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Automated tuning of a CO_2 laser to a required oscillation line without a spectral instrument

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***Abstract*. The method is proposed for tuning CO_2 laser to a required oscillation line without a spectral instrument based on the coincidence of transition frequencies belonging to different vibrational – rotational bands of the CO_2 molecule. This coincidence leads to the anomaly in the gain distribution over rotational sublevels, thereby affecting the laser output parameters. The method was successfully applied to a completely automated low-pressure, longitudinal-discharge cw CO_2 laser and a pulsed TEA CO_2 laser.**

Keywords: *CO_2 laser, tuning to a line, anomalous amplification, coincidence of lines.*

The use of tunable CO_2 lasers for solving many applied problems, for example, in spectroscopy and gas analysis requires a rapid and reliable tuning of the laser strictly to a desired oscillation line. The laser is conventionally tuned to the required line with the help of an external spectral instrument (monochromator, spectrum analyser, etc.). In some papers (see, for example, [1]), a cell with a gas with the known resonance absorption lines was used for this purpose. However, the use of such additional devices considerably complicates the laser system and makes difficult the automation of tuning to the required lasing line.

In this paper, we propose an original method for search for a required lasing line and describe a fully automated process of tuning a CO_2 laser to this line without using any additional spectral devices. The method is based on the known fact of accidental coincidence of transition frequencies belonging to different vibrational – rotational bands of the CO_2 molecule (see, for example, [2, 3]). This coincidence leads to the anomaly in the gain distribution over rotational sublevels. We propose to use such anomalous lines as reference lines for tuning the laser to the required oscillation wavelength. In this case, it is appropriate to select lines with anomalous gain in certain spectral regions, for example, in the band wings, where these lines can be reliably separated, especially during automated tuning.

The method was worked out for a low-pressure, longitudinal discharge cw CO_2 laser (the active medium length was $L \sim 1$ m) and a UV-preionised pulsed TEA CO_2 laser ($L \sim 0.7$ m). The lasers were tuned by rotating a diffraction grating mounted in a specially developed precision electromechanical device based on a computer-controlled step motor (Fig. 1). This device and design of the CO_2 lasers are described in detail in [4, 5].

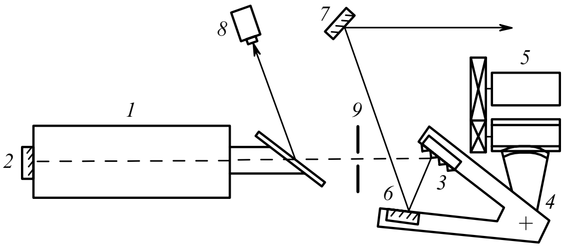

Figure 1. Optical scheme of a tunable CO_2 laser: (*1*) active element; (*2*) highly reflecting mirror; (*3*) diffraction grating; (*4*) rotation unit; (*5*) step motor; (*6*) auxiliary mirror; (*7*) fold mirror; (*8*) photodetector; (*9*) aperture.

Consider the method of tuning fully automated low-pressure, longitudinal-discharge CO_2 laser to an oscillation line without a spectral instrument. The active element of this laser is a GL-501 standard sealed off, water-cooled gas-discharge tube. The laser resonator is formed by a highly reflecting mirror of curvature radius ~ 3 m and a plane 150-lines mm^{-1} diffraction grating mounted in the rotation unit. The grating in the autocollimation orientation was used in the first diffraction order (the reflectivity was $\sim 95\,\%$). The design of the rotation unit of the diffraction grating allows the accommodation of an additional reflecting mirror, which forms together with the grating a two-sided reflector [6], providing the invariable direction of the output radiation during tuning over laser lines. The indicator signal of laser radiation required for the full automation of laser tuning was obtained from an MG-30 pyroelectric detector on which weak radiation reflected from the gas-discharge tube window was incident (Fig. 1).

