Calibration of an Automatic System Using a Laser Signature

Edward F. PLINSKI*, Antoni IZWORSKI, Jerzy S. WITKOWSKI***

Wroclaw University of Technology
***Institute of Telecommunications and Acoustics, **Institute of Engineering Cybernetics**
Wybrzeze Wyspianskiego 27, 50-370 Wroclaw, Poland
(tel.: +48 71 3202505, fax: +48 71 3203189, e-mail: Edward.Plinski@pwr.wroc.pl)

ABSTRACT

The specific phenomenon, which appears in tuned CO_2 lasers, called a laser signature, is used as a standard for calibration of the servomechanism. The proposed servomechanism can be used for continuous investigations of the laser signatures of different laser media.

Keywords: CO_2 laser, laser signature, servo-mechanism, automation, adaptive system, expert system.

1. INTRODUCTION

In a very approximation, an excited medium (with inverted population), and an optical resonator creates the laser. From an optical point of view, we have two “sets” of frequencies: a set of emission line frequencies ν_L of the excited laser medium (or a singular line, which takes part in a laser operation), and a set frequencies ν_R possible to obtain in an optical resonator – see Fig. 1.

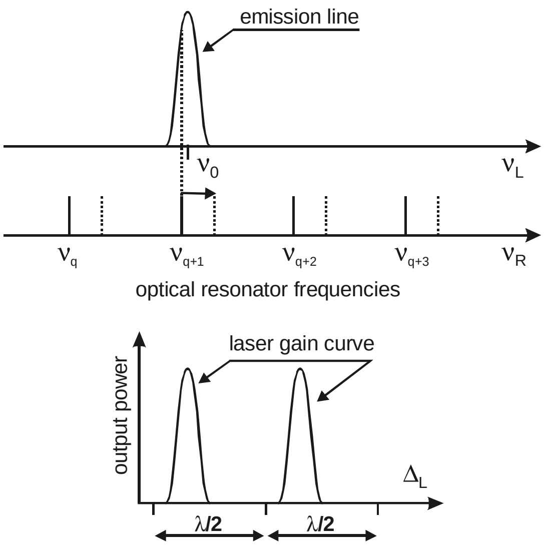

Fig. 1. Mechanism of the laser generation on frequency ν_{q+1} in the range of the emission line with a center at ν_0. (ν_R - frequencies of the laser medium spectrum, ν_L – resonant frequencies of the optical resonator). The resonator tuning is indicated with the arrow. Bottom – the laser gain curve obtained when the laser is tuned of half-lengthwave (ΔL – a translation of the laser mirror M_R – see Fig. 2)

When the laser is tuned (Fig. 2), then the laser longitudinally mode, let us say ν_{q+1} restores the profile of the emission line giving a laser gain curve – see Fig. 1. The gain curve is observed with each half-lengthwave $\lambda/2$ of tuning ΔL (from node to node of the standing wave in the resonator cavity), where L – length of the optical resonator. The picture is much more complicated, when the excited laser medium creates many emission lines. The CO_2 medium is a good example.

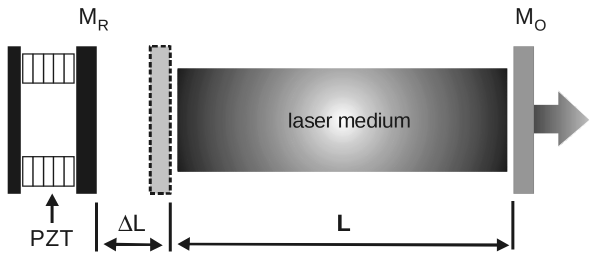

Fig. 2. The scheme of the laser used in the experiment. The laser can be tuned with piezo-ceramic transducers PZT of a few values of the half-wave ΔL. M_R – rear, total reflective mirror, M_O – output mirror

A spectrum of the CO_2 molecule consists a number of emission lines grouped in many bands, and branches. The most useful for the CO_2 laser operation is a band with the frequency center of appr. 10.4 μm. The band consists two branches P, and R, where the strongest line P20 is the most attractive for the laser operation [1]. When we tune the laser resonator, then different resonant frequencies of the optical resonator can be in coincidence with frequencies of the emission lines of CO_2 laser medium.

