Electromagnetic system for the management of the output power of the carbon dioxide laser

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Abstract. The methods to control the output power of the gas-discharge lasers are shown. An electromagnetic system for the management of the output power of the carbon dioxide laser is described. The results of calculation and modeling of the magnetic field in the working gap of the electromagnetic system are presented. Experimental studies on the distribution of magnetic induction in the electromagnetic system are carried out.

Laser technology is used in various technological fields. From all available types of lasers of greatest interest is a gas-discharge carbon dioxide laser (CO₂ laser) which can be used for cutting glass and welding of metals, and also for medical operations in cosmetic surgery and dentistry. Carbon dioxide lasers can have very high output power – up to tens of kW in continuous mode. The advantages of pulse mode operation of the technological CO₂ laser are due to the nonstationarity nature of the pumping and generating processes. Technological operations require both smooth change of output power and the formation of a pulse with the specified amplitude and shape with a temporal resolution of about 1 ms.

Existing methods of the CO₂ laser power management are not always optimal, which greatly complicates their application. Power modulation can be carried out using [1]:

– mechanical modulators. They are simple and reliable, but do not allow to smoothly change shape, duration and average power of a laser pulse;

– electro-optic modulators. They have low inertia, but have a strong sensitivity to damage and low radiation resistance of the crystal, also they are very expensive;

– acousto-optic modulators. These modulators have low radiation resistance of the crystal and a very large inertia;

– current (internal) modulators. These modulators are quite common; they do not require additional optical elements, which simplifies the overall laser system. However, under a significant change in current of the laser occurs oscillatory process of establishing the coherent laser power caused by temperature change of the resonator and a change in the composition of the gas mixture.

To eliminate these disadvantages it is advisable to use an electromagnetic modulation. In this case, for modulation of the CO₂ laser power a transverse magnetic field is used [2, 3]. Electromagnetic modulation method is based on the plasma-optical effect, which is due to the interaction of the magnetic field with the active medium of the laser. This method allows controlling
the output power of the laser by changing its value from maximum to zero according to a linear law with a sufficient speed.

In the sealed-off gas-discharge lasers of medium pressure action of a transverse magnetic field on the output power is due to changes in the zone of interaction of the active medium with the field of the resonator and discharge current – with increase of the magnetic field induction these values decrease. The performance of the magnetic control of the CO\textsubscript{2} laser is determined by the time of plasma movement inside the tube, the rise time of the magnetic field, the lifetime of excited molecules and the settling time of the radiation in the resonator.

For the CO\textsubscript{2} laser controlled by a transverse magnetic field in dynamic mode, the time lag of the output laser power relative to the input signal (current through the control coil when a magnetic field is generated by a system of electromagnets) depends on the following main factors:

– delay of the increase of the magnetic field;
– end-time of the discharge movement in a magnetic field.

Since rigorous theoretical analysis of the developed electromagnetic system is very complex the most appropriate way is its modeling using special programs and experimental study of the prototype.

For the magnetic control of the discharge it is necessary to determine the geometry of the magnetic circuit and to calculate the parameters of the circuit for the coils of the electromagnets. Changing the geometry of the pole pieces it is possible to change the cross-sectional area of the working gap in the area of management. Increasing this area reduces the average magnetic induction in the control gap, but the magnetic field becomes more uniform and decreases the share of the field, lost due to scattering.

Calculation of the magnetic field distribution in the working gap was performed using the software package FlexPDE [4]. FlexPDE is a software program designed to build scenario models for the solution of differential equations by the finite elements method. FlexPDE produces operations required to convert the description of the system of differential equations into the model for calculation by the finite elements method, finds solution for this system and presents the results in a graphical form.

The first stage of modeling was to estimate the homogeneity of the magnetic field in the working gap when using from one to seven electromagnets (the limit on the maximum number of electromagnets equal to seven is due to the dimensions of the laser tube). Coils of the electromagnets intended for use in the developed system have a frame made of organic glass with a thickness of 5 mm to prevent breakdown, which is wound with insulated wire with a diameter of 1.5 mm. Coil consists of 9 layers and 23 turns in each layer. Figure 1 shows plots of the distribution of the magnetic field $B$ along the tube of the laser depending on the position $x$ relative to its center for a system of one, three and seven electromagnets.

