

# A high-power CO<sub>2</sub> laser with wide-range tuning of pulse shape and duration

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The design and characteristics of a high-power CO<sub>2</sub> laser are reported. The active medium of the CO<sub>2</sub> laser is pumped by a non-self-sustained discharge controlled by electron beams. The volume of the active medium is 20 l (10 × 20 × 100 cm), the gas pressure ranges from 50 to 200 Torr. A distinctive feature of the laser is a possibility to change the radiation pulse duration from 50 μs to continuous-wave radiation and the pulse repetition frequency up to 5 kHz, as well as to vary the pulse shape by a preset law. A high controllability of the laser output characteristics is due to the possibility of governing the parameters of the electron beam, which regulates the non-self-sustained discharge pumping the laser. This opens wide possibilities for determining optimal parameters of the high-power CO<sub>2</sub> laser radiation in various laser technologies, such as cutting, welding, production of nanopowders, thin film deposition, and so on.

Implementation of control over the duration of pump pulses of a NEIL-20 CO<sub>2</sub> laser with the mean output power of 20 kW is reported. The method of control and its schematic realization are described.

The electron-beam-controlled CO<sub>2</sub> lasers (lasers pumped by the non-self-sustained discharge controlled by an electron beam) were proposed in 1970 (Refs. 1 and 2). By the mid-70s, their mean output power achieved hundreds kilowatts (Ref. 3), and the pulse energy – up to tens kilojoules (Refs. 4 and 5). The electron-beam-controlled lasers with high mean power usually operate in the continuous-wave mode. This involves considerable difficulties associated with fabrication of simple, reliable, and long-lived repetitively pulsed electron accelerators. However, there exist some approaches in the present day acceleration technology allowing conversion of continuous electron beams into repetitively pulsed ones.<sup>6</sup>

This paper considers a possibility of controlling the pump duration and, consequently, the duration of output pulses without change of the mean pump and output power, using a rather simple system for controlling the electron beam current.

The investigations were conducted with a NEIL-20 CO<sub>2</sub> laser.

The schematic layout of the NEIL-20 CO<sub>2</sub> laser is shown in Fig. 1. The laser chamber had an active gas volume of 10 × 20 × 100 cm with a 20 × 100 cm anode. The maximal mean density of the electron beam current in the plane of the discharge chamber anode was  $j_e = 120 \text{ A} \cdot \text{cm}^{-2}$ , and the electron energy varied within 180–200 keV. The volume flow rate of the laser mixture could be changed up to the maximal value  $V_{\text{max}} = 8 \text{ m}^3 \cdot \text{s}^{-1}$  by controlling the fan speed.

The use of a magnetic clutch for rotation of the fan shaft ensured complete tightness of the gas-dynamic module. Radiation was generated with the aid of a three-pass telescopic cavity with a 50% transparency. To put out radiation, a KCl plate was used.

When operating in the cw mode, the electron-beam-controlled CO<sub>2</sub> laser has the following characteristics:

Radiation wavelength	10.6 μm
Mean output power	20 kW
Focal spot diameter	1 mm
Energy of accelerated electrons	200 keV
Volume of the gas-dynamic module	3 m <sup>3</sup>
Flow rate of the working mixture in the interelectrode gap	50–100 m/s
Discharge voltage, max	6 kV
Accelerator voltage, max	200 kV
Nominal electrical power contributed to discharge	200 kW
Current density of electron beam	$5 \cdot 10^{-4} \text{ A/cm}^2$
Discharge gap volume	10 × 20 × 100 cm
Power of the electron accelerator	20 kW

