PERFORMANCE OF A 324-MHZ KLYSTRON FOR A HIGH-INTENSITY PROTON ACCEREATOR

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Abstract

A 324-MHz high-power pulsed klystron with a modulating anode has been developed as an rf source for the 200-MeV proton linear accelerator in the High-Intensity Proton-Accelerator Facility. A maximum power of 3 MW and a working power of 2.5 MW are required to feed the power to RFQ, DTL and SDTL structures. This tube is pulse-operated with an rf pulse width of 600-650 μsec and a 50-pps repetition rate. Seven klystrons were manufactured up to April in 2002. At the first stage of development, undesirable oscillations due to back-streaming electrons from the collector and some instabilities were observed. After intense studies and modifications of the critical parts, we could obtain klystrons with the specified requirements. We have already ordered 16 more klystrons for this project. At the same time, a proton-beam test has been conducted at the KEK facility. This paper describes the development and performance of the 324-MHz klystron.

1 INTRODUCTION

The KEK/JAERI Joint Project, an accelerator complex, comprises a 600-MeV proton linac, a 3-GeV rapid-cycling synchrotron and a 50-GeV synchrotron [1]. The 600-MeV linac comprises a 200-MeV, 324-MHz low-β section, a 972-MHz section from 200 MeV to 400 MeV and a 972-MHz super-conducting section from 400 MeV to 600 MeV. Recently, due to a budget shortness, the construction of the last two linac sections was postponed to the Phase II plan. The development of the 60-MeV linac in KEK started as a low-energy front of this KEK/JAERI project, comprising a negative hydrogen-ion source, a 3-MeV RFQ linac, a 50-MeV DTL and a SDTL [2]. The accelerating frequency is 324 MHz. High-power, high-duty rf sources are required for these structures and a 324-MHz klystron with a modulating anode has been manufactured as the rf power source. Although the maximum rating of the klystron is 3-MW for 600-650 μsec rf pulse duration and a 50-pps repetition rate, the actual working level of the klystron is 2 MW. Thus, because working rf power must be well controlled both in amplitude and phase, the klystron is required to generate a saturated output power of 2.5 MW at the same duty and voltage. It is operated therefore at a 2-MW output power level by controlling the drive power. Since a klystron with a modulating-anode is used, modulating-anode power supplies with a vacuum tube and a semi-conductor as the switching device were developed and tested. Both modulators have been successfully operated in a test facility of KEK shown in Fig. 1.

Detailed specifications of this klystron have already been reported [1]. Seven tubes were manufactured to develop the full specification. The development of prototype tubes is described in chapter 2, and the final development is described in chapter 3 of this paper.

Figure 1 Klystrons, waveguide systems and control cabinets in 324-MHz klystron gallery in KEK.

2 PROTOTYPE KLYSTRON

Strong spurious oscillations were observed in the first test of the prototype klystron. These occurred under high-voltage operation in the voltage range of 65-72 kV, higher than 90 kV without any drive input power. The oscillation frequency was nearly the same as the operating one. After experimental investigations, it was clarified that the backstreaming electrons scattered in the collector induced these strong oscillations. This was confirmed by impeding the backstreaming electrons under a weak deflecting magnetic field in the collector. This phenomenon was also analyzed by a computer simulation, including the effect of scattered electrons at the collector wall, calculated using the EGS4 code [3]. It was then clarified that this phenomena was the same those widely observed in the TWT and magnetron devices [4]. In the prototype klystron design, the diameter of the tube determined by the frequency-scaling low was larger than the cathode diameter. Therefore, the drift-tube diameter near to the cathode was chosen to be smaller than it, and then the diameter was expanded in order to reduce the focus magnetic field strength. The amount of back-streaming electrons was shown to be determined by the aspect ratio of the drift-tube diameter to the collector-diameter. A detailed analysis showed that the smaller was

