DEVELOPMENT OF THE KLYSTRONS FOR THE HIGH INTENSITY PROTON ACCELERATOR FACILITY

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Abstract

The linac of High Intensity Proton Accelerator Facility requires 324MHz klystrons for the acceleration of less than 200MeV and 972MHz klystrons for the acceleration from 200MeV to 400MeV. Toshiba has developed a 324MHz klystron (E3740) in collaboration with KEK and manufactured prototypes of the E3740 klystron. In initial test, we confirmed our design of an electron gun and a window, which are the key points of the klystron development. This klystron was tested at the test facility of KEK and showed performance of an output power of 2.5MW at a beam voltage of 106.6kV with an efficiency of 52%. The first tube of the 972MHz klystron (E3766) was completed. This klystron is now under testing at the new test facility of JAERI. At preliminary test, this klystron produced an output power more than 2MW at a beam voltage of 97kV with an efficiency of 52%.

1. INTRODUCTION

The Japan Hadron Facility of KEK and the Neutron Science Project of JAERI merged to the High Intensity Proton Accelerator Facility. The facility will provide a highly intense proton beam for neutron scattering experiments and nuclear physics experiments. The accelerator complex will comprised a 400MeV linac, a 3GeV rapid cycling synchrotron and a 50GeV synchrotron. The facility will be established at Tokai site of JAERI. [1] The proton linac requires 20 klystrons operating at 324MHz for the acceleration of less than 200MeV, and 23 klystrons operating at 972MHz for the acceleration from 200MeV to 400MeV. The block diagram of the linac is shown in Figure 1.

Required RF power for the cavities of linac is 0.5MW to 2.0MW. The klystron will operate in the RF power range of 80 to 90% of a saturated power. The design parameters for the 324MHz klystron (E3740) and the 972MHz klystron (E3766) are shown in Table 1.

The design and test results on the two types of new klystrons are presented

Table 1:Design parameters of the E3740 and the E3766

Parameter	E3740	E3766
Frequency	324MHz	972MHz
Structure	5 cavities	6 cavities
RF Window	Coaxial WR-2300	Pill Box WR-975
RF Pulse Width	650 μ sec	650 μ sec.
Repetition Rate	50pps	50pps
Beam Pulse Width	700 μ sec	700 μ sec
Beam Voltage	110kV	110kV
Anode Voltage	94kV	94kV
Beam Perveance	1.37 μ perv.	1.37 μ perv.
Output Power	3MW	3MW
Efficiency	55%	55%
Gain	50dB	50dB
Tube Length	4550mm	2930mm

2. INITIAL TEST [2]

Firstly, a test diode and coaxial type window were built and tested. The purpose of the diode test was to verify the perveance, reliability of the gun under a high voltage near to 120kV and the beam transmission predicted by the electron trajectory simulation. In this test, we obtained stable performance at the cathode voltage of 110kV and the beam perveance was 1.33 microperv. That value was agreed with the design value. In addition, no serious breakdown was observed.

Output window for klystron was also tested separately. We designed and tested a 432MHz coaxial type window instead of 324MHz one, so that the existing 432MHz RF source could be applied. The coaxial line is converted to a rectangular waveguide of WR-1800 through a coaxial

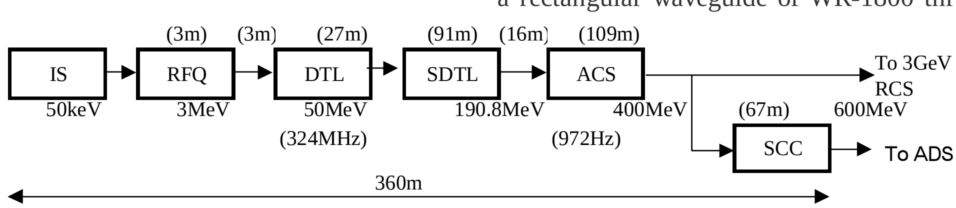

Figure 1: The block diagram of linac

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to waveguide transition. The purpose of the test was to verify the reliability of a high power operation up to 2MW and RF transmission estimated by the computer simulation code HFSS. The window was tested up to the peak power of 2MW with the pulse width of 650 microseconds and the repetition rate of 50pps at KEK test facility. Although some glow on the surface of the ceramic near the inner conductor was observed, but no serious breakdown was found. We started on the 324MHz window design based on this result.

