Frequency shift in a long CW operation of gyrotron

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Abstract

It is known that the gyration output frequency varies with a long time CW operation. When the condition for the operation is the same as the magnetic field and accelerating voltage, output frequency depends on radials of cavity. Generally, electromagnetic wave in the cavity makes a loss and this energy is changed into thermal. This effect changes cavity size. In this experiment, we measure the relation between output frequency and cavity temperature. In measurement system, the output frequency is measured by a heterodyne receiving system. However, cavity temperature can't be measured directly. So we measure cavity cooling water temperature to calculate cavity temperature. As the result of this experiment, when the output power is 4W, the drift of output frequency is 71 MHz and the increase of the water temperature is by 1.3 degrees. And when output power is 8W, drift of output frequency is 119 MHz and the increase of water temperature is by 2.0 degrees. This result shows that the cavity radius and frequency depend on the power of electromagnetic wave at cavity.

1.Introduction

The gyrotron, millimeter and sub millimeter wave light source is a higher power light source than other devise (BWO, FEL, and ets). Several applied technologies like plasma heating and ceramics sintering have been developed with this characteristic. Gyrotrons can change the output mode with frequency. It is useful to use material science (ESR). In this device, the output power and the output frequency have been stabilized. Now, the power stability is 0.1%, and the frequency fluctuation is 100kHz at output frequency of 301GHz[1)]. However, this stability is only for a very short time. In a long time CW operation, it has frequency shift about 10MHz. This phenomenon makes it difficult to stabilize the gyrotron output with the phase lock loop. Now, the possible time of phase lock is only about 10 second. In this paper, there is an analysis of the principal of gyrotron frequency shift to high quality stabilization.

2.Experimental

In principal of gyrotron, there are three factors to cause the frequency shift (magnetic field, accelerating voltage of electron, and cavity size). The experiment was conducted by keeping those two factors in the same condition. Then the frequency shift occurred. This result means the frequency shift is raised as the cavity size changes. In the resonate cavity of gyrotron, electron beams are interacted by electric magnetic wave. The frequency of this electric magnetic wave is proportion to the radial of the cavity. The relation between resonating frequency of cavity f and the radial of cavity r is as follows

$$f = c\rho'_{mn}/2\pi r \qquad (1)$$

Here ρ'_{mn} is the root of solution to a differential of Bessel function)

This equation show that the gyrotron output frequency is down by cavity expanding.

In this experiment, we used Gyrotron FUⅣ(fig.2). Heterodyne receiving system is used for the gyrotron frequency measurement system (fig.3). In the gyrotron tube, vacuum revel mast be high. It became can't be measured the cavity inner wall temperature directly. This time, we measure the cavity cooling water temperature to know the cavity wall temperature shift. The cavity cooling system is showed in fig.1. The relation between cooling water temperature and cavity wall temperature is calculated by heat conduction equation.

$$\begin{cases} q = -\kappa \nabla T \\ c\rho \dfrac{dT}{dt} = -\mathrm{div}(q) \end{cases} \qquad (2)$$

Here q is heat flux, κ is heat conductivity, T is temperature, c is specific heat, ρ is density

And solution of eq.2 is

$$T = T_1 + \mathrm{A}\ln\left(\frac{r}{r_1}\right) \qquad \mathrm{A} = -\frac{Q}{2\pi\kappa l} \qquad (3)$$

Here, r_1, r_2 is inner and outer radial of cavity, T, T_1 is cavity temperature and cooling water temperature, Q is heat value of passing through the cavity wall.

The gyrotron output frequency is

$$f = \frac{v_c}{2\pi} k_\perp \qquad k_\perp = \frac{\rho'_{mn}}{r} \quad (4)$$

Here $k_\perp$ is wave number of perpendicular by magnetic field and v_c is velocity of light. The relation between radial of cavity and cavity temperature is

$$r = r_0\{1 + \alpha(T - T_0)\} \quad (5)$$

Here α is heat expanding rate, r_0 is radial of cavity temperature at T_0.

