High Power RF Test of the L-Band CW Klystron

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Abstract

A high power klystron has been developed as a RF source of the high power CW electron linac (10MeV, 100mA, 1.249135GHz) at Japan Nuclear Cycle Development Institute (JNC) [1]. We have succeeded in the development of the klystron to drive both CW mode(beam voltage 90kV) and pulse mode(100 μsec pulse width, 50 pps, beam voltage 147kV). The klystron with a long pill-box type beryllia window has achieved CW power of 1040kW at beam voltage 83kV and peak power of 4.2MW at beam voltage 147 kV[2]. This paper describes key points of the designs and results of the high power RF tests of the third klystron about CW mode.

1. Introduction

JNC high power CW linac was constructed for studying feasibility of nuclear waste transmutation. The design of this klystron was required for CW mode 1.2MW and pulse mode 4.2MW. The outline is shown in Figure 1 and the specifications are given in Table 1.

Extensive window development was necessary to achieve continuous power of 1.2MW at L-band. A long pill-box type beryllia window (long window) was designed and withstood the RF power of 1.7MW(CW), that has been verified by means of a traveling wave resonant ring. No multipactoring has been observed up to 1.7MW(CW).

The first klystron adopted long window has achieved CW RF output power of 885kW, efficiency of 47%, and beam voltage of 85kV. Such the characteristics of long window were studied in the first klystron and some ideas were adopted in the design of the second and third klystron in which the efficiency was improved. The second and third klystron were used for JNC linac.

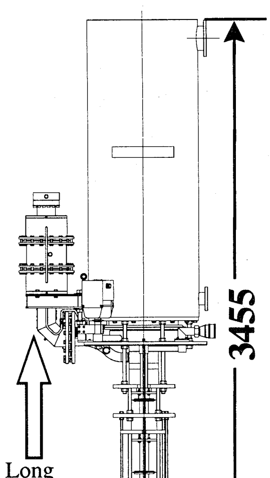

FIGURE 1. The outline of the klystron.

Table 1. Main specification of klystron.

Operation Mode	CW	Pulse
RF Frequency	1.249135GHz	
RF Power	1.2MW	4.2MW
Efficienc	65%	50%
Beam Voltage	90kV	147kV
Cathode Current	25A	56.5A
Beam Powe	1.86MW	8.3MW
Drive Power	12W	15W
Pulse Width	-	0.8msec
Repetition Rates	-	250pps
Cavity number	6	

2. Development of the klystron

The vacuum-side surface of the ceramic in long window were coated with 60Å thick titanium nitride (TiN) to prevent multipactor. The inner periphery of the disc and the outside of the cylinder is cooled by water of 10cm^3/min with water pressure 3kgf/cm^2.

The resonant frequency of the fourth and the fifth cavity was calculated to improve efficiency by using klystron two-dimensional analysis code (KUBALI)[3]. This code has been developed by the cooperative research with Kyoto Univ. Energy Science and Engineering Laboratory. According to the calculation, maximum output efficiency 62.8% was obtained at the resonant frequency 1280MHz of those cavitys, 85kV beam voltage, and the design beam perveance 0.9μAV$^{-3/2}$ for CW mode.

It was necessary to reduce the fluctuation of the beam for the improvemnt of the output efficiency. The magnetic flux density in the gun was increased to achieve the balanced force condition for Brillouin flow by enlarging the internal diameter of the gun pole piece. As a result of the analysis about the beam trajectory by using the EGUN code, the rippled rate of the beam was reduced by half. The bucking coil was also installed near the gun pole piece for the easy finding of optimal operation points.

3. The third klystron

We tested basic characteristics of the third klystron in the Toshiba factory. Figure 2 shows the measured efficiency as a function of the beam voltage with the modulating anode voltage ajusted for a beam perveance of

$0.9\mu AV^{-3/2}$. The third klystron had achieved the maximum CW output power of 1.04MW with efficiency of 58.2% at a beam voltage 83kV, which agreed with calculated value within 2% error by KUBALI code. The maximum efficiency was 64% at a beam voltage of 90kV, the pulse width of 16μsec, and repetition rates of 200pps.

The focusing coil consists of 5 pieces of coisl. Efficiency was increased when the magnet field of the No.5 coil near the output cavity was reduced. Figure 3 shows the saturation output efficiency as a function of this current at pulse operation. The output power is very sensitive to it. The No.5 coil current was not decreased under 10A with CW operatiion because the beam hit the nose of the output cavity, while another coils current were 12.8A and the bucking coil current was 1.3A.