3. KLYSTRON DESIGN

3.1 ELECTRON GUN

Symons reported the relationship of an RF efficiency η and beam perveance P (I/V$^{3/2}$) can be expressed as below: [3]

$$\eta(\%) = 90 - 20 \times P(\mu perv.)$$

If a microperveance is to be chosen 1.5, RF efficiency is 60% at the maximum. To compromise requirements of high voltage insulation and also higher efficiency, the operating cathode voltage was decided to be 110kV. Because the gun with modulating anode will be unstable when a cathode voltage is more than 120KV. The E3740 and the E3766 have been designed to operate at a cathode voltage of 110kV and a modulating anode voltage of 94kV with a beam perveance of 1.37microperv. In order to minimize the cost of a power supply, we selected the same operating voltage and beam perveance for both klystrons.

Results from EGUN [4] indicated that additional bucking coil might improve beam trajectory. Figure 2 gives an example of simulation of the E3740 klystron. The beam diameter is 30mm, and the diameter of drift-tube is 48mm and the beam ripple is less than 3%.

In case of the E3766 klystron, the beam diameter is 21mm, and the diameter of drift-tube is 30mm and the beam ripple is less than 2%.

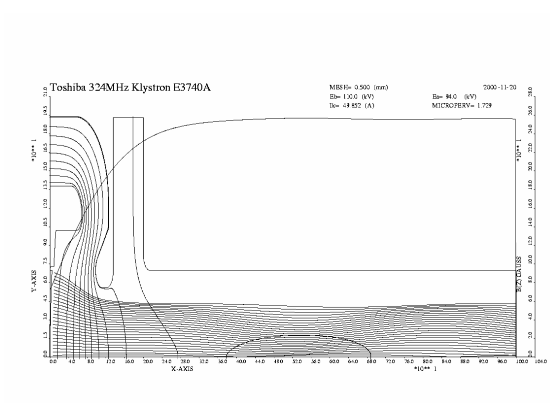

Figure 2: Modulating anode gun design of E3740

An "M"-type cathode [5] is adopted in order to assure the long life and the stable emission.

As mentioned in the reference, the gun surface gradients must be limited to be about 75kV/cm in DC operation. [6] Results from simulation indicated that the surface gradients are less than 65kV/cm at the cathode voltage of 120kV.

3.2 INTERACTION CAVITIES AND BEAM SIMULATION

The E3740 is a five-cavity klystron. The second-harmonic cavity is used to enhance RF efficiency. The second-harmonic cavity was located between the second and third fundamental cavities. The parameters of interaction cavities were optimised using DISK[7] (a one-dimensional, large-signal klystron code), and FCI [8] (Field Charge Interaction 2+1/2 PIC code).

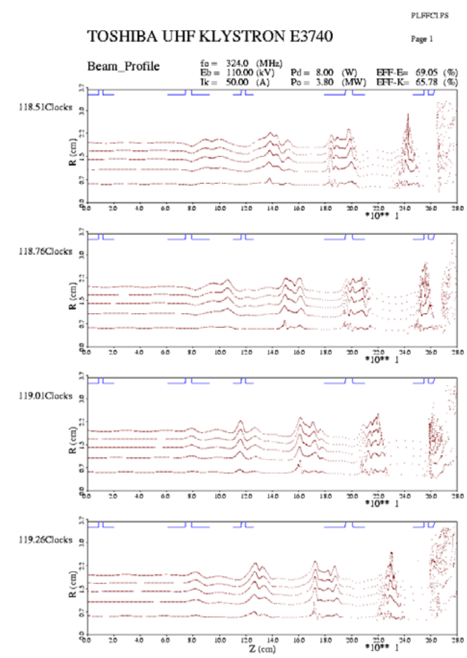

Figure3: FCI Simulation Result
(Vbeam=110kV,Ik=50A,Pd=8W,Po=3.8MW)

