INSTALLATION AND OPERATION OF A 28 GHz GYROTRON FOR THE RIKEN SUPERCONDUCTING ECR ION SOURCE

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Abstract

We introduced a 28 GHz gyrotron with a maximum output power of 10 kW as a microwave source for the RIKEN superconducting ECR ion source. In its first test, large power ripples were observed in the output microwaves, and its operation was difficult at a power less than 1 kW. These ripples could be reduced by increasing the electric capacitance in the rectified circuit of the cathode power supply. In October 2011, the ion source could be continuously operated with the 28 GHz gyrotron for two months, and it supplied U and Xe beams to the experiments at the RI-Beam Factory. In this period, we observed fluctuations of 20-30% in the beam current from the ion source, which were correlated with the RF power. As a result of these investigations, the cause of these fluctuations was found to be attributed to the current in the solenoid coil of the gyrotron. These fluctuations could be reduced to within 7-8% of the total RF power by exchanging the solenoid power supply with new one with a current stability of less than 1×10^{-5} per day.

INTRODUCTION

At the RI-beam factory (RIBF) at RIKEN, all atomic elements up to uranium can be accelerated to an energy of 345 MeV per nucleon by a cascade of a heavy ion linac and four ring cyclotrons. Experiments in nuclear physics using secondary beams produced from these intense primary beams are being performed intensively. Because U beams have a large cross-section to generate many isotopes of interest, an increase in the beam intensity is of great need. In order to increase the intensity of U^{35+} used for beam acceleration at the RIBF, we have been developing a superconducting 28 GHz ECR ion source [1, 2]. This ion source uses a 28 GHz gyrotron. The gyrotron is produced by Mitsubishi Electric Corporation and has a maximum output power of 10 kW. The first test at the RIKEN site was performed with a dummy load in September 2010, and after improvement to its power supply, the superconducting ECR ion source was operated with the gyrotron in April 2011. Moreover, the 28 GHz ion source supplied U and Xe beams to the RIBF experiment successfully for two months from October to December of 2011 [3].

28 GHz GYROTRON

The newly developed 28 GHz superconducting ion source uses a gyrotron microwave source. Figure 1 shows the schematic drawing of this gyrotron, and its parameters are listed in Table 1. Electron beams produced from a magnetron-type electron gun are injected into an open

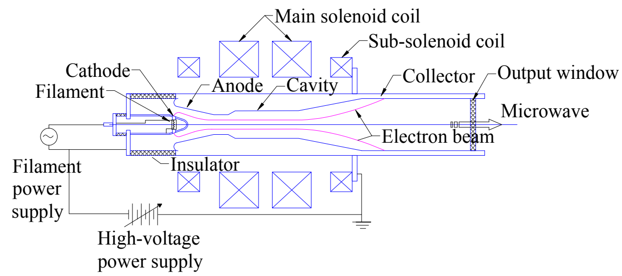

Figure 1: Schematic drawing of the 28 GHz gyrotron.

Table 1: Parameters of the Gyrotron

frequency	28±0.1 GHz
Mode	TE02
Electron beam voltage (max.)	22 kV
Electron Beam current (max.)	1.6 A
Input power (max.)	60 kW
Main Solenoid current (typ.)	195 A
Sub Solenoid current (typ.)	18.5 A
Output power (max.)	10 kW

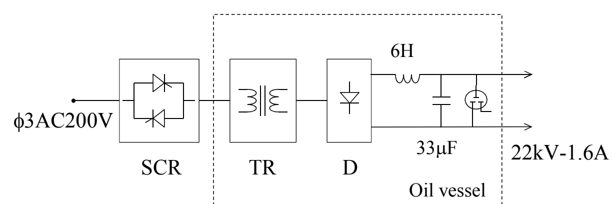

Figure 2: Electric circuit of the cathode power supply.

resonator along solenoid fields, producing 28 GHz microwaves by electron cyclotron resonance in the cavity. The maximum acceleration voltage and current of the electron beams are 22 kV and 1.6 A, respectively. The gyrotron uses cathode and filament power supplies along with two dc power supplies for the solenoid coils, as shown in Fig. 1. Figure 2 shows a diagram of the electric circuit of the cathode power supply. The AC input power is controlled with thyristors at low voltage, and it is rectified into direct current after it is boosted up with a transducer. The cathode power supply also has a protection circuit with a three-gap device in order to protect the gyrotron from an arc event. The output RF power is controlled by the current and voltage of the electron beam. Figure 3 shows the relationship between the cathode voltage and the RF power for a fixed beam current of 1.2 A. The RF power was measured from the temperature rise of a dummy load. Each point in Fig. 3

