S-BAND KLYSTRON FOR LONG PULSE OPERATION

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Abstract

The electron linac for infrared to ultraviolet free electron laser has been developed at the Laboratory for Electron Beam Research and Application in Nihon University. Each S-band klystron is required to provide a peak RF output power of 30MW with the pulse duration of 20µs at the repetition rate of 12.5Hz. The output power of the current Mitsubishi PV-3030A1 klystrons is restricted to approximately 20MW due to damage to the output RF windows at higher output powers. An upgrade version of PV-3030A3 type, i.e. a PV-3040N klystron was fabricated for a durability test of the RF window at an output power around 30MW. The PV-3040N klystron has an improved vacuum port to protect the RF window from breakdown by quick vacuum recovery. Furthermore, the material of the RF window has been replaced by the one used in PV-3050 type, which will improve the output power limit at long pulse operation.

1 INTRODUCTION

A high performance electron linac for free electron laser (FEL) has been studied at the Laboratory for Electron Beam Research and Application (LEBRA) in Nihon University as collaboration with High Energy Accelerator Research Organization (KEK) [1]. The S-band high power RF has been supplied by two Mitsubishi PV-3030A1 klystrons, which were moved from KEK after being used for several years in the injector linac of photon factory (PF). The maximum operating power of the klystrons has been restricted to approximately 20MW at the pulse duration of 20µs due to damage to the klystron output RF windows.

The FEL system in LEBRA currently serves infrared (IR) FEL at a wavelength of 1.5µm [2]. The klystron output RF power of 30MW is necessary to achieve lasing in the visible to ultraviolet range. Although the PV-3030A1 klystron was designed for relatively short output pulse, operation with the pulse duration of 20µs has been attained at the peak output of 20MW and the repetition rate of 12.5Hz by the increase of the vacuum pumping system downstream the RF window. However, increase of the output power up to 30MW seemed quite difficult without improvement of the dielectric strength at the RF window. Thus, a PV-3040N klystron was fabricated as an upgrade version of PV-3030A3 type. This paper reports about the effect of increased vacuum pumping on the RF window and the property of the PV-3040N klystron.

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2 PROBLEM IN KLYSTRON RF WINDOW

2.1 Status of klystron operation

The status of klystron operation from 1997 through 2001 is listed in table 1. In this period nine klystrons were broken due to the dielectric breakdown frequently repeated at the RF window surface [3]. The breakdown phenomenon was monitored with the power supply current of the ion pump placed downstream the RF window. However, the current of the ion pump power supply for the klystron indicated no signal of breakdown. The klystrons had been already used for a long time in the injector linac of PF at KEK, therefore the inside the klystrons might be sufficiently aged. These facts suggest that the damage to the RF window was caused by the breakdown on the outer surface of the RF window and instant degradation of the vacuum in the waveguide.

Table 1:Status of the klystron operation

Kly No	Tube Type	Number	Mounted	Dismounted	Status	Max. Performance
#1	A1	87514	97.02.25		Broken	24MW×20µs ×2Hz
	A1	90503			Broken	
	A1	90507	98.02.07 99.05.24	99.02.15 00.04.19	Broken	20MW×20µs ×12.5Hz
	A2	91506	99.02.15	99.05.24	Broken	19MW×13µs ×2Hz
	A1	89511	00.04.19		Running	20MW×20µs ×10Hz
#2	A1	88516	98.02.09	98.05.26	Broken	21MW×8µs ×2Hz
	A2	91502	98.05.27	98.06.18	Broken	26MW×20µs ×2Hz
	A2	92505	98.06.19	98.07.08	Broken	21MW ×12.5µs×2Hz
	A2	92502	98.07.08	98.12.10	Broken	26MW×20µs ×2Hz
	A2	92503	98.12.10	99.06.11	Broken	26MW×20µs ×2Hz
	A1	89506	99.06.12		Running	20MW×20µs ×12.5Hz

2.2 Damage of klystron RF window

The photograph of a sample of damage at an RF window is shown in figure 1. There are notable tracks of dielectric breakdown on the flange surface and pinholes at the ceramic window plate.

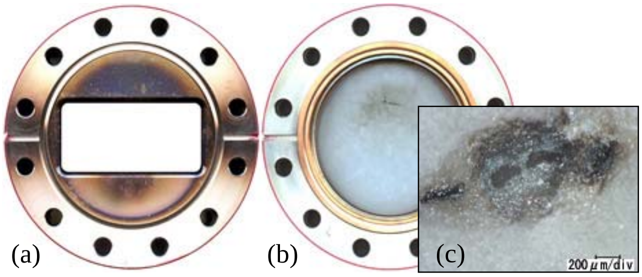

Figure 1: Damage to the klystron RF window. (a) A photograph of the flange surface. (b) The ceramic RF window. (c) Close-up of a pinhole.

