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REPRESENTATION OF THE LASER SELF-MIXING EFFECT IN AN ACOUSTIC SIGNAL

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The goal of the work is to check the possibility of observing the optical phenomena in the gas laser plasma using a microphone. An RF excited slab-waveguide carbon dioxide laser is used in the experiment. The investigations are performed on a three mirror resonator structure. An outside mirror is fixed to a vibration exciter to obtain a returnig wave to the laser resonator. In that way a self-mixing phenomenon is observed with the optical detector. The response of the laser plasma changes is detected as an acoustic signal. The results of the investigations can be useful for controlling the laser tuning.

Key words: CO_2 laser, laser plasma, acoustic wave, laser signature, self-mixing.

1. Introduction

A carbon dioxide laser shows some spectral phenomena specific only for this kind of the laser. The most sophisticated phenomenon is so called a “line hoppings” effect. It occurs when the laser is tuned. Then, different modes of the optical resonator can be in coincidence with different emission lines of a carbon dioxide molecule. Due to a strong competition between rotational transitions responsible for the laser action, a CO_2 laser operates only on one chosen emission line [1]. When the laser is tuned, it “jumps” from line to line giving as a result a specific picture of the output laser power changes called a laser “signature” [2]. The effect can be applied for a tuned CO_2 laser, where the laser is tuned from line to line without any additional spectral elements like a diffraction grating [3]. Another effect considered in this work is a self-mixing effect, called some times a back-scattering effect. The phenomenon is observed in all kinds of lasers, where some part of the output radiation comes back to the laser cavity. The effect is extremely sensitive, and even coming back radiation from a quite not reflecting surface significantly changes the laser operation [4]. The effect can be theoretically described in terms of a three resonator optical cavity. The aim of the work is to investigate mentioned above phenomena with a microphone. All changes of the laser beam intensity inside the laser cavity influence thermodynamic parameters of the laser plasma. Finally they change a refractive index of the laser medium and involve the laser tuning, as a consequence. The tuning is detected with an optical detector, and changes of the laser plasma pressure are monitored with a microphone in the presented experiments.

2. Theoretical background

The CO_2 laser signature is predictable, and can be calculated numerically. We used a simplified method of the calculations, which gives a good confirmation of the experiment [5]. In our procedure only the "distance" in frequency between a chosen CO_2 emission line λ_i and a resonance of the optical resonator is considered comparing to the procedure given by SHIFFNER [6]. We used a formula [5]:

$$2L/\lambda_i = N_i + R_i, \qquad \lambda_{\text{chosen}} \Leftarrow \text{MIN}(R_i), \tag{1}$$

where λ_{chosen} means an emission line "chosen" by a laser resonator for fixed length L of the resonator. The numerical procedure gives an integer N_i and the minimum value of the remainder R_i of the division L by $\lambda_i/2$ and indicates a suitable number λ_{chosen} of the emission line (i.e. P18 or P20 ...). Next, L is changed and the procedure is repeated.

The behavior of the laser operation, when it is perturbed with a coming back laser signal, can be explained in terms of a three mirror laser cavity, where an output (second) and third (reflecting back) mirrors are substituted by a common mirror, which an effective reflectivity Z is given by a formula [8]:

$$Z = \left(R_2 + R_3\, e^{2ikL_E}\right) \Big/ \left(1 + R_2\, R_3 e^{2ikL_E}\right), \tag{2}$$

where R_2, R_3 – reflectivities of the output laser mirror and third (target) mirror, respectively, k – wavenumber vector, L_E – distance between second and third mirrors. The analysis of the angle of the complex Z gives the results which explain the behaviour of the laser. For a periodical move of the third mirror, a very specific picture of the signal appears (Fig. 1, bottom). It is a triangle-like signal, and the slope of the signal is symmetrical (mirrored) against to a maximum amplitude (Fig. 1, top) of the third mirror move. It is an important result, which has wide applications in Doppler velocimeters, where the symmetry of the signal is used to recognize the direction of the target move [4].

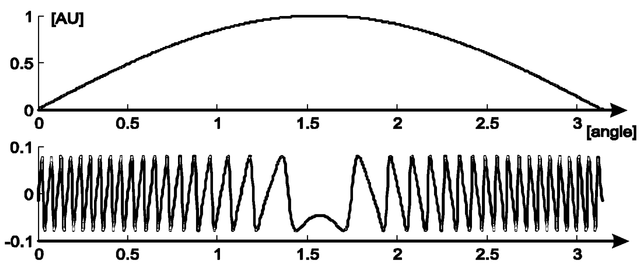

Fig. 1. Driven signal (top) and angle of Z (bottom – see the triangle-like shape) – numerical result.

3. The experimental setup

The investigations were performed on the construction of an RF transversely excited slab-waveguide CO_2 laser. The structure of the laser consisted two aluminium water cooled electrodes 380 mm long and 20 mm wide separated with a 2 mm gap. The plasma was excited with a 125 MHz radio frequency current from a 2 kW (max) generator via a suitable matching circuit. The structure was filled with a typical CO_2 laser gas mixture in proportion of $\mathrm{CO_2 : N_2 : He} = 1 : 1 : 3$ under a pressure of 40 Torr. The output power was about 25 W in a continuous wave regime.

