HYDROGEN MASER WITH SINGLE-STATE SELECTION SYSTEM

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Abstract. The design and the results of researching of Hydrogen Maser acting with an improved output signal power and double selection atom system is described.

The selection system consists of two standard focus magnets with an anti-helmholtze coil between them. A large storage bulb (V_b=3l) and a long cavity (L_c=400mm ; D_c=260mm) is used. Undesired atoms removing efficiency is ~70%. Power delivered to the microwave receiver is 1×10^{-12}W with atomic line Q-factor 2×10^{9}.

1.Introduction

The state selection system usually employed in a hydrogen maser uses a single inhomogeneous state selection magnet. With this system the atoms in both upper hyperfine levels (F=1, m_F=0; and m_F=0) enter into the storage bulb. The presence in the maser storage bulb of atoms in the other magnetic sublevel of the ground state is undesired because of the atomic line Q-factor reducing, and a frequency shift due to the magnetic field inhomogeneity. Output signal power decreases also. All these factors cause further frequency stability reducing. Especially they effect a short-term frequency stability when the receiver noise influence is noticeable. The power delivered by the atoms to the cavity with taking into account spin exchange collision (for the chosen resulting Q-line (Q_l) and optimal storage time (T_b)) [1], [2] is as follows:

$$P_0 = \frac{\hbar\cdot\omega^3\cdot V_a}{16\cdot\sigma\cdot v_r\cdot\alpha\cdot Q_l^2}\left(1-6q+q^2\right) \qquad (1)$$

$$q = \frac{h\cdot\sigma\cdot\bar{v}_r\cdot\alpha\cdot V_c}{8\pi\cdot\mu_0^2\cdot\eta\cdot Q_c\cdot V_a}; \qquad \eta = \frac{\langle H_z\rangle^2_a}{\langle H^2\rangle_c}$$

where $\alpha = \frac{N_{tot}}{N_1 - N_0}$, N_{tot} is the number of all atoms entering the bulb; N_1 and N_0 – the numbers of atoms in the states of (F =1, m_F=0) and (F=0, m_F=0) respectively; Q_c – loaded cavity Q-factor; η - magnetic filling factor; σ - spin-exchange collision cross section; V_b – storage bulb volume; V_c – cavity volume; q - maser quality factor; $\bar{v}_r$ - average relative velocity of atoms in the storage bulb; μ_0 is the Bohr magneton.

The power delivered into the microwave receiver is:

$$P = P_0\frac{\beta}{1+\beta} \qquad (2)$$

where β - a coupling coefficient.

As a maser q-factor is $q \sim \frac{1}{Q_c}$ then $q = q_0(1+\beta)$, where q_0 - the maser quality factor for unloaded cavity. Equation (2) thus becomes

$$P = \frac{\hbar\cdot\omega^3\cdot V_a}{16\cdot\sigma\cdot v_r\cdot\alpha\cdot Q_l^2}\left(1-6q_0(1+\beta)\right)\frac{\beta}{1+\beta} \qquad (3)$$

For $\beta = \frac{1}{\sqrt{6q_0}} - 1$ the output power is maximum:

$$P = P_{\max} = \frac{\hbar\cdot\omega^3\cdot V_a}{16\cdot\sigma\cdot v_r\cdot\alpha\cdot Q_l^2}\left(1-\sqrt{6q_0}\right)^2 \qquad (4)$$

Equation (4) shows that if undesirable atoms are removed (parameters α and q_0 are reduced by a factor 2) the output power should be considerably increased. For example, for q = 0,06 it should be increased by a factor 4.

2.The design

For the improvement of the magnetic state selection the method of a sudden field reversal [3], [4] was used. The selection system is shown schematically in the Fig.1.

It consists of two hexapole selection magnets and a field reversal region between them: a DC electric current is circulating in opposite direction in two coils located in a magnetic shield and produces a weak magnetic field the direction of which varies rapidly in a space along the atomic beam.

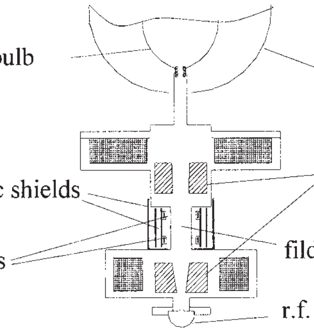

Fig.1. Schematic representation of a single-state selection system

Such selector was installed in the H-maser which was proposed as a highly stable local oscillator [2]. The main features of this device are: $Q_c = 36\cdot10^3$; $Q_{c0} = 50\cdot10^3$; $V_b = 3\cdot10^3 sm^3$; $V_c = 17{,}5\cdot10^3 sm^3$
The enter channel of the storage bulb was chosen so that the calculated storage time (the life time of atoms within the bulb) - $T_b \approx 1s$, ($Q_{l0} \approx 4.5\cdot10^9$); $\eta' = \eta\frac{V_b}{V_c}$ -was estimated as 0.45.

The differences in magnetisation of sorting magnet pole pieces lead to the situation when disperse magnetic fields spread over the reversal region and cause the additional inhomogeneity of magnetic field. Because of this the direction of the CD-current in the coils (for switched on single state selection system) is chosen in such a way, that the sorting magnetic field doesn't disperse magnetic field coincides with the direction of the reversal coil field at the exit from the field reversal region.

CD-current in the coils was chosen thus that the maser generation power was maximum when the intensity of the H-maser beam flux becomes maximum.

When the measurements of the H-maser parameters were made without using the single state selection system, the CD-current in the reversal coils was redirected thus that the field in the reversal region was homogeneous.

