KEK Preprint 98-16
April 1998
A/R

High Power CW Klystrons and Maintenance of Water Quality

S. ISAGAWA, H. BABA, K. BESSHO, K. EBIHARA,
Y. KANDA, H. NAKANISHI, M. TAIRA and M. YOSHIDA

Contributed to the 1st Asian Particle Accelerator Conference (APAC98),
KEK, Tsukuba, Japan, March 23-27, 1998.

High Energy Accelerator Research Organization (KEK), 1998

KEK Reports are available from:

Information Resources Division
High Energy Accelerator Research Organization (KEK)
1-1 Oho, Tsukuba-shi
Ibaraki-ken, 305-0801
JAPAN

Phone: 0298-64-5137
Fax: 0298-64-4604
Cable: KEK OHO
E-mail: Library@kekvax.kek.jp
Internet: http://www.kek.jp

HIGH POWER CW KLYSTRONS AND MAINTENANCE OF WATER QUALITY

S. Isagawa, H. Baba, K. Bessho, K. Ebihara, Y. Kanda, H. Nakanishi, M. Taira and M. Yoshida,
KEK, High Energy Accelerator Research Organization, 1-1 Oho, Tsukuba, Ibaraki, 305-0801, Japan

Abstract

To bring out a full performance of high power klystron, it is essential to keep the operational environment always in a good condition. Controlling the quality of water is in particular the most important both to prevent corrosion and to get the larger collector dissipation, the more stable body loss and the smaller reflection from water loads. Once the water degrades, various damages soon appear: vacuum leaks in brazed and/or welded seams; formation of unwanted compounds; meltdown of teflon in water loads; etc. On the other hand, possibility to apply positively such severe environmental conditions around klystron collectors and high power rf output circuits to modifying the quality and the structure of materials is also discussed.

1 INTRODUCTION

In KEKB, high power CW klystrons of 1 MW (Philips) and 1.2 MW (Toshiba) that have been developed for TRISTAN are to be used at a little bit higher frequency, 508.887 MHz without drastic changes of specifications. The operating conditions are, however, much more severe, as the higher average power is necessary and the faster V_c compensation is required not to lose e^+e^- beams when one of the klystrons faults. Various improvements have been made on both tubes to get characteristics' upgrading [1].

Such characteristics can be, however, only realized by keeping operational conditions good, especially those of cooling water. Klystrons are installed perpendicularly in above-ground galleries. Collectors are cooled by vapor cooling method, assisted by circulation of hot deionized water. Ours is the largest vapor cooling system in the world for klystrons. Bodies are cooled by another deionized water channel and one more channel is added for window cooling in case of 1.2 MW tubes. In the test field the acceptance test and R&D works are continued with a 1.2 MW water load (Nihon Koshuha) that is cooled by another independent water circulating system.

2 COLLECTOR DISSIPATION

The collector of the klystron, made of pure copper, dissipates the residual kinetic energy remaining in the electron beam after the final beam-gap interaction. If its temperature increased above the loading limit, it could become irremediably deformed. To increase the collector dissipation, its outer surface has narrow periodic (1.2 MW tube) or biperiodic (1 MW tube) grooves. To stabilize the tube against vibration, a stream-forming cylinder made of copper is attached with stainless steel spacers (1.2 MW tube), or some elaborate stainless steel structure called steam duct is fixed on the collector (1 MW tube). The latter ensures the constant dip in water of the collector tip.

In the acceptance test, a full beam, reduced drive operation is performed to check the collector dissipation above 900 kW for 5 min (1 MW tube) and 1200 kW for 15 min (1.2 MW tube). Due to degradation, however, these values are not always maintained. One of the most important factor is the water quality. Especially silicon is the most dangerous material as it causes the steam skin along the collector (danger of Lydenfrost phenomenon). Grease, gaskets and O-rings containing silicon must be strictly avoided. A foaming test measuring the disappearing time of foams after 30 s' shaking is effective to check its content easily. Quantitative analysis has been made, however, in our laboratory by using ICP-AES (Inductively Coupled Plasma - Atomic Emission Spectroscopy). When a Philips tube, for example, v01, died due to collector leak in December 1987, Si was 1.66 mg/l, about 3 times as large as the allowable level.