The relation between frequency and cavity temperature is

$$\frac{\Delta f}{f_0} = \frac{f - f_0}{f_0} = \frac{r_0 - r}{r_0} = -\alpha T \quad (6)$$

$$\frac{\Delta f}{f_0} = -\alpha\left(T_1 + A\ln\left(\frac{r}{r_1}\right)\right) \quad (7)$$

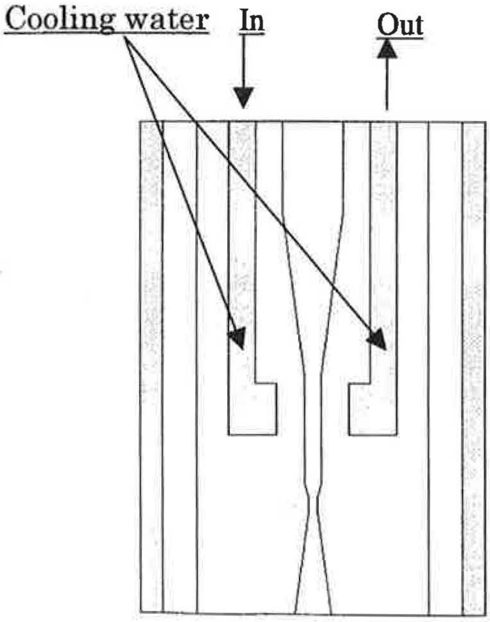

Fig.1 Cavity cooling system

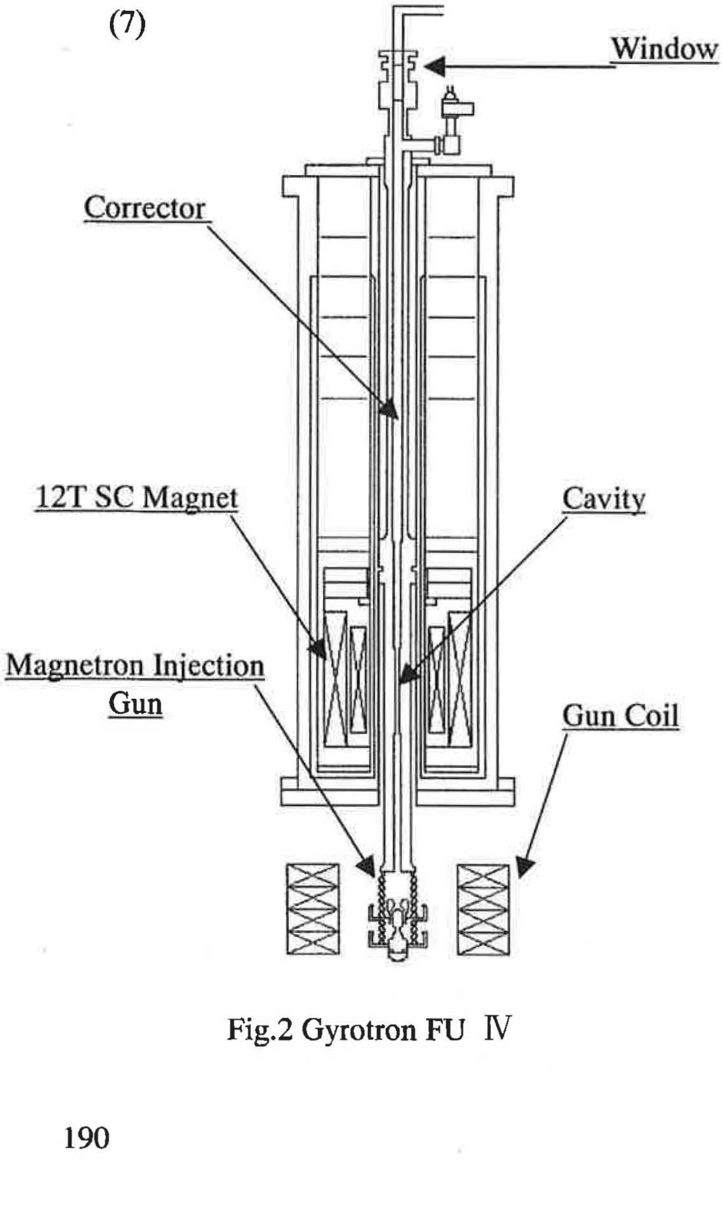

Fig.2 Gyrotron FU Ⅳ

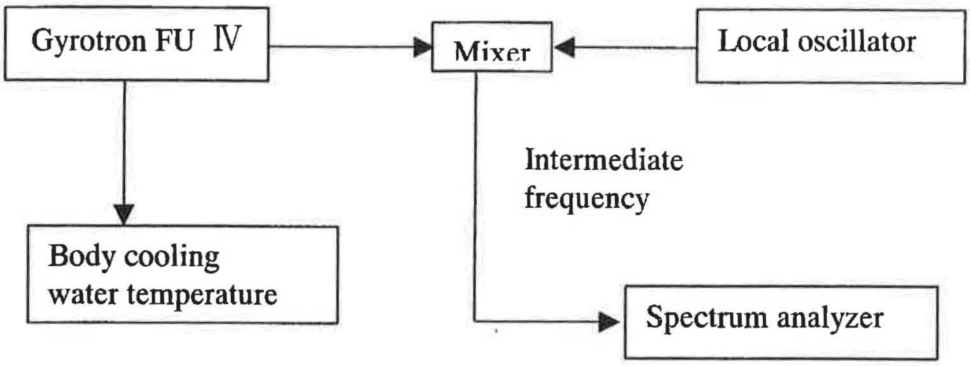

Fig.3 Heterodyne receiving system

