L-band Pulsed Klystron For The JHP

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ABSTRACT

An L-band high-power klysrton for the JHP (6 MW output power and 600 μsec pulse width) was designed at KEK. High-power tests of the test diodes were performed up to a beam voltage of 140 kV, a pulse width of 600 μsec and a repetition rate of 50 pps. The capability to meet the specifications of the gun and the collector was confirmed. High-power tests of the rf window were also performed up to rf powers of 4 MW (600 μsec pulse width) and 5 MW (375 μsec pulse width). We obtained good results for an rf window using high-purity alumina (99.7%). The design considerations and manufacturing process are also described. Manufacturing a prototype tube has been completed and the tube is undergoing the high-power tests.

I. INTRODUCTION

The 1-GeV proton linac for the Japanese Hadron Project (JHP)[1], which is now under development at KEK, requires 36 L-band klystrons in its high-β section. Although the klystrons will be operated at an rf output power of 4 MW under an unsaturated condition, an output power of 6 MW is required in order to achieve reliable operation. The specifications of the L-band high-power klystrons are given in Table 1.

A Thomson TH2104A klystron has been operated in order to test accelerator structures and waveguide components at the testing hall[2]. The power capability of this tube was less than what we desired. Since the performance of the klystrons is a key ingredient for the successful operation of the rf system, manufacturing the prototype klystron so as to meet our desired value has been planed. For manufacturing a reliable klystron, we must carefully consider not only the tube design, but also the manufacturing process. This report describes the tube design, the manufacturing process, the test diode operation, a high-power test of the rf windows and the current status of the prototype tube.

II DESIGN OF KLYSTRON

A. *Gun Design*

A breakdown analysis of the gun showed that the gun design for a pulse width of 600 μsec would be similar to one for cw operation. Since we adopted the same cathode as that of the SLAC-5045 S-band klystron[3], 5045-tube operation at a beam voltage of 320 kV with a pulse width of 5 μsec corresponded with operation at 182 kV and 600 μsec, respectively, from the view point of the voltage enhancement factor described in ref.[4]. It was considered that a Spectra-Mat scandate dispenser cathode of 9 cm in diameter would be reliable based on experience at SLAC. The average peak current density of the cathode was 1.63 A/cm^2 in our case. Since the drift-tube diameter was chosen to be the same as that of the S-band case, although it needed a stronger focusing field than the usual design value, it was an advantage in that the third harmonic was cut-off.

Table 1 Specification of the klystron

Frequency	1296	MHz
Peak Beam Voltage(Max.)	140	kV
Peak Beam Current(Max.)	104	A
Beam Pulse Width(Max.)	600	μsec
Repitition Rate(Max.)	50	pps
Peak Beam Power(Max.)	15	MW
Average Beam Power(Max.)	450	kW
Peak RF Power(Max.)	6	MW
Average RF Power(Max.)	180	kW
Efficiency	>40	%
Gain	>50	dB
No. of Cavity	5	
Cathode/Gun	BI Cathode/Diode Type	
Focusing Magnet	Electromagnet	

B. *Collector*

It was required that the collector have a sufficient capability when the full beam power was dissipated in the case of no drive rf power. We imposed two limitations: that the average power density over the collector be less than 200 W/cm^2, and that the maximum power density be less than 300 W/cm^2. A beam analysis was performed using the EGUN code[5] and the relativistic universal curve formula. Finally, our collector was chosen to be approximately 25 cm in diameter and 90 cm long. A thermal analysis was also conducted under the assumption that the collector be water-cooled by flowing water through grooves on the outside of the collector with a very high Reynolds number in order to achieve an efficient heat transfer. We found that the temperatures of the inside and outside of the collector were approximately 100 and 150 °C, respectively, under a water flow rate of 240 *l*/min. Figure 3 shows the simulation results.

C. *Interaction Region*

For the interaction region, 5 integrated cavities were adopted based on a consideration of the power gain. A second-harmonic cavity was not used for the first design. The rough configuration of the cavity location was established from the data of the existing high-power pulse tube by using a scale law of the reduced plasma wavelength and operating frequency. The one-dimensional disk-model code (JPNDISK)[6] and the 2.5-dimensional FCI code[7] were used to optimize the cavity location and frequency. The focusing magnetic distribution near to the cathode was very similar to that of the SLAC-5045 case, due to the same gun dimensions. The length from the input cavity to the output cavity was approximately 68 cm. The length between the penultimate and the pre-penultimate cavity was chosen to be long in order to increase the efficiency. An FCI analysis for optimizing the parameters showed that an efficiency of more than 55% is possible.