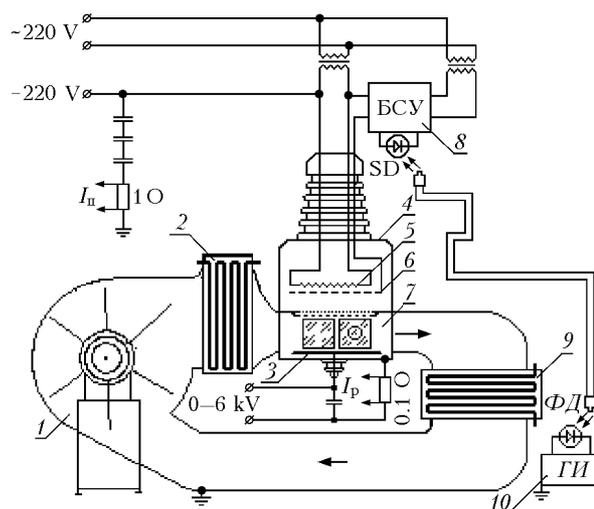


Fig. 1. Functional diagram of the high-power CO<sub>2</sub> laser: gas-dynamic module 1, water heat exchanger 2 and 9, anode 3, electron accelerator 4, filamentary cathode 5, grid electrode 6, discharge chamber 7, grid-control unit 8, pulse generator 10.

In the process of discharge, the pump power  $p = jE$  at the constant electric field  $E$  can be controlled only by the discharge current  $I$ . The discharge current, in its turn, is connected with the electron beam current, and, with the mean beam current kept constant, the mean output power must be nearly constant regardless of the mode of energy contribution to the gas. Changing the duration of the electron beam current, it is possible to change the duration of the pump current and, consequently, the output power.

To do this, both the continuous-wave<sup>7</sup> and repetitively pulsed<sup>8</sup> electron beams generated in accelerators based on high-voltage Marx generators, Tesla transformers, Blumlein generators with accumulators based on distributed-parameter lines, and so on, can be used. It is clear that the pulsed mode requires an application of complex devices with a strict requirement to the rate of the voltage rise. This requirement is caused by the fact that, at low rates of voltage rise and drop, a significant part of the electron beam is retarded in the foil separating the vacuum and gas volumes, thus favoring its damage.

In our case, the transition to the repetitively pulsed mode can be accomplished by applying a blanking pulse with periodically varying duration to the accelerator grid, earlier used only for equalization of the current density of the electron beam.

An advantage of this approach is that, regardless of the rate of voltage rise across the grid electrode, any electron falling within the grid–anode gap gains the energy close to  $\varepsilon = eU$ , where  $e$  is the electron charge;  $U$  is the voltage applied to the grid–anode gap. Since  $U$  is constant, a virtually monoenergetic electron beam comes to the foil.

This property is of principal importance, because it allows the energy loss in the foil to be minimized and the foil service life to be increased drastically. A disadvantage of this approach is that all elements of the control circuit are under the accelerating potential.

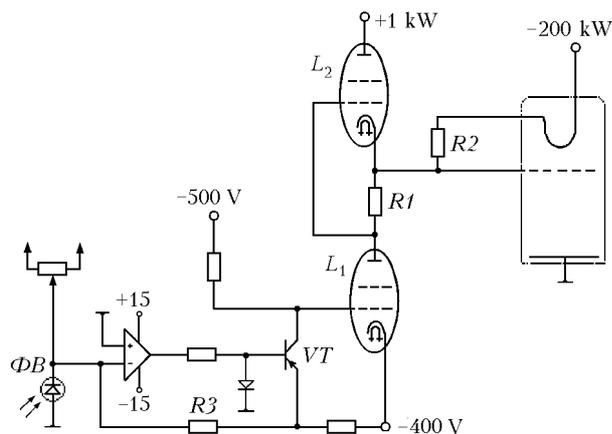


Fig. 2. Grid control circuit.

Among the versions considered, the control circuit shown in Fig. 2 turned out to be the best. In this circuit, the voltage across the grid electrode is controlled by changing the intensity of the LED

radiation, which comes to the photodiode  $PD$  through a light guide. A light guide plays also the role of dielectric decoupling between the high-voltage and low-voltage elements of the laser power supply and control systems.

The properly modulated radiation is fed to the photodiode, operating in the photoresistive mode, which ensures linear conversion of the radiation intensity into the current strength. A 100% negative feedback is applied to the operational amplifier and the output transistor  $VT$ , so that they convert the photodiode current into the voltage controlling the grid potential of  $L_1$  and, consequently, the current of this lamp connected in cascade with  $L_2$ .

