Development of the L-Band Multi-Beam Klystron at Toshiba

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Abstract
A 10-MW L-band Multi-Beam Klystron (MBK) has been under development. The MBK with six low-perveance beams in parallel through the klystron enables us to operate for these required specifications at a lower cathode voltage with higher efficiency. At the initial beam test (without RF), the beam transmission rate from the gun to the collector was measured to be more than 99% at the cathode voltage of 115 kV with 1.7-ms pulse length and repetition rates of 10 pps. No parasitic oscillation was observed. With RF, an output power of 10.3 MW was obtained at 115 kV with an efficiency of 68.4%. The pulse length was extended to 1 ms at this power level at the repetition rate of 10 pps.

1. Introduction

A 10-MW L-band Multi-Beam Klystron (MBK), the Toshiba E3736, for DESY X-FEL and a future linear collider, is under development at Toshiba in collaboration with KEK[1]. The pulsed klystrons for these accelerators are required to provide the 10-MW output power at 1.3 GHz with 1.5-ms pulse length and repetition rates of 10 pps[2].

By using several low-perveance electron beams in parallel, a higher RF efficiency is expected due to the lower space charge force that enables tighter beam bunching. Symons reported the relationship between the RF efficiency η and the beam perveance P ($I/V^{3/2}$) as below: [3]

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

If the micro-perveance $P(\mu perv.)$ is chosen to be large, say, 2.0, which is typical for conventional (single beam) klystrons operated at 10 MW output power, the expected RF efficiency would be limited to 50% at the maximum. If a lower perveance is chosen for the same output power, the klystron needs to operate at a higher beam voltage. For long pulse operation, it will raise concerns on possible breakdown problem at the electron gun and the resulting reduction of the klystron reliability. In the TOSHIBA MBK E3736, six beams with low perveance of 0.56 each are chosen. According to the Symons relationship, this configuration makes plausible an efficiency of over 65%.

2. MBK Design

2.1 Design outline

Figure 1 shows the cut-away view of the multi-beam klystron E3736. The klystron has six beam-lets emitted from the diode electron gun that consists of six cathodes and a focus electrode. There are six cavities in total. The 2nd harmonic cavity was employed as the 3rd cavity. The cavities are all ring-shaped, operated in TM_{010} mode and common for all beams. The electron beams travel through six drift tubes and interact with RF field of the common cavities. Two pillbox windows with the WR650 waveguide were used for power transmission to outside of the tube.

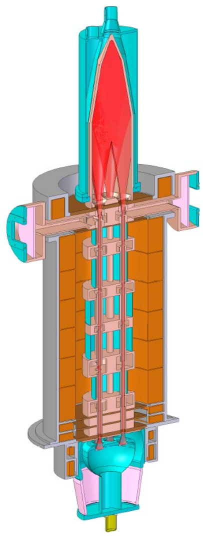

Figure 1: The cut-away view of The Toshiba E3736 Klystron

The design parameters for the TOSHIBA E3736 klystron are listed in Table 1.

Table 1: Design parameters of the E3736 MBK

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

The design goal was to achieve 10-MW peak power with 65-% efficiency at 1.5-ms pulse length at 10-Hz repetition rates. The total beam perveance is 3.38 (the provenance of each single beam is only 0.56).

2.2 Electron Gun

Figure 2 shows the photograph of the gun area with six cathodes.

Figure 2: Electron Gun of the E3736

By choosing the coaxial cavities operated in TM_{010} mode, we succeeded to separate the beam-lets by 120 mm and to make the cathode diameter as large as 38 mm. Therefore, the cathode loading was reduced to less than 2.1 A/cm^2 to improve the cathode life time. The focusing of off-axis electron beams was one of the challenges in the MBK development. The DGUN [4] code indicated that the additional backing coils improve beam trajectory. The matching coils located between the gun and the input cavity can adjust the beam diameter. The “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 75k V/cm in DC operation[6]. Simulation results indicated that the maximum surface gradient is less than 60 kV/cm at the cathode voltage of 115 kV. This result gave us good safety margin with long pulse operation. One of the critical issues for the gun design using off-axis electron beams was the actual dimension of the gun at operating temperature. The cold dimension of electron gun was determined using the ANSYS code.