2.3 Waveguide vacuum pumping system

The layout of the vacuum pumping system downstream the klystron RF window is illustrated in figure 2. The vacuum in the waveguide is pumped with a 60l/s ion pump located about 2.6m downstream the klystron RF window. The vacuum conductance of the waveguide between the klystron RF window and the ion pump was estimated to be 8.2l/s [4]. The second RF window isolating the vacuum between the klystron and the linac has the same structure as the klystron RF window. The RF power passing through the second window is almost the same as that passed through the klystron RF window. However, the second RF window was never damaged by the RF power. The conductance between the second RF window and the ion pump was estimated to be 20l/s, which is about 2.5 times larger as compared to that for the klystron RF window. This suggests that the difference of performance between the two RF windows was caused by the difference of the vacuum conductance.

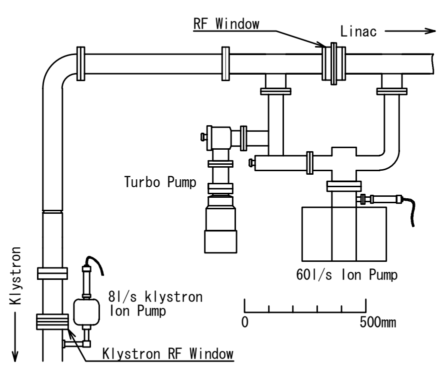

Figure 2: Layout of the waveguide and the vacuum pumping system downstream the klystron RF window.

3 IMPROVEMENT TO VACUUM PUMPING

A quick recovery of the vacuum around the RF window is important to suppress further dielectric breakdown at the next RF pulse. In order to increase the pumping speed around the klystron RF window, two vacuum pump ports were added at the waveguide close to the RF window, as shown in figure 3. These ports were estimated to increase the conductance from 8.2l/s to 43l/s. By the combination with ANELVA 8l/s ion pumps the effective pumping speed around the RF window was estimated to be 17l/s, which is greater than the effective pumping speed of 15l/s at the second RF window.

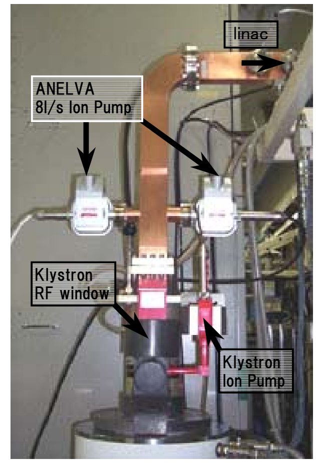

Figure 3: The photograph of the waveguide with two additional ANELVA 8l/s ion pumps located about 40cm downstream the klystron RF window.

The behaviour of the vacuum recovery in the waveguide around the klystron RF window has been simulated on the basis of the pumping speed as discussed above. Figure 4 shows the result of the simulation after the pressure suddenly changed from 10^{-6}Pa to 10^{-4}Pa by the emission of gases out of the RF window surface carried by the dielectric breakdown. An improvement of the vacuum recovery time by the additional pumps is evident in the figure 4.

By the increase of the vacuum pumping system, the output power of 20MW was achieved at the pulse duration of 20μs and the repetition rate of 12.5Hz. Although nine klystrons were broken by damage to the RF windows before the improvement of the vacuum pumping system, no klystron was broken in the operation of the linac over 3,900 hrs after the improvement. However the operation has been restricted to the output power of 20MW due to possible damage to the RF windows at higher output powers.

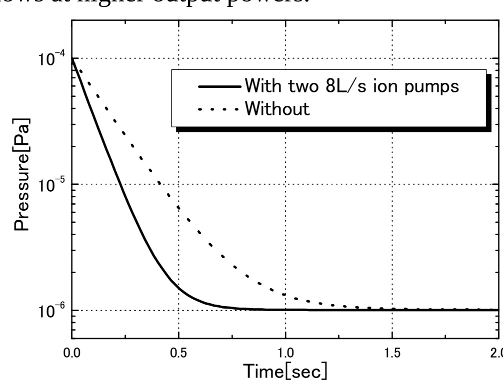

Figure 4: The result of simulation for the vacuum recovery after the dielectric breakdown at the klystron RF window.

