NEW KLYSTRON TEST FIELDS AND IMPROVED VERSION OF 1.2 MW WATER LOAD

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Abstract

Two klystron test fields were built side by side in a KEKB power source building D2 for R&D on high power cw klystrons as well as various rf power components. Each field can be operated separately from KEKB rf transmitters with one-on-one power supply, sharing a vapor condensing system. X-ray shields were reinforced. An improved version of 1.2 MW slanted-tube water load has been developed as a host one for the test field. In an acceptance test on a klystron it must endure rf loading up to 1.2 MW stably for a long time in a frequency range between 508.230 MHz and 509.237 MHz. Tap water is used as an ideal rf power absorber and its flow over 640 l/min passes through a long PFA tubing threaded through a tapered rectangular waveguide. Improvements were made on waterproof quality, water flow conductance, corrosion resistance and rf-leakage by modifying structures and materials of end collars and flange tubings. This type of water load has been continuously operated above 1 MW for 3 h with VSWR about 1.06 without any failure. VSWR over the whole power range could be limited below 1.13.

1 INTRODUCTION

High power cw klystrons developed for TRISTAN in close cooperation between KEK and industry have been used in KEKB, at a bit higher frequency, 508.887 MHz without a drastic change in specifications. The operating conditions are, however, much severer, as the higher average power is necessary at full e^+e^- beams and the faster V_c compensation is required so as not to lose beams when one klystron faults. In the test field variety of high power rf activities have been continued with a 1.2 MW slanted-tube water load, namely, acceptance test, performance test, aging or repairing works and R&D on klystrons of different type.

Some klystrons need to be tested; some to be studied while the others to be aged only for a long time. Dying tubes have increased that make a diagnostic operation, even if for a short time, necessary on each. These circumstances required us building plural test fields.

2 KLYSTRON TEST FIELDS

Two klystron test fields, D2-DT and D2-ET, were thus prepared side by side in D2. Shown in Fig. 1 is the schematic drawing of one unit of them. A B-type KPS (Klystron Power Supply) driving one klystron is prepared for each. In a waveguide (WR1500) system a four port phase-shift high-power circulator is installed whose 3rd and 4th ports are terminated with water-cooled coaxial power absorbers. Forward and reflected powers can be measured with calibrated power meters at the 55dB directional couplers installed in the waveguide. Tap water is circulated with a pump, exchanging heat with facility water at a plate heat exchanger. The heat exchange capacity is 700 l/min × 25 K for D2-ET but smaller like 470 l/min × 30 K for D2-DT, assuming 30°C as the input temperature of the facility water. The main flow rate is checked with a turbine flow meter (TFM) which was initially calibrated with a volume meter, but routinely measured with an electromagnetic flow meter (EMFM). The maximum flow rate of circulating water is about 650 l/min. From the temperature difference between T_{out} and T_{in} the rf power absorbed in the water load can be calorimetrically calculated. Abnormal heating above 60°C at the output flange can switch off the rf.

X-ray shields were reinforced at the test fields. Additional leads were placed in and around focusing coils, on top of boilers, and around klystron collars. Most effective was the in-line X-ray trap that was installed in the steam line just above the collector. The background level could be suppressed below 0.1 μSv/h everywhere around klystron (~1 meter apart from its surface) when operated at a power level above 1 MW.

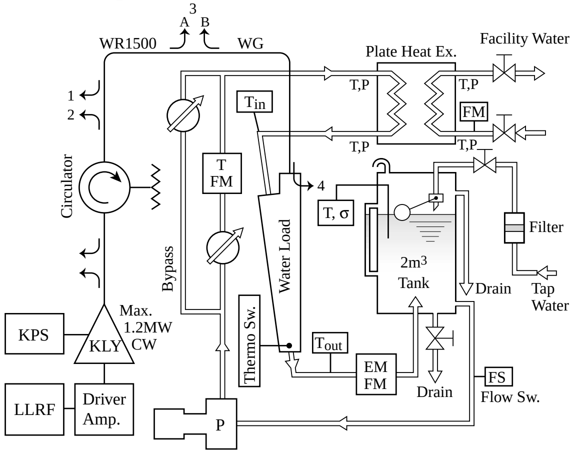

Figure 1: A schematic drawing of one unit of test field.

