THE INEXPENSIVE REPETITIVELY PULSED CO_2 LASER

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Abstract

Experiments were performed to obtain inexpensive construction of repetitively pulsed CO_2 lasers. A 2.2 cm bore, 150 cm discharge tube containing CO_2 and N_2 gas mixture was operated at 24 KV to produce output in excess of 0.1 joule.

The output was approximately doubled when He gas was used along with CO_2, N_2 gases.

At maximum output energy the ratio of electrc field to pressure was approximately 20 V/cm torr.

Good control of discharge and high circuit efficiency was obtained with a simple circuit operated at 30 or 60 pulses per second synchronized to the 60 Hz power line.

I. INTRODUCTION

The use of high power laser as a heat carrier to produce effects such as heating, melting and vaporization leads to many engineering applications.

The CO_2 laser has a number of advantages over solid state lasers. Among them are high efficiency and high average power.

Axially pulsed discharge was the first method to obtain high peak power extracted from CO_2 lasers.

Multijoule pulses at repetition rate between 20 and 100 pulses per second (PPS) were obtained by Hill[1] who used one megavolt maximum voltage pulse transformer circuit.

Output energy of the order of 100 joules was induced from excitation of large volume of gases by other workers[3] using a 60 KV initially charged, 8-stage Marx generator.

These high performance lasers are usually large in size and require unconventional high voltage.

Such devices need further improvement to be a widely used tool by the industry.

In general, practical applications of a laser such as hole drilling, plate cutting and surface material removal do not require very high power. 1 joule per pulse is quite enough to provide efficient interaction with metals despite the high reflectivity at 10.6 micron which is the wave length of the CO_2 laser. The power required for evaporation of most nonmetallic material is even less.

Therefore, a practical pulsed CO_2 laser should be smaller in size, lower in working voltage, yet the output energy still meets the requirement of practical work.

The purpose of the present work is to study such a practical laser system, and its contents are two-fold:

(1) The construction and performance of relatively small laser system which is excited by conventional high voltage of 20 KV−30 KV.

(2) The improvement of capacitor discharge circuits.

The basic characteristic of this laser was found to be similar to those devices previously reported[1,3]. The experimental data presented here in this paper should be helpful for designers who are interested in practical applications of the CO_2 laser.

In Section II, the experimental setup for making an axially excited pulsed CO_2 laser will be described and illustrated. The experimental results and their interpretation will be presented in Section III. While the conclusion will be made in Section IV.

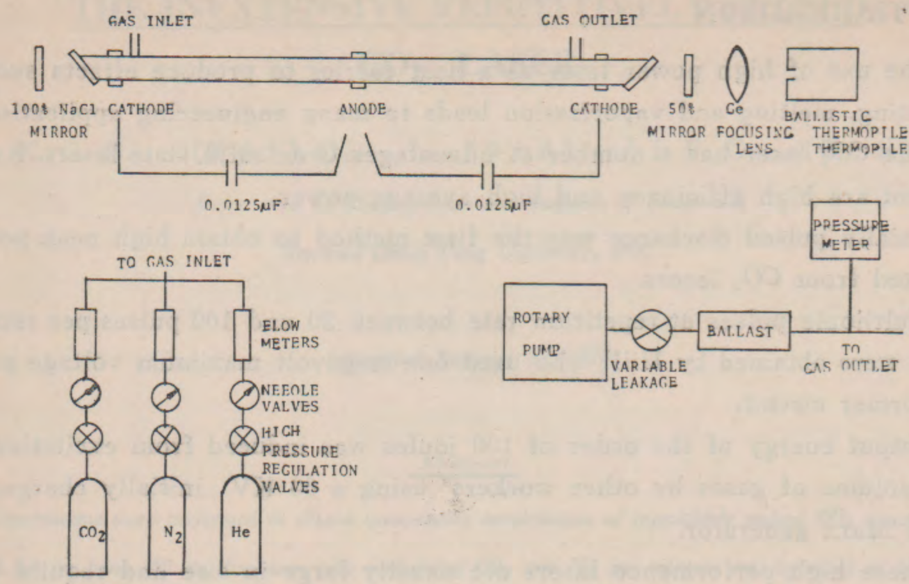

Fig. 1 Block schematic of the pulsed CO_2 laser.

II. EXPERIMENTAL SETUP

The discharge length of the laser tube was 150 cm, and the inside diameter was 2.2 cm. The discharge tube was constructed with two cathodes at both ends and one anode in the middle of the tube. This arrangement of electrodes reduced the required high voltage by a factor of 2.

No cooling device was applied to the discharge tube. *NaCl* Brewster angle windows were used.