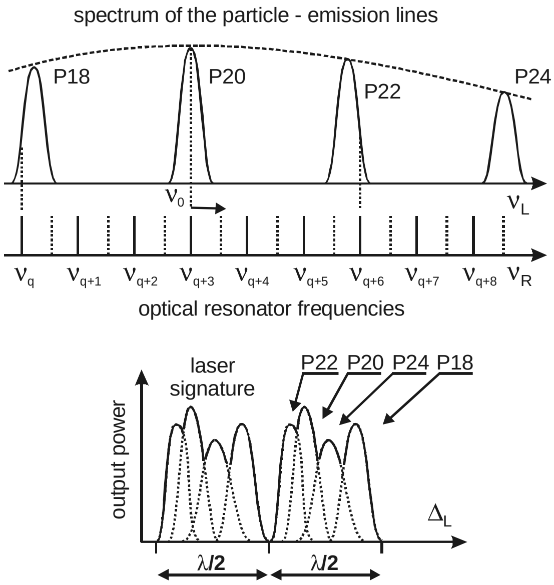

Fig. 3. The laser signature developing, when the laser resonator is tuned of half-wavelength. The names of the emission lines are indicated (top). The line hopping is shown (bottom) during the signature developing

Of course, each line being in coincidence with the resonant can take part in a laser action. Theoretically, the laser can operate on many emission lines simultaneously. Fortunately for the experiment, a strong competition exists between different rotational levels in the CO_2 medium, and the laser usually operates only on one chosen line, as a consequence [2]. Exactly, on that line, which center frequency ν_0 is the closet to the resonant frequency of the resonator. Fig. 3 explains the effect. As seen, the resonant frequency ν_{q+3} is the closest to the center of the emission line P20. When the resonator is tuned, then we can expect "jumps" from line to line. The observed picture of the output laser power is called a laser signature [3]. The signature is reproducible with each half-lengthwave $\lambda/2$ of tuning ΔL (usually a few signatures – a few $\lambda/2$). The laser signature is stable, and easy to calculate for chosen length L of the optical resonator [4].

2. EXPERIMENTAL

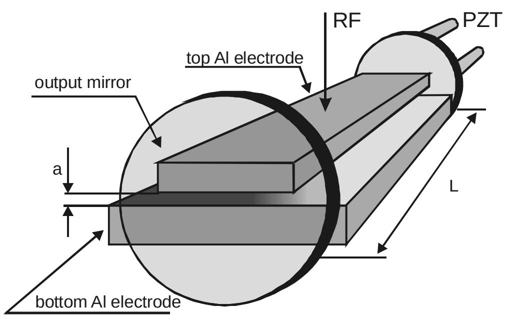

Fig. 4. Scheme of the slab-waveguide laser structure

The RF excited laser in Fig. 4 has aluminium electrodes with an area 380 x 20 mm^2 (top), and 400 x 110 mm^2 (bottom), spaced by a = 2 mm. The laser head is fed with a RF generator of 2kW power via a matching circuit [5]. The negative branch unstable resonator has a rear mirror M_R with radius of 430 mm and output mirror M_O with a radius of 370 mm. The mirror spacing, defined by a low expansion Invar bar, is L = 402 mm for appr. confocal operation, but can be increased to 414 mm, giving a diverging output beam. The rear mirror M_R mount has a piezo-electric transducers (PZT), for cavity length scanning (a few wavelengths). The positive branch unstable resonator with a rear mirror M_R = 5800 mm and an output mirror M_O = 5000 mm, giving a geometrical out-coupling of 16%, creates the second structure of the laser used in the experiment.

