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MEASUREMENT OF NATURAL LINE WIDTH OF THE EMISSION OF A GAS LASER WITH COUPLED MODES

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Many recent investigations are devoted to theoretical and experimental studies of fluctuations in gas lasers. Investigation of the frequency fluctuations makes it possible to determine the natural laser line width due to spontaneous emission.

The natural emission line width is usually measured by obtaining beats from two independent lasers, after which one measures the spectral density S_ν of the beat-frequency fluctuations. A typical plot of $S_\nu(f)$ for this case is shown in Fig. 1 (curve 1). The value of S_ν connected with the natural emission line width does not depend on the observation frequency [1], and the rise at low frequencies is due to the line broadening resulting from technical causes: instability of the cavity dimensions, fluctuations of the pressure and temperature of the air, etc. By measuring S_ν in a region where it is no longer dependent on the frequency, it is possible to determine the natural laser-emission line width, which is π times larger than S_ν. This method, which is used in [2], has made it possible to measure the natural radiation line width, the minimum value of which turns out to be 0.06 Hz in this experiment. Measurement of the line width by this method leads to difficulties connected with the need for obtaining a single-frequency regime, exact alignment of the wave fronts of the emissions of both lasers at the photodetector, and stabilization of the frequency difference between the two lasers; all this calls for the use of a complicated automatic-tuning system.

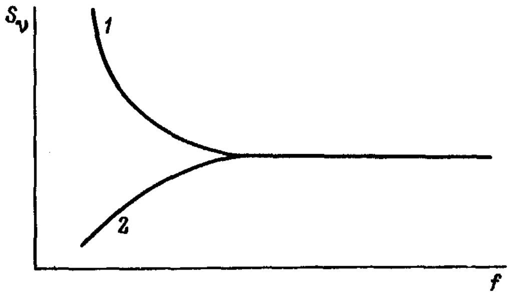

Fig. 1

A method free of the foregoing shortcomings is one based on measurement of the line width of the intermode beats of one laser. However, its use in [3] did not lead to measurement of the natural line width of the radiation, owing to the beat instability caused by various external and internal factors. To eliminate this shortcoming, we used in the present investigation synchronization between longitudinal modes, obtained as a result of modulating the phase in an electrooptical crystal. The crystal was placed in the laser cavity and was under an electric field whose frequency was equal to the beat frequency [4,5]. The frequency dependence of the spectral density of the beat-frequency fluctuations is shown for this case in Fig. 1 (curve 2). Synchronization correlates the low-frequency fluctuations of the frequencies of the modes, causing them to disappear from the beat line. This leads to a dip in S_ν at low frequencies. However, the synchronization is "inertial" for high-frequency fluctuations. The frequency at which the dip in the spectral density of the beat-frequency fluctuations ends characterizes the time of establishment of synchronization and is determined by the width of its band. In the given experiment, the laser generated three modes. It can be shown that S_ν of the beats in this case is equal to half the spectral density of the frequency fluctuations of each of the outer modes (at equal mode power). Therefore, by measuring S_ν of the beats at high frequencies, where it no longer depends on the frequency, we can find the spectral density of the fluctuations of the frequency of the outer modes and determine their natural width.

As shown in [6], the natural width Δf of the gas-laser emission line is connected with the resonator bandwidth $\Delta\nu$ by the following expression:

$$\Delta f = \alpha \frac{(\Delta\nu)^2}{P},$$

where α is a constant for a given type of laser. In our experiment P and $\Delta\nu$ were chosen such as to make Δf not less than 0.05 Hz. According to the theoretical and experimental investigations [1,7], the natural line width of vacuum-tube oscillators is smaller than 10^{-5} Hz. Consequently, the natural width of the modes of the laser used in our investigation was larger by several orders of magnitude than the natural line width of the synchronizing generator (which used 12C3C tubes). It can therefore be assumed that the measurement error due to the natural line width of the synchronizing generator was negligibly small.

The block diagram of the setup is shown in Fig. 2. The radiation of the laser, in which synchronization was realized, was fed to the photodiode. To increase the signal/noise ratio, the beats were initially amplified by a low-noise parametric amplifier 1 having a high input resistance. The signal was then fed from the output of the parametric amplifier to the main amplifier 2, amplitude limiter 3, frequency detector 4, and low-frequency selective voltmeter 5, with the aid of which the spectral density of the beat-frequency fluctuations was measured. The modulating voltage from generator 6 was fed to modulator 7. The number of modes was controlled by a scanning interferometer 8.

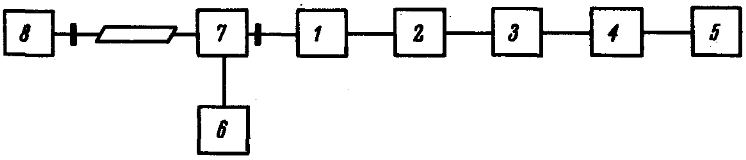

Fig. 2

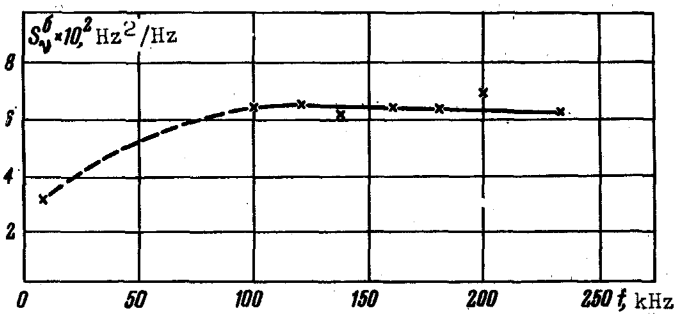

Fig. 3

We used a standard LG-35 laser, in which one of the mirrors had a reflectance 95%. The laser generated at 0.63 μ wavelength, and the power in one mode was on the order of several dozen microwatts. The distance between the longitudinal modes was 112 MHz.

The experiment was performed in accordance with the following procedure. At first the voltmeter was used to measure the voltage U_{ph} due to the signal from the photodiode. Then, generator 6 was connected to the input of the parametric amplifier 1 in place of the photodiode, and its amplitude was set to be the same from the photodiode in the previous measurement. In this case the selective voltmeter 5 measured the noise voltage U_n due to the line width of the generator 6 and the intrinsic noise of the parametric amplifier. At 200 kHz this voltage was smaller by 4 - 5 times than the voltage U_{ph}. The value of the voltage U_{laser} corresponding to the natural width of the laser line was determined by the formula:

$$\overline{U^2_{laser}} = \overline{U^2_{ph}} - \overline{U^2_n}$$

One of the experimental curves is shown in Fig. 3. The dashed line shows the part of the curve which could not be plotted because of the large modulation of the radiation intensity by the gas discharge noise and by the mechanical vibrations. It follows from this curve that the natural width of the outer modes is 0.4 Hz.

The proposed method can be used to investigate the frequency fluctuations of gas lasers.

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