OPTICAL QUANTUM GENERATORS (LASERS) — 0.63 μ,
WITH IODINE ABSORPTION CELL

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Frequency-stabilized optical quantum generators (lasers) are finding everywhere a greater application in measurement techniques. An increase of frequency stability is the basis for the improvement of the characteristics of the outgoing radiation of these lasers, used as reference instruments.

The most promising is a laser with a radiation wavelength of 0.63 μ, whose frequency stabilization is effected by the sharp resonance of saturation absorption in an iodine cell. In a number of countries (USA, German Federal Republic, France, etc.) 0.63-μ lasers with cell absorption using both natural and isotopic iodine already have been developed and used as reference means of measurement [1-3]. Values of laser frequency instability of order 10⁻¹¹-10⁻¹² have been achieved for absorption cells with iodine-127 and 129, respectively. The frequency reproducibility (wavelength) of these generators amounts to 10⁻¹⁰, which exceeds the reproducibility of the krypton frequency standard by almost two orders.

In [1-3], the degree of contrast of the detected resonances does not exceed 0.1%, which does not allow the frequency of the laser to be stabilized with respect to the first derivative, as there is a background slope of the curve of uniform iodine absorption, which considerably distorts the shape of the contour of the output power. It is necessary, therefore, to use the more complex method of the third derivative [3].

The results of the first investigations are considered below, carried out on a helium-neon (He³-Ne¹⁹²) laser with natural iodine-cell absorption. The absorption cell was made in the form of an optical delay line. It can be seen from [4] that this allowed the contrast of certain known resonances to be increased up to 0.5%.

By optimizing the saturating field in this cell, we obtained resonances with a contrast of 10-30%. The increase of contrast of the sharp power resonances, used as frequency datum points, is of great importance for ensuring the stable operation of an automatic frequency-tuning (AFT) system for a laser, and the production of high frequency stability.

Structurally, the laser used was made according to the design described in [5]. The resonator consists of four massive Invar-steel rods, end and intermediate flanges for fixing the mirrors, and the discharge tube with the cell. The mirrors and the Brewster window, separating the discharge tube and the cell, are internal. The resonator of the delay line, formed by a spherical (R = 2 m) and a plane mirror with a transmittance of 0.001, permit six transits of the beam to be achieved with a distance between mirrors of 50 cm. Thus, the total effective absorption length is equal to 3 m. The reflection cycle of the beam is closed by the plane mirror. These parameters of the delay line resonator, allow the density of the saturating field to be increased by approximately a factor of two, relative to the case described in [5].

The discharge tube of the laser, with a diameter of 1.8 mm and a discharge gap length of 45 cm was filled with a mixture of helium-3 and neon-22 up to a total pressure of 400 Pa in the ratio of 7:1. With a discharge current strength of 8-10 mA, the output power was 0.01 to 0.05 mW. The iodine pressure in the cell was set by the temperature finger and varied within the limits of 0.13 to 0.3 Pa. When scanning the length of the resonator, on the contour of the output power a series of contrast resonances was observed. The region of difference generation of the laser being investigated was determined by the frequency beats observed on the contour of the output power of the laser heterodyne, operating in the single-
frequency mode. The classification of the resonances obtained has not yet been carried out; however, it can be said that the appearance of a group of previously unobserved resonances is found in the region of the Lamb dip of the laser heterodyne. The frequency stabilization of the laser was carried out by the resonances obtained, according to the well-known method [6].

With a closed ring of AFT feedback, the discrimination characteristic (first derivative) of the output power contour was noted, with a slow change of voltage of sawtooth shape, on one of the piezoceramic cylinders of the laser [7]. The magnitude of the voltage permitted two contours to be recorded, which could be selected for stabilizing the frequency of the laser with any of the resonances obtained. The modulation amplitude of the optical frequency was equal to 0.3 MHz for a modulation of 10 kHz.

Figure 1 shows a record of the discrimination characteristics of the output-power contour of the laser and a record of the voltage fluctuations taken from the output of the phase detector of the AFT system in the stabilization mode.

The voltage fluctuations of the phase detector are proportional to the frequency instability of the laser. In order to measure the instability, the width of the resonance is used as a frequency scale, which is measured by experiment and is denoted in Fig. 1 by the letter $\Gamma$. The radiation of the laser being investigated in the mode of free oscillations was mixed with the radiation of a laser heterodyne, which in the single-frequency mode has an output power contour width of 750 MHz. Difference frequency beats were observed on the screen of an oscillograph, on the laser-heterodyne contour. A slowly varying sawtooth voltage up to an amplitude of 100 V was applied to the piezoceramic cylinder. As a result of this, the beat frequency shift on the contour from the original position amounted to 40 MHz, with an error in determining this range of 1 kHz, taken as the average of ten series of measurements. Knowing the voltage necessary to record the discrimination characteristics in the interval of a single power contour, and the sensitivity of the piezocylinder, the width of the resonances was determined, which on conversion to the half height of the resonance, on the average was found to be equal to 2.4 ± 0.3 MHz.

The frequency instability of the laser was determined as the ratio of the maximum size of the amplitude of the frequency fluctuations to the transition frequency itself. Over a measurement time of 100 sec and an averaging of 0.5 sec, the frequency instability amounted to (2 to 3)$\cdot10^{-12}$. The power resonances are numbered in Fig. 1. It can be seen that the AFT system captured the frequency after the ninth resonance. The peaks of the signal during opening of the feedback ring of the autotuning system are marked by a star. Frequency fluctuations were recorded when the sensitivity of the pen recorder was increased by two orders. The maximum amplitude of the fluctuations is equal to 1.2 kHz. To the right, below, is shown the resonance width $\Gamma$ and its first derivative.

It should be noted that stabilization of the laser was carried out with respect to several of the resonances obtained and that during prolonged operation of the generator in the stabilization mode, no spontaneous "knocking out" of frequency with a power resonance was observed. The considerable contrast of these resonances allowed the frequency of the laser to be stabilized with respect to the first derivative of the output-power contour and enabled...