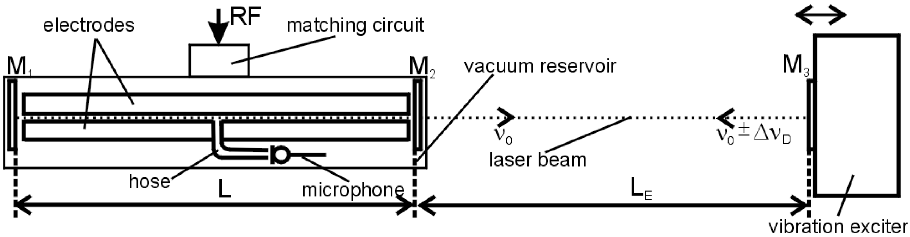

Fig. 2. Experimental setup. ν_0 – frequency of the output laser radiation, $\Delta\nu_D$ – Doppler shift.

The structure of the laser (Fig. 2) was equipped with an optical unstable kind resonator formed by a 5800 mm radius rare mirror M_1 (total reflecting) and -5000 mm output mirror M_2 (92% reflectivity). The use of the unstable kind resonator ($L = 400$ mm in length) gave a single-mode operation of the laser by definition. A total reflecting, flat mirror M_3 $(L_E = L)$ was used as a third one. A HgCdTe fast (1.5 GHz) optical detector and microphone (with a 20 kHz band in normal conditions) were used. A part of the laser output beam was directed to the detector via a beam splitter (not indicated in the figure). The microphone was placed inside the vacuum laser reservoir, and connected to the laser work place via a plastic hose 15 cm long and 2 mm in diameter. The 1 mm hole was drilled across the bottom electrode to make a direct contact with a plasma – see Fig. 2. A beat frequency signal was created in a three-mirror optical resonator configuration. The third, outside mirror was fixed to a vibration exciter. The mirror was vibrating with a frequency of a few Hz with an amplitude of about decimal parts of millimeter.

4. Measurements

The optical beat frequency signal was monitored with the optical detector, see the oscillogram in Fig. 3 (bottom). Simultaneously, changes of the plasma pressure were detected with the microphone, see Fig. 3 (top). As seen, the microphone signal follows the optical detector signal. The amplitude of the acoustic signal is higher for higher frequencies of the optical signal. Carefully looking, it is visible, that the shape of the optical signal (Fig. 3 – bottom) is triangle-like. The explanation can be derived from Eq. (2) – compare to Fig. 1 (bottom). It is necessary to emphasize, that the laser used operates in a single longitudinal mode. Although, it was possible to observe a beat frequency between higher modes, but it was in the conditions of the wrong adjusted laser (they appeared along the waveguiding direction: top electrode – bottom electrode). For comparison, we performed the experiment with a slow move of the mirror M_1. As seen in Fig. 4, it is possible to detect a "line hoppings" effect and register the laser signature with a microphone. Equation (1) can be used to simulate numerically the result obtained [5].

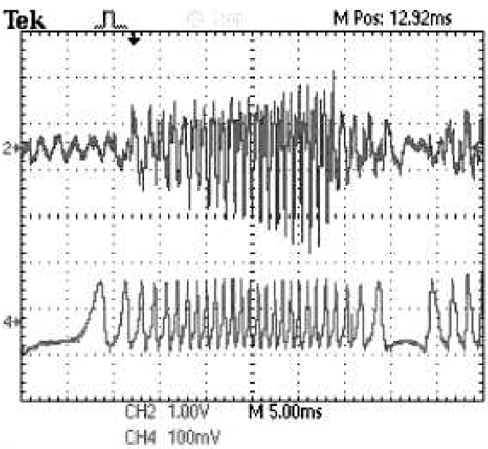

Fig. 3. Beat frequency signal registered by a microphone (top) and optical detector (bottom – see the triangle-like shape).

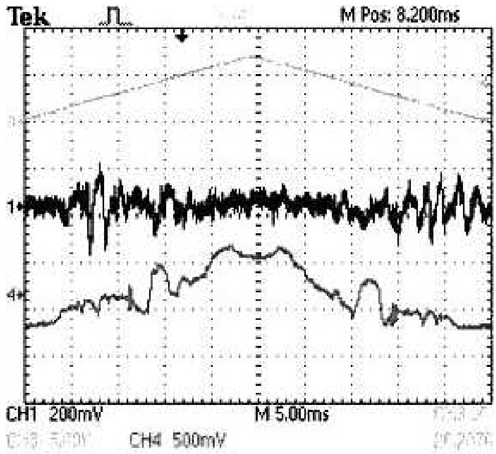

Fig. 4. Driven signal on a vibration exciter (top), signature registered by a microphone (center) and optical detector (bottom).

5. Conclusions

Reassuming, the experiments have shown that changes of the laser radiation intensity inside the gas laser cavity can be detected with a microphone. In the designed experiment, changes of the laser radiation intensity were produced by a three-mirror resonator, where an external mirror was periodically moved along the laser axis. In that way, it has been shown, that a microphone can be an useful device to monitor a self-mixing phenomenon, and can be applied in such devices like Doppler velocimeters. On the other hand, it has been shown, that a microphone can detect a laser signature, the phenomenon, which can be applied for controlling of the CO_2 laser operation on chosen emission lines.

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