INTERACTION OF THREE MODES OF A GAS LASER IN THE LOCKING REGION

S.A. Gonchukov, O.E. Porodinkov, E.D. Protsenka, and V.A. Semchishev
Moscow Engineering Physics Institute
Submitted 8 July 1971
ZhETF Pis. Red. 14, No. 4, 235 - 238 (20 August 1971)

1. The temporal characteristics of lasers in the mode locking regime have by now become the subjects of many studies [1]. On the other hand, the spectral properties have been investigated mainly only theoretically [2 - 4].

We report here the results of an investigation of the spectral properties of radiation in the mode locking region. The measurements were performed on an $He-Ne^{20}$ laser of 0.63 μ wavelength. The laser generated on three axial modes with distance 380 MHz between them. The intermode beats separated from a germanium photodiode were amplified and fed to a radio-frequency mixer. The small-beat signal (the difference frequency between the mode beats) obtained in this manner was recorded directly with an oscilloscope.

2. Figure 1 shows oscillograms of the small-beat signal obtained while scanning the laser in the region of symmetrical tuning of the three modes relative to the line center ω. In the locking region, which subtended in our case ∿40 MHz, the signal has a complicated form with a characteristic narrow resonance at symmetrical tuning $x = \omega - \nu_2 = 0$, where ν_2 is the frequency of the second mode. The resonance at low gas pressures is directed downward, and at high pressures upward. At the transition pressure, equal in our case to 2 Torr, the signal has the form shown in Fig. 1b. Attention is called in this case to the absence of mode locking in a small vicinity of $x = 0$, subtending 2 - 3 MHz.

It is easy to show that the small beat signal is proportional to $E_2^2 E_1 E_3 \cos\psi$, where E_i is the field amplitude of the i-th mode and ψ is the relative phase angle. The behavior of the fields as a function of the detuning in the region of $x = 0$ is due mainly to mode competition, which leads to considerable changes of E_1 and E_3, whereas E_2^2 changes little. The quantity $E_2^2 E_1 E_3$ always has a maximum at $x = 0$, and consequently the inversion of the resonance is connected with ψ.

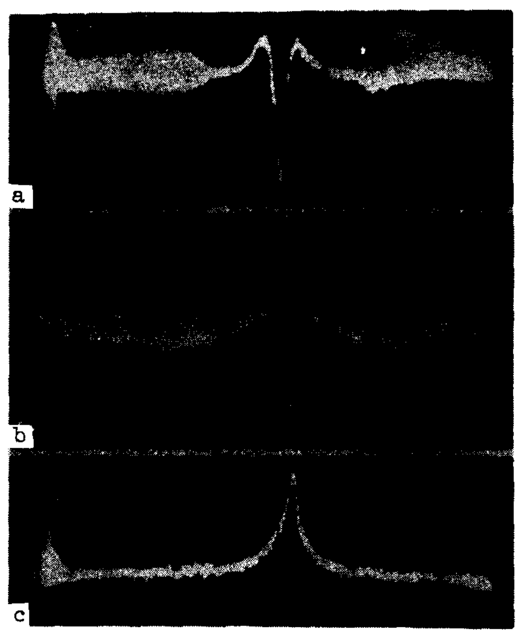

Fig. 1. Oscillograms of small beats at gas pressures 1.6 Torr (a), 2 Torr (b), and 2.5 Torr (c). The oscilloscope sweep length corresponds to 200 MHz.

3. Using Lamb's theory [2] we can write for ψ:

$$\dot{\psi} = \sigma + A\sin\psi + B\cos\psi, \qquad (1)$$

where σ is a term that takes into account the pulling and interaction

$$A = 2E_1E_3\eta_{13} - E_2^2E_1E_3^{-1}\eta_{21} - E_2^2E_3E_1^{-1}\eta_{23} \qquad (2)$$

$$B = -(2E_1E_3\xi_{13} - E_2^2E_1E_3^{-1}\xi_{21} - E_2^2E_3E_1^{-1}\xi_{23})$$

and η and ξ are the Lamb coefficients.

