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OSCILLATION FREQUENCY OF THE AMMONIA BEAM MASER

BY

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ABSTRACT

For the purpose of precise measurement of the oscillation frequency of the maser on $J=K=3$ line of ammonia, two masers were used. The oscillation frequency of one maser was used as a reference and that of the other was measured under various operating conditions.

The oscillation amplitude *versus* frequency characteristics was found to be in good agreement with the theory. Based on these characteristics, it has been shown that the oscillation frequency at the maximum amplitude is lower than the frequency measured by the absorption method.

The shift of the center frequency due to the change in focuser voltage was observed to agree with the theory. The oscillation frequency *versus* focuser voltage characteristics was measured for various cavity tunings.

The shift of the oscillation frequency with the change in source pressure was also measured for various cavity tunings.

These two ammonia beam masers combined with the absorption type atomic clock can provide a more accurate standard for frequency and time.

1. Introduction

Atomic clocks of different types (**1**~**5**) based on the spectral line have been constructed and studied. Since the first ammonia maser was constructed, the gas maser has been expected to be a new type of more accurate standard for frequency and time. However, the oscillation frequency of the maser has been observed to shift slightly (**6**, **7**).

In this paper, various frequency shifts of ammonia beam maser were measured precisely.

2. Experimental apparatus

The block diagram of the experimental apparatus is shown in Fig. 1. The respective parts are described in the following.

(A) The maser No. 2

As a reference, the maser No. 2 was used. The vertical cross-sectional view of the maser No. 2 is shown in Fig. 2. The cavity, the focuser and the effuser are similar to those of the maser No. 1(8), except that they are vertically arranged. A 3-inch oil diffusion pump whose pumping speed is 300 lit/sec, is connected directly to the maser tube.

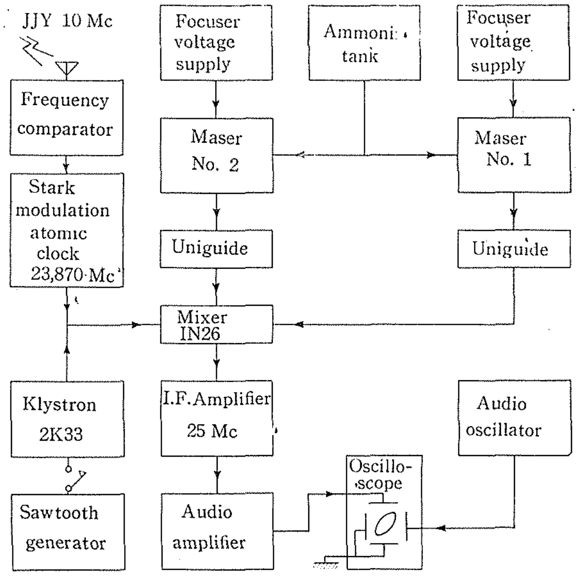

Fig. 1. Block diagram of the apparatus.

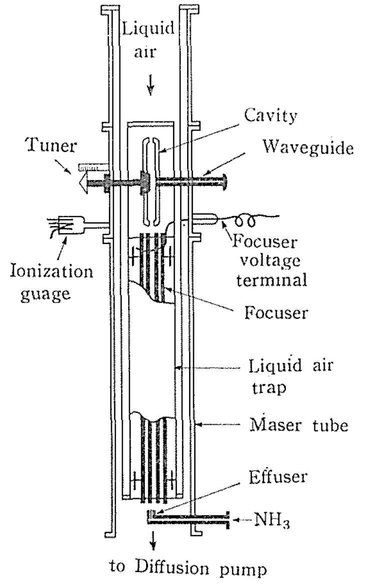

Fig. 2. Cross-sectional view of the maser.

(B) The detecting system

For observing the beat frequency between the masers No. 1 and No. 2, the superheterodyne detecting system with a common local oscillator is used. Consequently, the beat frequency has not been affected by the fluctuation in the frequency of the local oscillator. In order to avoid any frequency pulling effect, the uniguides are used as shown in Fig. 1.

3. Experimental procedure

Before carrying out the frequeny comparison, the oscillation of each maser must be confirmed and the oscillation frequency of one maser (used as a reference) is measured using the Stark modulation atomic clock (5). Then the frequency comparison is carried out by observing the Lissajous figure on the cathode ray oscilloscope formed by the beat between two masers and the signal from a calibrated variable audio frequency oscillator.