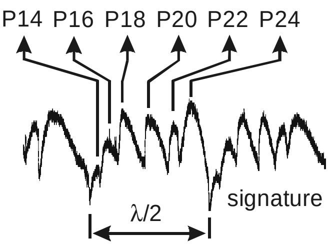

Fig. 5. The laser signature. WOLS effect is registered (see the main text)

Fig. 5. shows a real result of the investigation on the laser signatures. The laser is tuned of ΔL = $\lambda/2$. The signal is registered with a HgCdTe detector, and a scope (compare to Fig. 3). When the laser is tuned we observe line hopping. Accidentally, we can see so called WOLS effect (Well-Ordered Laser Signature), where the signature restores the order of the emission lines according to a CO_2 spectrum from P14 to P24 lines, in line [6].

A similar experiment is performed with the laser equipped with a positive branch unstable resonator [7]. Fig. 6 shows the signature, where well-ordered P lines are disturbed with a few lines of an R branch (10.6 μm band). The result is obtained on a L = 414 mm long optical resonator. A diffraction grating is used to recognize the CO_2 laser emission lines. The output laser beam is deflected at the grating into different angles and visualized at the UV screen (top). This case can be illustrated graphically like in Fig. 7. Exactly, a diagram at the figure is obtained in a theoretical way.

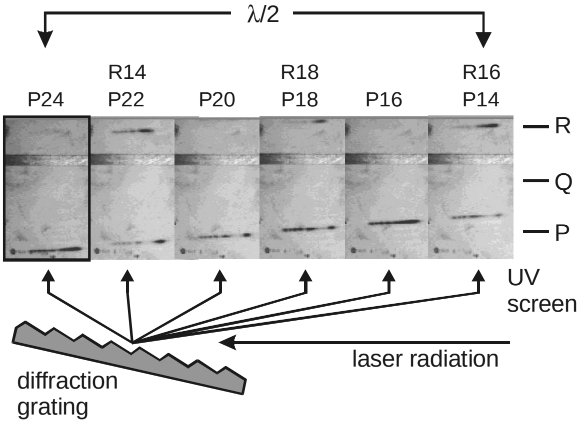

Fig. 6. Partly well-ordered signature (P lines) obtained on a positive branch unstable resonator of the slab-waveguide CO_2 laser

We elaborated a numerical procedure, which calculates the laser signature for given frequencies of the emission lines, and given length *L* of the optical resonator (the shape of the emission lines is not taken into account).

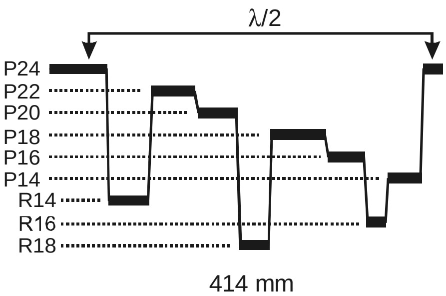

Fig. 7. Graphical representation of the laser signature calculated for the experimental result in Fig. 6

The series of signatures in line creates a specific picture (histogram) of the carbon dioxide laser for some strictly determined spectrum of the laser medium. Fig. 8 shows a theoretically calculated line hopping (laser histogram) in the range of appr. four half-wavelengths starting from the length L = 410.4 mm of the resonator for different isotopes of the carbon and oxygen molecules.

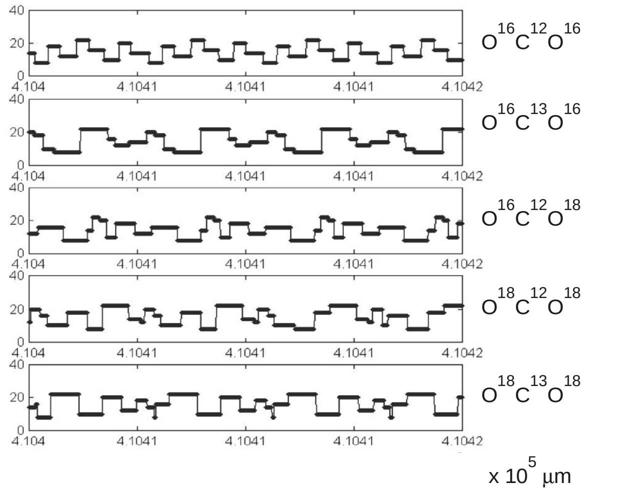

Fig. 8. Theoretically calculated line hopping (laser histograms) starting from the length L = 410.4 mm of the resonator for different isotopes of carbon and oxygen molecules

3. AUTOMATION OF THE INVESTIGATION PROCESS

A calibrated servo-mechanism is necessary to obtain the laser histogram in the large range of the resonator tuning (ex. a few centimeters). As mentioned above, the laser signature, or series of signatures in line (laser histogram) is reproducible, and stable. And, it can be used as a standard to calibrate a servo-mechanism.