The insufficient area of the *NaCl* windows caused 40% loss of the tube cross section.

The optical resonant cavity was formed by two mirrors separated 180 cm away. The output mirror was a 50% reflectivity dielectric coated *Ge* flat plate. A gold coated mirror with 2 mm hole at the center and 10 meter radius of curvature was used a 100% reflectivity morror. A *He-Ne* laser beam passed from the 2 mm hole was used for the alignment of two mirrors. The optical energy loss from the 2 mm hole was assumed to be negligible.

The pressure ratio was calculated from readings of inlet flow meters of three different gases.

The total pressure was measured by a mercury meter at the outlet terminal of the discharge tube.

A D. C. power supply of 60 KV maximum voltage, 100 *mA* maximum current was available.

The A.C. high voltage was obtained with a 15 KV, 30 *mA* (rms) transformer. 8 capacitors were connected in series to give 0.0125 *uF* effective capacitance in order for exciting half of the discharge tube.

Spark gaps were used as high voltage switches. The spark gap triggering system was made of typical T.V. fly-back transformer, horizontal deflection power tube and timing circuits. The spark gap triggering system provided the following triggering modes:

(1) Manual triggering.

(2) 0.5 to 15 PPS adjustable repetition rate.

(3) Synchronization to external signal with variable delay.

(4) Synchronization to external signal with variable delay but at half frequency of the external signal. The detail of the spark gap triggering system is described in Fig. 9.

The external signal pick up, the scale of 2 divider and the variable delay circuit were designed for 60 PPS and 30 PPS repeated pulses synchronized to the 60 *Hz* power line.

The laser output was focused and measured by a HADRON/TRG model 101 ballistic thermopile and 102C energy/power meter (microvoltmeter).

The focusing lens was a uncoated *Ge* lens. It has a focus length of 5 cm, the total loss of the lens was calibrated by a *CW* CO_2 laser.

III. EXPERIMENTAL RESULTS AND DISCUSSIONS

1. Single pulse performance

Single pulse performance was made in order to understand the basic property of the laser of this type. Conventional capacitor discharge circuit with a D.C. power supply was used (Fig. 6).

Relatively low pressure was chosen because of the permissibility of wide range of the applied voltage. The applied voltage was varied from less than 20 KV to 30 KV.

Frequent adjustment of the spark gap distance was necessary because one single spark gap distance could be used over only a limited range of applied voltage. For a fixed voltage, there was a range of permissible spark gap distance. The distance has no influence on the output energy as long as the spark gap works.

Beside the varied voltage, the single pulse experiment was also perform ed with different gas mixtures and capacitors.

(1) The dependence of output energy on excitation

For all the cases, the output energy increased as the applied voltaege increased until an arc discharge occured. Although the stored energy in the capacitors also increased with the increasing voltage, the highest efficiency was always obtained at the maximum voltage where there was no existence of an arc discharge.

This phenomenon indicates that higher efficiency might be obtained by improving the discharge technique. The miximum atainable electric field to pressure ratio with this set of capacitors was 20 V/cm torr.

When the capacitance was increased, the glow to arc transition occured at lower applied voltage. This resulted lower efficiency is due to the fact that the maximum atainable electric field to pressure ratio was reduced.

The signal level of the output energy was below the sensitivity of the measuring instrument when the applied voltage was only slightly above threshold voltage.

(2) The influence of N_2, *He* gas additives

The dependence of output energy on gas composition is illustrated in Fig. 2, Fig. 3 and Fig. 4. No output was observed with pure CO_2 gas.

The best result obtained with CO_2, N_2 mixture was $CO_2 : N_2 = 1:1$, 1:2 was almost as good as 1:1 while additional He was used. In other words, the ratio of CO_2 to N_2 partial pressure was more flexible with additional He gas. This can be explained that when He is absent, CO_2 itself plays an important role of relaxing the lower level CO_2 molecule. Almost twice efficiency was

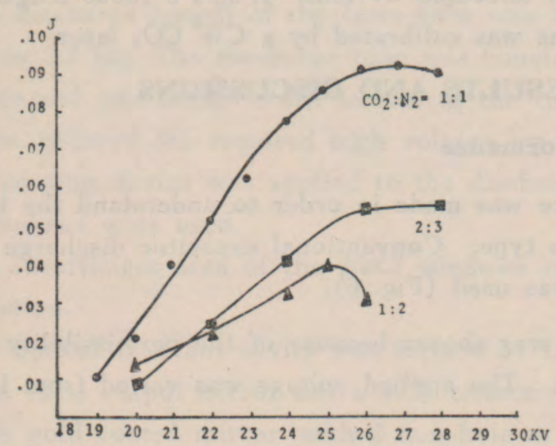

Fig. 2 Dependence of output energy on N_2 partial pressure and ap plied voltage, He=0 torr.

