100kW DUMMY LOAD USING WATER FOR A KLYSTRON MODULATOR

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Abstract

A dummy load capable of handling the peak voltage of 37 kV and the average power of 100 kW using water as a resistor has been designed and constructed to perform the high-power tests of an X-band klystron modulator. Two coaxial electrodes are used to make the dummy load in a compact size. The load impedance is regulated in the range of 5 ~ 12 Ω stably.

Introduction

In KEK, 100 MW-class klystron at X-band and its modulator are developing for the Japan Linear Collider. As a first step of this development, the fabrications of 30 MW and 120 MW klystrons are under progress. In order to operate these klystrons, a PFN-type modulator has been constructed [1]. For the high-power tests of this modulator, a dummy load is necessary. It requires the maximum input voltage of 37 kV and the average power of 100 kW. It also requires two different impedances which are 5.0 and 11.6 Ω. The dummy load using solid resistors becomes very large and expensive for this power level. Thus, we have developed a compact dummy load using coaxial electrodes which are filled with circulating water as a resistor. In this paper, the design, specifications and results of performance tests of the dummy load are described.

Design and Structure

Specifications

Specifications of the klystron modulators are listed in Table 1. A cross sectional drawing of the dummy load is shown in Fig. 1. It consists of two coaxial electrodes which are fixed to a tank. The inner electrode can be moved by a motor remotely to adjust the input impedance. Specifications of the dummy load are summarized in Table 2.

Table 1
Specifications of the X-band klystron modulator

Operation mode	XB-50K	XB-72K
Peak power output	77 MW	269 MW
Average power output	39 kW	97 kW
Output pulse voltage	30 kV	37 kV
Output pulse current	2581 A	7342 A
Output impedance	11.6 Ω	5.0 Ω
Pulse width	2.5 μs	1.8 μs
Pulse repetition rate	200 pps	200 pps

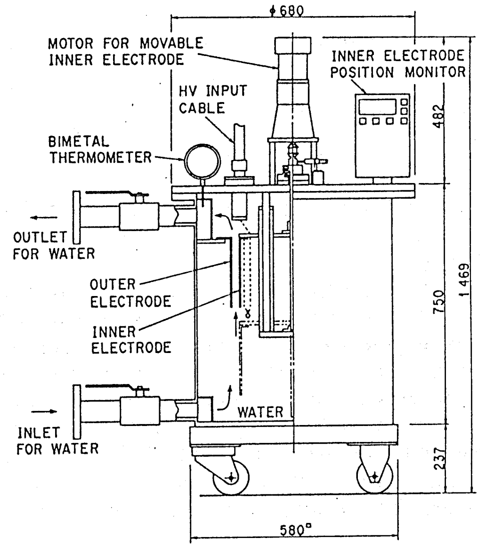

Fig. 1. A cross section of the dummy load.

Table 2
Specifications of the dummy load

Peak input voltage	37 kV
Average input power	100 kW
Input impedance	5 ~ 12 Ω
Input temperature of water	30 ~ 40 °C
Water flow	300 l/min.
Resistivity	~ 50 Ωm

Water resistor

The tap water is used as a resistor. It contains electrolytes such as Na^+, Ca^{++}, Cl^-, and so on, and the value of its resistivity is usually 30 ~ 100 Ωm. This value is also dependent on the temperature and the density of the electrolyte. A neutral detergent is used as an electrolyte to control the resistivity of the water. The resistivity of the water is very important parameter to determine the impedance of the dummy load. In order to study characteristics of the tap water for weight density of the detergent, the resistivity of water was measured by an electric conductivity meter BB3FA (Orugano Co., Ltd.). Figure 2 shows the resistivity of tap water as a function of temperature at 0.0 and 0.55 in unit of weight percentage. The variable width of the resistivity was approximately 50 Ωm at around 30 °C. It was also found that the resistivity shifts which were caused by the deviation of temperature of the tap water for 0.0 and 0.55 weight % were approximately -1.9 and -0.6 %/°C at around 30 °C, respectively. Thus, if the required stability of the impedance is 2 %, the stability of water temperature must be less than ± 1 °C.