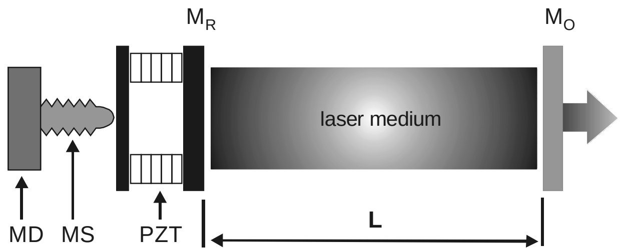

Fig. 9. The laser with a servo-mechanism (explanation in the main text)

Fig. 9 shows schematically a possible construction solution of the servomechanism. The automatic control system consists a set of piezo-ceramic transducers (PZT), and a micrometric screw MS with a motor-driver MD. The process of the calibration is done in four steps:

- at the first step, transducers PZT tune the laser resonator (translates the mirror M_R) of a few tens micrometers – a few λ/2 (it depends on the kind of the PZT),
- at the second step, the PZT comes back to the same position (the same length L of the resonator) – the voltage on the PZT is set on the initial value,
- at the third step, the screw MS takes over the role of the translator. The screw translates the laser mirror of the same distance (a few λ/2) with suitable corrections using PZT,

- at the fourth step, the PZT takes over the role of the translator again.

In that way, the servomechanism is calibrated.

In details, the servomechanism controls the micrometric screw MS as follow:

o the micrometric screw MS travel is equal to 500 μm per one turn and the total operating length – to 20 mm (in one experiment, a part of this range will be used). The screw is operated by a stepped motor MD enabling to make 200 steps per one complete revolution of the motor. Another actuating track is the piezo-ceramic transducer (PZT) that enables to achieve the shift within the range of 0-10μm for the input voltage 0-70V. The information that the object under control has moved out is obtained due to the HgCdTe detector that provides the information on the intensity of the laser beam. The time constant of the detector does not exceed one millisecond.

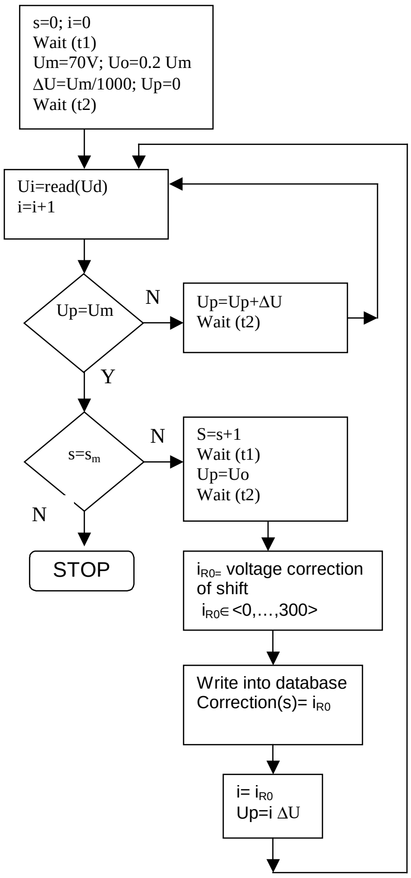

Fig. 10. Algorithm of the control of the calibration process

o The calibration process control algorithm is presented in Fig. 10. After a turn is done with the stepped motor, the delay t1 is inserted, needed for stabilisation of the micrometric screw position. Similarly, the delay t2 provides for stabilisation of the detector state after the voltage change across PZT. The voltage control range amounts to 0V up to 70 V and has been divided into 1000 intervals (this corresponds to the resolution of the controller analogue output).

o After carrying out a turn with the motor, the initial value of the control voltage Up=Uo has been assumed. It was preset to the value of 20% of the control range. A motor turn results in setting the shift value L at a considerable error (ca. 2 μm), therefore a voltage correction procedure for the shift has been introduced.

