DEVELOPMENT OF 10 MW L-BAND MULTI-BEAM KLYSTRON (MBK) FOR EUROPEAN X-FEL PROJECT

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Abstract

A 10MW L-band Multi-Beam Klystron (MBK) has been developed and tested by Toshiba, Japan for the European XFEL and a future linear collider projects. The Toshiba MBK has six low-perveance beams operated at low voltage of 115kV (for 10MW) and six ring-shaped cavities to enable a higher efficiency than a single-beam klystron for a similar power. After the successful acceptance testing at the Toshiba Nasu factory in March 2006, attended by a DESY stuff, the final acceptance test was done at DESY laboratory in June 2006. In these tests, the output power of 10.2MW, more than the design goal (10MW), has been demonstrated at the standard beam voltage of 115kV at the RF pulse length of 1.5ms and the beam pulse of 1.7ms at 10Hz. The efficiency was 66%. The robustness of the tube was also demonstrated by being operated continuously more than 24 hours above 10MW. Total time of operation on the test stand at DESY already exceeds 750 hours (upto date February 4, 2007). A horizontal version of the Toshiba MBK is now under construction.

INTRODUCTION

A 10-MW L-band Multi-Beam Klystron (MBK), the Toshiba E3736[1,2], for European XFEL and a future linear collider, 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[3]. Thales and CPI are developing MBKs of different design for the same specifications for DESY. 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:

$$\eta(\%) = 90 - 20 \times P(micro - perveance).$$

If the micro-perveance P 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% (the theoretical limit is now 79%).

MBK DESIGN

Design Outline

Figures 1 (left and right) show the cut-away view of the Toshiba MBK E3736 and its photograph, respectively. The total length is approximately 2.3 m.

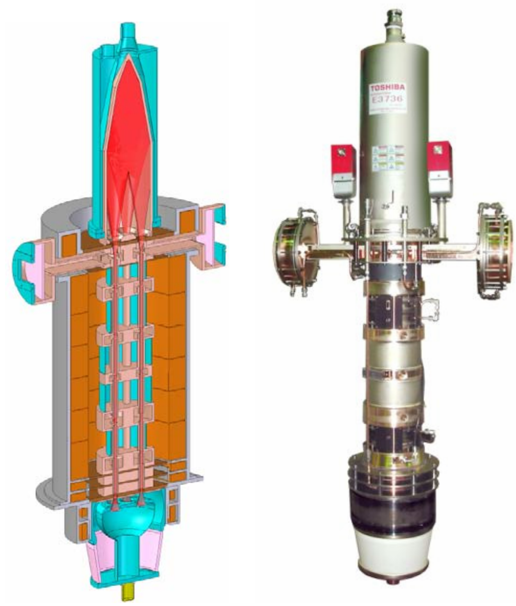

Figure 1: The cut-away view (left) and the photograph (right) of Toshiba MBK, E3736.

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 to keep the total length of the klystron within the specification. The cavities are all ring-shaped, operated in TM010 mode and common for all beams. The electron beams run straight up through six drift tubes and interact with the RF fields of the common cavities. Two pillbox windows with the WR650 waveguide were used for power transmission to outside of the tube.

The design parameters for the Toshiba MBK E3736 are listed in Table 1. 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 perveance of each single beam is only 0.56).

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Table 1: Design parameters of the E3736 MBK

Frequency	1300	MHz
Output Power	10	MW
Average Output Power	150	kW
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	<2.0	A/cm^2
Structure	6	cavities
RF Window	Pill Box WR-650	
Tube Length	2270	mm
Solenoid Power	<4	kW

Electron Gun

Figure 2 shows the photograph of the gun area with six cathodes. By choosing the coaxial cavities operated in TM010 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 2.0 A/cm2 to improve the cathode life time. The focusing of off-axis electron beams was one of the challenges in the MBK development. The DGUNcode indicated that the additional backing coils improve the beam trajectory. The matching coils located between the gun and the input cavity can adjust the beam diameter. The “M”-type cathode is adopted in order to assure the long life and the stable emission. The gun surface gradients must be limited to be about 75kV/cm in DC operation. 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.

Figure 2: Electron gun of the E3736 MBK.

Interaction Cavities and Beam Simulations

The simulation model of the input cavity is shown in Fig. 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.

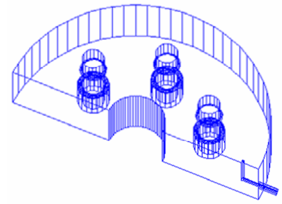

Figure 3: Cross section of an input cavity.

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

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 multi-pactoring discharge, the inner side of Al_2O_3 ceramic is coated with thin TiN layer.

KLYSTRON PERFORMANCE

The test of the tube was started without RF (beam test) to measure the beam transmission rate from the gun to the collector. The beam current that reaches the collector was measured from the voltage induced in a ceramic gap between the tube and collector. It 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. The green curve in Fig. 2 shows a 1.7m-long pulse of the beam current (133A) at the collector. Neither parasitic oscillation nor gun oscillation was observed. Then, the test was proceeded to the RF test. After some modifications of the tube and the hard conditioning, the RF pulse was finally stretched out to 1.5ms at the cathode voltage of 115 kV with 1.7-ms pulse length and repetition rates of 10 pps. The wave forms at this voltage are shown in Fig. 4. The output power was measured in the calorimetric way from the temperature rise in the cooling water of the two dummy loads. Figure 5 shows the measured output power and efficiency as a function of the beam voltage. The output power of 10.2 MW was obtained at 115 kV with efficiency of 66%. The measured performance is summarized in Table 2.