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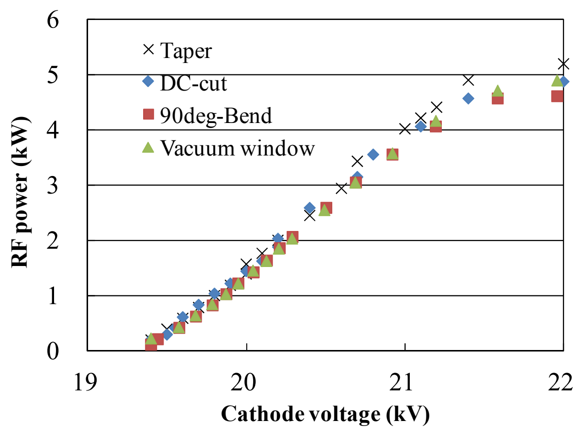

Figure 3: RF power versus cathode voltage.

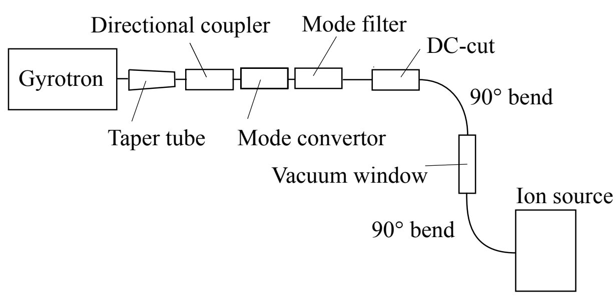

Figure 4: Microwave transmission line.

corresponds to a case where the dummy load was placed just behind the corresponding component indicated in the legend.

TRANSMISSION LINE

Figure 4 shows a drawing of the microwave transmission line. The gyrotron produces TE_{02}-mode microwaves, which are converted into the TE_{01} mode by a mode converter and a mode filter after passing through a taper tube and a directional coupler. The microwaves are then transmitted to the ion source via a DC-cut, two 90° bend tubes, and a vacuum window. The size of the output window of the gyrotron is ϕ63.5 mm, and the tubes downstream of the directional coupler have an inside diameter of ϕ32.512 mm. The directional coupler detects forward and reflected microwaves. The coupling is 50 dB and the diode detectors (DS2640, Herotek Inc.) are used to measure the power. The output voltages in the diode detectors have been calibrated to the power obtained from the temperature increase in the cooling water of a dummy load. Initially, the output of the detector was not stable at a power greater than 5 kW. Because the temperature of the directional coupler exceeded 50°C, we replaced the directional coupler with a water-cooled one. Figure 5 shows the diode voltage for the forward and reflected microwaves as a function of the RF power. Each point corresponds to the position of the dummy load. The voltages for the reflected waves represent only the relative power because setting level of an attenuator is

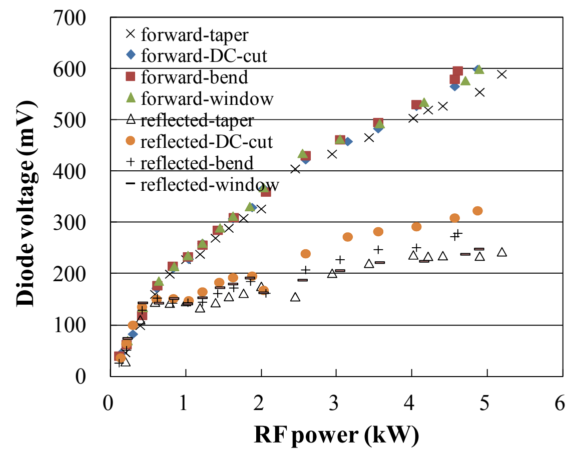

Figure 5: Output of the diode detector.

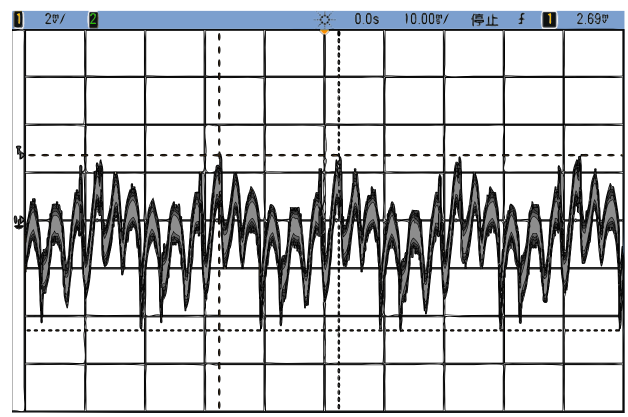

Figure 6: Waveform from the diode detector before improvement. Scales are 10 ms/div and 5 mV/div.

different from that in the forward wave, and most of the voltages seem to originate in the forward wave owing to the poor directivity. The mode converter changes the TE_{02} mode into the TE_{01} mode with an efficiency of 95%. The mode filter absorbs microwaves with modes other than the TE_{01} and TE_{02} modes.