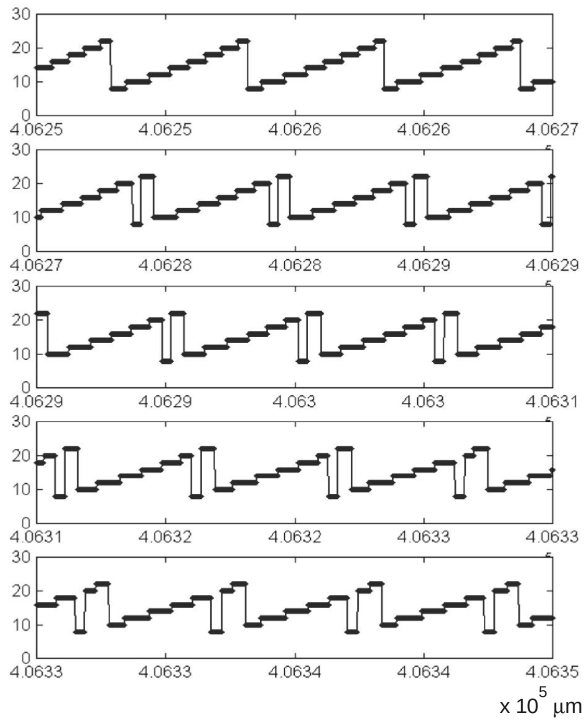

Fig. 11. Developing of the laser signature in the range of 406 250 to 406 350 μm (laser histogram) – theoretical result. WOLS effect is registered (lines P8 to P20 in line) at the top of the figure

The calibrated (with the known signature) servomechanism is independent of the chosen laser medium. The automation introduced to the laser arrangement can help with the automatic investigations of the laser signatures in the wide range of the laser resonator length. As an example see the laser histogram in Fig. 11. It starts from the well-ordered signature (eight P-lines from P8 to P22). Fig. 12 shows the experimental result of the first part of the histogram shown in Fig. 11.

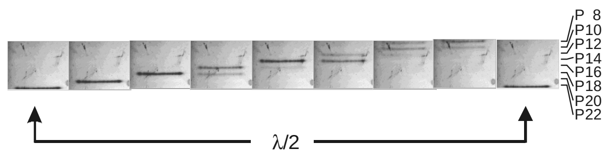

Fig. 12. Well-Ordered Laser Signature - experimental result (see the theoretical result at Fig. 11 – top)

4. CONCLUSIONS

Stable and reproducible signatures of the CO_2 laser can be a good standard to calibrate servomechanisms used for investigations of the laser histograms (series of signatures in line). The servomechanism coupled with a given structure of the laser can be applied for investigations of the laser signatures in the large range of the laser tuning independently of the laser medium. The adaptive system to control the laser mirror is used for the corrections of the mirror position errors. The system finds the optimum voltage correction value, to find the optimal position of the laser mirror. The information about the optimum control is collected for each investigated position of the step motor (number of the pitches). Created in that way the data base will be used in further investigations to develop the expert system, which should be helpful for the investigations of the laser histograms of different lasers. The lasers which show the signature effect can be easy created in the frame of the CO_2 laser by use of the different isotopes of carbon, and oxygen like $O^{16}C^{12}O^{16}$, $O^{16}C^{13}O^{16}$, $O^{16}C^{12}O^{18}$, $O^{18}C^{12}O^{18}$, $O^{18}C^{13}O^{18}$, $O^{16}C^{14}O^{16}$, $O^{18}C^{14}O^{18}$, $O^{16}C^{13}O^{19}$, or $O^{17}C^{12}O^{17}$. Described above the arrangement for identification of the laser lines can be used as a diffractive mechanism of the laser marker, where the described above control of the lines generated by a laser is obvious [8]. The automation of the described process can help with searching suitable laser signatures for different laser experiments, ex. very sophisticated signatures investigated by Buholz for some heterodyning experiments [9], or well-ordered signatures [6].

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