4. Experimental results

(A) Oscillation amplitude *versus* frequency characteristics

The oscillation amplitude *versus* frequency characteristics of the maser have been observed under various focuser voltages and source pressures. The oscillation frequency was changed by varying the tuning of the cavity. These results are shown in Figs. 3 and 4.

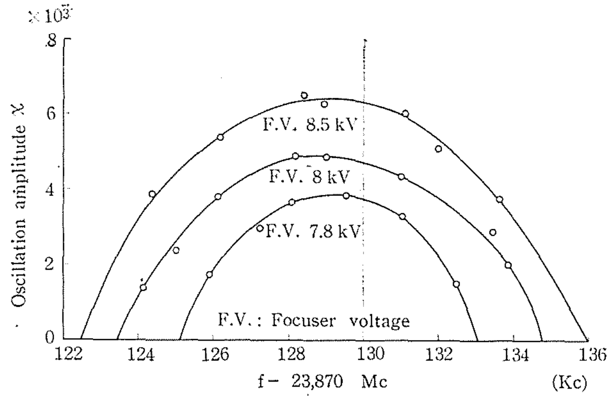

Fig. 3. Oscillation amplitude *versus* frequency characteristics for various focuser voltages (source pressure: 5 mm Hg). The dotted line shows the center frequency measured by the absorption method.

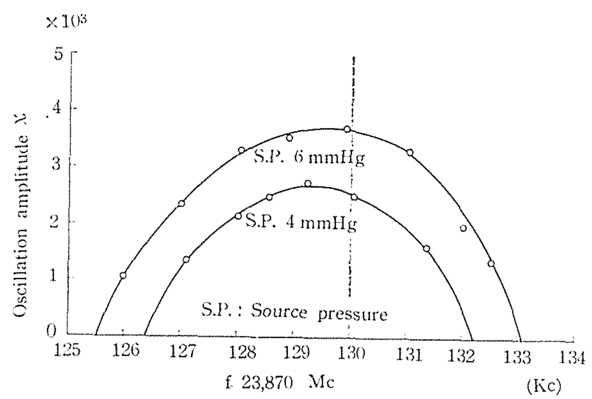

Fig. 4. Oscillation amplitude *versus* frequency characteristics for various source pressures (focuser voltage: 10 kV): The dotted line shows the center frequency measured by the absorption method.

The center line of the ammonia consists of three hyperfine components due to the electric quadrupole moment of nitrogen nucleus N^{14}. The intensities of these three components in the maser oscillation are different from those at thermal equilibrium. The ratio of relative intensities for $F_1=3$, 4 and 2 of the 3-3 line in the maser oscillation has been calculated as 1:0.9174:0.0470 (**9**). The relative intensity of $F_1=2$ component is much smaller than the other two, so it can be neglected in the calculation. Thus the oscillation amplitude *versus* frequency characteristics is expressed as the emission of two hyperfine components at ω_1 and ω_2 (**9**):

$$\theta_1 = [(\omega-\omega_1)^2+\chi^2]^{1/2} L/2\langle v\rangle ,$$
$$\theta_2 = [(\omega-\omega_2)^2+\chi^2]^{1/2} L/2\langle v\rangle ,$$

and

$$C_0 = C_1 \frac{\sin^2\theta_1}{\theta_1^2}+C_2 \frac{\sin^2\theta_2}{\theta_2^2} ,$$

where ω is the oscillation frequency, χ the oscillation amplitude, L the cavity length, $\langle v\rangle$ the effective average velocity and C_0 a constant corresponding to the relative intensity at the threshold of oscillation, and the ratio $C_1:C_2$ is $1:0.9174$ on 3–3 line of ammonia. In Fig. 5, the theoretical curves for $V=10$ kV are shown

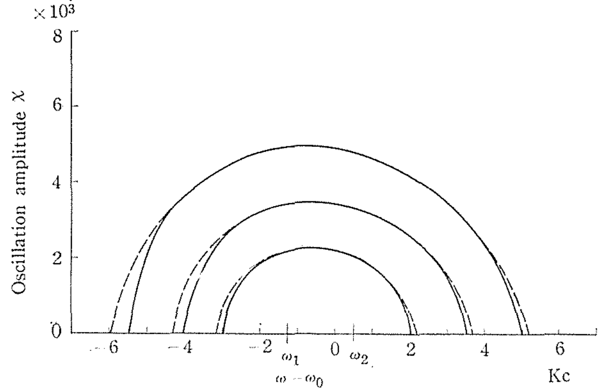

Fig. 5. Theoretical oscillation amplitude *versus* frequency.