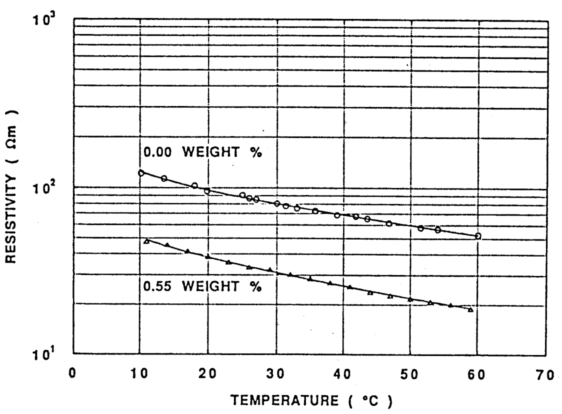

Fig. 2. Resistivity of tap water as a function of temperature.

Coaxial electrodes

A detailed drawing of the coaxial electrodes is shown in Fig. 3. They are made of stainless steel, SUS 304, with a thickness of 3 mm. The impedance of the dummy load is adjusted by moving the inner electrode to vary the effective coupling surface between the outer and inner electrodes. Since the maximum designed voltage was 40 kV, the gap width between the inner and outer electrodes was determined to be 20 mm by assuming that the limitation of the electric field strength of water was 2 kV/mm. The length of the inner electrode, L is given by

$$L = \frac{\sigma d}{2\pi r Z},$$

where σ is the resistivity, d the gap width between the electrodes, r the radius of the coaxial electrode and Z the minimum impedance. The L was determined to be 200 mm, by giving σ=50 Ωm, d=20 mm, r=150 mm and Z=5.0 Ω. The power is absorbed into water between electrodes. The water flow was determined to be 300 l/min. to keep the temperature rise within 5 °C.

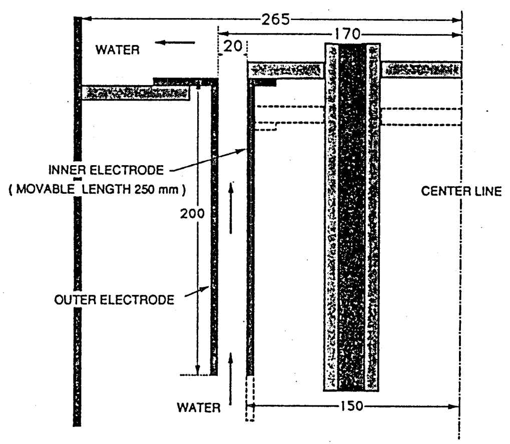

Fig. 3. A cross section of the coaxial electrodes.

Cooling-water system

In the dummy load using water-resistor, the controls of both the input temperature and the electrolyte of the water are very important to keep the impedance stably. Thus, a cooling-water system with a closed-loop and high precision temperature control using a heater was adopted to realize these requirements [2]. A flow diagram of the cooling-water system is shown in Fig. 4.

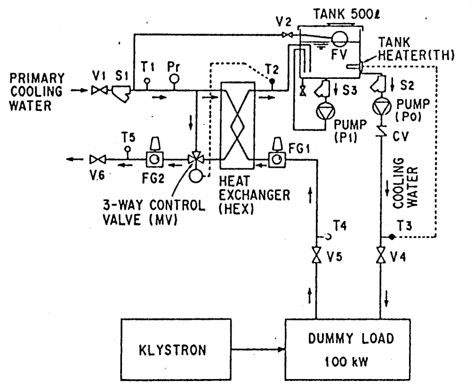

Fig. 4. Flow diagram of the cooling-water system.

It consists of a tank with a heater (TH) and pump (P1), a circulating pump (P0), a heat exchanger (HEX) and a three-way valve (MV). The tank has a capacity of 500 litters, a 5 kW heater TH to control the water temperature, and the P1 to keep the water temperature uniformly. The P0 has a rated delivery of 300 l/min. and a discharge pressure of ~ 2.5 kgf/cm^2. As a primary cooling-water, we use the laboratory cooling-water system. In order to control the temperature of the cooling-water with an accuracy of ± 0.5 °C, the controls of the MV and the TH are carried out by the feedback control (PID) using the thermister sensor T2 and T3, respectively.

Performance tests

Prior to the practical use of the dummy load for a klystron modulator, the characteristics of its load impedance were measured by varying the position of the inner electrode. Figure 5 shows the impedance of the dummy load as a function of the position of the inner electrode at water temperature of 30 °C, 35 °C and 40 °C. The variable width of the impedance was approximately 6 Ω in this range of the temperature.