4 FABRICATION OF PV-3040N KLYSTRON

4.1 PV-3040N klystron

A new klystron, PV-3040N type, was fabricated for a durability test at higher output powers than 20MW, provided that the pulse duration is 20µs and the repetition rate is 12.5Hz. The PV-3040N klystron is an upgrade version of PV-3030A3 type that has common configuration with PV-3030A1 type [5]. Therefore, no change is required for the klystron assembly tank.

Figure 5 shows the photograph of the PV-3040N klystron. The klystron vacuum pump is located close to the waveguide as compared with PV-3030A3 type, as the vacuum duct was replaced with a short and thick one. The RF window was replaced with the same one as used in a higher power PV-3050 type.

The result of simulation for the vacuum recovery inside the RF window is shown in figure 6. It is evident that the time spent to recover the vacuum from 10^{-4}Pa to 10^{-7}Pa is significantly reduced by the improvement of the vacuum conductance between the RF window and the ion pump.

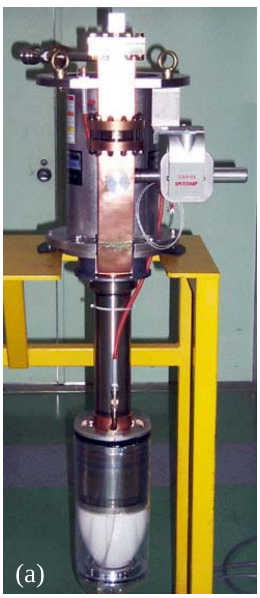

Figure 5:The Photograph of the PV-3040N klystron. (a) Overview of the PV-3040N klystron. (b) Close-up around the klystron ion pump.

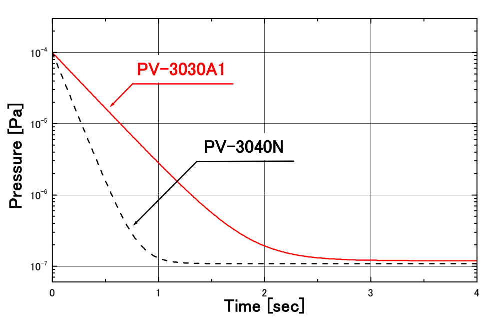

Figure 6:The results of vacuum recovery simulation for PV-3030A1 and PV-3040N klystrons.

4.2 Operation test of PV-3040N klystron

A preliminary high power test of the PV-3040N klystron was performed at a bench in Mitsubishi Electric Corporation. Figures 7 and 8 show the characteristics of the PV-3040N klystron, the power transfer curve, efficiency and output power obtained in the test, where the operating condition was the repetition rate of 50Hz and the RF pulse width of 4µs. The power transfer curve of the PV-3030A1 klystron is also shown in figure 7 for the comparison. The maximum output power of 42.3MW was obtained in the test operation at the above condition.

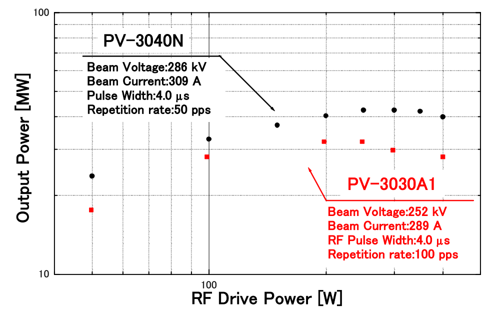

Figure 7: Typical power transfer characteristic as a function of RF drive power.

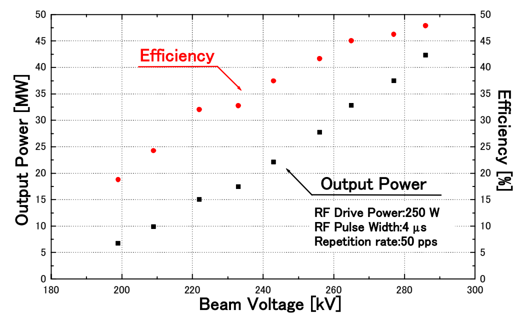

Figure 8: Typical efficiency and RF output power characteristics at saturation as a function of beam voltage.

5 CONCLUSION

A quick vacuum recovery around the klystron RF window is effective to avoid window breakdown, especially for the klystron operation at high power, long pulse width and high repetition rate.

The PV-3040N klystron is expected to achieve the output power of 30MW at the pulse width of 20µs and the repetition rate of 12.5Hz. High power test of the PV-3040N klystron at a long pulse width and high repetition rate is intended in 2002.

6 REFERENCES

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