Operational Characteristics of a TE CW CO_2 Laser with a DC Auxiliary Discharge

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***Abstract*—This paper describes a TE CW CO_2 laser with a special gas flow scheme and an auxiliary discharge configuration. In this laser system, mixed gas was forced to flow through a structure of square tubes with meshes on both sides. An array of auxiliary electrodes was added to produce a dc auxiliary discharge between these electrodes and a tubular cathode. By introducing these structures, uniformity and stability of the main discharge could be significantly improved, and more electrical input power could be deposited into the laser gases at higher pressures and higher discharge currents. An output power exceeding 3000 W/m was obtained at a gas mixture of $CO:CO_2:N_2:He = 4:10:25:40$ and a total pressure of 7.9 kPa. Without the auxiliary discharge, the maximum output power was less than 1600 W/m, and a stable discharge could not be obtained at a pressure above 4 kPa. The spatial distributions of unsaturated gain along the direction of gas flow and contours with constant gain were also drawn. By introducing molecular sieve 3A, the system could be operated continuously over 15 h under sealed-off conditions.**

I. INTRODUCTION

THERE are two important factors to limit the laser power output of TE CW CO_2 lasers, namely, high gas temperature and discharge instabilities. When the gas temperature is overheated beyond a critical temperature of 600 K, the population inversion would vanish [1]. However, it was found that the lasing behavior is limited by discharge instabilities rather than high gas temperature [1]. When discharge instabilities occur, a normal glow discharge transits to an arc and the laser gain drops to zero abruptly. Moreover, electrodes may be damaged permanently by a localized arcing. Therefore, it is necessary to install some auxiliary devices to delay the onset of discharge instabilities, and thus to increase the electrical power input of a TE CO_2 laser. One of the more important factors in avoiding discharge instabilities is that the electron density should be distributed uniformly [2], [3]. There are many factors which influence the uniformity of the electron density distribution. These are electrode configuration, surface conditions of the electrodes, and gas flow conditions. Usually, in dc excitations, either a cathode or anode is sectionalized in order to provide a more stable discharge. For instance, electrodes are often constructed in multielement form such as segmented plate or rod anodes with tubular cathode [4], [5] or pin cathodes with a plate anode [5], [6].

Some manufacturing defects will invariably exist on the surface of the electrodes, and in addition, some oxides or organic compounds deposit on them. Both of these conditions will result in a spatial variation of the surface resistance. As a consequence, these contaminations will affect the spatial homogeneity of the glow discharge and thereby also the onset of discharge instability. This being the case, the treatments of the electrodes and the cleanliness of the vacuum chamber are important. The surfaces of the electrodes should be very carefully polished. Sometimes a chemical etching process is necessary to obtain a sufficiently clean and smooth surface.

Some preionization techniques are provided to obtain uniform and stable glow discharges at high pressures and discharge currents. The external field may be in the form of pulses, RF, or an auxiliary dc source [7]–[9]. With the help of these external ionizing sources, a more uniform electron density distribution can be obtained. Thus, more power can be deposited into the laser gases at higher gas pressures.

The speed of gas flow and other aerodynamic conditions can also have a significant stabilizing effect on TE lasers [10]. For industrial TE CO_2 lasers, the gas flow speed is usually set in the range of 30–50 m/s. Under this condition, a typical laser output power is limited to 1500 W/m [4]–[6], [9], [11]. It was also observed that introducing a turbulent flow conditioning device, such as a baffle, grid, or bar, could control the velocity profile and thereby affect the characteristics of the electric discharge, for instance, the electric field, the electron temperature, and the charge distribution [10]. A uniform turbulence tends to smooth out the charge distribution and results in a more uniform gas temperature and gain distribution along the optical axis. Also, the stability of the discharge can be enhanced by increasing the level of turbulence.

In the present paper, a TE CW CO_2 laser has been designed with special turbulent devices for gas flow conditioning and auxiliary electrodes for glow discharge preionization. The operational characteristics of this laser system, with and without an auxiliary discharge, are described in detail. The system could be operated 15 h continuously without replenishing the gas mixture. Therefore, the operational cost of gas was reduced greatly.

