CURRENT STATUS OF DEVELOPMENT IN TETD OF HIGH-POWER VACUUM MICROWAVE DEVICES

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Abstract

TETD (Toshiba Electron Tubes and Devices Co., Ltd.) has been developing a wide variety of klystrons and input couplers in collaboration with some research institutes in Japan. This article presents recent status of the development, including a C-band and an S-band pulsed klystrons for SPring-8 Joint Project for XFEL, 1.3-GHz horizontally-oriented multi-beam klystron and a 1.3-GHz horizontal TTF-type input coupler for European XFEL Project, a 972-MHz long-pulse klystron for J-PARC, and a 1.3-GHz CW klystron for an energy recovery linac. As an application to fusion experimental devices, a 77-GHz quasi-CW gyrotron is also presented.

KLYSTRONS FOR SPRING-8 XFEL PROJECT

For SPring-8 Joint Project for XFEL, TETD developed a 5712-MHz C-band klystron E37202, and a 2856-MHz S-band klystron E37306. Test results of these klystrons are listed in Table 1, and outside view of E37306 is shown in Fig. 1. These klystrons were developed based on the prototype C-band model E3746[1]. As is already reported on E3746 series, three-cell traveling-wave structure was adopted as an output circuit of E37202, so that this C-band klystron can sustain its output of more than 50 MW in 2.5-μs pulse duration. As an output circuit of E37306 was also employed three-cell structure, on the assumption that output power from multi-cell is less sensitive to magnetic field variation compared to that from single cell structure. Beam perveance values of E37202 and E37306 were designed to be common, allowing the same pulse-forming network to be used in the power supplies of these klystrons. Cavity parameters were calculated using a particle-in-cell simulation code named FCI. Under beam conditions of 358 kV and 326 A, C-band klystron E37202 successfully generated a stable output power of 51.8 MW in 2.5-μs pulse duration at 60-pps repetition rate, achieving efficiency of 44.4%. S-band klystron E37306, under beam conditions of 364.4 kV and 337.6 A, generated output power of 50.7 MW in 2.5-μs pulse duration at 60-pps repetition rate, corresponding to efficiency of 41.2%. Performances of the klystrons satisfied requirements from the project. Concerning S-band klystrons, output power dependence on the magnetic field strength was measured. Figure 2 shows output power dependence of E37306 and E3730A, where the latter is an S-band klystron with a single-cell output circuit. It is clearly seen that output power of E37306, with three-cell output circuit, is less sensitive to magnetic field variation.

Figure 1: 2856-MHz, 50-MW klystron E37306.

Table 1: Test results of klystrons for SPring-8 Joint Project for XFEL; E37202 and E37306

Parameter	E37202	E37306	Unit
Operation frequency	5712	2856	MHz
Peak output power	51.8	50.7	MW
Beam voltage	358	364.4	kV
Beam current	326	337.6	A
Drive power	260	292	W
RF pulse width	2.5	2.5	μs
Beam pulse width	4.2	4.5	μs
Pulse repetition rate	60	60	pps
Efficiency	44.4	41.2	%

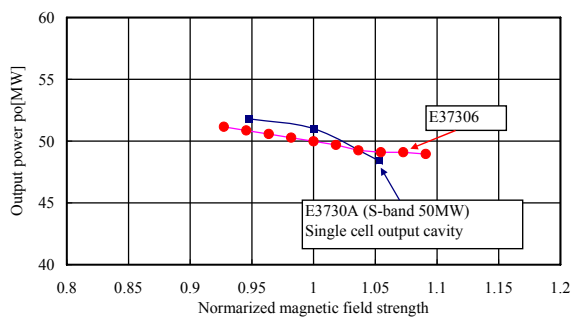

Figure 2: Output power dependence on magnetic field strength of S-band klystrons E37306 and E3730A.

MULTI BEAM KLYSTRON AND INPUT COUPLER FOR EURO-XFEL PROJECT

TETD and KEK collaboratively developed for DESY a 1.3-GHz 10-MW horizontally-oriented MBK (multi-beam klystron), which will be used in the European XFEL Project. This is a modified version of vertically-oriented MBK, which was already reported in the previous conferences [2][3]. Figure 3 shows outside view of the klystron. Output characteristics of this MBK, which are the results of the acceptance test at DESY, are listed in Table 2. Under beam voltage of 118.8 kV and beam current of 129.5 A, E3736H successfully generated output of 10.2 MW in 1.5-ms pulse duration at 10-pps repetition rate, achieving efficiency of 65.4%. Compared to an existing single-beam klystron with the same output power, beam voltage is reduced by 50 kV, which contributes to cost reduction of power supplies and reliable operations. The result of the acceptance test satisfied required specifications, and the prototype was already approved by DESY.