D. *RF Window*

The window was designed as the conventional pill-box type, of which length was approximately $\lambda/4$, using an alumina ceramic with a diameter of 19 cm. Two window designs corresponding to the different material were made (see Sec.5). There was a water-cooling jacket over the window ceramic sleeve. It was necessary to study reliable manufacturing and brazing techniques for the window assembly. A TiN(O) coating to prevent multipactoring was also considered. The thickness of the film was determined based on experience with the window of the cw UHF klystron used in TRISTAN. It was chosen to be approximately 60 Å.

F. *General*

The output window was mounted in a straight output waveguide, which was similar to that of the Thomson TH2104A tube. In order to avoid any direct emission of secondary electrons or X rays from the output cavity gap, it was slightly changed and the size of the output waveguide at the iris position was chosen to be small. Overall tube size was approximately 2.4 m. The size of the electromagnet was approximately 62 cm in diameter and 88 cm long.

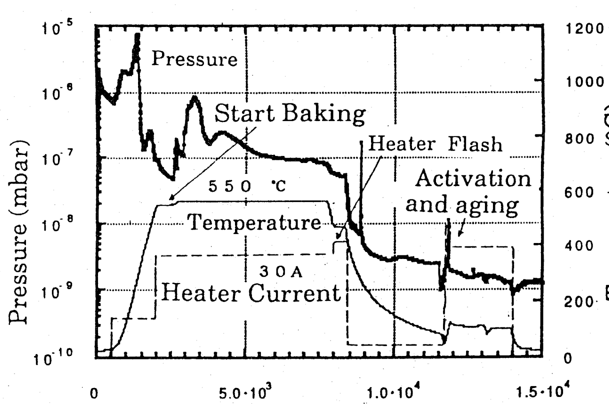

Figure 1. Processing data of baking tube.

III. MANUFACTURING PROCESS

In order to study the entire process of manufacturing the tube, tube design and part of the processing were carried out at KEK. Machining and brazing/welding tube parts were carried out at Mitsubishi Heavy Industry(MHI). At first, the materials used in the tube were carefully chosen; especially, stainless steel, which is used for the focusing electrode, was chosen to be vacuum-melted 316L; the inside copper material was chosen to be copper of class-1 grade according to the ASTM standard. An induction heating vacuum furnace used in cathode processing was designed at KEK; cathode processing and its evaluation were performed at MHI under collaboration with us. An evacuation-baking furnace was introduced at KEK; tube baking at 550 °C for about 150 hours and pinching-off the tube were carried out at KEK. Other necessary processing, such as heater-firing processing and voltage aging (high-voltage processing), were also performed at KEK. For the rf interaction region, cold-test measurements of the cavities were conducted by changing the cavity wall diameter at MHI; the final dimensions were determined. Our entire processing schedule was based on that of the SLAC tube-manufacturing division. Figure 1 shows the processing data at the evacuation-baking furnace.

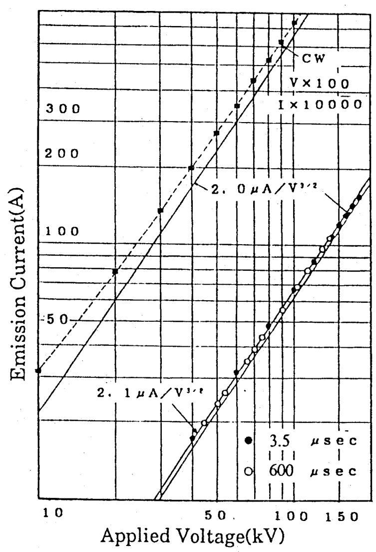

Figure 2. The emission characteristcs

IV. PERFORMANCE OF A TEST DIODE

High-power tests of the test diode were performed in order to check the gun performance and the power-dissipation capability of the collector as the first step. The first test diode was operated up to a beam voltage of 137 kV, a pulse width of 375 μsec and a repetition rate of 10 pps. It failed due to a melt-down of the collector. We found a misalignment of the gun assembly of the demountable structure. A second test diode was redesigned and tested; it was operated up to the 180 kV beam voltage with a short pulse width of 3.5 μsec and 50 pps repetition rates without any faults, and operated up to the 140 kV beam voltage with a long pulse width of 600 μsec and 50 pps repetition. The emission characteristics were investigated, and the Spectra-Mat cathode operated satisfactorily under the long pulse-width condition. Figure 2 shows the emission characteristics as a function of the applied voltage. The perveance of the tube slightly depended on the heater wattage, due to the characteristcs of the scandate dispenser cathode. We measured the temperature distribution of the collector by setting several thermocouples at the collector wall. Figure 3 shows a comparison between the measured temperature distribution and the computer simulation. The results show that the collector had sufficient capability for full beam power dissipation. The fault-rate data were accumulated during high-voltage processing by changing the pulse width and repetition rates. Finally, we obtained a fault rate of less than 0.5 faults/hr. under full power conditions after 500 hr. of running. Since we repeated similar processing from low to high duty in order to investigate the voltage processing carefully, we needed a long total running time to complete the processing.