II. EXPERIMENTAL APPARATUS

Fig. 1 shows the schematic diagram of the gas flow conditioner and the electrode configuration of the present

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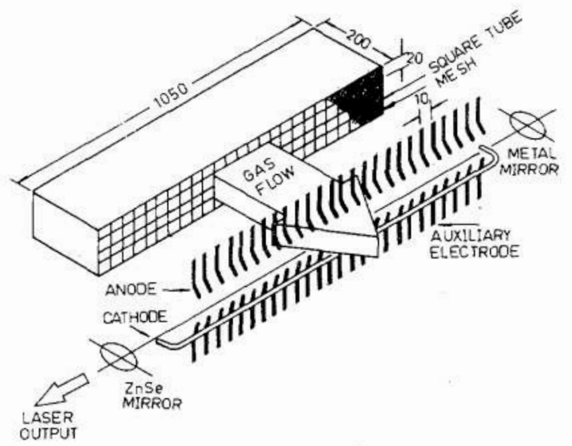


Fig. 1. Schematic diagram of discharge region.

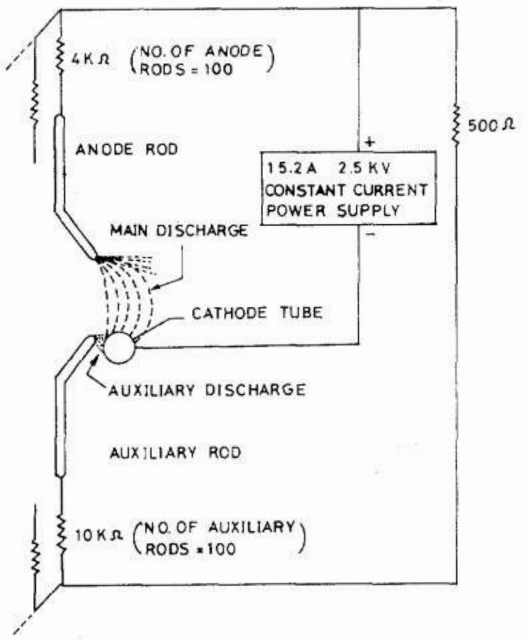


Fig. 2. Electrical schematic diagram of the excitation system.

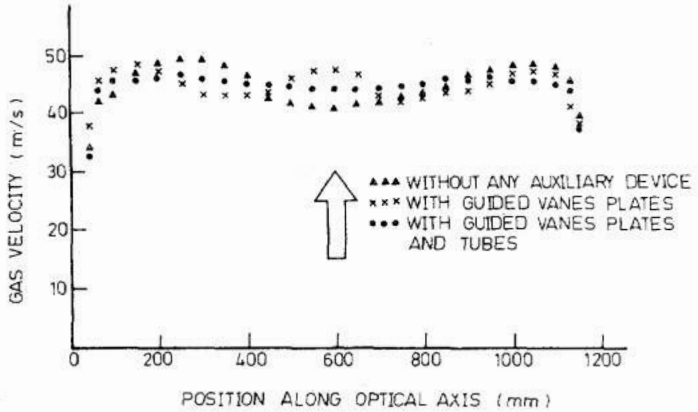


Fig. 3. Gas velocity profile along the optical axis.