The conductivity of water is another important factor. If it increased, the Cu collector could be eaten away by water. Such a crisis really came in November 1993. Tubes were troubled in succession: one leaked; another suffered from a water leak at a brazed joint in the body cooling circuit; and the other had contamination in the boiler and drastically changed color in the collector.

Probably due to insufficient rinsing after regeneration of an ion exchanger with hydrochloric acid, the chloride ion (Cl^-) content grew up to 305 mg/l, about three orders of magnitude larger than normal. Contents of Ni, Cu, Zn, Si and the like were also large. Collectors, usually covered with thin black layer of cupric oxide, CuO, turned reddish-brown and much two-tone (green/dark red-copper) colored contaminants, mainly composing of cuprous oxide, Cu_2O, accumulated in the boiler. The collector tip was covered with fresh blue-green crystals that were determined to be one kind of verdigris, $CuCl_2 \cdot 3Cu(OH)_2$, indicating overheating occurred. Violent reaction accompanying some kind of radicals and gaseous chlorine must have happened.

The formation of Cu_2O is probably due to temperature rise on collector caused by delicate change of wetting, i.e., contact angle, mainly depending on Si. Such an accident, if happened, is very dangerous as the contaminants prevail very soon. In the crisis in 1993, collectors and boilers were cleaned up, all the contaminated water in boilers and storage tanks were replaced, the ion exchange resin was renewed and about 3 months were required to resume normal conditions.

3 1.2 MW WATER LOAD

In contrast to deionized waters for klystron, the cooling water for 1.2 MW water load must be lossy and conductive. In the frequency range above 10 MHz, the dipole characteristic of water predominates, but the loss tangent near 500 MHz grows not yet sufficiently large. The load becomes objectionably long and impractical. Pure water does not work unless it is cryogenically cooled; therefore, conductive water is necessary. On the other hand un-deionized facility-water which is commonly used for, e.g., klystron power supplies, however, can not be used, either, as it is often contaminated with iron rust and mesh-filters are easily blocked in a short time. Salt or stabilized ethylene glycol may be used, but the former is corrosive and the concentration of the latter is difficult to be kept unchanged. For the 1.2 MW-waveguide-type water load in the test field in KEK we thus have used the tap water as the absorbent of rf. Merits to use tap waters are as follows: stable contents; easiness of renewal; non poisonous properties; and big absorbing power of rf.

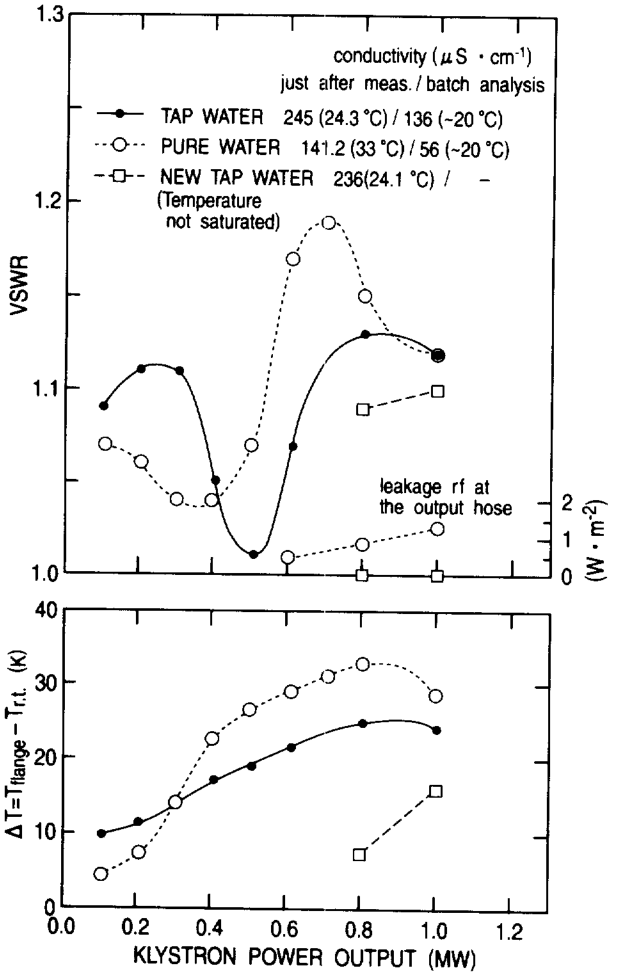

Figure: 1 VSWR, temperature rise of water-outlet-flange and leakage rf versus klystron output power. 1.2 MW-waveguide-type water load was used at 508.58 MHz.