Initially, due to the proper choice of the offset current specified by a potentiometer,  $VT$  is open, the potential drop across the grid and the cathode of  $L_1$  is close to zero, and the highest current passes through  $L_1$ . This current provides for the voltage drop across the resistor  $R_1$ , which is sufficient for complete disabling of  $L_2$ .

The lamp  $L_1$  is fully open,  $L_2$  is fully disabled, the potential nearly equal to the potential of the cathode of  $L_1$  (300 V) is established across the control system output and the grid electrode of the accelerator, and the electrons from the emitter do not come into the accelerating gap.

As the photodiode is fully illuminated,  $VT$  is closed, the potential drop across the grid and the cathode is equal to  $-100$  V,  $L_2$  is open, and the anode potential of  $L_2$  (1000 V) is fed to the grid electrode.

Thus, this control circuit enables the potentials from  $-300$  to 1000 V to be applied to the grid electrode of the accelerator, and this ensures a total control over the current of accelerated electrons.

The circuit is equipped with independent power supply, which includes a rectifier, a pulse-phase voltage stabilizer, and a voltage converter. The following voltages are generated at the output:

+1 kV across  $L_2$ ;

$-400$  V across  $L_1$ ;

+200 V applied to the tetrode screen grid;

+6.3 V for heating the tetrode cathode (two sources are used);

$\pm 15$  V for feeding the operational amplifier.

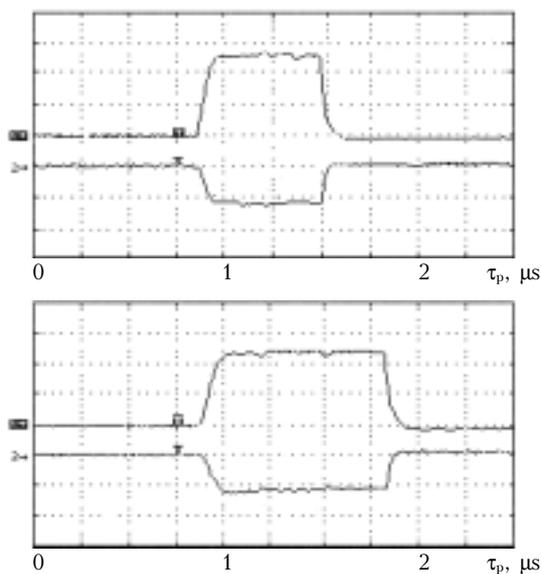
The module consumes the current up to 3 A from 20 V dc voltage source and allows the control for the power contributed to the discharge up to 1 MW at 50  $\mu$ s speed.

The use of the grid control module permits us to study the energy characteristics of the electron-beam-controlled laser operation by setting different pulse durations and repetition frequencies, as well as to determine optimal conditions for obtaining the highest efficiency and output energy.

As the laser operated in the cw mode, the characteristic dependence of the discharge current on the electron beam current was recorded. It is important to demonstrate an unambiguous dependence of these parameters for the laser operating in the repetitively pulsed mode with electron beam pulses of different durations.

The control pulses were fed to the grid control circuit from a G5-54 generator through a photon-coupled communication line. Analysis of the oscillograms of the discharge current and the electron beam current (Fig. 3) has shown that a steady-state current is established in the gas in the process of the electron beam injection into the laser active gas volume, and its duration in our case is determined by the beam current pulse length, and the pulse shape copies the shape specified by the generator.

We have also analyzed the dependence of  $I_d$  on  $U_d$  at the constant electron beam current  $I_b \sim 200 - 220$  mA. The results obtained indicate the linear growth of the discharge current until breakdown, whose voltage is determined by the pressure of the mixture injected into the discharge gap.



**Fig. 3.** Oscillograms of the discharge current (1) and the electron beam current (2).

Due to the possibility of operating in both continuous-wave and repetitively pulsed modes with generation of pulses of different shapes and durations, this laser can be considered as a unique system. The obtained results suggest an unambiguous control for the discharge current and, consequently, the output power of the CO<sub>2</sub> laser. The rates of the pulse rise and drop enable this laser to be used in studying various physical and technological processes.

The laser opens wide possibilities for determination of optimal parameters of radiation for various laser technologies, such as the laser cutting and welding, thin film deposition, production of nanopowders of solid substances, and others.

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