THE TOSHIBA E3736 MULTI-BEAM KLYSTRON

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Abstract

A 10-MW, L-band multi beam klystron (MBK) for TESLA linear collider and TESLA XFEL has been under development at Toshiba Electron Tubes & Devices Co., Ltd. (TETD) in collaboration with KEK. The TESLA requires pulsed klystrons capable of 10 MW output power at 1300 MHz with 1.5 ms pulse length and a repetition rate of 10 pps. The MBK with 6 low-perveance beams in parallel in the klystron enables us to operate at lower cathode voltage with higher efficiency. By choosing the coaxial cavities operated in TM_{010} mode, the cathode loading can be reduced for long life operation. This klystron is a six-cavity klystron. The 2nd harmonic cavity was employed as the 3rd cavity to satisfy the phase sensitivity requirement due to the change in the beam voltage. Tow pillbox windows with WR650 waveguide were chosen for power transmission. From the space limitation, a low-height waveguide was coupled to an output cavity. The design work and the fabrication have been accomplished and the testing is under way. We started conditioning and testing of prototype #0 from the beginning of August 2004. The preliminary testing up to a beam voltage of 100kV (specification=115kV) demonstrated the output power more than 6.2MW with an efficiency of 59%. The testing at higher voltage will start soon. The design overview and the initial test result at the factory are presented.

INTRODUCTION

Each author The TESLA project is a 33km long 500 to 800GeV electron/positron linear collider.[1] The TESLA X-FEL laboratory is a 1.5km long 20Gev electron linear accelerator for free electron laser application. [2] The superconducting cavity technology is adapted to the accelerators. The 500GeV TESLA project requires 572 klystrons operating at 10MW output power with 1.5ms pulse length. [3]

KEK has investigated a basic design X-band multi-beam klystron as power sources of Global linear collider (GLC) main linac. [4] Our design work started based on our experience of this X-band MBK design. TOSHIBA/KEK team improved the preliminary design to meet the DESY's requirements. The design parameters for the TOSHIBA E3736 klystron are shown in Table 1.

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Table 1: Design parameters of the E3736 MBK

Parameter	Value	Units
Frequency	1300	MHz
Output Power	10	MW
Average Output Power	150	kV
Beam Voltage	115	kV
Beam Current	132	A
Efficiency	>65	%
RF Pulse Width	1.5	ms
Repetition Rate	10	pps
Saturation Gain	47	dB
Number of Beams	6	
Cathode Loading	<2.1	A/cm^2
Structure	6	cavities
RF Window	Pill Box WR-650	
Tube Length	2270	mm
Solenoid Power	<4	KW

MULTI-BEAM KLYSTRON [5]

Fig. 1 shows the cut-away view of the multi-beam klystron E3736.

Symons reported the relationship of an RF efficiency η and the beam perveance P ($I/V^{3/2}$) can be expressed as below: [6]

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

If a microperveance $P(\mu perv.)$ is to be chosen to be 2.0 that are typically selected for the conventional (shingle beam) klystrons operated at 10MW output power, expected RF efficiency is 50% at the maximum. A low microperveance klystron must operate at higher beam voltage. In case of long pulse klystrons, it might be cause of breakdown problem at electron gun and hence reduce the klystron reliability.

By using several low perveance electron beams in parallel in a klystron, a higher RF efficiency is expected due to the lower space charge forces that enable a tighter beam bunching.

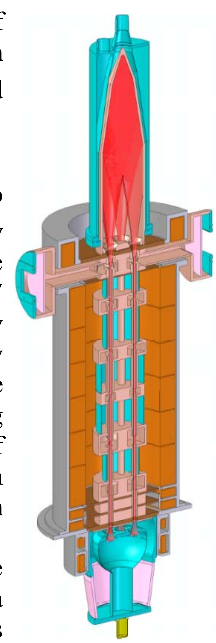

Figure 1: Cut-away view of the TOSHIBA E3736 multi-beam klystron.

For TOSHIBA MBK E3736, 6 low perveance beams of 0.56 $P(\mu perv.)$ are chosen. So achievement of efficiency of over 70% is theoretically expected.

KLYSTRON DESIGN

Design Outline

The simulation model of the input cavity is shown in Fig. 2. The cavities are ring-shaped common cavities operated in TM_{010} mode and 6 beams behave truly in a MBK way. By choosing this type of cavities, the separation of beam-lets are 120mm and the cathode diameter becomes 38mm. Therefore the cathode loading can be reduced to less than $2.1 A/cm^2$ for long life operation. To avoid parasitic oscillations, we investigated high order mode of each cavities.

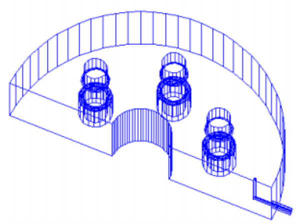

Figure 2: Cross section of an input cavity.

Electron Gun

6 low perveance beams of 0.56 $P(\mu perv.)$ are chosen. By choosing the coaxial cavities operated in TM_{010} mode, the separation of beam-lets are 120mm and the cathode diameter becomes 38mm. Therefore cathode loading can be reduced to less than $2.1 A/cm^2$ so that cathode life time was improved. DGUN [7] indicated that additional backing coils improve beam trajectory. The matching coils located between the gun and the input cavity can adjust the beam diameter.