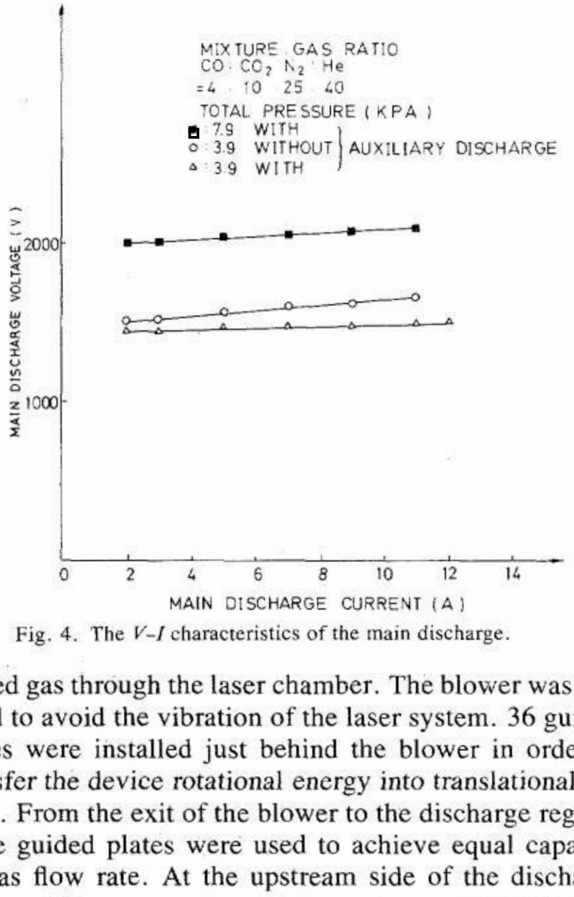


Fig. 4. The V–I characteristics of the main discharge.

laser system. The directions of gas flow, glow discharge, and optical axis are perpendicular to each other. The main discharge electrodes consisted of an array of 100 stainless steel rod anodes and a 105 cm long, water-cooled copper tube as a cathode. The spacing between rods was 10 mm. Near the cathode, an array of 100 auxiliary electrode rods was added to preionize the main discharge. Each anode and auxiliary electrode had a diameter of 3.2 mm, with the diameter of the tubular cathode being 12.5 mm. The distance of the main discharge gap and the auxiliary discharge gap were 28 and 3 mm, respectively. A complete electrical schematic diagram of the excitation system is shown in Fig. 2. Each anode and auxiliary electrode was connected to a ballast resistor of 4 and 10 kΩ, respectively. An additional resistor was added to maintain the auxiliary discharge current between 3 and 4 A. The voltages and currents of the main and auxiliary discharge were recorded by an x-t recorder, respectively.

An axial blower, with a flow rate of 200 m^3/min and a static pressure of 110 mmAq, was used to circulate the mixed gas through the laser chamber. The blower was isolated to avoid the vibration of the laser system. 36 guided vanes were installed just behind the blower in order to transfer the device rotational energy into translational energy. From the exit of the blower to the discharge region, three guided plates were used to achieve equal capacity of gas flow rate. At the upstream side of the discharge region, 152 square tubes with stainless steel meshes on both sides were added to produce uniform gas flow turbulences. The dimensions of each tube were 30 × 20 × 200 mm long. After these devices were installed, a uniform gas flow of 45 ± 1.2 m/s along the optical axis was obtained (Fig. 3).

The optical resonator consisted of a gold-coated molybdenum mirror and a ZnSe output mirror with 45 percent transmission. The radii of curvature of the total reflector and the output mirror were 7 and 10 m, respectively. The resonator length was 1.5 m; of this, approximately 1 m length was filled with the active medium. The optimum position of the resonator axis was determined by gain measurements in the discharge region, and was found to be 18 mm downstream from the center of the cathode tube.

