A HIGH-POWER KLYSTRON

Kazutaka HAYASHI, Hiroshi IYEKI
Mitsubishi Electric Corp. CEW
8-1-1 Tuskaguchi Hon-machi, Amagasaki, Hyogo 661

Abstract

Design and trial fabrication based on simulations are now being performed as part of the development of an S-band high-power pulse klystron for use in linear accelerators. A 60MW output klystron was developed, and an output of 62.5MW was obtained. In parallel with this work, the 30MW klystrons currently ranked as standard equipment have been improved. A pulse width of 4μs and an output of over 40MW were confirmed for the revised model PV3030A3. These results are being consolidated in the development of a compact, high output 50MW klystron (PV3050) that will serve as a standard device in the coming generation.

Introduction

Since 1965, Mitsubishi Electric Corp. has been producing pulse klystrons, paralleling the history of electron linac development in Japan. Table 1 shows the characteristics of Mitsubishi pulse klystrons. The klystrons of 5~7MW output power are used mainly for industrial and medical linacs. The ones of higher output power are used for research linacs. The 30MW class klystrons, for example PV3030A, have been served as the standard tubes in electron linacs for research in Japan.

To meet the demands for high energy linacs, high-power pulse klystrons have been developed actively by several laboratories and companies. In S-band, for example, the type 5045 klystron (67MW operation)[1] by SLAC (Stanford Linear Accelerator Center); development of a 150MW klystron[2] by a group with SLAC as a leader; and the E3712 klystron[3] by Toshiba Corp. Mitsubishi has developed the high-power klystron that is suitable for use in the KEK (National Laboratory for High Energy Physics) B-factory (KEKB) injector linac[4].

In this paper we describe the development and status of S-band high-power klystrons at Mitsubishi for linacs. A 60MW output klystron was developed and the 30MW klystron (PV3030A) has been improved. These results are being consolidated in the development of a compact, high output 50MW klystron. Details of the design and performance of these klystrons (Table 2) are reported.

Table 2. Characteristics of High-Power Klystrons

	30MW	40MW	50MW	60MW
Type	PV3030A	PV3030A3	PV3050	PV3060
Frequency (MHz)	2856	2856	2856	2856
Output Power (MW)	33	40	50	60
Duty Factor	0.0004	0.0002	0.0002	0.0002
Efficiency (%)	44	45	45	45
Saturated Gain (dB)	51	51	51	53
Beam Voltage (kV)	265	280	308	350
Beam Current (A)	285	285	359	414
Pulse Width (μs)	4	4	4	2

Table 1. Mitsubishi Pulse Klystrons

Tube Type	Frequency (MHz)	Output Power (MW)	Average output (kW)	Usage
PV2012	2856, 2988	5, 7, 10	10	linac
PV2014	2856	25	30	linac
PV3105	S-band	~5	~10	radar
PV3030	2856	33	12	linac
PV3035	2856	35	14	linac
PV9004	9300	4	4	linac

60MW klystron development

A 60MW output klystron was developed for future linac use. The problems encountered in developing ever-higher power klystrons are electron gun arcing and microwave discharges in cavities and the output window. The major challenge in the development of this tube was to handle the 60MW output power with one window.

Electron Gun:

The perveance of this tube was set at 2.0 $\mu AV^{-3/2}$. A scandiate dispenser cathode was used because of its low operating temperature. The cathode diameter was 85mm. Figure 1 shows the simulation result for the electron gun.

Cavities:

The klystron body section had five cavities. Figure 2 shows the bunching simulation obtained with the FCI code[5] which uses 2-1/2 dimensional PIC (particle-in-cell) method. The code is sufficiently powerful to simulate high-power klystrons where it deals with a tightly-bunched high-power beam. Moreover,

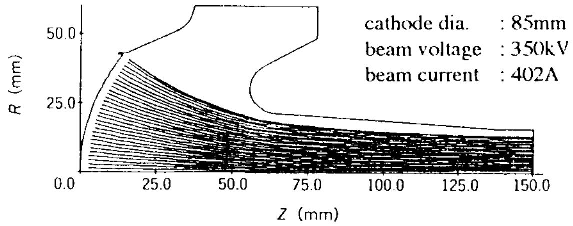

Figure 1. The simulation result for the electron gun.

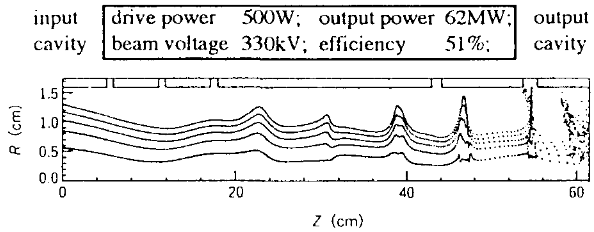

Figure 2. The bunching simulation result.

there were microwave discharge problems. Around the magnetic field strength (102mT) where the cyclotron frequency is equal to operating frequency (2856MHz), the electron cyclotron resonance condition is satisfied. At about half (51mT) of the cyclotron magnetic field strength, a multipactor condition is satisfied over the portion of the cavity nose. Under such conditions, a microwave discharge often occurs and causing gain loss and unstable operation. To avoid the discharge, it is necessary that we carefully choose the magnetic field strength and cavity nose shape.