Figure 1 shows dependence of VSWR and temperature rise of water-outlet-flange on klystron output power at 508.58 MHz. The original conductivity of deionized water in the tank was ~ 3 μS/cm (at ~ 20°C). The input water temperature was 23 ~ 25°C and the flow rate was 577 l/min at its maximum. As the conductivity and tan δ depend also on water temperature, the behavior is not so simple. Superiority of tap water to deionized one is, however, obvious. At KEKB frequency, 508.887 MHz, VSWR becomes a little bit worse than this frequency.

Although this load worked reliably over 9,000 h, the recent investigation showed that some arc marks existed around the cylindrical water-outlet-flange and the Ni plated brass (BS) was seriously corroded by water. Many rashes came out of the flange, which were determined to be $Zn_4(CO_3)(OH)_6 \cdot H_2O$ by X-ray diffraction analysis. Replacement of BS to stainless steel and improvements of rf shield are now being examined.

4 MATERIAL MODIFICATION UNDER EXTREME ENVIRONMENT

We have two extreme environments peculiar to high power CW klystrons: one is that in the high power rf output; and the other is that in the collector cooling boiler.

4.1 High Power CW Microwave Output

The high power rf of 1~1.2 MW CW can afford a super extreme environment from a point of view of material modification. We had an experience of finding a transition from opaque to transparent grain boundaries in a klystron window ceramic that was aged by rf for a long time under heavy multipactoring conditions. Microwave can excite plasma in low pressure gas and make many reactive radicals and/or ions in liquid like water. Not only plastics but also even ceramics could be melted down by its irradiation only below 30 kW if vapor involving glow discharge happened. In a case when a new type of 1 MW water load from Titan Beta was tested, using the un-deionized facility-water, dark reddish brown powder was collected from a strainer in the water circuit. The X-ray fluorescence analysis showed that main elements of the powder were Fe and Zn. The marvel was that, according to X-ray powder diffraction analysis, this iron came from the structure Fe_3O_4, one kind of ferrite that is never produced under normal conditions.

4.2 Boiler to Cool Klystron Collector

The collector of the klystron is made of OFHC copper, installed in the boiler and cooled by pure running water as well as latent heat of vaporization. The flow rate is about 80 l/min for 1 MW tube and about 100 l/min for 1.2 MW tube, respectively. The X-ray background is very high inside the boiler lead shield. Due to the acceleration effect worked on the out-of phase electrons, the maximum energy of impinging electrons reaches almost twice as much as the beam voltage, about 90 kV.

When the stream-forming cylinder was broken, the spacers made of stainless steel dropped down and the cylinder made of copper directly touched and rubbed with grooved outer surface of the collector. The bubbles and the steam flow were disturbed and overheating and/or overpressure must have been made locally, which formed many reactive radicals in the boiled water. The two-phases-mixing water colliding with the broken cylinder must have produced many supersonic waves, either. The boiled water became very erosive and the touching area was seriously thinned down.

According to the X-ray diffraction analysis, Cu, Cu_2O and metallic Ag were detected on this surface. The CuO, normally detected on black surface of collector and stream-forming cylinder, was scarcely detected from this rubbed surface. It was just on such areas that we found two interesting material modifications:

1) Silver liquated out of the collector, was refined, and precipitated on rubbed surface of copper. The only possible source is the brazed part of the collector that consists of Ag-Cu alloy. The content of Ag was large. In order to estimate its quantity the surface of the sampled plate of copper (about 2cm × 1.5cm) was dissolved in conc. HNO_3 to make 20 ml of solution. It was diluted 5 times, measured with ICP-AES, and its signal height was compared with a standard sample. A semi-quantitative analysis using ICP-AES showed that the average content and the average thickness of Ag were roughly about 0.2 mg/cm^2 and 200 nm, respectively. This means that the brazed part of the collector was eaten away during operation with the damaged stream-forming cylinder. On the other hand this reaction mechanism might be usable to dress scrap metal or ore, and to refine silver;