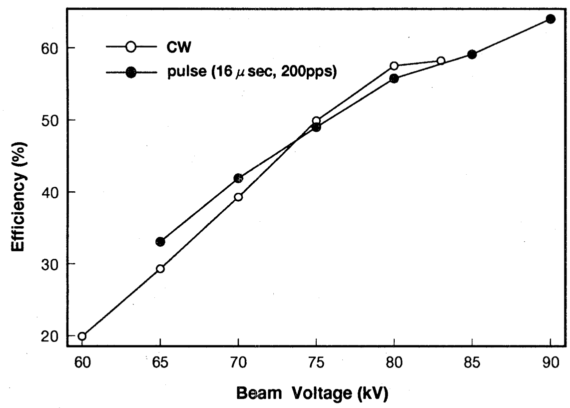

FIGURE.2 Efficiency vs. the beam voltage.

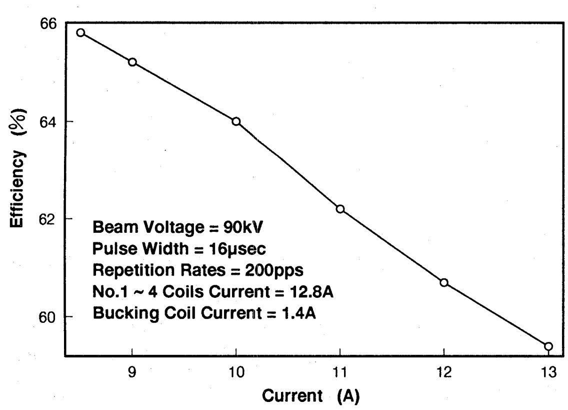

FIGURE.3 Efficiency vs. the No.5 coil current.

Examples of the ceramic temperature rise ΔT, monitored by an infrared thermometer are shown in Figure 4. ΔT was 34.5 degree at CW output power of 1.04MW. The window temperature rises linearly with the applied power. We do not observe abnormal temperature rise even at 1MW output power.

The variance of dielectric loss (tanδ) of ceramic disks and the effect of the standing wave showed that these rises of the klystron was 1.16 times larger than temperature rises of the long window alone at the resonant ring test.

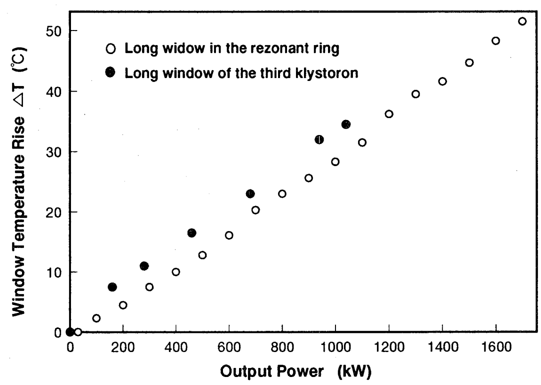

FIGURE.4 Temperature rise of ceramic vs. output power.

4. High Power RF test in the JNC facility

The specification of the klystron power supply is shown in Table 2. There are three different modes for the klystron operation. The klystron is able to be operated complete CW (90 kV CW) but our facility power station can not supply over electric power of 1MW, which make the klystron operate 20% duty. The modulating anode system is adopted for mode 1 and mode 2. For mode 3, the beam voltage modulation is employed, using pulse transformers and solid-state switch. We measured the output power of the third klystron in JNC facility by using mode 1 and mode 2 of this power supply.

The schematic diagram of high power RF test is shown Figure 5. RF forward signal from the directional coupler entered rf-detector through rf cable, band bass filter, and isolator. The forward P_{rf} was got by adding maximum input power of rf-detector to the sum of coupling and attenuation of rf transmission line. Similary, backward power was measured, too. VSWR was 1.06 at this test. Figure 6 shows expanded view of top part of the RF pulse of output power at mode 1. Fluctuation of the RF power is less than ±0.3% of amplitude and within ±0.2 degree of operating phase at an RF power level of 940kW and the pulse width of 2.8msec. We used the stabilized output power and measured output voltage V_{rf} of top part of the RF pulse for high power RF test.

Table 2 Main specification of klystron power supply.

Operation Mode	Mode 1	Mode2	Mode 3
Cathode Voltage	90kV	65kV	147kV
Beam Current	50A	13.8A	113A
Pulse Width	1~4ms	CW	<0.1m
Repetition Rates	<50pps	CW	<50pps
Peak Power	4.5MW	0.9MW	16.6M
Number of Klystron	2	1	2

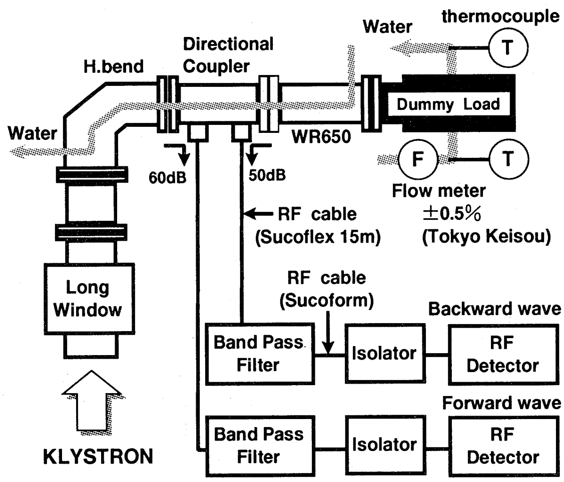

FIGURE 5. A schematic diagram of high power RF test.

