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Frequency stabilization of cw CO_2/SF_6 lasers

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Frequency stabilization of low power cw CO_2 lasers to the centre of SF_6 absorption peak is presented. The stability 8 parts in 10^{12} for 1 s averaging time is obtained.

1. Introduction

The frequency of laser radiation is submitted to strong fluctuations because of mechanical vibrations of the laser resonator, thermic drifts of laser mirrors, turbulation of air in the optical resonator volume, acoustic vibrations, variations of temperature and pressure, fluctuations of laser current and other effects giving uncontrolled changes of the optical path of the laser beam inside the optical cavity. Stabilized laser radiation is necessary in many applications of cw lasers, such as metrology, plasma diagnostics, atomic and molecular spectroscopy, interferometry, geophysical research, wavelength and other precision length measurements. There are many stabilization frequency method of the laser radiation [1]. Among all these methods [2] the method which uses saturation effects in resonant-emissive or resonant-absorbing media, i.e., Lamb dip effect, occupies a particular position. The Lamb effect was observed for the first time in resonant-emissive medium of a He-Ne laser 0.63 μm [3].

This effect is applied also in laser saturation spectroscopy, called Lamb dip spectroscopy or Doppler free spectroscopy [4, 5]. The application of the Lamb dip effect in laser spectroscopy enables us to reduce successfuly the Doppler broadening of the investigated absorption bands and to achive a high resolution of laser spectrometers equipped with an absorption cell.

Narrow absorption peak has found its application also in experiments with frequency stabilization of output laser radiation. Prime experiments have been performed with a He-Ne laser 3.39 μm equipped with an internal CH_4 absorption cell [6], a He-Ne laser 0.63 μm equipped with a inside I_2 absorption cell [7] and a CO_2 laser 10.6 μm equipped with an external SF_6 absorption cell [8]. An external absorption cell can be applied when the output laser power is sufficiently high to saturate the absorber [9]. This condition is satisfied for a cw CO_2 laser and sulfur hexafluoride molecules as the absorber [10].

2. Experiment and results

An experiment was carried out in a set-up of a laser heterodyne (Fig. 1). The laser heterodyne made it possible to measure the frequency stability of the investigated lasers. The lasers were placed on a heavy granite slab which insulated the arrangement from mechanical vibrations. The pyrex discharge tube 60 cm in length and 1.4 cm in diameter with gas mixture $CO_2:N_2:He = 1:1:4$ at the total pressure of 10 Torr was closed with NaCl Brewster-angle windows.

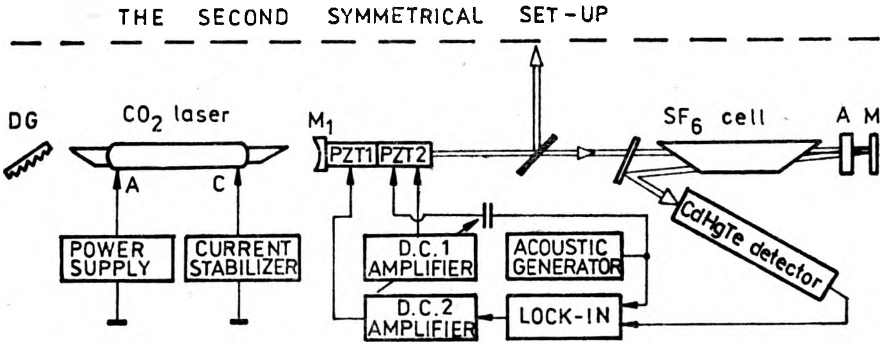

Fig. 1. Experimental set-up of the laser heterodyne: DG — diffraction grating, M_1 — coupling-out hole mirror, A — attenuator, M — totally reflecting mirror, Lock-in — 232 B POLON nanovoltmeter