2) Cu_2O is another interesting material found on the periphery of the white silver ground. Around this area large amounts of brilliant red crystals were found, maximum about 100 μ in size. Some crystals grow perpendicularly like bamboo shoots, taking columnar structure. Others commonly show the cube, octahedron and dodecahedron. They are transparent and are various shades of red and a fine ruby-red. Some of them contain several brilliant red spots in rather dark red crystal structures, resembling ladybugs in appearance.

According to the X-ray micro diffraction analysis, these crystals proved to be cuprites whose chemical structure is Cu_2O. In the diffraction analysis, one large single crystal whose crystal plane was about 30 $\mu\phi$ was selected and irradiated with focused X-rays (Cu K_α), about 30 $\mu\phi$ in diameter; thus only one crystal was selectively analyzed. The electron beam conditions were 45 kV and 250 mA. The diffraction pattern precisely coincided with a reference pattern of cuprite (Cu_2O). How such a crystal structure was formed is still unclear but attracts much interest.

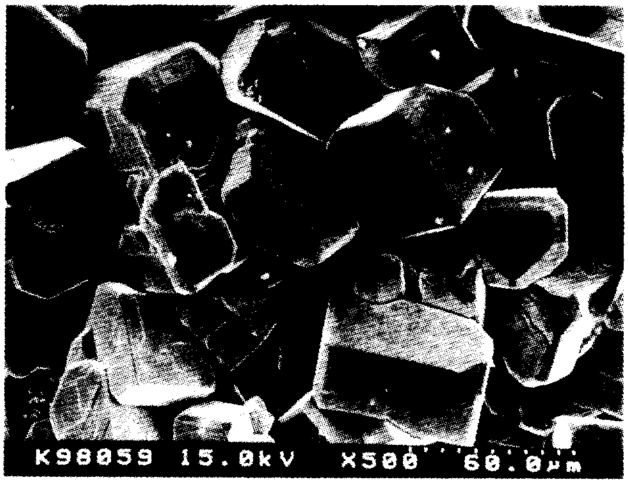

Figure: 2 A SEM photo of cuprite (Cu_2O) single crystals formed on a damaged stream-forming cylinder made of Cu.

5 CONCLUDING REMARKS

Keeping water quality good proved to be very important to maintain the full performance of high power klystrons and high power microwave components like water load. In case of out-of-control, deionized water could become harmful and promote corrosion. A small quantity of Si can degrade the collector dissipation seriously. Water for the 1.2 MW water load, on the other hand, must be kept lossy by using tap water instead of deionized water.

Combined with extreme conditions like super power microwave, boiled water, steam bubbles and strong X-ray, a reactive tower could be made involving various reactive radicals. In some cases, conditions could be made which very much resembled those in the mantle and wholly unexpected things could happen: Metallic silver was separated from the brazed copper, refined and precipitated; The verdigris, $CuCl_2 \cdot 3Cu(OH)_2$, was made if the pH of the deionized water shifted lower and chloride content grew up; Many beautiful ruby-like single crystals of cuprite, Cu_2O, were made both on a collector and on a damaged stream-forming cylinder; Ferrite, Fe_3O_4, was made in a water channel of water load if the un-deionized water were used under high power microwave irradiation.

Such research concerning material modification has just been started. If the mechanism was made clear, materials could be modified under extreme environments intentionally. The high power klystrons might give a chance and a place to such applications without disturbing the machine operations.

Thanks are due to Nissan Arc, Ltd. for identifying the cuprite by X-ray micro diffraction analysis.

6 REFERENCES

[1] S. Isagawa: 'Present Status of High Power CW Klystrons', Proc.11th Sympo. on Accelerator Science and Technology, CAST, Ako-shi, Hyogo-ken, Japan, Oct. 1997, pp.185-187, KEK Preprint 97-139.