DESIGN AND TESTING OF THE HORIZONTAL VERSION OF THE MULTI BEAM KLYSTRON FOR EUROPEAN XFEL PROJECT

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Abstract

Toshiba Electron Tubes & Devices (TETD) has been developing 10-MW L-band Multi Beam Klystrons (MBKs) for the European XFEL project and future linear colliders. In order to allow horizontal installation in the XFEL tunnel, the horizontal version of MBK, MBK E3736H, has been designed, fabricated and tested. The MBK has six low-perveance beams operated at low voltage of less than 120 kV (for 10MW) and six ring-shaped cavities. After the successful acceptance testing at TETD in August 2007, the final acceptance test was carried out at DESY in February 2008. In the tests at DESY, the MBK achieved an output power of 10.1 MW at a beam voltage of 118.8 kV and at an RF pulse width of 1.5ms with an efficiency of 65.4%. The stability of the tube was verified by being operated continuously more than 24 hours above 10-MW output power. These tests demonstrated that MBK E3736H fulfilled all the requirements necessary as the RF power source of the XFEL linac.

INTRODUCTION

A 10-MW L-band Multi Beam Klystron (MBK) for European XFEL and a future linear collider is required to provide the 10-MW outpour power at 1.3 GHz with 1.5-ms pulse width and a repletion rate of 10 pps[1]. TETD developed a vertical version of MBK, MBK E3736, which meet the above requirements in 2006 [2,3]. In order to meet the requirements for installation in the XFEL tunnel, the horizontal version of MBK was required. The horizontal version of MBK, MBK E3736H, has been designed, fabricated and tested.

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 and the beam perveance as

$$\eta(\%) = 90 - 20 \times P(\mu perv.). \quad [4]$$

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 and E3736H, 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%.

MBK DESIGN

The design parameters for the MBK E3736H are listed in Table 1. The design goal was to achieve 10-MW peak power with 65% efficiency at 1.5- ms pulse width at 10-pps repetition rate. The total beam perveance was 3.38 (the perveance of each single beam is only 0.56).

Fig. 1 shows outside view of the MBK E3736H.

Table 1: Design parameters of the E3736H 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

Figure 1: The horizontal version of the MBK E3736H

The MBK was mounted horizontally and installed together with the solenoids and its stand. The total length and weight were approximately 2.5 m and 2800 kg, respectively.

The klystron has six beams 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 is 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 are used for power transmission to outside of the tube.

The results of the vertical version of MBK, the E3736 prototype, showed that our MBK design was verified [2,3]. The same electric design was adopted. The device should operate in a horizontal orientation. High mechanical integrity was required in the structural design so that the tube could be installed into the solenoids horizontally. A particular attention was paid to the cooling circuit of drift tubes and cavities to avoid output power and phase variation by thermal deformation.

KLYSTRON PERFORMANCE

The first horizontal version of MBK, MBK E3736H, completed the factory acceptance test at TETD. The test of the tube was started without RF (beam test). Neither parasitic oscillation nor gun oscillation was observed. Then, the test was proceeded to the RF test. Tuning the cavities was completed for adjusting of the RF characteristic by the short pulse RF test at the vertical position. After the tuning, the RF pulse was finally stretched out to 1.5ms at a cathode voltage of 117 kV with 1.7-ms pulse width and a repetition rate of 10 pps at the horizontal position. Output power variation did not occur in the process of increasing pulse width and repetition rate. The MBK achieved an output power of 10.3 MW at a beam voltage of 117 kV with an efficiency of 67%. The waveforms at this voltage are shown in Fig. 2. There was about 5% sag on the HV pulse. The HV pulse dropped from 120 kV to 114 kV at the end. Therefore the average voltage was about 117 kV. Average output power was measured calorimetrically. The obtained average output power was 154.7 kW. Fig. 3 shows the measured output power and efficiency as a function of the beam voltage.

The stability of the tube was verified by being operated under the load VSWR=1.2: 1. We demonstrated continuous operation with 10 MW output for 24 hours. There was no fault by gun or window arcing during this test.

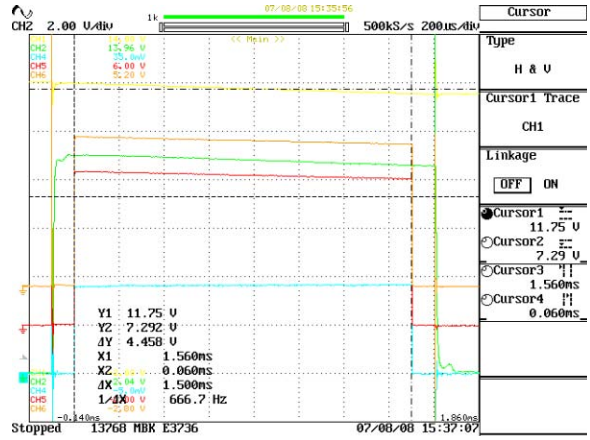

Figure 2: Waveforms. Cathode voltage (117kV, 1.7ms-long, yellow), collector current (133A, 1.7ms-long, green), RF output from the two ports (10.3MW in total, 1.5ms-long, red and orange).

