THE C-BAND 50MW KLYSTRON USING TRAVELING-WAVE OUTPUT STRUCTURE

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Abstract

The second tube of the C-band 50 MW klystron (model TOSHIBA E3746 series) has been developed in the course of the C-band rf-system R&D [1]. It uses the half-π mode traveling-wave structure in the output circuit in order to enhance the power-conversion efficiency and reduce the electric field gradient in the output circuit.

The three-cell traveling-wave structure was analyzed by the coupled-resonator model, and parameterized in a 3-by-3 impedance matrix form. The electrical performance at a hot condition was evaluated by a particle-in-cell simulation code: FCI, which predicted a power efficiency of 44%. The agreement of the simulation of FCI-code and test result was within 1%.

1 INTRODUCTION

In the future accelerators such as e+e- linear colliders, the system has to be highly reliable and efficient. The R&D of C-band accelerator system has been carried out at KEK since 1996.

Among the R&D work, two 50 MW C-band klystrons (TOSHIBA E3746 series) have been developed. The first tube using a conventional single gap in the output circuit was tested in August 1997, and generated a 50 MW peak power in 1 μs pulse duration at 20 pps pulse repetition rate, and also in a long pulse mode it generated 46 MW in 2.5 μs at 50 pps [2,3].

In the second tube, the output circuit was replaced to a traveling-wave structure to achieve over 50 MW peak power in 2.5 μs pulse width. The drift tube diameter at the output structure was enlarged to reduce the beam loss. The second tube was tested in April 1998, and generated a stable output power of 54 MW with 2.5 μs pulse duration, and 44% power efficiency at 50 pps repetition rate. The performance of the developed klystron agreed well with the predictions by the FCI-code.

2 DESIGN

The target performance of the E3746 klystron is shown in Table 1. The target value of peak power was chosen by scaling from the existing S-band klystrons to the C-band frequency.

The cross-sectional view of the E3746 klystron is shown in Fig.1. The left half in Fig.1 shows the first tube and the right half shows the second tube.

The output circuits consists of two output waveguides and two output windows, and they are recombined to one output port at the external circuits after the ceramic windows.

Table1:Main target parameters

Parameter		Unit
Output Power	50	MW
Operating Frequency	5712	MHz
Beam Voltage	350	kV
Beam Perveance	1.53	$\mu A/V^{3/2}$
RF Pulse Width	2.5	μs
Pulse Repetition Rate	50	pps
Drive Power	< 500	W
Power Efficiency	45	%
Gain	> 50	dB

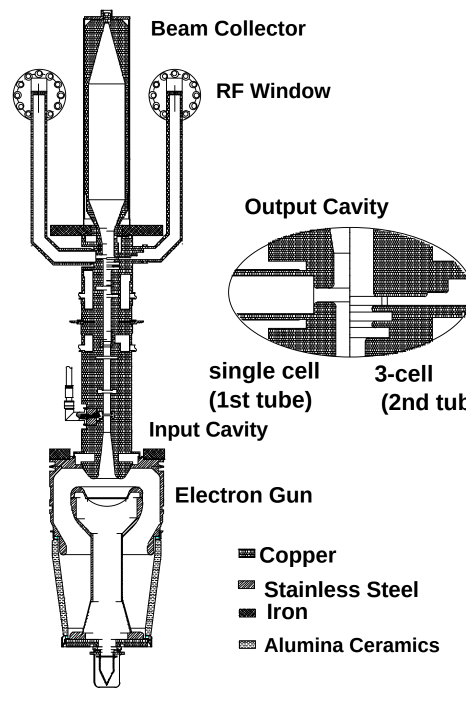

Figure 1: Cross sectional view of E3746 Klystron.

At the high power test of the first tube, the electron gun operated stably without diode-oscillation or high-voltage breakdown, and also rf windows showed nice high power performance. A stable 50 MW output power was generated in 1 μs pulse width. However the measured power efficiency was slightly lower than the target value.

The second tube uses a half-π mode traveling-wave output structure, which has advantages described below.

(1) Electric field gradient in the output cavity is reduced.

(2) The drift tube-diameter at downstream side of the output cavity can be enlarged without deteriorating the power efficiency, thus a high-voltage breakdown associated with the beam loss can be eliminated.

(3) Since the traveling-wave smoothly decelerates the electron beam in synchronous with the beam velocity, the power conversion efficiency is enhanced.