TETD developed for LAL a high-power input coupler which will also be used in the European XFEL project [4]. Design of E42100 is based on the TTF-3 coupler, and its outside view is shown in Fig. 4. Considering future mass production, the total number of parts was considerably reduced in order to cut production costs. Metallic joints were all vacuum-brazed to assure high reliability. The prototypes were accepted by LAL in February 2008.

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

Parameter		Unit
Operation frequency	1.3	GHz
Peak output power	10.1	MW
Beam voltage	118.8	kV
Beam current	129.5	A
RF pulse width	1.5	ms
Beam pulse width	1.7	ms
Repetition rate	10.0	pps
Efficiency	65.4	%
Gain	47.9	dB

Figure 3: 1.3-GHz, 10-MW horizontally-oriented multi-beam klystron E3736H.

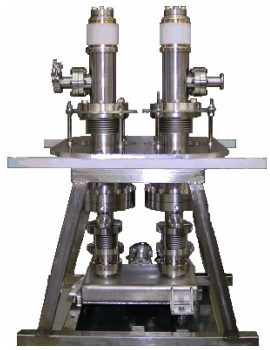

Figure 4: 1.3GHz high-power input coupler E42100.

KLYSTRON FOR PROTON ACCELERATORS

TETD developed in collaboration with JAEA and KEK, a 972-MHz, 3-MW long-pulse klystron E3766, which will be used for ACS accelerator in a proton linac of J-PARC [5]. Gain cavities incorporated in the first two prototypes have relatively wide gap to keep a bandwidth of 10 MHz. RF electric field in the gap was assumed to be axially symmetric with respect to the gap center, leading to TM011 and TM021-mode monotron oscillations. As described in the previous report, 3-MW stable operation was obtained in the third tube. Further studies enabled more stable operation at higher output power, and efficiency reached more than 60% (specification requires more than 55%). Test results are listed in Table 3, and the outside view is on Fig. 5.

Figure 5: 972-MHz, 3-MW klystron E3766.

Table 3: Test results of a klystron E3766

Parameter		Unit
Operation frequency	972	MHz
Peak output power	3.1	MW
Beam voltage	110.0	kV
Anode voltage	89.2	kV
Beam current	46.4	A
RF pulse width	0.6	ms
Beam pulse width	0.7	ms
Pulse repetition rate	50	pps
Efficiency	60.7	%
Gain	51.9	dB

KLYSTRON FOR ERL PROJECT

TETD has been developing with KEK, an L-band CW klystron E3750,RD, which will be employed as an RF source for the main accelerator in ERL (Energy Recovery Linac). Test results of the prototype are listed in Table 4, and its outside view is on Fig. 6. With beam voltage of 20.5 kV and beam current of 2.48 A, the maximum output power reached 30 kW, which is more than a required value 25 kW, and efficiency marked about 60% as described in Fig. 7.

Figure 6: 1.3GHz, CW klystron E3750,RD.

Table 4: Test results of a klystron E3750,RD

Parameter	Test results	Unit
Operation frequency	1.3	GHz
Peak output power	30.3	kW
Beam voltage	20.5	kV
Beam current	2.48	A
RF input power at saturation	0.18	W
Efficiency	59.6	%
Gain	52.3	dB

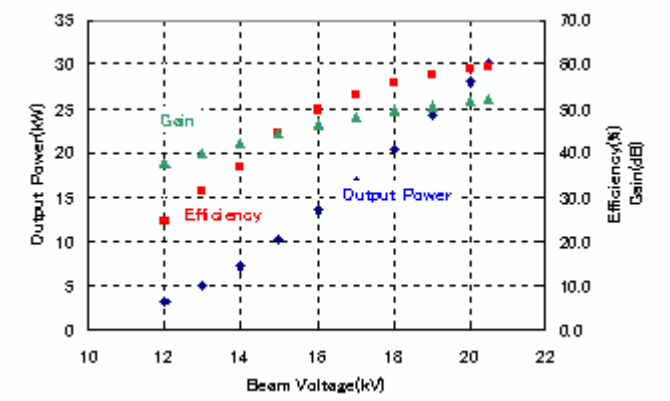

Figure 7: Test results of a klystron E3750,RD; dependence of maximum output power and efficiency on beam voltage.

APPLICATION TO FUSION EXPERIMENTAL DEVICES

NIFS (National Institute for Fusion Science), University of Tsukuba and TETD have developed a 77-GHz, quasi-CW gyrotron E3988. This gyrtron will be applied for ECH in LHD (Large Helical Device). Figure 8 shows outside view of the gyrotron. The first tube successfully operated under high-power and long-pulse condition at the test bench. The second tube is now under aging process.

Figure 8: 77-GHz, quazi-CW gyrotron E3988.

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