3 1.2 MW WATER LOAD

Through the construction and the operation of TRISTAN the 1.2 MW slanted-tube water load [1] worked well over 9,000 h each in the former test field in D8. After prolonged usage of it, however, several difficulties have been revealed:
1) Accumulation of rust on an inner wall of the PFA pipe due to partial use of non stainless steel (S.S.) in the circulating water circuit; 2) Arc marks around the cylindrical water-outlet-flange and small rf leakage through the water outlet due to insufficient, rf loss and

electrical contacts (Pure water was sometimes misused instead of tap water.); 3) Poor watertightness between the PFA pipe and flange tubings; 4) Misuse of Ni plated brass (BS) to end collars and flange tubings; They were seriously corroded by water. Many rashes came out of tubings, which were determined to be $Zn_4(CO_3)(OH)_6{\cdot}H_2O$ by X-ray diffraction analysis [2].

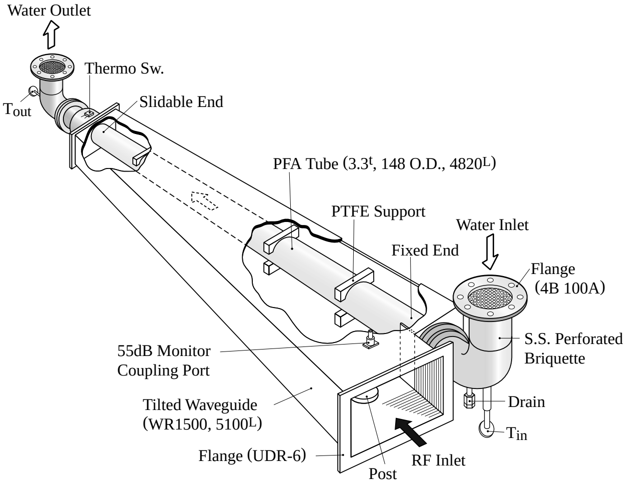

Figure 2: A 3D view of the improved 1.2 MW water load. It is set with its axis vertically tilted 3.5~4° to prevent entrapment of air bubbles which could damage the PFA.

Shown in Fig. 2 is the 3D view of the improved version of 1.2 MW slanted-tube water load. The PFA pipe is sealed up with end collars, the inlet one is fixed and the outlet one is slidable to absorb the thermal expansion of PFA. They are sectioned to 3 instead of 2 to improve the watertightness of O-ring seals and electrical contacts of beryllium copper fingers. End collars and flange tubings are all made of Ni plated S.S. Flange tubings of 4B 100A instead of reduced 65A ensure the water flow conductance.

This enabled the application of perforated-briquette structure to extreme ends of flange tubings. Holes were drilled, 61 in number, 10 mm in diameter and 138 mm in length, along the axis of a 4" S.S. columnar block which was then welded between an elbow and a 4B 100A flange and Ni plated. Dimensions were determined as follows. The cutoff frequency of the dominant TE_{11} mode in a circular waveguide (inner radius r) filled with a dielectric material whose dielectric constant is ε is expressed as

$$f_c = 3 \times 10^8 \,[\mathrm{m/s}] / (1.64 r \sqrt{\varepsilon}).$$

Assuming 74 as the dielectric constant of water, the cutoff radius is 20 mm for the KEKB frequency f_c = 508.9 MHz. To expect 50dB attenuation with a reasonable length about 138 mm the inner diameter must be below 10 mm. The cross section made by 61 such holes is 4789 mm^2 that is still 1.5 times larger than that for 65A tubing.