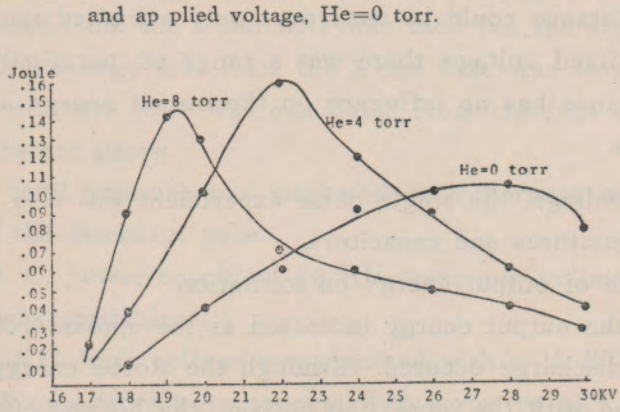

Fig. 3 Depenqence ot output energy no N_2partial pressure and applied voltage, He=6 torr.

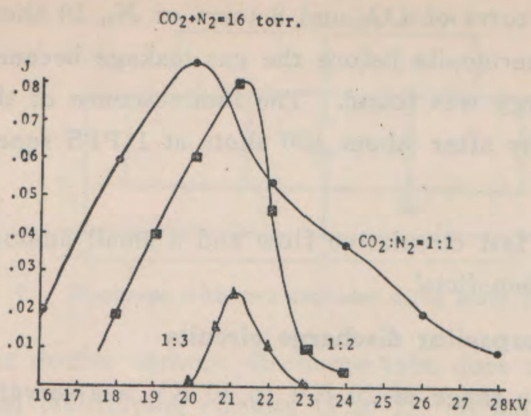

Fig. 4 Dependence of output energy on He partial pressure and applied voltage.

obtained while additional He of a fraction of the CO_2 partial pressure was added into the CO_2, N_2 mixture.The output energy decreased more sharply with more heliun additive when arc discharge occured.

2. Effects of repeated pulse

The air cooled discharge tube provided rather poor heat sink during high repetition rate operations. Sustained operation was achieved at 30 PPS repetition rate, 23 KV applied voltage and 30 1/min flow rate. The average input power of this condition was 200 watts. At 60 PPS repetition rate, arc discharge occured between the cathode near the gas outlet and the anode. This effect was caused by the nonuniform distributed temperature along the tube under the influence of the gas flow. To correct this, one can use fast flow to avoid high temperature, or use symmetrical flow. The most important reason for using fast flow in high average power CO_2 lasers is that it is the best way to cool the gas[2].

Performance of sealed off operation was studied in order to find the suitable rate of maintanance flow if fast circulative flow is used.

The ballistic thermopile is a slow response measuring device. The gas leakage became a problem when the discharge tube was sealed off. Not many quantiative data were taken because of these measuring difficulties.

For most cases, focusing the output radiation on a piece of glass and observing the bright spart was the only information available about the output energy.

The life time of the gas was strongly dependent upon the gas temperature and the electric field to pressure ratio.

With a gas mixture of 8 torrs of CO_2 and 8 torrs of N_2, 10 shots was measured with the ballistic thermopile before the gas leakage became serious and no change of output energy was found. The luminescence of the laser induced spark decreased slowly after about 100 shots at 1 PPS repetition rate.

This suggests that using fast circulative flow and a small amount of maintenance flow should be beneficial.

3. Performances of capacitor discharge circuits

Using high voltage of the range of 20 KV to 30 KV has serveral advantages:

(1) The cost of the electric components is lower.

(2) There are less problems constructing the discharge tube, such as cooling, gas inlet and outlet.

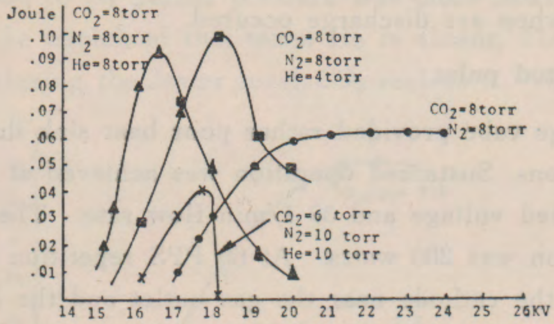

Fig. 5 Effect of large capacitance

(3) Ignitrons, and thyratrons are commercially available in this range of voltage. For voltage higher than 30 KV, the spark gap is the only existing switch. Separate current sources must be used for the discharge tube havingtwo cathodes.