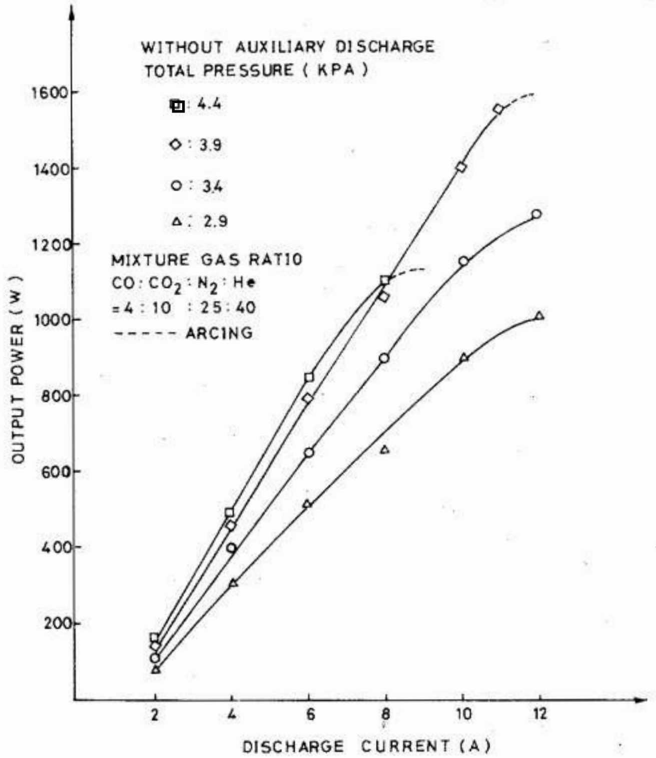


Fig. 5. The laser power versus discharge current without an auxiliary discharge.

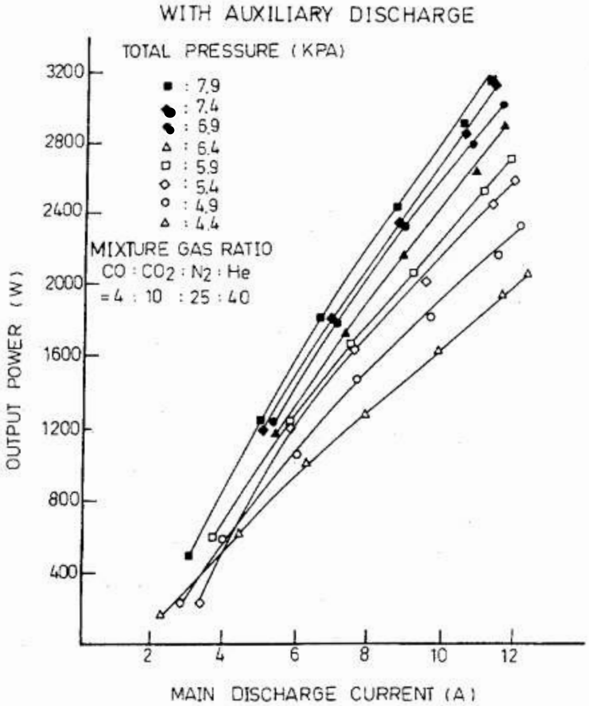


Fig. 6. The laser power versus discharge current with an auxiliary discharge.

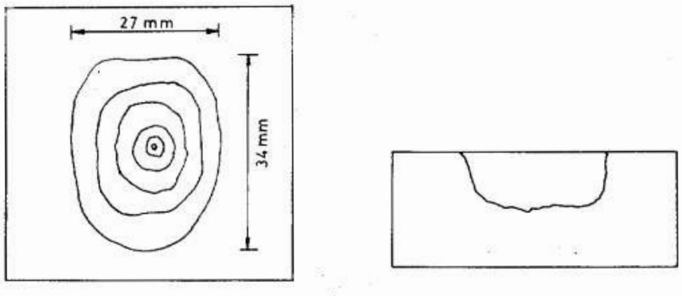
III. EXPERIMENTAL RESULTS

A. Discharge Characteristics

Fig. 4 shows typical voltage–current characteristics of a dc main discharge. It was found that the voltage of the main discharge decreased with an addition of auxiliary discharge. A similar result was reported in [12], in which an electrode for silent-discharge (SD) assisted glow discharge was added. The discharge voltage increasing slightly with time was due to the contamination (e.g., the outgassing of vacuum chamber) and the dissociation of CO_2 gas which increased the operating pressure slightly. It was also found that the initially sustaining voltage also decreased with the auxiliary discharge. This could avoid arcing discharges between the electrodes and the walls of the vacuum chamber when the glow discharge was started.

B. Power Output Characteristics

Several different ratios of gas mixtures were tested; the most suitable ratio was $CO : CO_2 : N_2 : He = 4 : 10 : 25 : 40$. The dependence of laser power output on discharge currents, with and without an auxiliary discharge, are shown in Figs. 5 and 6. The results show a significant enhancement of output power by introducing the auxiliary discharge. This was due to the fact that stable discharges could be obtained at higher gas pressures (7.9 kPa) and higher discharge currents. Without the auxiliary discharge, stable discharges could not be obtained at a pressure higher than 4 kPa. (See Fig. 5.) A maximum output power of 3150 W was obtained at a total pressure of 7.9 kPa. This value was limited by the current capacity of the power supply used in the experiments. The main and aux-



(a) (b)

Fig. 7. The burn pattern of the output beam (a) front view (b) cross-sectional view.