The cooling water for 1.2 MW water load must be lossy. Pure water does not work due to insufficient loss tangent unless it is cryogenically cooled. 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 loads in KEKB we thus have used the tap water as the ideal conductive absorbent of rf [2]. Merits are as follows: stable contents; easiness of renewal; nontoxicity; and the moderate power dissipation. In this type of load it is highly desirable that the power be dissipated uniformly along the length of the water column. If the heat dissipation is so localized, the PFA pipe is damaged by superheating of the water and steam generation.

Typical example of quality of tap water is as follows: *pH* 7.3, σ 0.27 mS/cm, Cl^- 41 ppm, SO_4^{2-} 40 ppm, Na^+ 32 ppm, K^+ 6 ppm, Mg^{2+} 9 ppm, Ca^{2+} 22 ppm, Fe 55 ppb, Al 140 ppb. The conductivity, σ, is a linear function of temperature and thus the Joule loss must be quadratic as shown in Fig. 3. The *tan* δ in the figure represents data for pure water, the larger the cooler [1,3]. The total combined loss must have therefore a minimum concerning water temperature in a practical range.

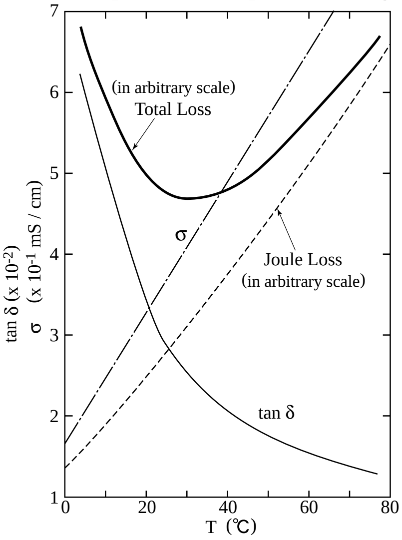

Figure 3: The total loss consisting of *tan* δ and Joule losses. The conductivity, σ, is the measured data.

4 PERFORMANCE OF WATER LOADS

The improved version of 1.2 MW water load has been tested in both D2-DT and D2-ET. Figure 4 shows a typical example of power dependence of *VSWR* of the D2-ET water load and its variation with respect to the water flow rate. As can be imagined from Fig. 3, *VSWR* takes a maximum: at lower power levels *tan* δ loss is dominant; at higher power levels conductive loss is dominant. In our system the facility water in Fig. 1 exchanges heat with atmosphere at an outdoor AFC (Air Fin Cooler), and thus the water temperature is considerably influenced by the outdoor temperature. Especially in the coldest winter the circulating tap water cannot be warmed up, the conduction loss mechanism never works and thus the power-reflection-maximum shifts to higher power input side. In such a case the water flow rate should not always be the maximum. By closing the bypass line of TFM in Fig.1 the flow rate could be adjusted to 572 l/min, which gave a stable *VSWR* below 1.06 above 1 MW (filled circles in Fig.4). As the water flow rate decreased further, the water temperature increased and the conductive loss became dominant at the lower and lower power level. Throttling too much is, however, risky because of the rise of the outlet temperature of the water load. Except for the coldest wintertime the bypass line can be opened to get the flow rate about 640 l/min.

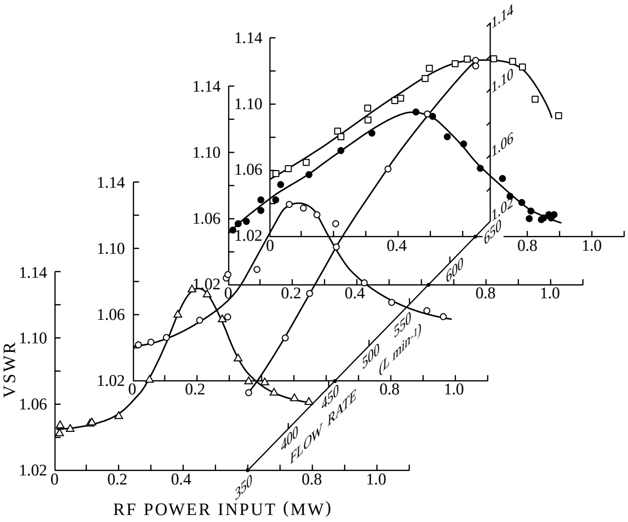

Figure 4: Power dependence of *VSWR* of the water load at D2-ET and its variation with respect to flow rate of water.