The laser was tuned by rotating the diffraction grating around the optical axis of the resonator. The rotation angle provides the accuracy of the angular position of the grating no worse than $10''$ [4]. To set the drive strictly to the initial (zero) position, a special zero-position sensor was developed, which provided a high accuracy and reproducibility of

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the connection of the initial position of the rotation unit equal to the tuning step [4]. Note that the error by a step does not affect the accuracy of grating setting to the required line because the angular distance between the adjacent lines, taking the diffraction grating dispersion into account, is, as a rule, $\sim 350''$ (which is equivalent to 90 steps of the motor).

The system for laser tuning is controlled with PC, for which the special interface and program package were developed. The rotation angles of the diffraction grating with respect to the resonator optical axis corresponding to each lasing line were preliminarily entered into the PC memory. The rotation angles expressed in terms of motor steps were calculated from the known dispersion of the diffraction grating.

During laser operation, the calculated rotation angles of the diffraction grating can differ from their real values by a constant value. This is caused first of all by the arbitrariness in setting zero of the rotation angle sensor. At the same time, even if this arbitrariness is taken into account, the difference can appear, for example, due to a change in the refractive index of the active medium caused by a small variation in its chemical composition in the electric discharge. However, in this case the spectral intervals between the laser lines and, hence, the relative angular distance between the corresponding positions of the diffraction grating will not change. Therefore, it is appropriate to find the experimental correction to the calculated angular positions of the diffraction grating expressed in terms of the motor steps with respect to the position specified by the zero sensor. This correction will be the same for all the laser lines.

The program for laser tuning allows us to determine this correction in the semi-automatic regime by using an external spectral instrument. In this case, the angular position of the diffraction grating is determined for the laser line selected as a reference line, and the possible difference between this position and the corresponding theoretical value is entered into the computer memory as the required experimental correction. Such a procedure allows the calibration of the laser tuning system and its metrological certification.

Consider now the fully automated laser tuning without using a spectral instrument. In this case, the correction is determined by the anomalously intense laser line, which can be reliably identified in the output spectrum. As such a line, it is convenient to use the P(56) line of the $00^01 - 10^00$ band, which virtually completely coincides with the P(23) line of the $01^11 - 11^10$ band ($\Delta\nu \sim 40$ MHz [7]). Consider the algorithm of the automatic search for this line. Figure 2a shows the gain for the laser lines in the long-wavelength wing of the P branch of the $00^01 - 10^00$ band, which were obtained in the following way.

First we accurately measured the gain at the intense P(42) line in the discharge tube by probing the active medium with a weak beam from a stabilised cw CO_2 laser tunable over rotational–vibrational lines. The probe laser and the measurement method are described in papers [4, 8]. The gains for the weaker lines with the rotational quantum number $J > 42$ [for which the measurement error was considerably greater than that for the P(42) line] were determined from the accurately measured gain at the P(42) line from the well-known calculated dependence of the gain on the number of a vibrational–rotational line [9]. The translational temperature of the active medium required for this procedure was experimentally determined by the method used in [8]. For the P(56) line, the contribution from the gain of the P(23) line of the $01^1 - 11^10$ band was also taken into account.

One can see from Fig. 2a that the P(56) line of the $00^01 - 10^00$ band has the anomalous gain comparable with the gain of the P(48) line, while the gains of the adjacent P(50), P(52), P(54), and P(58) lines are substantially lower. Therefore, by selecting appropriately the loss factor of the resonator (by varying the discharge current or changing the diameter of the intracavity aperture), we can obtain only one P(56) line in the resonator, whereas lasing at the other adjacent lines will be absent.

