Development of 10MW L-Band 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 February4, 2007). A horizontal version of the Toshiba MBK is now under construction.*
Keywords: *L-band, multi-beam, klystron.*

Introduction

A 10-MW L-band Multi-Beam Klystron (MBK), the Toshiba E3736[1], 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[2]. 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:

$$\eta(\%) = 90 - 20 \times P(miro - pervenace.).$$

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 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.

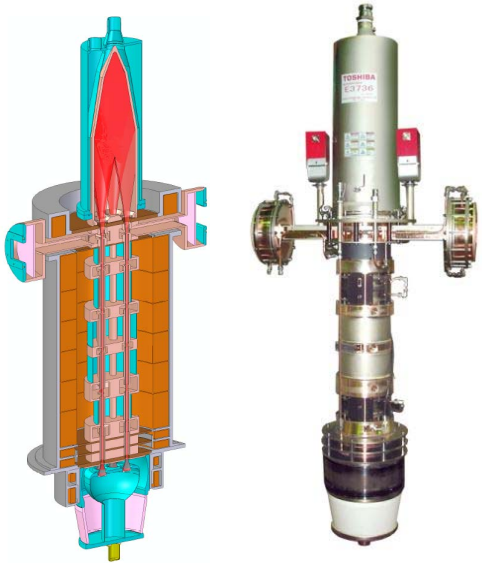

Figure 1: The cut-away view (left) and the photograph (right) of Toshiba MBK, E3736.

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

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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 travel 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).

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

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.k with 1.7-ms pulse length and repetition rates of 10 pps. The wave forms at this voltage are shown in Fig. 2. The output power was measured in the calorimetric way from the temperature rise in the cooling water of the two dummy loads. Figure 3 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%. It was measured that the tube has 4.1 MHz bandwidth, more than the required bandwidth (3MHz).

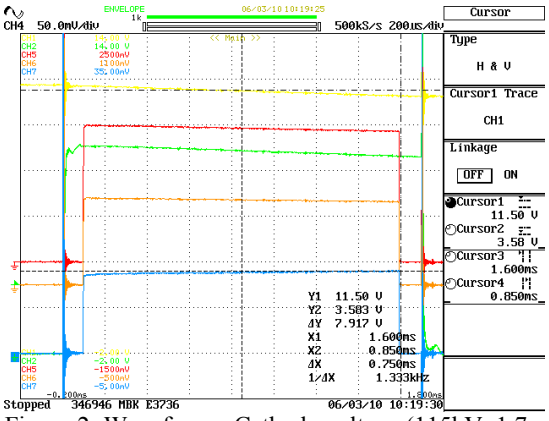

Figure 2: Waveforms. Cathode voltage (115kV, 1.7ms-long, yellow), collector current (133A, 1.7ms-long, green), RF output from the two ports (10.2MW in total, 1.5ms-long, red and orange).

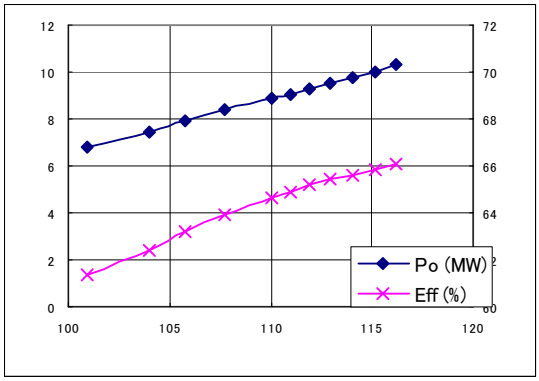

Figure 3: The measured output power and efficiency as a function of the beam voltage.

Conclusions

The Toshiba MBK klystron, E3736 is the first high power multi-beam klystron that has been advanced to practical use and product commercialization from the development stage. It demonstrates the validity of the multi-beam concept and the effectiveness of its technology for energy saving and high-powerization of microwave devices in a wide variety of applications.

References

1. A. Yano, et al., “The TOSHIBA E3736 Multi-beam Klystron”, LINAC04, 2004.
2. S. Choroba, “The TESLA RF System”, RF2003, 2003.