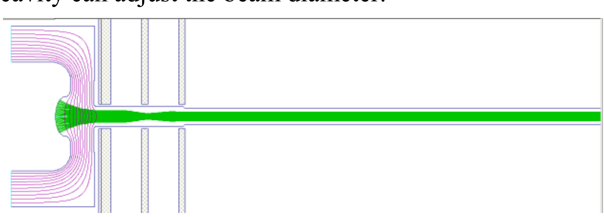

Figure 3: Electron gun design of E3736 MBK.

An "M"-type cathode [8] 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. [9] Simulation results indicated that the surface gradients are less than 60kV/cm at the cathode voltage of 115kV.

One of the critical issues for gun design using off-axis electron beams is actual dimension of the gun at operating temperature. The cold dimension of electron gun was estimated by ANSYS code.

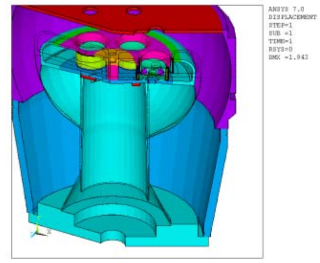

Figure 4: The thermal calculation. Figure 5: The gun.

Interaction Cavities and Beam Simulation

The E3736 is a six-cavity klystron. The 2nd harmonic cavity was employed as the 3rd cavity to satisfy the phase sensitivity requirement due to the change in the beam voltage. The parameters of interaction cavities were optimised by FCI [10] (Field Charge Interaction 2+1/2 PIC code). The simulations show that the efficiency is close to 75% at a drive power of 150W.

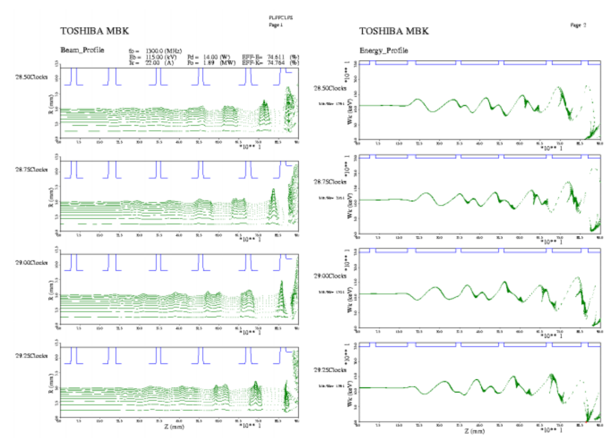

Figure 6: FCI simulation result.

Output Structure

Fig. 7 shows the simulation model of the output structure. Tow pillbox windows with WR650 waveguide were chosen for power transmission. From the space limitation, a low height waveguide was coupled to an output cavity. The matching post located the low height waveguide improves the rf transmission.

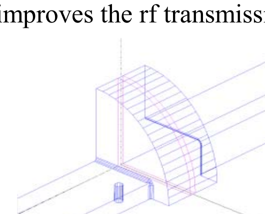

Figure 7: The simulation model of output window.

The calculated Qext of output cavity was about 44. Fig. 8 (right) indicates it as about 44.

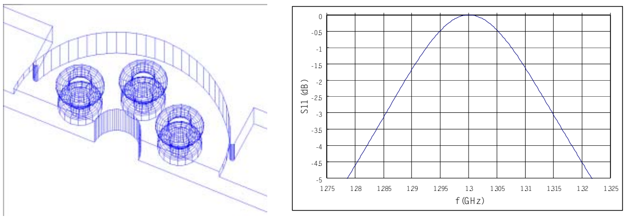

Figure 8: The simulation model and the result of the output cavity.

To suppress the multipactoring discharge, Al_2O_3 ceramic of vacuum side is coated with a TiN thin layer.

KLYSTRON PERFOMANCE

Result of Preliminary Test

Fig. 9 shows the photograph of the E3736 multi-beam klystron. Aging and testing has just started. No parasitic oscillation was found. The beam transmission rate from the gun to the collector was about 99%. At the preliminary test, the prototype #0 produced an output power of up to 6.2MW at a beam voltage of 100kV with an efficiency of 59%. After the beam test up to the beam voltage of 115kV and short pulse rf test, we will start the operation with a full rf pulse of 1.5ms.

Figure 9: The E3736 KLYSTRON.

CONCLUSION

The design and fabrication of the first prototype of E3736, 10MW, L-band multi beam klystron were completed. The E3736 MBK is designed to incorporate the coaxial cavities operated in fundamental mode. By choosing this type of cavities, the cathode loading can be reduced to less than $2.1A/cm^2$ for long life operation. At initial test, no parasitic oscillation was observed. The beam transmission rate from the gun to the collector was about 99%. This result was to verify the beam transmission predicted by the electron trajectory simulation. The preliminary testing of the first prototype up to a beam voltage of 100kV (specification=115kV) demonstrated the output power more than 6.2MW with an efficiency of 59%. The testing at higher voltage will start soon. We expected that the E3736 MBK is able to generate the enough RF power required for the TESLA XFEL and the TESLA linear collider. We have been continuing the first prototype test to confirm the operation at beam voltage of 115kV with a full rf pulse of 1.5ms and reliability. We are going to modify the design for the production model based on the results of first prototype described in this paper.

ACKNOWLEDGMENTS

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