions of the conical transition region between output gap and collector, including the pole piece hole, were narrowed down to approximately 50 percent of their previous values. Shown in Fig. 2 is the most advanced version of narrowed transition and pole piece hole realized in V28.

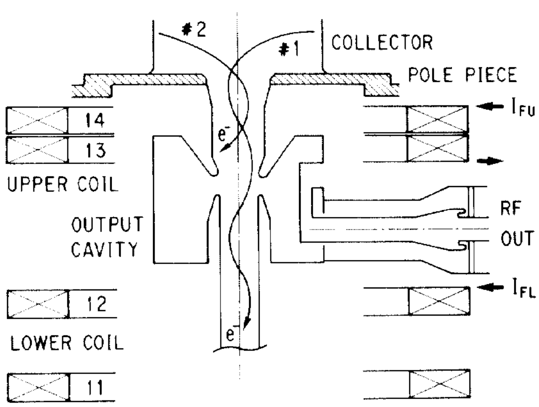

Figure 2. Cross sectional view of upper part of YK1303.

A further reduction of the transition diameter without a corresponding optimization of the magnetic field profile is limited by an increase of beam interception in this region. The magnetic field was not optimized in order to preserve total interchangeability of old and new tubes and focusing coils in operation at KEK.

B) Rejected electrons from the output gap

The effect of load conditions (magnitude and phase of gap voltage) was investigated and typical results are given in Fig. 3. Low efficiency points on the VSWR=1.15 circle correspond to low-Q_L conditions and do not show irregular anode currents or rf instabilities under any operating conditions. High efficiency points correspond to high-Q_L conditions. Here the klystron has a tendency to anode current and rf instabilities in particular with sub-saturation drive and deviating focusing fields. Efficiency optimized output coupling is therefore not recommended. The moderate efficiency point in the center is free from instabilities with respect to drive variations and is not critical with respect to magnetic field variations (see Fig.4 in reference [1]).

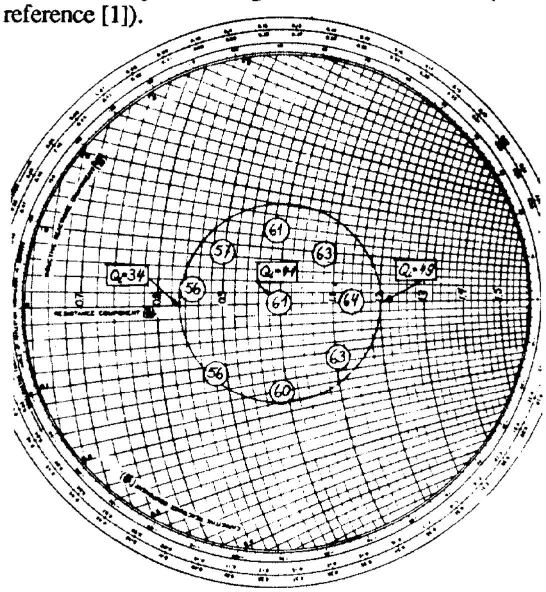

Figure 3. YK1303- Efficiency vs. Output Loading Conditions (Typical Characteristic).

C) Tuning and Q of intermediate cavities

Spurious output at discrete side band frequencies was found to be related to resonant frequencies of intermediate klystron cavities. An attempt was made to suppress side-band oscillation by reducing Q_0 of the cavities by surface treatment and applying lossy coatings. This method of Q-reduction was, however, not very effective. Tests were not continued.

D) 5- vs. 6-cavity design

Two recent tubes (V01A, V28) have been built with 5 cavities within the same body length and with the same performance specification, whereas the standard YK1303 has 6 cavities (incl. 1 harmonic cavity).

E) Drift tube and anode shaping

The role that is played by the anode with regard to generation of spurious output is still disputed to be either essential for the feedback mechanism or just indicative of fast back streaming electrons. In any case it is desirable to stop or reduce irregular anode current components.

Two measures were taken as follows:

1) a reduction of radial dimensions of the drift section

between gun and the 1st cavity in order to intercept more back streaming electrons before they reach the anode.
2) an increase of the radial dimensions of the anode aperture to reduce interception by the anode.

Evaluation of measures *3A)* to *3E)* suffers from the fact that very often several design modifications had to be tested simultaneously in one test vehicle. Also there still remain some minor discrepancies between test results of KEK and Philips test fields. They may reflect an influence of the tube periphery, such as characteristics of anode voltage supply and stability of load reflections, which need further investigation.

4. Stability Test on YK1303

In order to find a condition for stable operation, stability check experiments are being continued on a new tube V28. Focusing coil of YK1303 consists of 15 identical elements (See Fig. 2). The lowest one (No.0, not shown in Fig. 2) is prefocusing coil that is driven by an independent current I_{PF}. The main coil that is usually operated as a whole was divided into two groups, the upper one (No.13 and No.14; current I_{FU}) and the lower one (No.1~No.12; current I_{FL}). Typical anode current instabilities are shown in Fig. 4 with respect to I_{FL}, I_{FU} and rf output power P_0 three-dimensionally, and in Fig. 5 with respect to cathode voltage (beam perveance), respectively.