![Figure 1](image)

*Figure 1. Plots of the distribution of the magnetic field $B$ along the tube of the laser depending on the position $x$ relative to its center for a system of one (a), three (b) and seven (c) electromagnets.*

As the number of magnets increases the uniformity of the magnetic field along the tube of the laser improves, this reduces the maximum amplitude of the induction. It is obvious that the uniformity of
the magnetic field even when using seven electromagnets (figure 1(c)) is not satisfactory and this system is not suitable to control the output laser power.

To correct the magnetic field inhomogeneity can be used a special equalizer that allows aligning the value of the magnetic induction along the laser tube [5, 6]. Figure 2 shows charts of the magnetic field induction distribution along the laser tube, depending on position relative to its center for the system of equalizers and one, three and seven electromagnets.

![Figure 2](image1.png)

**Figure 2.** Charts of the magnetic field induction distribution along the laser tube, depending on position relative to its center for the system of equalizers and one (a), three (b) and seven (c) electromagnets.

The use of the equalizer allows aligning the magnetic field even when using a single electromagnet (figure 2(a)). However, with increasing number of magnets the alignment of the field distribution along the laser tube improves and the value of the magnetic induction increases. The program FlexPDE allows not only to calculate the distribution of the magnetic field, but also to get the pattern of the magnetic field distribution in the system being developed. Results of the calculation of the magnetic field distribution in the central part of the working gap and at the edge of the electromagnetic system are shown in figure 3.

![Figure 3](image2.png)

**Figure 3.** Results of the calculation of the magnetic field distribution in the central part of the working gap (a) and at the edge of the electromagnetic system (b).

Simulation results gave an opportunity to design and assemble prototype of the electromagnetic control system for the carbon dioxide laser. Measurements of the magnetic induction in the gap of the developed system was carried out with the help of milliteslameter. The measuring procedure was as follows: the space between the equalizers was divided into the cells of 10×10 mm and at the point of
intersection of the grid lines was carried out the measurement of the magnetic field. The measurements were carried out for both longitudinal and transverse components of the magnetic induction. Figure 4(a) shows the dependence of the magnetic induction in horizontal planes when the current of the electromagnets $I = 5$ A at different distances $y$ from the center of the system in the transverse plane. Figure 4(b) shows the distribution of the transverse component of the magnetic field with the same current of the electromagnets at various distances $x$ from the center of the system in the longitudinal plane.

**Figure 4.** Dependence of the magnetic induction in horizontal planes when the current of the electromagnets $I = 5$ A at different distances $y$ from the center of the system in the transverse plane (a) and the distribution of the transverse component of the magnetic field with the same current of the electromagnets at various distances $x$ from the center of the system in the longitudinal plane (b).

Based on the above graphs, we can conclude about the uniformity of the magnetic field distribution in the developed system, both in longitudinal and transverse section. Of additional interest is the investigation of the dependence of the magnetic field from the current through the coils of the electromagnets. Figure 5 shows the dependence of the magnetic induction in horizontal planes at different currents of the electromagnets.

**Figure 5.** Dependence of the magnetic induction in horizontal planes at different currents of the electromagnets.

According to the study of the developed electromagnetic system for control of the output power of the carbon dioxide laser we can draw the following conclusions:

– with the increase of operating current of the coils of the electromagnets the magnetic field is increasing and has almost linear character;
– range of the values of the magnetic induction decreases with the increase of operating current of the coils of the electromagnets;
– distribution of the magnetic induction along the laser tube is almost uniform.
Thus, the developed control system could allow not only to efficiently manage the average power of the CO\textsubscript{2} laser, but also to acquire pulses of radiation while using laser designed for continuous operation.

References
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