3. The results

To define the efficiency of the selection system the q-factor was determined when the system was in two states (switched off and switched on) by measuring of the ratio of the output signal power to noise power versus inverse Q-line.

Since our H-maser was equipped with a standard discharge bulb (volume about 10 sm^3) we couldn't achieve a maximum output signal power especially using single state selection system. So we fulfil the measurements with an distuned cavity ($f_c \neq f_0$).

The equation for the power radiated by the atoms depending on resulting inverse Q-line can be written as:

$$P = \frac{\hbar\cdot\omega^3\cdot V_b}{4\cdot\sigma\cdot v_r\cdot\alpha}\cdot\left(-\frac{2\tilde{q}}{Q_l^2}+\frac{1+\tilde{q}}{Q_{l0}}\cdot\frac{1}{Q_l}-\frac{1}{Q_{l0}^2}\right) \quad (5)$$

where $\tilde{q} = q\left(1+\delta^2\right)$ (6)

δ - relatively distuning of the cavity:

$$\delta = \frac{2(f_c - f_0)}{f_0}Q_c$$

From (5) and (6) can be obtained that:

the inverse line Q corresponds to the beginning of generation:

$$Q_{l0} = Q_l\left[\frac{1+\tilde{q}-\sqrt{1-6\tilde{q}+\tilde{q}^2}}{4\tilde{q}}\right] \quad (7);$$

a maximum power generation corresponds to:

$$\overline{Q}_{l0} = Q_{l0}\cdot\frac{1+\tilde{q}}{4\tilde{q}} \quad (8)$$

$$\frac{\overline{Q}_l}{Q_l} = \frac{1-\tilde{q}-\sqrt{1-6\tilde{q}+\tilde{q}^2}}{1+\tilde{q}} = 1-\frac{\sqrt{1-6\tilde{q}+\tilde{q}^2}}{1+\tilde{q}} \quad (9)$$

Fig. 2 shows the ratio of the output maser power (P) to the noise power (P_n) (in the bandwidth B=100Hz) versus inverse line Q_l with single state selection system (SSS-system), when f_c-f_0=0 (upper curve) and f_c-f_0=31.7 kHz (lower curve).

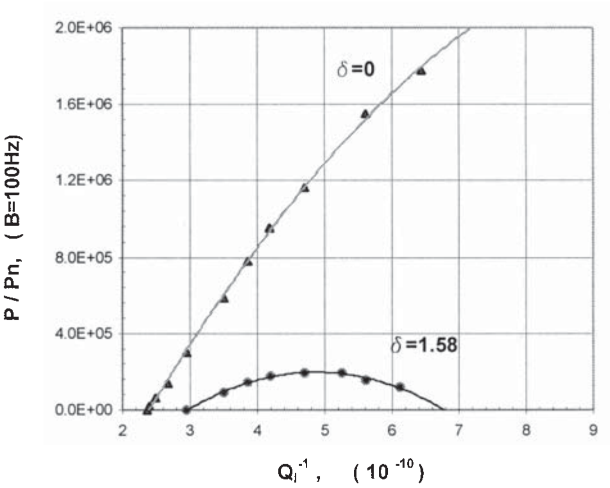

Fig. 2 . The ratio of output maser's power (P) to noise power (P_n) (in the bandwidth B=100Hz) versus inverse line Q_l with singl-state selection system for different value of resonant cavity's frequency f_c.

The same ratio without single state selection system when f_c-f_0=0 (upper curve) and f_c-f_0=21 kHz (lower curve) is shown in Fig.3

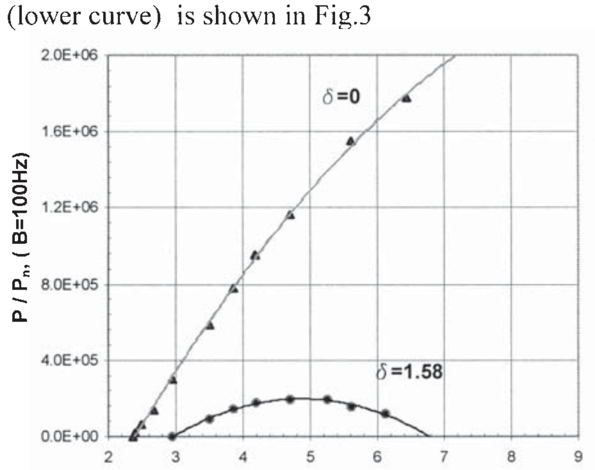

Fig.3 . The ratio of output maser's power (P) to noise power (P_n) (in the bandwidth B=100Hz) versus inverse line Q_l without singl-state selection system for different value of resonant cavity's frequency f_c.

. Using the results of the measurements shown in Fig. 2,3 and equations (6)-(8) we obtained:

q=0.039, Q_{l0}=4.38·10^9 in case when the single state selection system is switched on;

q=0.067, Q_{l0}=4.40·10^9 in case when the single state selection system is switched off.

So, the efficiency of elimination of the undesirable atoms by the single state selection system is about 70%. The output maser power for the line Q_l of 1.5×10^9 ($Q_l^{-1}=6.5\times10^{-10}$) was determined as 1.5×10^{-12}W with SSS-system and 0.8×10^{-12}W without it.

3. Summary

Using single state selection system one can increase maser power for chosen Q-line by a factor 1.8.

Further maser power increasing (by a factor of 4 or more) can be achieved by: increasing of the storage bulb volume; increasing of the couple coefficient β; using Q_c-enhancement technique; increasing of the efficiency of H-source.

References

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