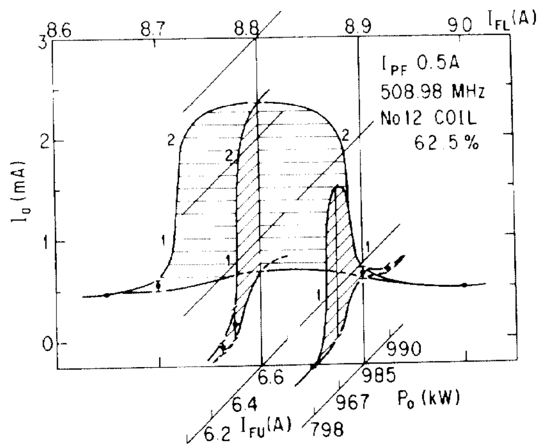

Figure 4. Anode current I_a vs. I_{FL}, I_{FU} and P_0. P_0 is in arbitrary scale. Hatching shows the extent of the irregular I_a.

From the fact that the anode current I_a is dependent on I_{FU} for upper two coils, we can clearly say that this irregularity is not due to interception of the primary beam but due to the back-streaming electrons. I_a spikes are also dependent on output power level. Both near saturation and below about 900kW, such an instability never occurs under any conditions.

Figure 5 tells us many things. For μBP below 0.65, for example, the tube is very stable. The back streaming electrons can get over the potential difference V_k-V_a and hit the anode if it's below 37.3kV. Near V_k of 88.3kV almost all such electrons can reach the anode rather stably, with the result that I_a sits at upper stable value about 2.6mA.

By drastically changing the field profile we found a completely different focusing solution. A good combination is, e.g., 0A, 8.2A and 6.2A for I_{PF}, I_{FL} and I_{FU}, respectively. The winding of coil No.12 was increased from 62.5% to 100% in this case to avoid body interception without loosing high efficiency above 60%. The smaller I_{FU} value can trap the slow returning electrons from collector as shown by #2 electron in Fig. 2. If the I_{FU} is high, the electron can escape through the transition region and be accelerated back to the gun with out-of-phase rf field at output gap as shown by #1.

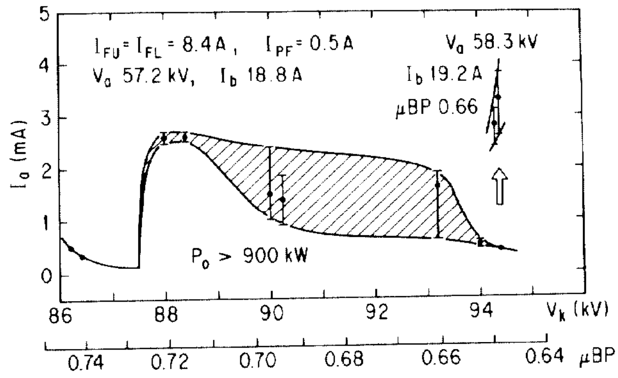

Figure 5. Anode current I_a vs. V_k and μBP

5. Summary

Problems with irregular anode current and side band oscillation have been reduced considerably. In particular one test vehicle (V01A) of the 5-cavity series *(3D)* with narrow first drift section *(3E)* in addition to the already standardized low-temperature cathode *(2A)* has shown a remarkable improvement. An efficiency of nearly 62 percent was obtained with excellent stability. This demonstrates that a 5-cavity design can meet the tube specification even with improved performance as compared with the previous 6-cavity design [1].

Modified collector aperture *(3A)* has also improved stability but efficiency could not be optimized to the same extent due to increased body interception. Further great improvement has been realized, however, by optimization of the magnetic field profile especially of the upper part.

All recent tubes have had improved adjustment facilities in the output-coupling section to optimize output cavity Q_L with regard to efficiency and stability *(3B)*. The limiting factor for this optimization must, however, be seen in the condition of the bunched beam entering the output gap. The bunching process must therefore be optimized to minimize velocity spread in order to allow high efficiency operation at high Q_L-values without rejecting slow electrons. Computer simulation has become a very efficient instrument for optimization of the bunching process [3] and promises further improvement.

6. References

[1] S. Isagawa et al.," Suppression of SBO and Stability Improvements of TRISTAN 1MW High Power Klystron ", Proc. 9th Symposium on Accelerator Science and Technology, KEK, Tsukuba-shi, Japan, August 25-27, 1993, pp.128-130, KEK Preprint 93-71 (Jul 1993).

[2] S. Deckers, Philips Research Laboratories, Eindhoven, Netherlands, Private Communication.

[3] E.-G. Schweppe et al., " Analysis and Optimization of RF Power-Klystrons by FCI-Code ", Proc. IEEE Particle Accelerator Conf., San Francisco, May 6-9, 1991, pp.757-759.