A bandwidth of 10MHz (-3db) is required for the E3766 klystron. In order to minimize variation of acceleration, output power is modulated at to cancel out the beam loading. The E3766 has six cavities designed for the requirement of a bandwidth. For the wide bandwidth operation, the gap lengths of the second and third cavities were designed longer than those of other cavities, so that the beam loading lowers the Q-values of the cavities. The calculated bandwidth is more than 12MHz (-3dB).

3.3 OUTPUT STRUCTURE

Figure 4 shows the simulation model of the output structure of the E3740. The coaxial line is converted to a rectangular waveguide of WR-2300 through a coaxial to waveguide transition. The calculated Qext was about 13. The right side graph figure 4 indicates as about 13.

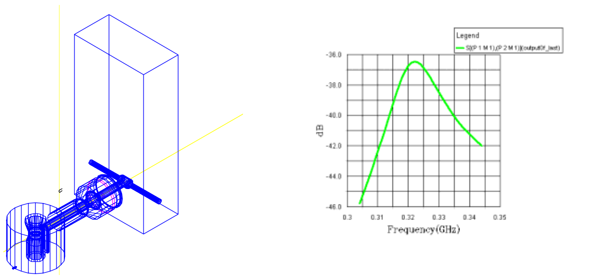

Figure 4: The simulation model and the result of the coaxial type window for the E3740

From the achievement of a 915MHz 200kW CW klystron, a pillbox window was chosen for the first output window of the E3766. Figure 5 shows simulation model of the output structure of the E3766. The output circuit consists of a standard single-gap re-entrant cavity with an iris into a waveguide. From the space limitation, a low height waveguide was coupled to an output cavity, and transformed to a full height one.

To suppress multipactoring discharge, Al_2O_3 ceramic is coated with a TiN thin layer.

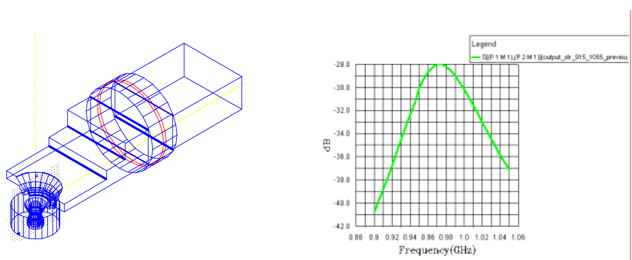

Figure 5: The Simulation model and the result of the output structure of the E3766

4. KLYSTRON PERFORMANCE

4.1 E3740

Figure 6: The E3740 KLYSTRON

Figure 6 shows the photograph of the E3740 integrated with the focusing solenoid and the oil tank. The klystron placed horizontally. The prototype of the E3740 produced 2.5MW at 106.6kV with the efficiency of 52%.

4.2 E3766

Figure 6 shows the photograph of the E3766 klystron. Aging and testing has just started. The preliminary test showed an output power of up to 2MW at a beam voltage of 97kV with an efficiency of 52%. The instantaneous bandwidth observed is 17MHz at -3dB.

Figure 7: The E3766 KLYSTRON

5. CONCLUSION

The E3740 and the E3766 produced the enough RF power required for the linac of the High Intensity Proton Accelerator Facility. However it seems there is some room to improve efficiency. The first tube of the E3740 production model with modified cavities is now testing. Regarding the E3766, we have been continuing the first prototype test to confirm the reliability. We are going to start designing the production model based on the results of first prototype described in this paper.

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