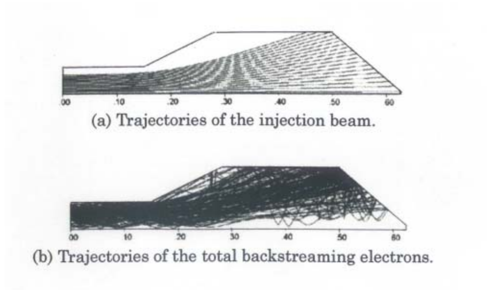

Figure 2 Beam trajectories in the collector of #1A klystron.

this aspect ratio, the greater were the number of backstreaming electrons. In Fig.2, the trajectory examples of the prime beam and the backstreaming electrons in the collector region are shown. From a simulation using the EGS4 code, it became clear that the backstreaming electrons could be decreased by using a larger-diameter collector or a smaller drift-tube diameter [5]. Several experiments using klystrons with different collector shapes were performed to eliminate these oscillations as well as associated unstable phenomena related to the input drive power. The test results after changing the collector diameter are summarized in Table 1. Clear improvements were obtained by these changes of the collector size. Finally, we obtained the performance, as shown in Fig.3. Nearly a 3-MW output power and an efficiency of 52% were obtained when the anode voltage was applied at a value 10% higher than the nominal dividing ratio between the cathode and the modulating anode voltage for a cathode voltage of 105.6 kV. These proto-type klystrons are now being used for high-power tests of the waveguide components and accelerator structure in a new klystron gallery at KEK.

Table 1 Collector shapes and experiment results for the oscillation threshold beam voltage.

Tube	Collector radius (cm)	Collector length (cm)	Oscillation threshold beam voltage (kV)
#1	6.5	62.4	63<V<71, 90<V
#1A	11.5	92.4	95<V
#2	11.5	122.4	104<V or no-oscillations up to 110kV

3 NEW DESIGN

In order to aim for more stable operation, a newly designed klystron, based on a more simple structure with a constant drift-tube diameter, was developed at Toshiba Corporation. In this design, the aspect ratio of the drift-

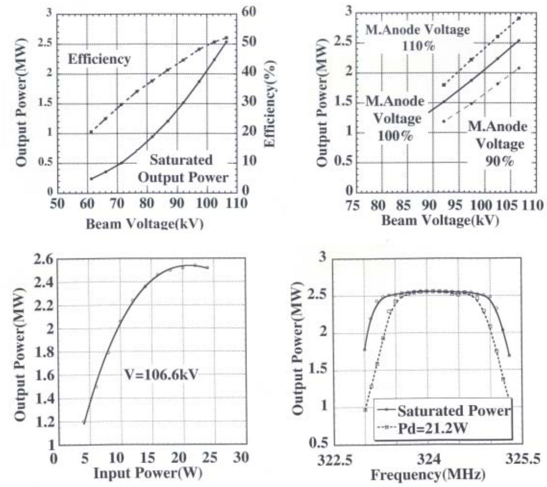

Figure 3 Performances of the prototype klystron #2.

tube diameter to the collector-diameter was chosen to be larger than that in the prototype klystrons. In order to achieve this design, the whole focusing magnetic field strength was increased from 200 to 350 Gauss. An example of the modulating anode gun design [6] calculated using the EGUN code is shown in Fig. 4.

This new tube was manufactured and tested in 2001. Though no spurious oscillation was observed in this new tube's performance, a slight instability was observed in the relation between the input and output characteristics. Since this was thought to be undesirable when we perform the amplitude and phase feedback control, an intense investigation was conducted. This instability involved very high-frequency components at around 1500 MHz. A further experimental investigation, by changing the focusing field and tuning each cavity, showed evidence that stray electrons caused the instability at the intermediate klystron cavity region. By choosing the proper magnetic field at this region, we succeeded in to suppress this instability. Partly, this instability may be