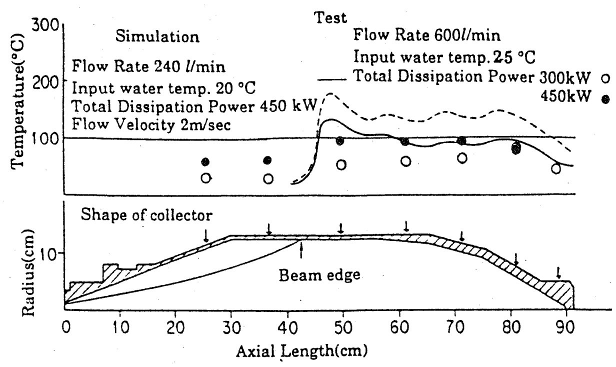

Figure 3. Test and calculation results of the collector .

V. HIGH-POWER TESTS OF THE RF WINDOW

Since the average rf power reaches 180 kW, the rf window was also a key part of the klystron components. The important items concerning an rf window include the type of alumina ceramic material and thickness of the TiN(O) film used to suppress multipactoring. The first design of the window was made using HA95 (95% alumina ceramic, NTK), and high-power tests were conducted[8]. Since the Mo-Mn meteraizing method for high-purity alumina was recently developed, the latest design of the window was made using HA997 (99.7% alumina ceramic, NTK); high-power tests were performed. Furthermore, a measurement of an effective tanδ of the TiN(O)-coated alumina using the special cavity; we found that the effective tanδ of the HA997 was 1 order as small as that of the HA95[9].

The high-power tests were carried out up to an rf power of 5 MW with a 375 μsec pulse width and 4 MW with 600 μsec using the Thomson TH2104A klystron. Two windows (HA997,TiN(O) film of 60Å and 100Å) were mounted in the waveguide system and the waveguide between the 2 windows was evacuated. The inside pressure was 10^{-9} Torr after 100 °C baking for one week; this pressure was considered to be the same condition as that inside the klystron. The other sides of the windows were filled with 1.5 kg/cm^2 SF_6 gas. The temperature at the center of the window was measured by an infrared thermometer. The power loss was also measured based on the temperature rise of the cooling water in the window jacket. We found that the center temperature of the HA95 was 78 deg.[8], and that of the HA997 was 4.5 deg. at a 5 MW rf power and a 375 μsec pulse width. A more precise analysis was reported at this conference[9]. We can say that the HA997 material is promising for our propose.

VI. STATUS OF THE PROTOTYPE KLYSTRON

The first prototype was completed at the beginning of this year, and has been installed in the test stand. We had experienced several problems, such as imperfect brazing and mistakes during processing. The schedule of tube manufacturing was therefore delayed and some parts slightly deviated from the original design. Figure 4 shows a picture of the first prototype. The heater-firing processing has been performed so as to lower the inside pressure. We will soon start voltage aging and a high-power rf test. Since the HA95 window was adopted in this prototype, there might be a some limitation to the peak output power. We also have a plan to make our next tube after evaluating the first tube.

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[8] Y.Takeuchi et al., "Development of L-Band Pillbox RF Window", Proc. of the 8th Symp. on Acc. Sci. and Tech., RIKEN, Wako, Japan, 1991. / There was a possibility that the temperature of the HA95 was less than the described value after a more pricise calibration.

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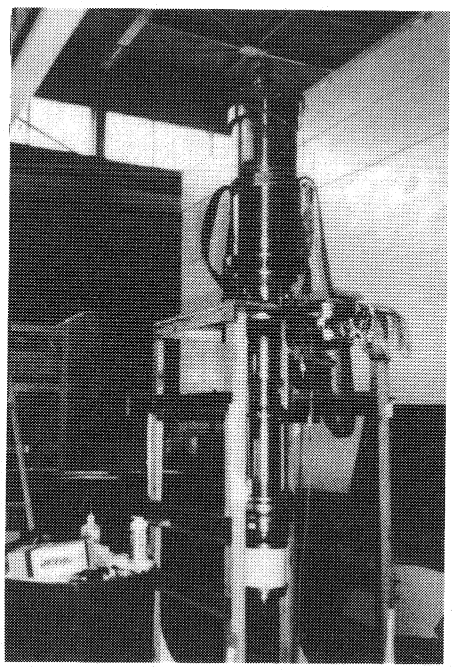

Figure 4. Potograph of prototype klystron.