The transfer curve at the beam voltage of 115kV is shown in Fig. 6. There is no discontinuity by multi-pactoring or parasitic oscillation in the transfer curve. Figure 7 shows the instantaneous bandwidth both at saturation and 90% of saturation. The tube has 4.1 MHz bandwidth, more than the required bandwidth (3MHz).

The robustness of the tube was also demonstrated by being operated continuously more than 24 hours above 10MW. Total time of operation on the test stand at DESY already exceeds 750 hours (upto date February 4, 2007).

The horizontal version of the E3736, which is more desirable to place tubes in a tunnel, is now under construction at Toshiba.

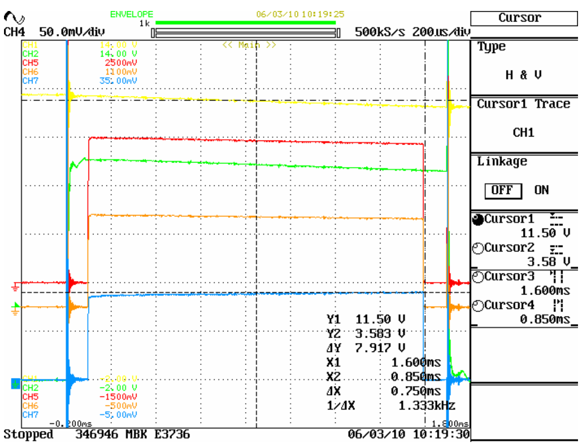

Figure 4: Waveforms. Cathode voltage (115kV, 1.7ms-long, yellow), collector current (133A, 1.7ms-long, green), RF output from the two ports (10.2MW in total, 1.5ms-long, red and orange).

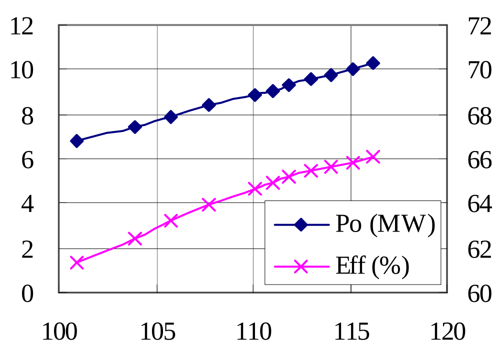

Figure 5: The measured output power and efficiency as a function of the beam voltage.

Table 2: Measured performance of the E3736 MBK.

Frequency	1300	MHz
Output Power	10.2	MW
Average Output Power	153	kW
Beam Voltage	115	kV
Beam Current	134	A
Efficiency	66	%
RF Pulse Width	1.5	ms
Beam Pulse Length	1.7	ms
Repetition Rate	10	pps
Saturation Gain	49	dB

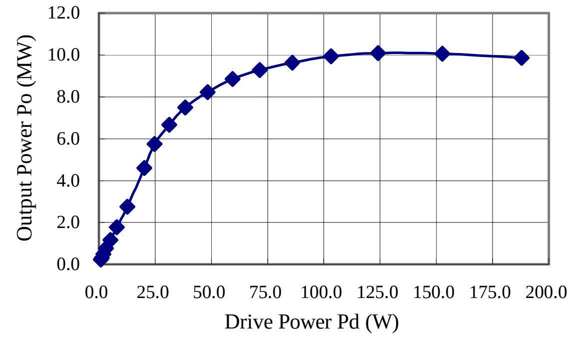

Figure 6: The transfer curve at the beam voltage of 115kV.

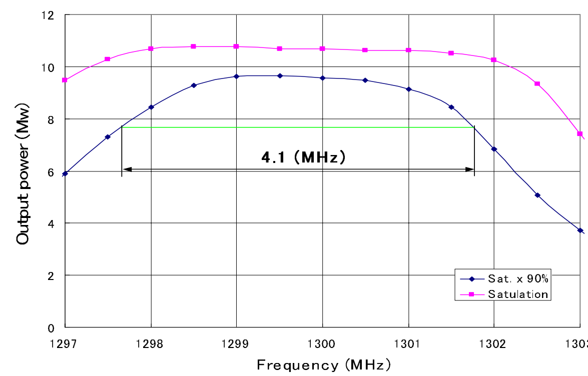

Figure 7: The instantaneous bandwidth both at saturation and 90% of saturation.

CONCLUSIONS

The development of the first prototype of E3736, the 10-MW L-band Multi-Beam Klystron, was completed. It is the first high power multi-beam klystron that has been advanced to practical use and product commercialization from the development stage. It shows the excellent beam transmission rate from the gun to the collector (more than 99 %) and achieved the RF performance better than the full specifications of the tube (10.2 MW output power with the efficiency of 66% at the standard beam voltage of 115kV with a full RF pulse of 1.5 ms at the repetition rates of 10 pps).

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