for various beam intensities. The characteristic curve must be somewhat modified in the region, where θ_1 or θ_2 is large, as shown by dotted curves (**9**). The experimental results are in good agreement with the theoretically expected characteristics. According to Figs. 3 and 4, the absolute value of oscillation frequency at the maximum amplitude, which seems to occur when the cavity is tuned to the frequency of the line, is lower than the frequency measured by the absorption method (**10**). The reason is that the relative intensities of hyperfine components in the maser oscillation are different from those at thermal equilibrium.

(B) Shift of center frequency

The shift of the center frequency with the change in the focuser voltage has been measured and is shown in Fig. 6. By the theory (**9**), the shift of the center frequency on 3–3 line, due to the unresolved hyperfine structure was calculated as a function of the focuser voltage.

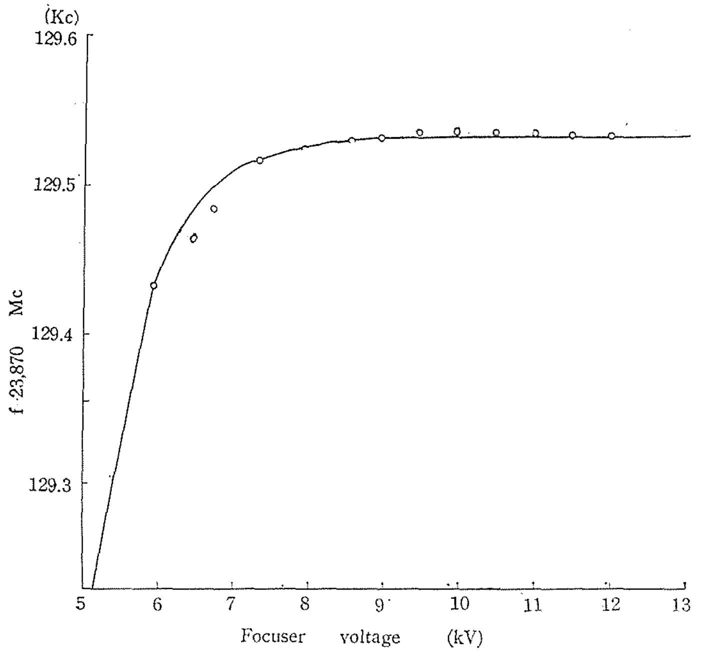

Fig. 6. Shift of the center frequency.

In Fig. 6, the circles show the observed values, while the curve shows the theoretically expected shift. The observed result agrees with theory.

(C) Oscillation frequency *versus* focuser voltage characteristics

The oscillation frequency *versus* focuser voltage characteristics have been measured for various cavity tunings and the result is shown in Fig. 7. The oscillation frequency of the maser is fairly pulled by the cavity tuning as shown in Fig. 7, and in §4(A). In the low focuser voltage region, the cavity pulling increases due to the decrease of the oscillation amplitude. Consequently the oscillation frequency shifts away from the line center.

(D) Oscillation frequency *versus* source pressure characteristics

The shift of the oscillation frequency with the change in the source pressure has been observed and measured for various cavity tunings. The result is shown in Fig. 8. This type of frequency shift can be explained by the decrease of the oscillation amplitude due to the reduction of the beam flux by scattering, since the tube pressure increases with the source pressure.