Figure 6 shows the arrangement of capacitors that meets this requirement.

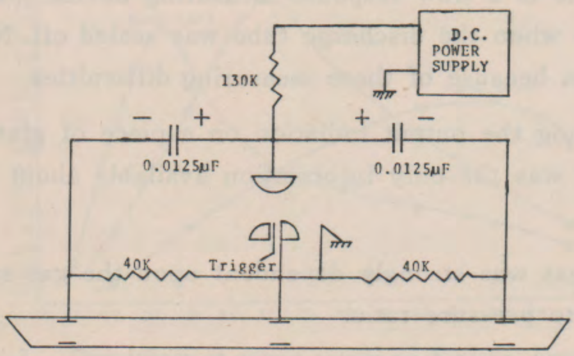

Fig. 6 Capacitor discharge circuit using a D.C. power supply.

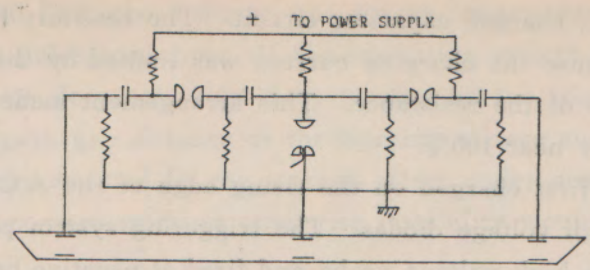

Fig. 7 Discharge with two cathodes using Marx potential doubler.

The double cathode discharge tube does not exclude the use of Marx potential multiplying circuits (Fig. 7). When a D.C. power supply is used to charge the capacitors, the limit of circuit efficiency is 50%. Another disadvantage of using a D.C. power supply is that the spark gap does not turn off itself, and repeated charge and discharge is impossible. Despite of these disadvantages, a D.C. power supply was still used in previous experiments, taking the advantage of accurate voltage measurement. A D.C. arc was usually formed at the spark gap after one shot. The D.C. arc was blowed off by a stream of air jet and made the previous experiments possible An air compressor and a convergent divergent nozzle were used to generate the jet flow. Of course, this method can not be used in a practical laser y stem. Some experimentists used a high voltage vacuum tube to control the charge of the capacitors and solved this problem successfully.

One way of turning off the spakr gap and improving the circuit efficiency is using A.C. as the high voltage source.

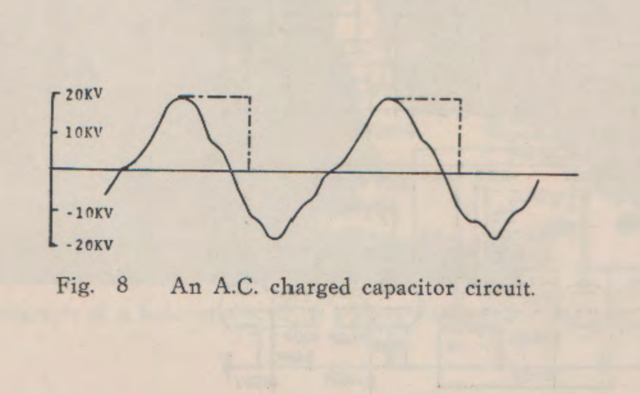

Fig. 8 An A.C. charged capacitor circuit.

Fig. 8 shows the A.C. charged capacitor circuit. The resistors in the circuit were reduced because the charging current was limited by the rate of change of voltage instead of the resistance. This arrangement made the circuit having a efficiency near 100%.

The capacitors were first charged on the rising edge of the A.C. voltage and held there by the high voltage diodes. The triggering system picked up the A.C. signal through a high voltage probe and fired at negative half cycle. This circuit worked at 30 and 60 PPS successfully. The 30 PPS operation was more suitable for testing a circuit because when prefire happened, it discharged at 60 PPS.

The prefire happened at the peak of the A.C. voltage. The output impedence of the high voltage transformer played an important role of protecting the circuit from damage by prefires. Suitable output inductance of the high voltage transformer should be considered while designing more powerful laser of this type.

The air is not a good filling gas for the spark gap because the air does not recover its sparking strength fast enough after a shot.