2.3 Interaction Cavities and Beam Simulation

The simulation model of the input cavity is shown in Figure 3. All the other cavities have similar shapes. To avoid parasitic oscillations, we investigated high order modes of each cavity. All cavities of the prototype have the tuning knobs.

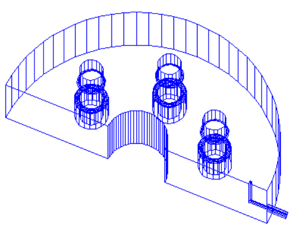

Figure 3: Cross section of an input cavity

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 [7] (Field Charge Interaction 2+1/2 PIC code). The FCI simulations show the efficiency of close to 75% at drive power of 150 W.

2.3 Output Structure

Two pillbox windows with the WR650 waveguide are used for power transmission to the outside. From the space limitation, a low height waveguide was coupled to an output cavity. A matching post is located at each of the low height waveguide to improve the RF transmission. The calculated external Q-value of output cavity was about 44. To suppress the multipactoring discharge, Al_2O_3 ceramic of vacuum side is coated with thin TiN layer.

Klystron Performance

Figure 4 shows the photograph of the E3736 multi-beam klystron. The total length is approximately 2.3 m.

Figure 4: The Toshiba E3736 Klystron

At the initial beam test (without RF), the beam transmission rate from the gun to the collector was measured to be more than 99% at the cathode voltage of 115 kV with 1.7-ms pulse length and repetition rates of 10 pps. This result verified the beam transmission prediction by the electron trajectory simulation code DGUN. Neither parasitic oscillation nor gun oscillation was observed. Then, we started the RF test. The transfer curve is shown in Figure 5. The output power of 10.3 MW was obtained at 115 kV with efficiency of 68.4%. There is no discontinuity by multipactoring or parasitic oscillation in the transfer curve.

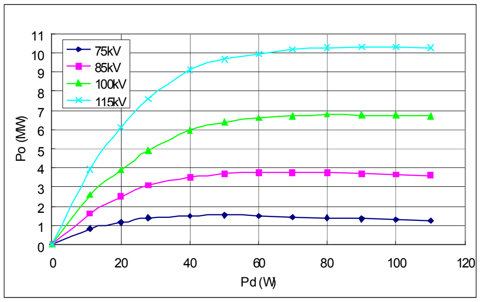

Figure 5: Measured output power vs. RF drive power at 1300 MHz.

The pulse length was extended to 1 ms at repetition rates of 10 pps. There is about 8% sag on the HV pulse. The HV pulse drops from 115 kV to 105 kV at the end. Therefore the average voltage is about 110 kV. To reduce the sag of the power supply, we plan to increase the voltage at the beginning of the pulse and achieve an average power of 150 kW in near future.

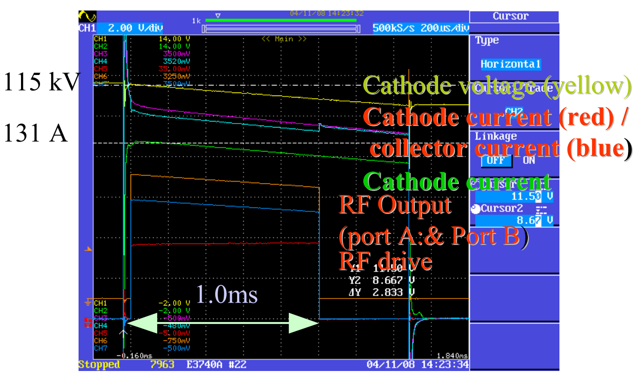

Figure 6: Waveforms

Conclusions

The design and fabrication of the first prototype of E3736, the 10-MW L-band multi-beam klystron was completed. At the initial beam test (without RF), the beam transmission rate from the gun to the collector was measured to be more than 99 % at the cathode voltage of 115 kV with 1.7-ms pulse length and repetition rates of 10 pps. No parasitic oscillation was observed. With RF, the output power of 10.3 MW was obtained at 115 kV with efficiency of 68.4%. The pulse length was extended with RF to 1 ms at repetition rates of 10 pps. The test performance was in good agreement with the simulation results. The E3736 MBK produced the enough peak power required for the DESY XFEL and a future linear collider. We are continuing the prototype test to confirm the operation at beam voltage of 115 kV with a full RF pulse of 1.5 ms and with good reliability.

Acknowledgments

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