The NaCl windows were enclosed in antihygroscopic boxes. The boxes have reduced the turbulation of air in the optical resonator volume. The balance reservoir of approximately 10 dm^3 connected to the laser tubes made possible the operation in sealed-off conditions. The discharge tube was excited by means of unstabilized high-voltage power supply. The mean dc voltage drop across the tube was 7.5 kV. Excitation was performed by using a hollow cylinder nickel cathode 2 cm in diameter, and 1.5-mm-diameter tungsten anode through a 100-kΩ ballast resistor. The current stabilizer was inserted in the discharge circuit on the side of the cathode. The optical cavity of 1.7 m in length was equipped with a plane diffraction greating (153 lines per mm) and a gold coated concave output mirror ($R = 10$ m) with a coupling-out hole [11]. The laser produced output power of approximately 2 W per one preselected emission line of 10.4 μm band in the nonflowing system. Transverse modes were suppressed by a diaphragm placed in the laser cavity. PZT 1 piezoceramic transducer and dc amplifier 1 gave the possibility of manual retuning of laser frequency in the range of the emission line width. The dc voltage applied to PZT 1 transducer was modulated at 515 Hz for both the lasers by a sinusoidal signal from an acoustic generator. The error signal was obtained by using a phase sensitive detector. PZT 2 transducer operated in the frequency of servo-control system.

The set-up of the laser heterodyne consisted of a glass absorption cell 40 cm in length and 2.5 cm in diameter ended with NaCl Brewster-angle windows. The absorption cell was filled with SF_6 at the pressure of 80 mTorr. The absorber was excited simultaneously with two travelling laser waves, i.e., with a saturate wave and a probe wave. An intense laser wave saturated the absorption which was monitored by a weak probe was travelling in the opposite direction. At the centre of the absorption line, where both the saturate wave and the probe was interacted with the same group of absorbing molecules, the intensity of the probe wave increased as a result of the decreasing saturation due to the intense saturate wave. An absorption peak obtained in this way (Fig. 2) was used to frequency stabilization of the lasers [12].

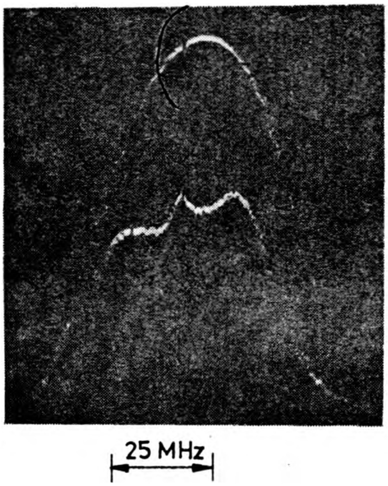

Fig. 2. SF_6 absorption peak on P16 preselected CO_2 laser line of 10.6 μm band. Upper curve — CO_2 emission line monitored before the absorption cell, lower cuvre — emission line monitored over repeated transition of the laser beam through-out the absorption cell

As it is known, stability of a laser equipped with an absorption cell depends on the contrast of absorption peak. In order to obtain a contrastive peak, the probe wave was four times attenuated with respect to the saturation wave. In this case, the contrast obtained was about 25 %. In order to reduce the signal-to-noise ratio, it is necessary to minimize the noise of the servo-loop system. Instead of this, maximization of the slope of the quantum discriminator characteristics, i.e., the slope of the discrimination characteristic of the absorption peak was performed in this work. Thus, according to the theoretical investigations [13], the intensity of the saturate wave was approximately twice as large as the absorption saturation intensity in this experiment. The measured absorption saturation intensity of SF_6 was 3.8 $Wcm^{-2}Torr^{-1}$ for P16 line of 10.6 μm band of a CO_2 laser [14]. The experiment was performed at the saturate wave intensity of about 1 Wcm^{-2} at SF_6 pressure of 80 mTorr. According to numerical calculations, maximal slope of the first derivative of absorption peak occurs for the modulation scan width of about 0.6 $\Delta\nu_L$ [15], where $\Delta\nu_L$ is the spectral width of the Lorentzian shape of an absorption peak. The spectral width of the obtained absorption peak was 3 MHz, the applied modulation scan width was 1.8 MHz.