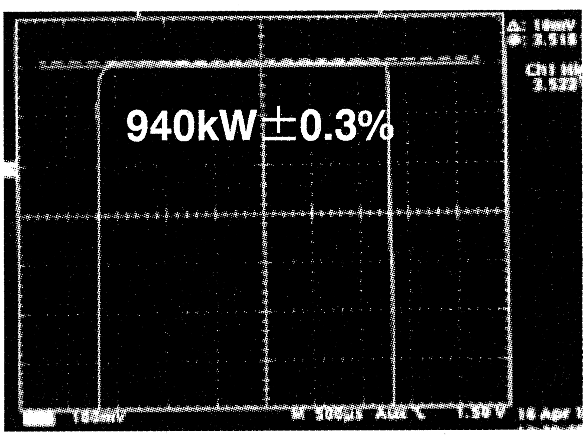

FIGURE 6. Expanded view of top part of the RF pulse.

On the other hand, the peak power was calibrated by a calorimetric method as follows. All output power was absorbed at the dummy load supplied by Nihon-Kohsyuha Corp. Cooling water flow V was 0.198m³/min and temperature rises dT of the dummy load were measured at the themocouple installed in the corner of the cooling pipes. The value of themocouple was calibrated by using the resistance thermometer bulb. In the case of the peak power over 250kW, the RF pulse width W was always kept at 2.35msec. Repetition rates R was gradually decreaseded from 47pps to 17pps in keeping dT of 3 degree. Peak power P_{dummy} (kW) can be calculated by means of Eq.(1).

$$P_{dummy} = 0.0698 \ V \ dT \ / \ (W \ R) \qquad (1)$$

We calculated peak power under 250kW as following conditions. We gradually increased the RF pulse width from 396msec to 714msec in keeping dT of 5 degree and repetition rate of 1pps at mode2. Cooling water flow was 0.241m³/min.

Figure 7 shows the power difference between P_{dummy} and P_{rf} as a function of P_{dummy}. As the difference between each power is not constant, coupling of the directional coupler depends on peak power.

Therefore, it is nessesary to calibrate peak power with the use of a calorimetric method. It can be easy to get peak power from the simple formula. P_{dummy} (dB) can be expressed by output voltage V_{rf} (V).

$$P_{dummy} = 78.077 + 21.308 \ \mathrm{Log}(V_{rf}) \qquad (2)$$

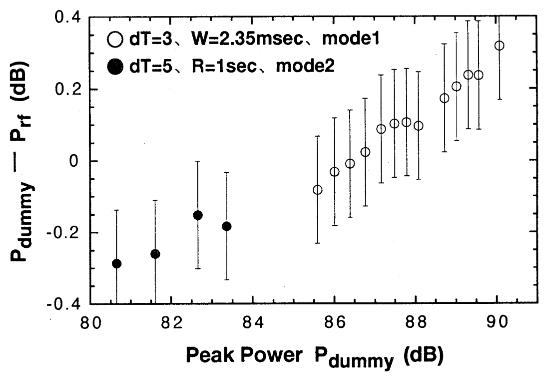

FIGURE 7. The power difference between P_{dummy} and P_{rf} as a function of P_{dummy}.

5. Conclusion

The third klystron had achieved CW power of 1.04MW with efficiency above 58% at a beam voltage 83kV and peak power of 1.4MW with 64% at 90KV and the pulse width of 16μsec.

We have succeeded in developing long window standed over 1.2MW and the CW klystron which produced over 1.2MW with 64%.

We can get peak power of the third klystron from the simple formula expressed as a function of output voltage of rf-detector.

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Reference

[1] Y.Wang, et. al , "Status of PNC High Power CW Electron Linac",APAC98,KEK Proceedings 98-10, pp.289-291 (1998)

[2] K.Hirano, et al."Development of the High Power Klystron with CW Mode and Short Pulse Mode". FEL99, Tu-P-14, (1999).

[3] K.Masuda, "Development of Numerical Simulation Code and Application to Klystron Efficiency Enhancement", PHD thesis, Dept., of Engineering, Kyoto University. (1996).