This phenomenon was observed when one of the capacitors was disconnected. When the spark gap distance was adjusted to give to best discharge

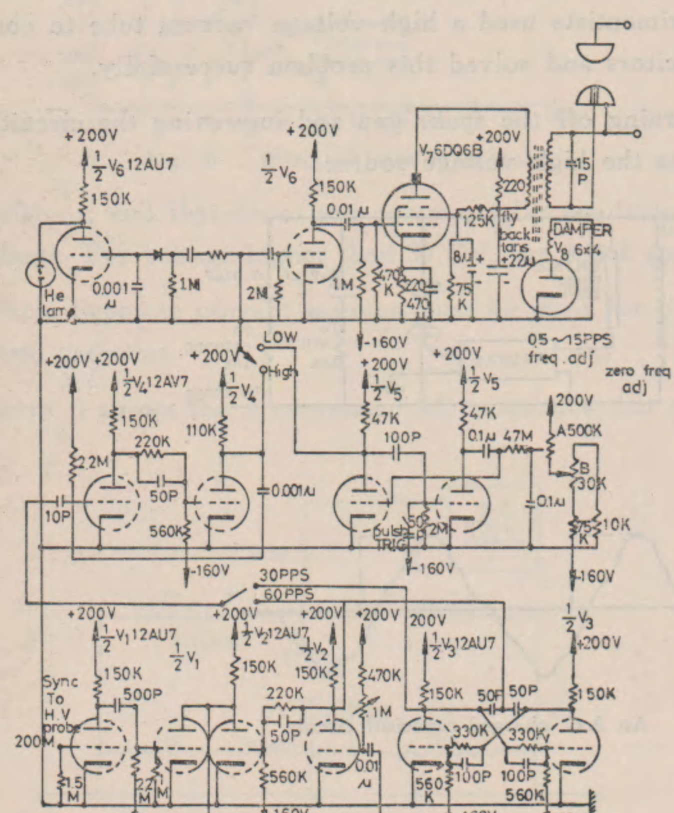

Fig. 9 Circuit diagram of the spark gap triggering system.

stability at 60 PPS, the distance was always longer than the distance suitable for single pulse operation. If the triggering system is turned off at this time, discharge does not proceed by turning on the triggering system alone. Either the spark gap distance or the working voltage must be readjusted. This effect was compensated by the loading effect under normal condition when two capacitors were working otherwise instability would have been in-duced.

To eliminate this problem, one can use hydrogen as the filling gas or simply use the hydrogen thyratron.

IV. CONCLUSIONS

The repetitively pulsed CO_2 laser has been proved to be the most competitive laser device for industrial applications. It provides high peak power with a simple inexpensive setup; it has long life time and low operation cost.

Energy of 0.1 joule per pulse is sufficient for evaporation of opaque materials such as glass, organic materials, etc. (Fig. 10 and Fig. 11)

Fig. 10 Photograph of a hole produced in a glass plate at the focal point of the pulsed CO_2 laser.

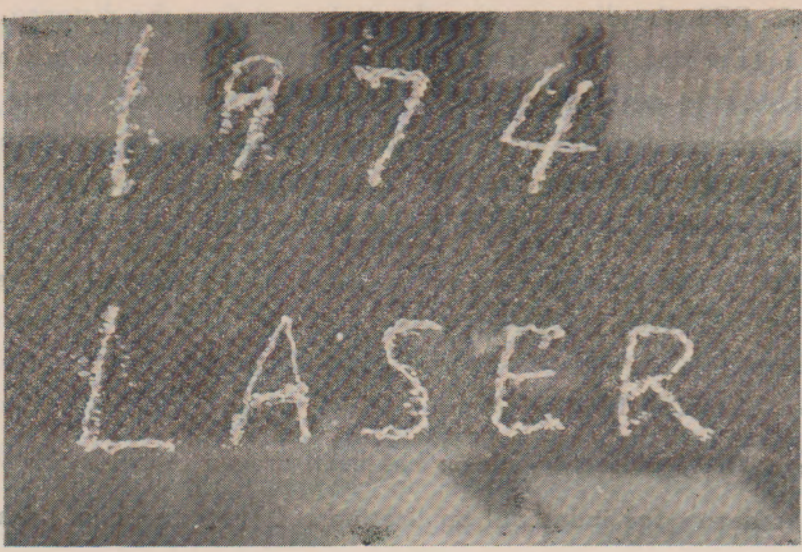

Fig. 11 Photograph of the characters engraved by our pulsed CO_2 laser.

Because the bore of a pulsed CO_2 laser can be extended to at least 15 cm, extending the output energy to 1 joule per pulse is possible without extending the working voltage[3]. Complete change of gas between pulses is not essential. Extending the repetition rate to 1000 PPS is possible without serious fluid mechanical problem.

The cost of the electrical system has been minimized when the repetition rate is chosen 30 PPS, 60 PPS or perhaps 120 PPS.

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