Let us consider ψ at $x = 0$. In this case $\sigma = B = 0$, and (1) takes the form $\dot{\psi} = A\sin\psi$. If $A \neq 0$, this equation has the solution $A > 0$, $\psi = \pi$ and $A < 0$, $\psi = 0$. $A = 0$ is a singular point of the equation, but in a small vicinity of $x = 0$, where it can still be assumed that $B = 0$, we are

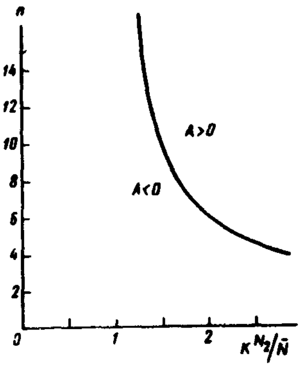

Fig. 2. Dependence of n on $k(N_2/\bar{N})$ for A = 0 at mode tuning near x = 0.

justified in writing $\psi = \sigma$, if account is taken of the strong variation of σ with the detuning. This yields $\psi = \sigma t$ + const, i.e., there is no mode locking.

At x = 0 we can assume $E_1^2 = E_3^2 = E_2^2/n$; we then get from (2) $A = 2E_1^2(\eta_{13} - n\eta_{21})$. For A = 0 we have

$$n = \frac{2\left(1 + \frac{N_2}{\bar{N}}k\right)}{k\frac{N_2}{\bar{N}} - 1},$$

where

$$k = \frac{\gamma^2 - \frac{\Delta^2}{2}}{\gamma^2 + \frac{\Delta^2}{4}}.$$

γ is the line width, Δ the distance between modes, and $\bar{N}$ and N_2 the average inversion density and its second harmonic.

It is seen from Fig. 2, which shows the hyperbola branch of interest, that, depending on the position of the working point on the curve, a locking regime with $\psi = 0$ and $\psi = \pi$ may or may not be realized in the vicinity of x = 0. Since $|k|$ decreases with increasing pressure, capture with downward, transition, and upward resonance is realized in succession at the appropriate values of the parameters $N_2/\bar{N}$ and η.

The value of $N_2/\bar{N}$ depends on the position of the amplifier tube in the resonator, and also on the discharge current, the gas pressure, and the tube diameter. The latter is quite significant for a capillary laser and makes it difficult to carry out a quantitative comparison of the theory with experiment.

4. The investigation has shown that in a small vicinity near the symmetrical mode tuning, the locking may disappear. Strong mode interaction in the locking region ensures attainment of narrow resonance. The resonance has a width on the order of 10^{-2} of the width of the homogeneous line and 100% contrast.

Resonances of this width have by now been obtained using an absorbing cell with I_2^{129}, and the contrast of these resonances was about 1% [6].

It is obvious that the obtained narrow structures, the width of which reaches 2 - 3 MHz, can be used for high stabilization of the laser radiation frequency relative to the line center of the atomic transition. A very important fact is that analogous resonances can be obtained in lasers working in the regime of generation modes, and also for other transitions.

[1] P.W. Smith, Proc. IEEE 58, 1342 (1970).
[2] W.E. Lamb, Phys. Rev. A134, 1429 (1964).
[3] D.G.C. Jones, M.D. Sayers, and L. Allen, J. Phys. A2, 95 (1969).
[4] A. Bambini and P. Burlamacchi, IEEE, J. Quant. Electr. QE-4, 101 (1968).
[5] I.P. Mazan'ko, M.I. Molchanov, N.D.D. Ogurok, and M.V. Sviridov, Opt. spektr. 30, 927 (1971).
[6] G.R. Hanes and C.E. Dahlstrom, Appl. Phys. Lett. 14, 362 (1969).