Fig.4 shows the measurement result of gyrotron output frequency shift and cavity cooling water temperature by time and Fig.5 shows the output power by time. The frequency shift is the largest at the beginning of operation and the shift rate became zero. The frequency seemed to be in inverse proportion to water temperature.

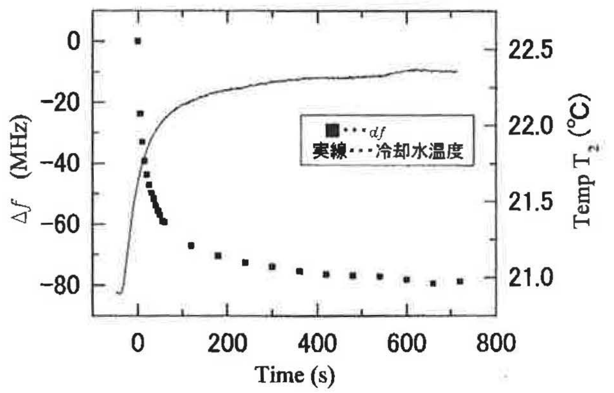

Fig.4 Gyrotron frequency shift and cavity cooling water temperature

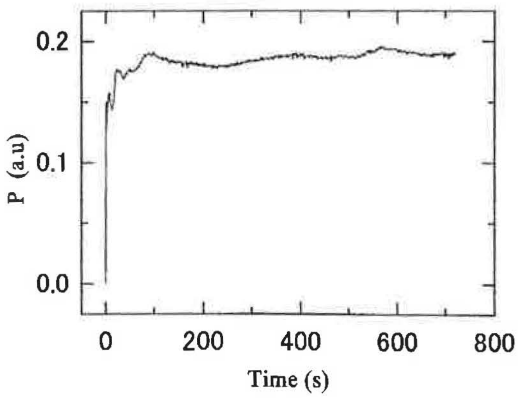

Fig.5 gyrotron output power by time

In Fig.6 shows the experimental frequency shift value with calculation line (eq.7).