REDUCTION OF THE RIPPLES IN THE RF POWER

The first test of the gyrotron was performed at RIKEN in September 2010 using a dummy load. Ripples of 300-500 W in the output power from the gyrotron were observed, making stable operation in the low-power region (<1 kW) difficult. The ripple waveform of the detector diode is shown in Fig. 6. The cathode voltage, beam current, and RF power were 22 kV, 1.5 mA, and 7.5 kW, respectively. The main component in the ripple frequency is at 300 Hz, and the magnitude of the ripple is approximately equivalent to the RF power of 400 W. Moreover, ripples of approximately 220 V were also observed in the cathode voltage. Even though we are operating at full power, the magnitude of both ripples did not change much, even at lower power.

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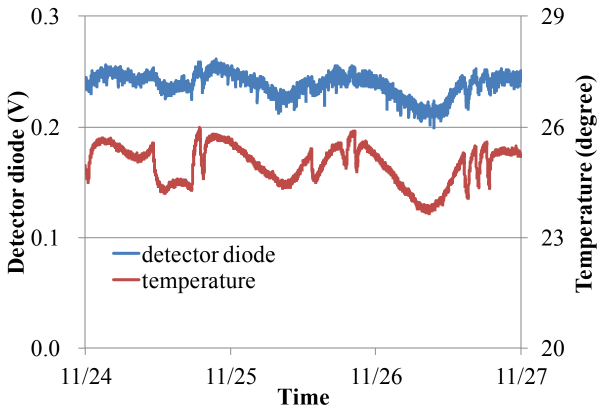
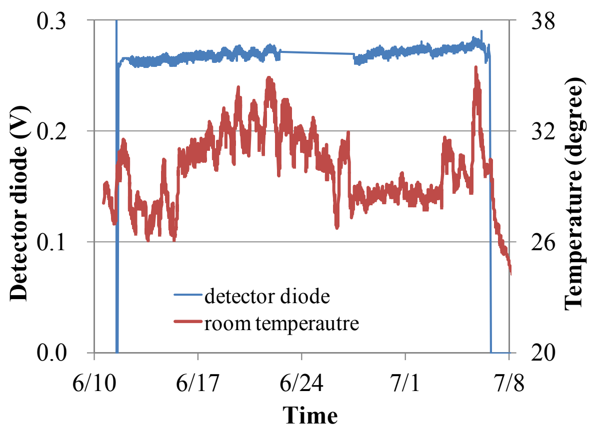


(a)



(b)

Figure 7: Detector diode voltage for the RF power and the room temperature during operation as a function of time (a) before and (b) after the stabilization of the output RF power.

Initially, the rectification circuit shown in Fig. 2 for the cathode power supply consisted of a 6 H inductor and a 3 μF capacitor. To reduce the voltage ripples, we increased the capacitance tenfold by adding four 7.5 μF paper capacitors with a maximum rated voltage of 37.5 kV. As a result, the ripples in the cathode voltage and RF power were reduced to approximately 15 V and 100-150 W, respectively, and operation below 500 W became possible. However, the reason why the ripples in the RF power did not decrease as compared to those in the cathode voltage is not clear.

STABILIZATION OF THE RF POWER

The ECR ion source with the 28 GHz gyrotron was operated from October to December 2011 in order to supply U and Xe beams to the RIBF experiments. During this period, 24-h operation was successfully achieved for a total of 70 days, except for two one-day breaks for the exchange of a uranium rod. Figure 7(a) shows the voltage change in the detector diode attached to the directional coupler for three days of machine time. The fluctuation in the diode voltage corresponds to a fluctuation in the RF power of approximately 300 W. This fluctuation seems to be correlated with the temperature of the room in which the power supplies are housed, as shown in Fig. 7(a). We investigated this phenomenon intensively because any fluctuation in the microwave power would influence the beam currents. As a consequence, we found that the RF power is very sensitive to the current in the main solenoid coil and that the current changes slightly, on the order of 1×10^{-4}/°C with the temperature of the room. In order to reduce this power fluctuation, we replaced the main solenoid power supply with another with a current stability of less than 1×10^{-5} per day. As a result, the RF power could be stabilized to within 7-8% of the total power in one month, as shown in Fig. 7(b).

REFERENCES

[1] T. Nakagawa et al., Rev. Sci. Instrum. 81 (2010) 02A320.
[2] Y. Higurashi et al., Rev. Sci. Instrum. 83 (2011) 02A308.
[3] Y. Higurashi et al., "Recent RIKEN 28 GHz SC-ECRIS Results," THXO03, these proceedings.

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