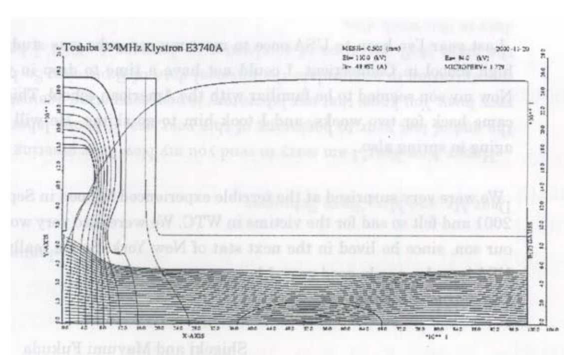

Figure 4 Beam trajectories in the gun region of newly developed klystron.

related to the high gain characteristics of about 60 dB, since the Q value of the first cavity was chosen to be larger than before. The final tube has an improved design and tuning for the intermediate cavity. A maximum output power of 3.04 MW was achieved at a cathode voltage of 110 kV, and an anode voltage of 95.8 kV. Practical operation outputting 2.5-MW power, which requires two focusing coil power supplies and the standard setting of the modulating-anode and cathode voltages giving the specified beam perveance, was achieved at a beam voltage of about 104 kV and an efficiency of about 56%. These data are shown in Fig. 5 and the waveforms are shown in Fig. 6.

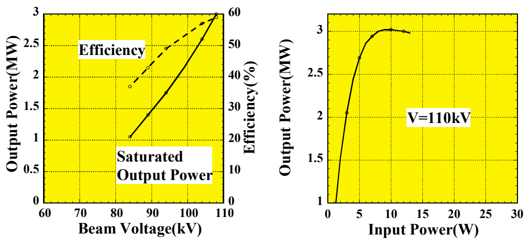

Figure 5 Characteristics of the newly developed klystron.

Since in this operation mode, the working point is chosen to be in a region of 10-20% lower than the saturation level in the range of the input drive power, this obtained result was satisfactory. We had tested 7 klystrons, and so far had no serious troubles, such as arcing, which the crowbar circuit started to act on. During high-power evaluation tests, troubles with the dummy load were experienced at a 3-MW output power with a 620-μsec pulse width and a 50-pps repetition rate. It was thus necessary to improve the high-power coaxial dummy load. The klystron window's performance was operated without any serious troubles. The original design adopted forced air-cooling to the window. We recently changed it to water-cooling after considering the maintenance. From a practical usage point of view, it was necessary to reinforce the X-ray shield of the klystron, though it is equipped with a lead shield at the region from the gun to the drift-tube and the collector region. Measuring the X-rays from the klystron at the full rating was performed and used to develop a compact X-ray shield. An additional shield was set in the region from the penultimate cavity to the output cavity. Therefore, a complete full model suitable for installing in the klystron gallery of the 200-MeV proton linac was established.

An rf feedback study and high-power component tests given in reference [7] were performed using this klystron in the gallery. High-power tests of the RFQ, DTL and SDLT structures [8] were also performed using these 324-MHz klystrons.

4 SUMMARY

The development of a 324-MHz high-power klystron was successfully conducted and all tubes required for the 200-MeV proton linac were ordered. RF performances including the high-power klystrons were also successfully obtained in the klystron gallery of the test facility of the Joint Project at the KEK. A commissioning study of the front accelerators of the 60-MeV proton linac is now being conducted. From the fall of 2004, the installation of klystrons in the newly constructed building at the Tokai site is scheduled.

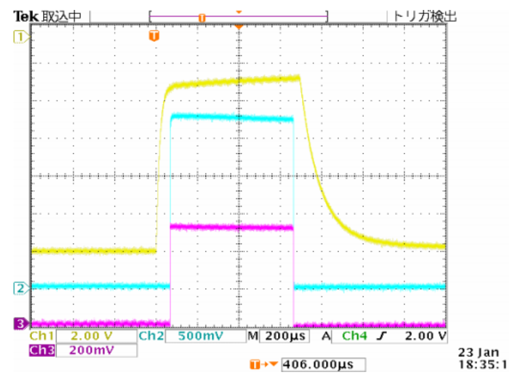

Figure 6 Waveforms of pulsed current from the cathode (top), output RF power (middle) and input RF power (bottom). One division for the horizontal scale is 200 μs.

5 REFERENCES

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