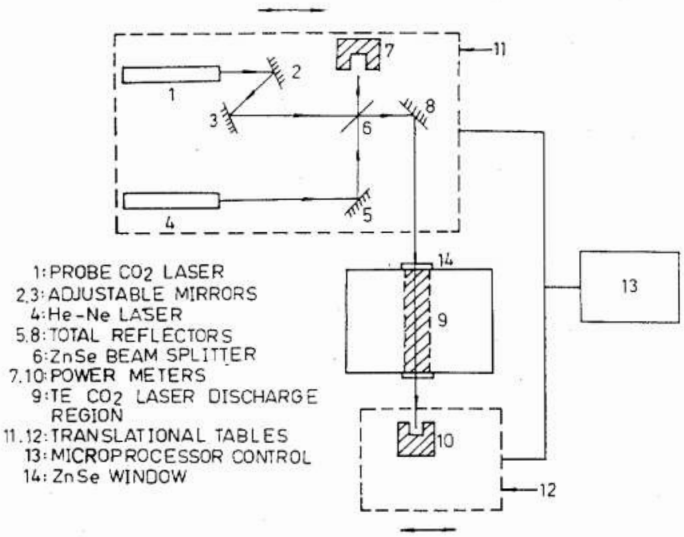


Fig. 8. Schematic diagram for gain distribution measurement.

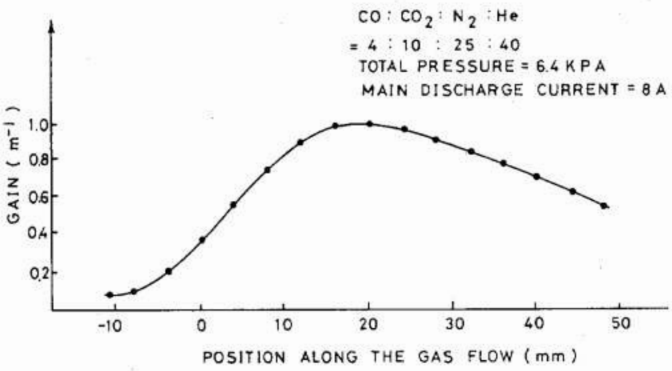


Fig. 9. Spatial distribution of gain along the direction of gas flow.

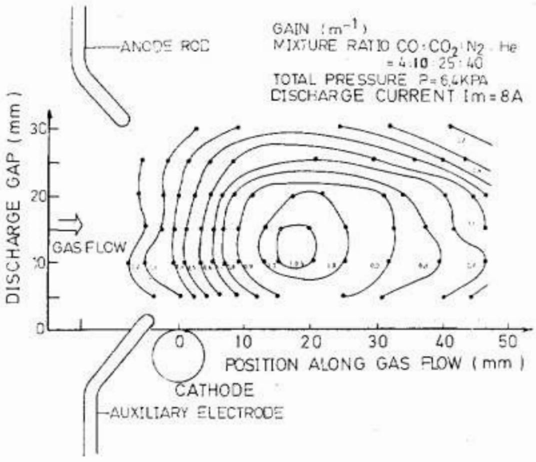


Fig. 10. Contours of constant gain in the discharge region.