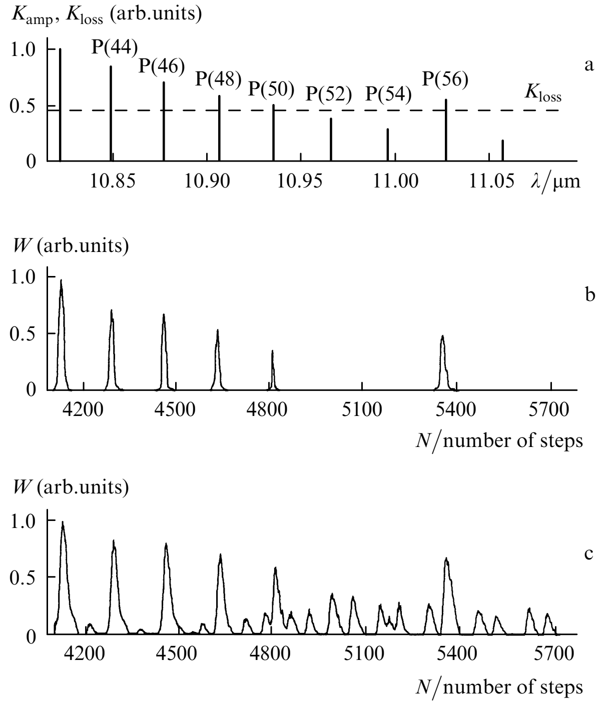

Figure 2. Gains of the P branch of the $00^01 - 10^00$ band (a) and the emission spectra of the laser in the regime of searching for the reference line (b) and in the operating regime (c).

The reference line was found in the following way. The diffraction grating was set to the position corresponding to the edge of the long-wavelength part of the spectrum, where no laser lines were observed. Then, gradual tuning to the blue is performed. In this case, the spectral interval between the laser lines is controlled by the relative change in the position of the rotation unit of the diffraction grating. It is appropriate to repeat such a tuning a few times, by varying the difference between the gain and loss factor (by changing the discharge current or the aperture diameter). The reference line is considered found after obtaining the spectral interval between the laser lines (the extreme reference line in the long-wavelength region of the spectrum and the preceding line) equal to several spectral distances between adjacent lines in this spectral region. The application of this criterion is based on the known fact of the quasi-equidistant spacing of the laser lines within a branch. The twofold and manifold spectral intervals between the extreme laser lines appear only when, by varying the difference between the gain and loss factor, lasing can be obtained in the long-wavelength part of the spectrum at one of the pairs of lines of the $00^01 - 10^00$ band [P(48) and P(56), P(50) and P(56), P(52) and P(56)] in the absence of lasing at the lines located between these pairs and after the P(56) line.

Note that such a procedure of finding the reference line provides its reliable identification and can be used for all the CO_2 lasers emitting in the long-wavelength spectral region up to the P(48) line of the $00^01 - 10^00$ band inclusive. The search for the reference line was performed automatically using the developed program (Fig. 3).

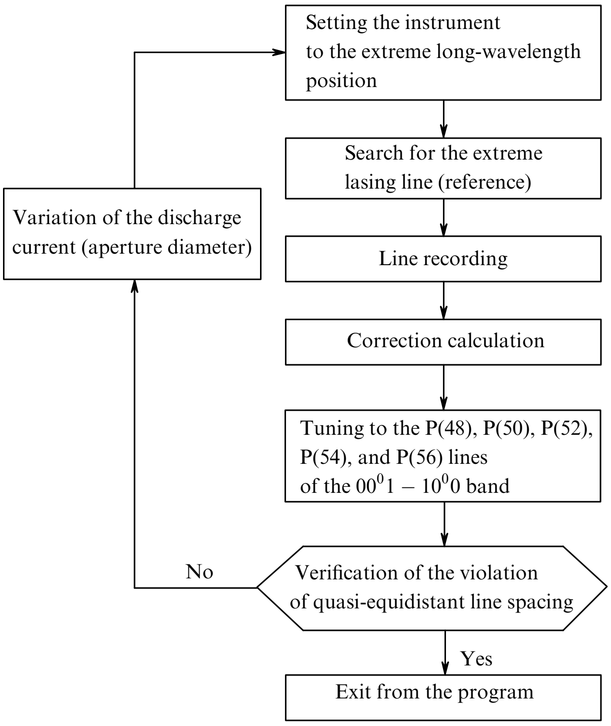

Figure 3. Scheme of the algorithm for determining the experimental correction.