The experimental result and calculation line are about the same slope and it means cavity heat expanding causes the frequency shift. The reason of an absolute quantity of difference between experimental value and calculation value is explained by the calculation line calculated for only constant condition. In this condition, the generation heat is changed into cooling water heat.

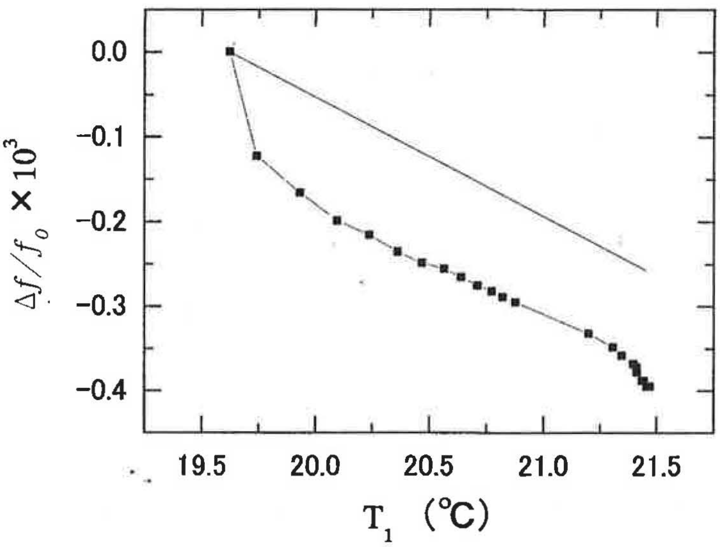

Fig.6 frequency shift value by cooling water temperature

In Fig.7 shows the frequency shift at two different output powers (4W and 8W).
The value of 8W shift is twice than 4W. It mean the expansion of the cavity radial is made by ohmic loss on the cavity wall.

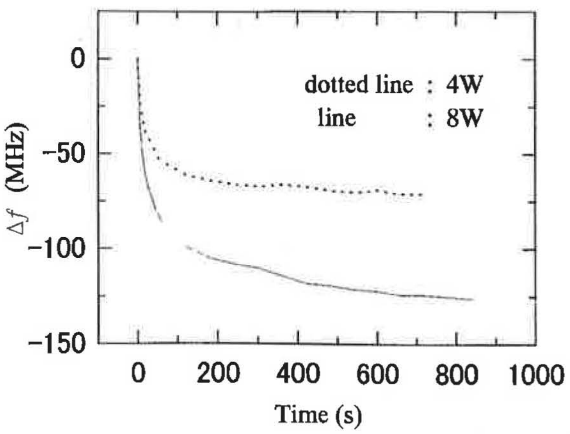

Fig.7 frequency shift by time

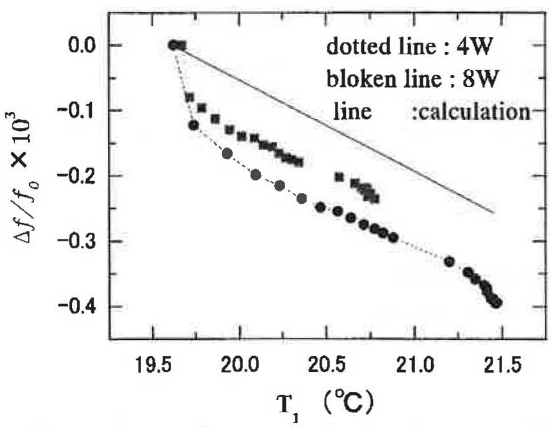

Fig.8 frequency shift at two different output powers (4W and 8W)

3.Conclusion

In this experiment we confirmed that expanding of resonator cavity makes the gyrotron output frequency shift. And the value of the shift is depends on the output power. This experiments proves the ,when gyrotron output frequency is stabilized the output power also needs to be stabilized. In order to keep the size of the cavity small, the cooling water temperature needs to be controlled as well.

Reference

1) I.Ogawa, T.Okada, T.Idehara, FIR Center Report **2** 14 (2001)