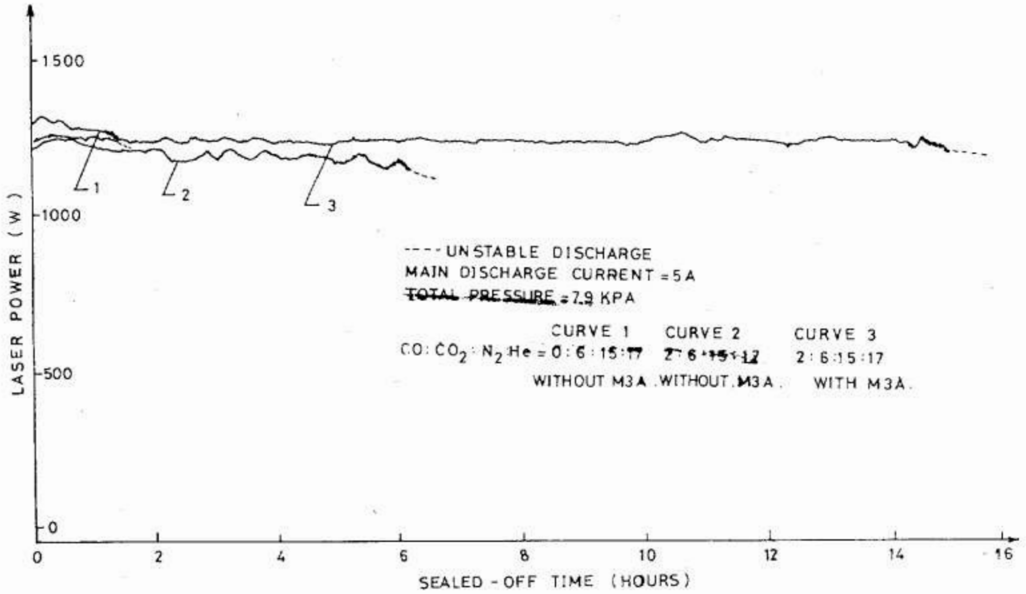


Fig. 11. The laser power versus sealed-off time.

iliary discharge currents were 11.2 and 4 A, respectively. The overall laser efficiency (including the electrical power input for main and auxiliary discharges and the power dissipation in the ballast resistors) was 8 percent.

Fig. 7 shows the burn pattern of the output beam on an acrylic plate. The dimensions of the rectangle-like shape were about 34 × 27 mm.

C. Gain Measurements

The gain along the direction of gas flow was measured. The measurement system is shown schematically in Fig. 8. The system was aligned by an He–Ne laser. The output power of the probe CO_2 laser was 2 W. Translational tables 11 and 12 were controlled to move synchronously by a microprocessor. The outpowers, measured in power meters 7 and 10, were recorded by an *x-t* recorder. Fig. 9 shows the gain distribution along the direction of gas flow. Contours of constant gain were also plotted. The result is shown in Fig. 10. From this figure, the optimum position of the optical resonator could be easily determined. It was located about 18 mm downstream of the center of the cathode tube, and about 15 mm from the top of the tube.

D. Sealed-Off Conditions

A small amount of CO gas was added to the gas mixture to reduce the dissociation of CO_2 in the lasing mixture [6]. Molecular sieve 3A was also added to selectively absorb the water vapor, which was produced by the outgassing of the vacuum chamber [6], [13]. Without these, the discharge became unstable and the output power would decay rapidly, after only several minutes of operation under sealed-off conditions (see Fig. 11). By using CO gas only, the discharge would remain stable for about 6 h. By utilizing both CO and molecular sieve 3A, the discharge would remain stable for about 15 h, without replenishing the gas mixture. The laser output power was stable at 1250 W ± 35 W when the main discharge current was maintained at 5 A.

IV. CONCLUSION

Compact size, high output power per unit length, and long-term sealed-off operation are the tendencies in the development of industrial lasers. A TE CW CO_2 laser for industrial applications has been fabricated. By adding a gas flow conditioner, the power output of the laser system could be increased about 50 percent. Moreover, the power output could be further enhanced about 100 percent by adding an array of auxiliary electrodes to preionize the main discharge. An output power of more than 3000 W/m was obtained at a gas velocity of 45 m/s. The system could be operated in a sealed-off condition for over 15 h if both CO gas and molecular sieve 3A were added.

If a double set of electrodes is used, such as one tubular cathode at the center and two linear arrays of anode rods at the top and bottom sides of the discharge region, and a fold cavity structure is used, then an output power of more than 6000 W/m can be expected. Such work is now in progress.

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