The water load installed in D2-DT performed a little bit differently. A typical example of power dependence of *VSWR* is shown in Fig. 5. In this case the bypass line of TFM was fully opened and a flow rate about 630 l/min could be obtained. *VSWR* shows a maximum around 0.2 MW and a minimum around 0.6 MW. The power dependence is also a function of base temperature of circulating water and thus influenced by the outdoor temperature. Data points oscillate between T_{high} and T_{low} with an interval about 40 min, depending on the base temperature. Between the maximum and the minimum of *VSWR* the conductive loss mechanism seems to be dominant. In this region the higher the base temperature, the lower the return loss. In one freezing cold morning the base temperature was very low and the reflection power increased with forward power almost linearly as represented by a dotted line. After a lunch break, however, the coldness relaxed and the higher reflection diminished. At the highest power level near 1.2 MW *VSWR* could be also kept below 1.06. Just contrary to the D2-ET case, the higher flow rate is preferable in this case, as the lower the base temperature, the lower the return loss.

Why the water load behaves so differently at DT and ET has not yet been confirmed. Possible causes are: 1) Difference of heat exchange capacity of plate heat exchangers; 2) Difference of or that of operational mode of klystrons used; 3) Difference of characteristics of directional couplers. Concerning 2) we measured powers of higher harmonics from each klystron and their change with operational mode, that is under-saturation, saturation and overdrive. Powers of the 2nd and the 3rd higher harmonics were about −29dB and −42dB with respect to the fundamental, respectively, and no significant change has been found. Measurements of *VSWR* have been repeated, inserting low pass filters between directional couplers and power sensors, but no difference has been obtained, either.

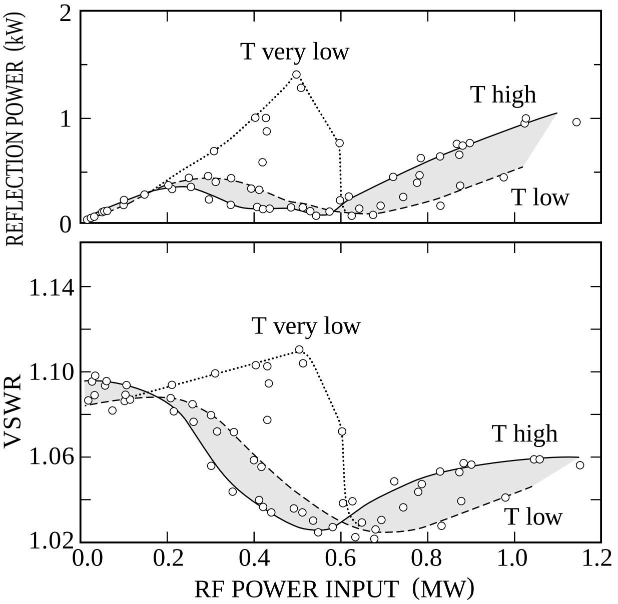

Figure 5: A typical example of power dependence of *VSWR* of the water load at D2-DT.

5 SUMMARY

New klystron test fields have been constructed and reliably operated. Works of aging and R&D on several repaired tubes have been accomplished very successfully, using improved as well as newly developed 1.2 MW water loads [4]. Safety, reliability, interchangeability, independence and versatility are key factors well realized in these fields. The improved version of 1.2 MW water load worked well by use of tap water. Plural loss mechanisms, namely dielectric and conductive losses, proved to be mixed in, depending on flow rate and water temperature. In new test fields the residual leakage of rf through water channel and that of X-ray through steam line and focusing coil completely diminished owing to cutoff water tubes, an in-line X-ray trap and additional lead shields. Further studies are still necessary to clarify the main cause of a little different return-loss behavior shown by water loads installed in respective fields.

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