In order to investigate the frequency stability, the beat frequency technique was used (Fig. 3) [16]. Measurements of the laser stability were performed for various averaging times. The obtained Allan variance [17] is shown in Fig. 4. For comparison, the results of the frequency stability to the centre of CO_2 emission line are also presented [18].

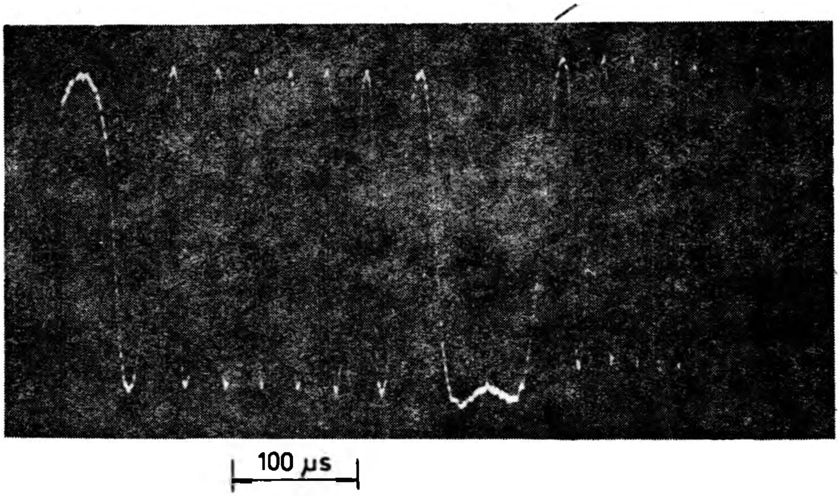

Fig. 3. Oscillogram of beat frequency signal of the lasers

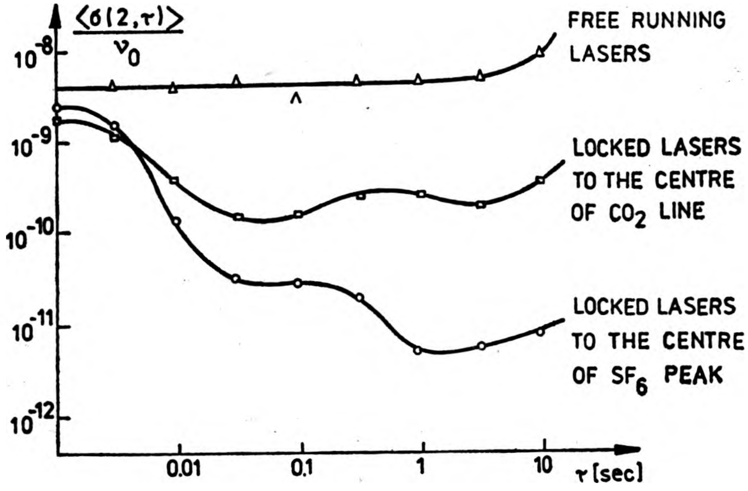

Fig. 4. Frequency stability of the investigated CO_2 lasers

In the presented set-up the stability of 8×10^{-12} obtained for 1 s averaging time is about two ranges of magnitude better than in the set-up with stabilization to the centre of the laser emission line. Better results are expected for CO_2/SF_6 lasers with longer absorption cell and an optical set decompressing the laser beam diameter to a few centimeters, the construction of which is being realized.

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Стабилизация частоты CO_2/SF_6 лазеров

Представлена стабилизация частоты CO_2 лазеров малой мощности в центре пика поглощения SF_6. Получена стабильность 10^{-12} для времени усреднения 1 с. Представлены результаты для сопоставления стабильности частоты в центре эмиссионной линии CO_2.