The multi-cell coupled cavity type output structure has been recently used for high power pulse klystrons, such as X-band klystrons at SLAC [4], where successful results were obtained. However there are still some problems in design described below.

(a) Optimum design procedure of the multi-cell cavity is not fully established.

(b) Countermeasure to prevent the parasitic oscillation phenomena is not fully established.

Thus, we decided to develop advanced design procedure for a traveling-wave structure. To do this, we laid the following basic guidelines.

(1) An equivalent circuit model is used for analyzing the multi-cell output cavity.

(2) To prevent the parasitic oscillation, the three-cell structure was chosen, which is the minimum number of cells to realize a traveling-wave.

(3) The half-π mode was chosen, since the impedance matrix becomes a simple form, also it makes frequency tuning simple.

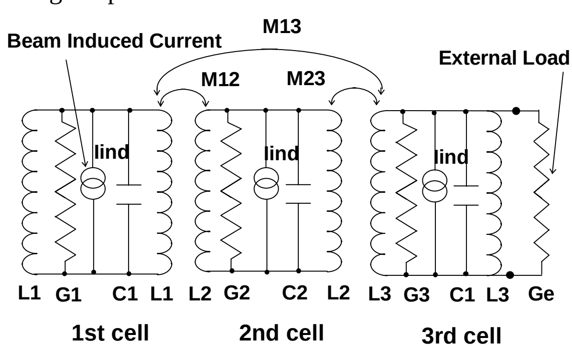

Figure 2: The equivalent circuit model.

The equivalent circuit for the three-cell structure is shown in Fig.2. Three resonator circuits are coupled each other through the mutual inductances M12, M23, M13. The current source in each circuit represents induced current by the beam. The conductance at the 3rd cell shows the output waveguide and external load. This equivalent circuit is identical to the coupled resonator model which has been widely used to analyze various kinds of accelerator structures. A special situation in klystron analysis is that the next neighbor coupling M13 plays an important role. Klystron output structure requires so large coupling coefficients between neighbor cells that the next neighbor coupling becomes non negligible.

The design procedure is,

(1) The beam rf current and beam energy at cavity center location of each cell are estimated by the beam simulation (FCI-code), mounting a single cell output cavity.

(2) The shunt impedance R/Q and the beam coupling coefficient of each cell are estimated from numerical simulation code, such as SUPER FISH, etc.

(3) Assume the same amount of the deceleration voltage in each cell. Compute the cell-voltage from the beam coupling coefficient.

(4) The mutual inductances M12, M23, M13, the external-Q and the cell resonance frequencies at half-π mode are computed by the impedance matrix using the estimated induced currents and the cell voltages.

(5) The physical dimensions of each cell are determined by numerical simulations. We repeat process (4) to (5) using the estimated R/Q and the beam coupling coefficient by the code.

(6) We run the FCI-code using the circuit parameters obtained above, and check the output power with the target value.

(7) The 3rd cell is connected to the output waveguides, thus we use 3D-simulation code HFSS, by which we decide the optimum iris size and cavity diameter.

At the actual design, almost all the cavity parameters were determined by the method described above in one process. We did not use FCI-code for a try-and-error parameter search.

The simulation result of the second tube is shown in Table 2. FCI said that the output power of 49 MW and the power efficiency as high as 44% can be obtained at the beam voltage of 350 kV.

Table 2: Design parameters (Values in parenthesis show the design parameter of the first tube.)

Parameter		Unit
Output Power	49	MW
Operating Frequency	5712	MHz
Beam Voltage	350	kV
Beam Current	317	A
Drive Power	300	W
Power Efficiency	44	%
Electric Field Gradient in Output Cavity	29.2 (45)	kV/mm
Drift Diameter of Collector Side	14 (9.5)	mm

In the second tube, the drift tube-diameter at the output structure was enlarged by 1.4 times than the first tube, and the electric field gradient in the output structure was reduced to 0.7 times lower than the first tube. Thus the second tube has more safety margin against rf-breakdown and beam-loss damage around the output structure.

3 TEST RESULT

The second tube was tested at KEK in April 1998. In this test, the output power was measured by the absolute calorimetric method. In this method, the output power is measured from the water temperature rise at the rf dummy load. In order to calibrate the temperature rise, an electrical heater was loaded in the water cooling system after the rf dummy load. The heat dissipation can be simply determined by the product of the terminal voltage and the current. This method is independent from the error in the flow rate of water measurement, thus it is very reliable.