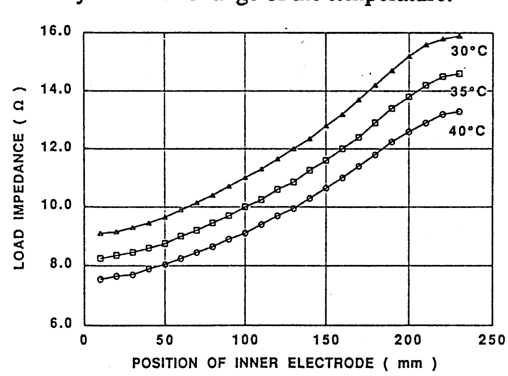

Fig. 5. Impedance of the dummy load as a function of the position of the inner electrode.

After the impedance of the dummy load was set at 11.4 Ω, we performed the high power test under the operation mode of XB-50K. The cooling-water system was controlled at the setting value of 30.0 °C. The waveforms of the input pulses were always monitored by a current transformer and capacitive divider. The 3.0 μs wide pulses with 33 kV voltage, 2900 A current and 200 pps repetition rate were fed to the dummy load. Figure 6 shows the current and voltage of the input pulse and the load impedance. The load impedance Z was calculated from the formula

$$Z = \frac{V_p - L\frac{dI_p}{dt}}{I_p - C\frac{dV_p}{dt}},$$

where V_p, I_p, L and C are the voltage of the input pulse, the current of the input pulse, and total inductance and capacitance of both cables and the dummy load, respectively. The total inductance L and capacitance C were estimated to be ~ 410 nH and ~ 8 nF, respectively.

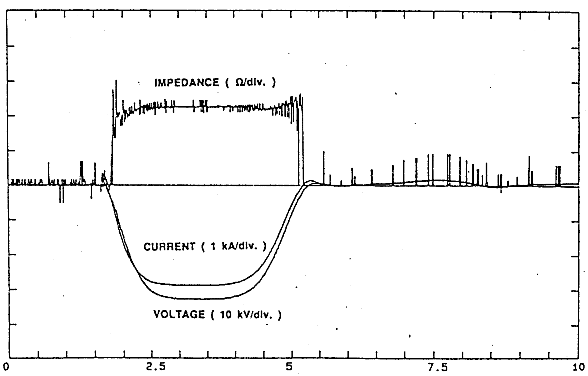

Fig. 6. Input pulse current, voltage and impedance at the dummy load.

At the same time, we monitored the temperatures at T1, T3 and T4 which are indicated in Fig. 4. Figure 7 shows the temperatures at T1, T2 and T3 as a function of time. The input temperature (T3) of the dummy load was sufficiently controlled during 12 minutes from the start. After that it slowly increases due to the poor capacity of the primary water-cooling system as seen in the temperature T1. The average power absorbed to the dummy load was estimated to be 60 kW from the temperature rise, which was in good agreement with that from the output power of the klystron.

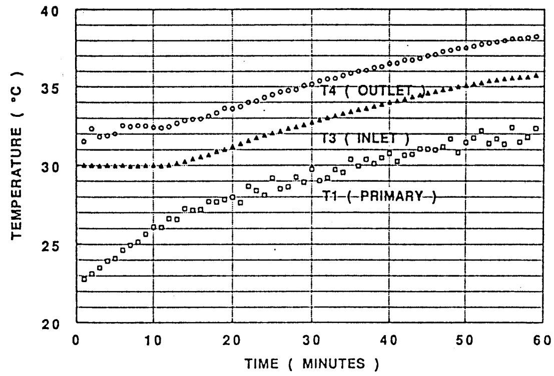

Fig. 7. Temperatures at T1, T3 and T4 as a function of time.

Summary

A dummy load using water as a resistor has been designed and constructed for the high power test of the klystron modulator whose peak voltage, average power and impedance are 37 kV, 100 kW and 5 ~ 12 Ω, respectively. The high voltage of 33 kV and the average power of 60 kW were applied without any serious problem and the impedance could be controlled with the impedance of 11.4 Ω. Future study to improve the stability of the long time will be made.

Acknowledgements

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References

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2. M. Akemoto et al.,"A Cooling-Water System for the Accelerator Test Facility," IEEE Particle Accelerator Conference, May 1991.