Output window:

The VSWR and electric field distribution of a pill-box type window were calculated using the analytical method[6]. Figure 3 shows calculated and measured VSWR for the design used. The VSWR is nearly unity at the operating frequency. The VSWR changes rapidly at the frequencies f1 and f2. Figure 4 shows 3D VSWR plot in which the pillbox length and frequency are varied. The electric field distribution calculation shows that a ghost mode resonance exists in and on the ceramic disk at frequencies at f1 and f2. Once a ghost mode resonance is exited, microwave discharge is inevitable. Therefore, the dimensions of the window were carefully chosen to avoid any ghost modes near the operating frequency. In parallel with the calculations, we made trial fabrications, using low loss-tangent alumina disk (HA997, NGK Spark Plug Co., Ltd.) with thin TiN coating[7]. After fabrication processes such as brazing and coating were established, several tests were performed in a resonant ring circuit, to ensure freedom from discharge problems.

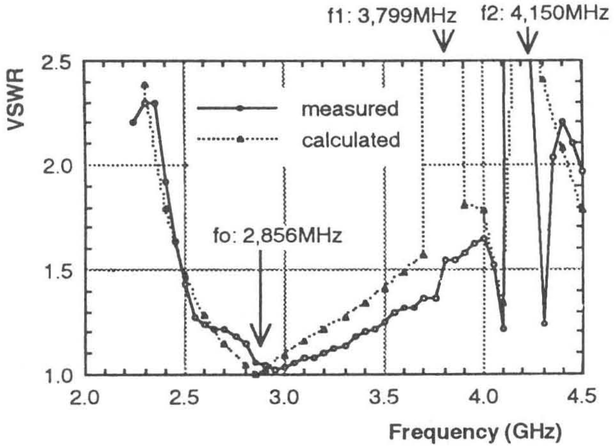

Figure 3. Calculated and measured VSWR of the window.

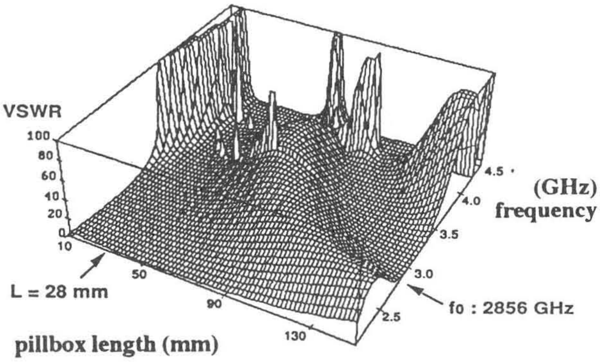

Figure 4. VSWR plot of the window.

Klystron Test Results:

The measured performance of the 60MW tube is shown in Figure 5 (dotted line). The output power was 62MW for 347kV beam voltage with an rf pulse width of $2\mu s$ and pulse rate of 20pps. The resultant perveance was $2.04\mu AV^{-3/2}$ and the efficiency was 43%. The gain was 51.4dB and the operation was stable.

Improvements of 30MW klystron

In order to attain a higher output, and more stable operation of the electron gun, several improvements were made in the structure, materials and fabrication processes of the 30MW klystron, maintaining mechanical compatibility with the former klystron. Structural improvements were made in three areas; (1) changing to a dispenser cathode; (2) designing an electron gun with lower field strength on the electrode, (3) use of a larger insulator in the gun and new output window. Cavity parameters were not changed.

The advantage of using a dispenser cathode is that it makes the electron gun more resistant to arcing in vacuum. The amount of Barium evaporation is less (especially in the manufacturing process) than it is for an oxide cathode. Therefore the surfaces of electrodes are cleaner, and less likely to initiate arcs. The shape of the electrodes — the cathode (80mm diameter), anode and wehnelt were changed to lower the electric field strength, while maintaining the same output beam condition from the gun. These improvements not only achieved stable high-voltage operation of the gun, but also enabled higher-voltage operation. The simulation results showed that higher beam power with proper magnetic field could produce higher output power, and this was confirmed at short-pulse high-voltage tests with modified focus-coil assembly and a modified pulse modulator[8] Using a larger (15% longer) insulator in the gun, and adapting the new output window (mentioned above) to the klystron resulted in the PV3030A3 (Figure 6, left), with a specified output power of 40MW. Figure 5 shows output power versus beam voltage, 51.5MW output power was observed at an rf pulse width of $4\mu s$[8].