Table 3 shows the experimental result, and Fig.3 shows the rf output power and the beam voltage waveforms. This klystron achieved 54 MW output power at the beam voltage of 369 kV, 2.5 μs pulse width and 50 pps repetition rate. The output waveform was always steady and stable for wide range of operating conditions. We tested the effect of reducing the focusing field, where no oscillation nor beam loss was observed.

Fig.4 shows the saturated output power as a function of the beam voltage and Fig.5 shows the input-output characteristic at the beam voltage of 362 kV. No unstable phenomena was observed in the input-output characteristic.

The test result of saturated output characteristics agreed well with the FCI simulation result. The difference between the measured output power and the simulation was within 1%.

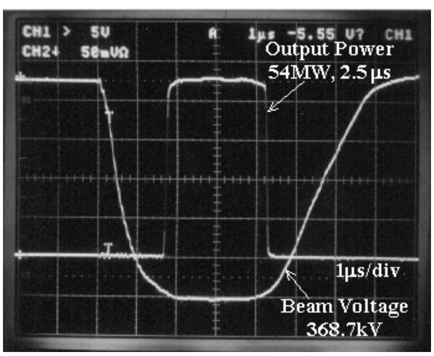

Figure 3: Output power and Beam voltage waveform.

Table 3: Test result

Parameter	1st tube	2nd tube	Unit
Operating Frequency	5712	5712	MHz
Beam Voltage	360.4	368.7	kV
Beam Current	326.4	333.0	A
Output Power	50.1	53.9	MW
RF Pulse Width	1.0	2.5	μs
Pulse Repetition Rate	20	50	pps
Drive Power	259	323	W
Power Efficiency	42.6	43.9	%
Power Gain	52.9	52.2	dB
Beam Perveance	1.51	1.49	$\mu A/V^{3/2}$
Solenoid Coil Power	6.38	4.55	kW

4 CONCLUSION

The second C-band klystron which uses the three-cell traveling-wave output structure successfully generated a stable 54 MW output power at 369 kV beam voltage, 2.5 μs pulse width, 50 pps repetition rate.

The test result showed a good agreement with the FCI-code simulation. It demonstrated that the design procedure established here is powerful and reliable for the design of multi-cell output structure.

As the next step, in order to improve the system efficiency, we will start development of a periodic permanent magnet (PPM) focused klystron from 1998, which eliminates the focussing magnet power.

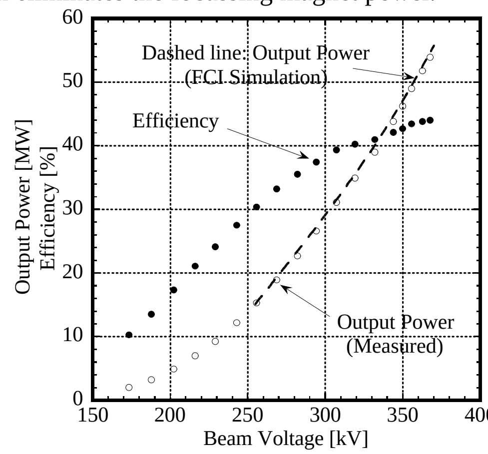

Figure 4: Saturated output characteristics.
(2 μs pulse width and 50 pps repetition rate)

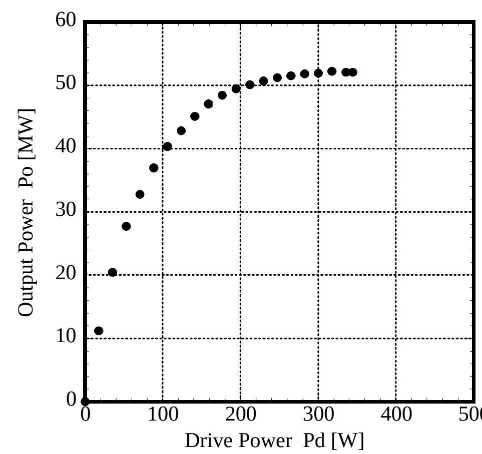

Figure 5: Input-output characteristics.
(2 μs pulse width and 50 pps repetition rate)

ACKNOWLEDGEMENT

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