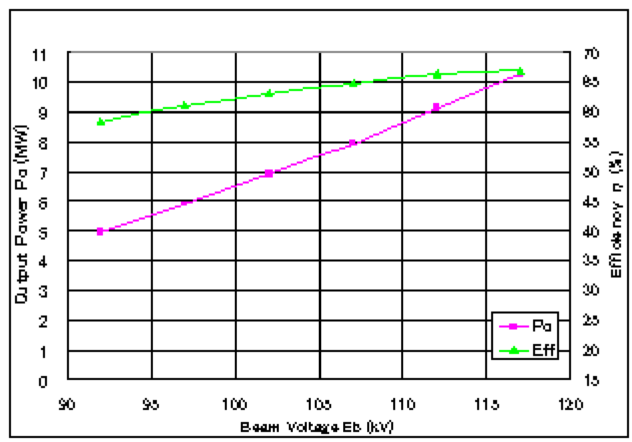

Figure 3: The measured output power and efficiency as a function of the beam voltage.

After the successful factory acceptance testing at TETD in August 2007, the final acceptance test was carried out at DESY in February 2008. Output characteristics of this MBK, which is a result of the acceptance test at TETD and DESY, are listed in Table 2.

Table 2: Result of the acceptance test at TETD and DESY concerning the MBK E3736H

Parameter	TETD	DESY	Unit
Operation frequency	1.3	1.3	GHz
Peak output power	10.3	10.1	MW
Beam voltage	117	118.8	KV
Beam current	130.8	129.5	A
RF pulse width	1.5	1.5	msec
Beam pulse width	1.7	1.7	msec
Repetition rate	10	10	pps
Efficiency	67	65.4	%
Gain	49.3	47.9	DB

Under a beam voltage of 118.8 kV and a beam current of 129.5 A, E3736H successfully generated an output power of 10.1-MW in 1.5-ms pulse width at 10-pps repetition rate, achieving an efficiency of 65.4%. The output power was measured in calorimetric way from temperature rise in the cooling water of two dummy loads. The transfer curves at a beam voltage of 118.8 kV (10-MW mode) and 106.8 kV (7-MW mode) are shown in Fig. 4. There was no discontinuity by multipactor or parasitic oscillation in the transfer curves. The waveforms at 10.1 MW are shown in Fig. 5. Fig. 6 shows the instantaneous bandwidth both at saturation and 90% of saturation. The tube had 3.5-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 10-MW output power.

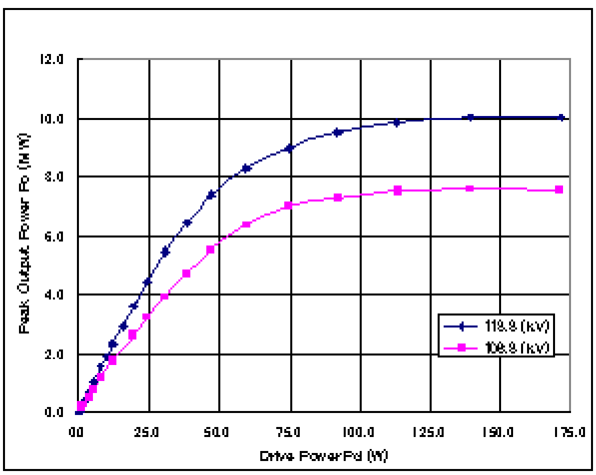

Figure 4: The transfer curves at the beam voltage of 118.8 kV and 106.8 kV.

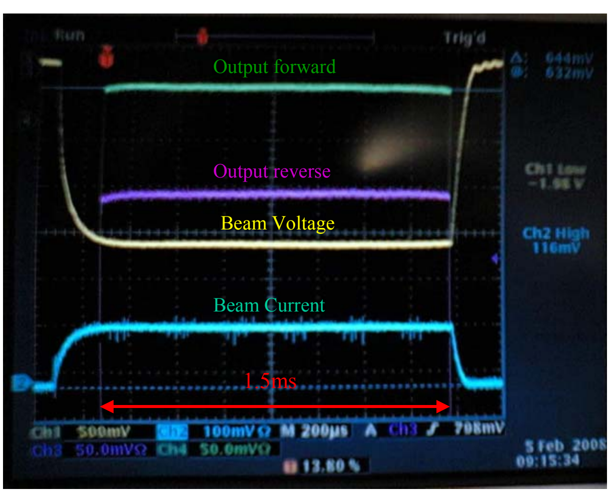

Figure 5: Waveforms. Cathode voltage (118.8 kV, 1.7ms-long, yellow), collector current (129.5 A, 1.7ms-long, blue), RF output forward (10.1MW, 1.5ms-long, purple).

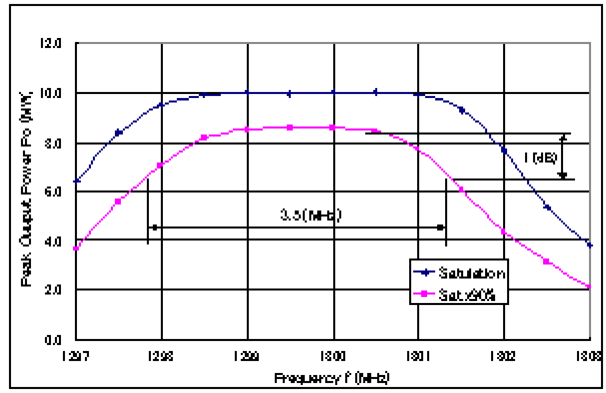

Figure 6: The instantaneous bandwidth both at saturation and 90% of saturation.

CONCLUSIONS

The development of the first horizontal version of MBK, TOSHIBA E3736H which delivered the 10-MW at 1.3 GHz, was completed. It is the first horizontal version of MBK that has been advanced to practical use and product commercialization from the development stage. In summary, the performance of the device shows that MBK E3736H fulfills all the requirements necessary as the RF power source of the XFEL linac (10.1 MW output power with an efficiency of 65.4% at a beam voltage of 118.8 kV with a full RF pulse width of 1.5 ms at a repetition rate of 10 pps).

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