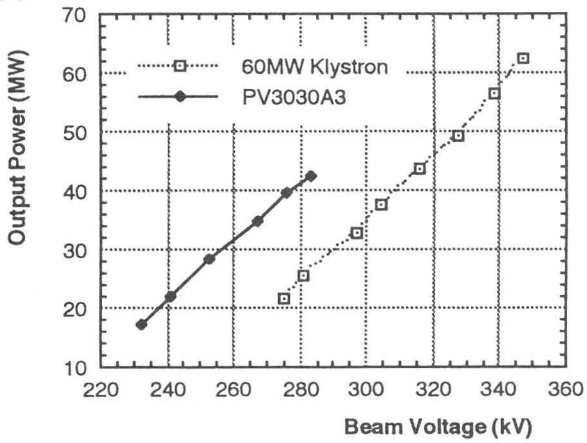

Figure 5. Output power versus beam voltage on two tubes.

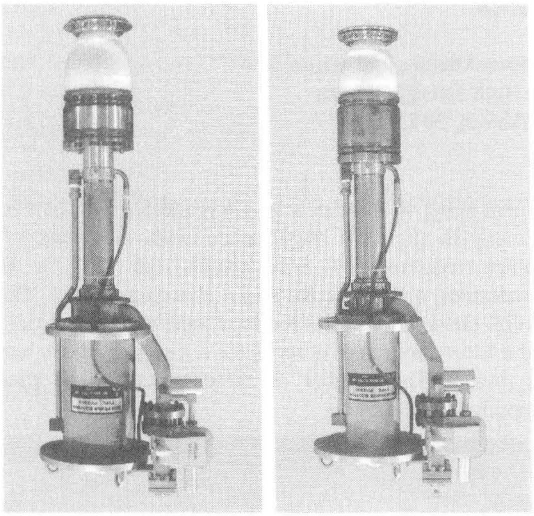

Figure 6. PV3030A3(left) and PV3050 klystrons.

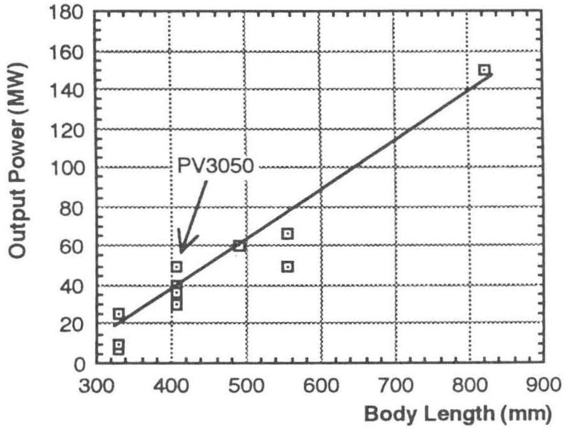

Figure 7. Output power versus body length.

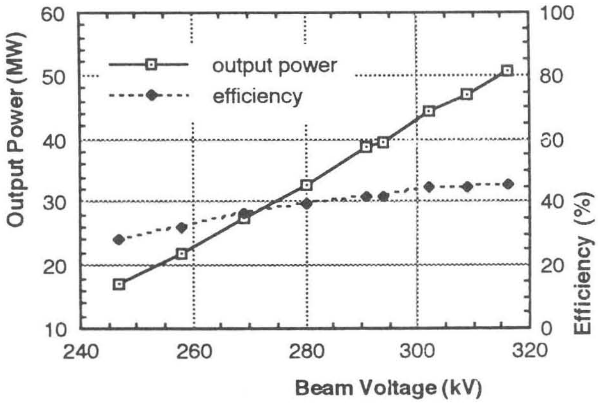

Figure 8. Output power versus beam voltage of 50MW tube.

A klystron for KEKB

The klystron output power required in the KEKB project is 50MW (future target is 60MW) as shown in Table 2. For the linac system constructed on the basis of the existing linac, there are several restrictions on size and magnetic field distribution[4]. The 60MW tube dose not meet the requirements for height and magnetic field, and the PV3030A3 appears to have insufficient life and and suffers from unstable operation of the electron gun. Therefore, a new compact 50MW klystron (PV3050) was developed using new tube parts similar to those described above. An electron gun was designed on the basis of the 60MW tube gun to ensure stable operation. The electrode shapes were changed to meet the beam input requirements of the klystron body section. The body was the same as that of the 30MW klystron, and the output window of the 60MW tube was used. The magnetic field design was based on that of the PV3030A3. A single window and compact size are characteristics of this tube. Figure 7 shows a plot of output power versus body length (distance between input cavity and output cavity) for several klystrons. Note that this tube falls above the line drawn for existing tubes.

Figure 6 (right) shows a photograph of the PV3050. The output power was 51MW for 316kV, with an rf pulse width of 4μs and pulse rate of 50pps. The resultant efficiency was 46% and the perveance was $1.98\mu AV^{-3/2}$. Figure 8 summarizes these results.

Conclusion

A 60MW output klystron was developed, and an output of 62.5MW (pulse width 2μs) was obtained. In parallel with this work, the 30MW klystrons currently used as standard equipment have been improved. A pulse width of 4μs and an output of over 40MW were confirmed for the revised design PV3030A3. These results are being consolidated in the development of a 50MW klystron (PV3050) that is suitable for the KEKB project. An output of 51MW (pulse width 4μs, pulse rate 50pps) was obtained. This tube, which is compact and has high output with a single window, will serve as a standard device in the coming generation.

Acknowledgments

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