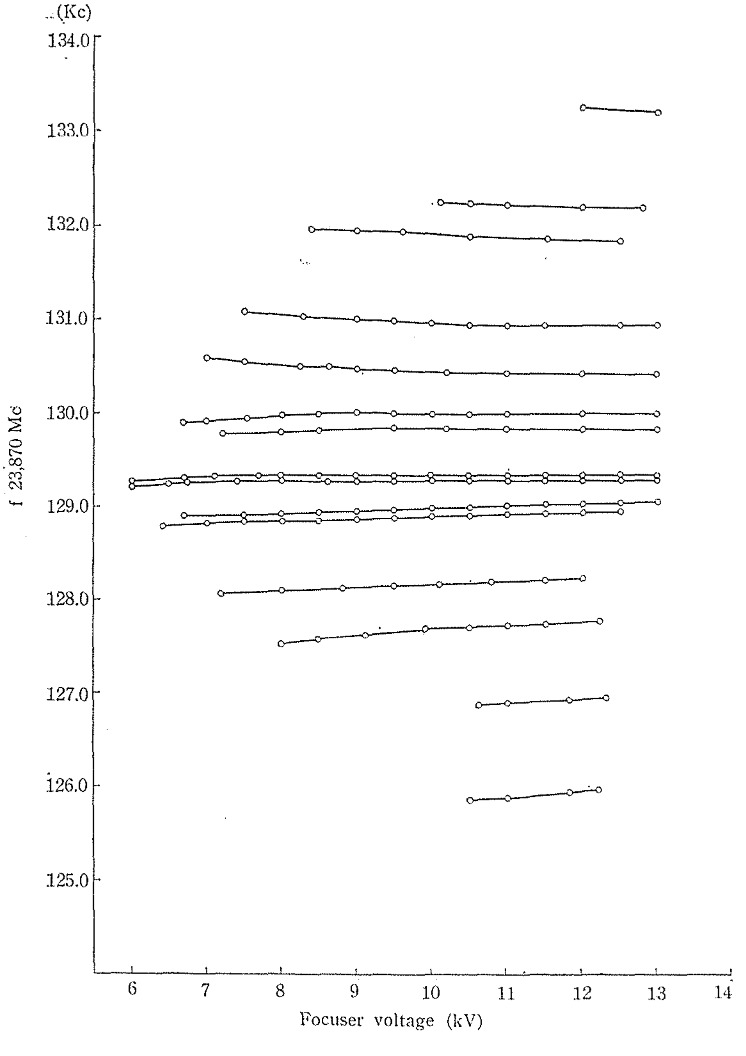

Fig. 7. Oscillation frequency *versus* focuser voltage characteristics for various cavity tunings.

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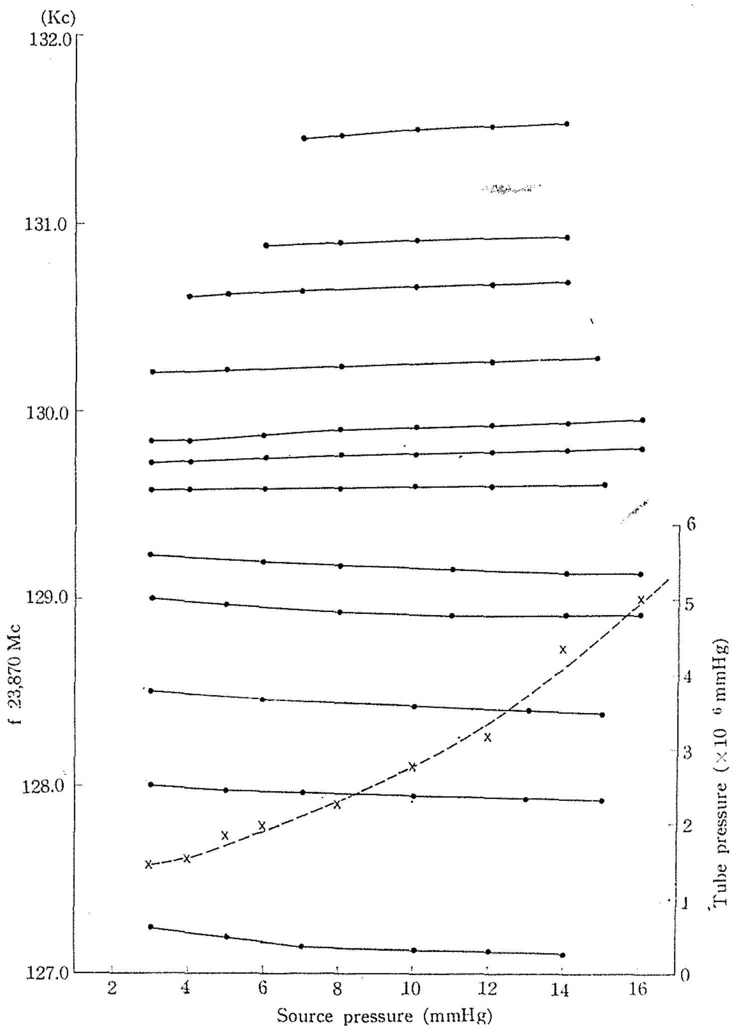

Fig. 8. Oscillation frequency *versus* source pressure characteristics for various cavity tunings.

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