Stable lasing at the P(56) and P(48) lines in the absence of lasing at the adjacent lines was obtained in our laser system when the aperture diameter was 7 mm and the discharge current was 30 mA (Fig. 2b). The fourfold spectral interval obtained between the extreme laser lines ($\sim$ 450 motor steps) reliably indicated that the criterion for violation of the equidistant spacing of the laser lines was fulfilled and allowed the reliable identification of the extreme laser line as the reference line of the $00^01 - 10^00$ band. The position of the drive expressed in the motor steps with respect to the position specified by the zero sensor, which corresponds to this line, was entered into the computer memory as the reference position.

After the identification of the reference line, the automated tuning to any specified laser line was performed by using the angular distances from this line to the reference calculated taking into account the known dispersion of the diffraction grating. The discharge current and the aperture diameter can be optimised by the output parameters. In this case, the output emission spectrum contains many additional lines [10] related to lasing at hot and sequential transitions (Fig. 2c).

For low-pressure, longitudinal-discharge laser systems with a shorter length of the active medium or a lower-Q resonator, when lasing at weak lines [up to the P(48) line] is hindered, having the gain comparable to that of the P(56) reference line, other anomalous lasing lines can be used as reference lines, for example, the R(38) line of the $00^01 - 02^00$ band, which coincides with the R(41) line of the sequential $00^02 - 02^01$ band (the line centres are detuned by 257 MHz) [2, 3].

We also studied the tuning of a repetitively pulsed TEA CO_2 laser to the specified lasing line without a spectral instrument. Analysis of the spectral properties of the high-pressure CO_2 laser showed that other anomalous lines are optimal in this case as the reference lines. Figure 4 shows a part of the output emission spectrum of the UV-preionised TEA CO_2 laser. The active medium length is $L = 70$ cm, the electrode width is 3 cm, and the interelectrode gap is 2 cm. The active medium had the composition $CO_2 : N_2 : He = 1 : 1 : 4$, the voltage across a 0.2-μF storage capacitor was 30 kV. The laser design and its operation are described in detail in [5]. One can see from Fig. 4 that the P(52) line of the $00^01 - 02^00$ band is most convenient as a reference line. By varying slightly the relation between the gain and losses in the resonator, we can achieve the condition at which no lasing will occur at the P(50) line, and the algorithm for searching for the violation of equidistant spacing of lasing lines will be applicable, which is similar to that considered earlier for a low-pressure, longitudinal-discharge laser. If the laser cannot generate lines with $J > 44$, then, as one can see from Fig. 4, the condition of violation of the equidistant spacing of lasing lines can be realised by using the absence of lasing at the P(38) line by selecting appropriately the relation between the gain and losses.

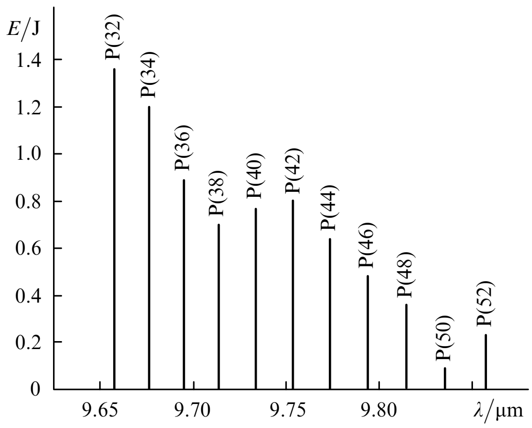

Figure 4. Part of the emission spectrum of the TEA CO_2 laser with anomalous lines of the P branch of the $00^01 - 02^00$ band.

The repeated verification of the tuning process with the help of an SPM-2 monochromator has demonstrated the reliability of tuning to the required line by this method. The method for determining the reference line with the anomalous gain can be also used for other lasers capable of emitting at different wavelengths.

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