Optimal Characteristics of a Long-pulse CO2 Laser by Controlling SCR Firing Angle in AC Power Line

Ki-Kyung Noh*, Geun-Yong Kim*, Hyun-Ju Chung*, Byoung-Dae Min*, Keun-Ju Song* and Hee-Je Kim*

Abstract - We demonstrate a simple pulsed CO_2 laser with millisecond long pulse duration in a tube at a low pressure of less than 30 Torr. The novel power supply for our laser system switches the voltage of the AC power line (60Hz) directly. The power supply doesn't need elements such as a rectifier bridge, energy-storage capacitors, or a current-limiting resistor in the discharge circuit. To control the laser output power, the pulse repetition rate is adjusted up to 60Hz and the firing angle of SCR(Silicon Controlled Rectifier) gate is varied from 30° to 150° . A ZCS (Zero Crossing Switch) circuit and a PIC one-chip microprocessor are used to control precisely the gate signal of the SCR. The maximum laser output of 35 W is obtained at a total pressure of 18 Torr, a pulse repetition rate of 60 Hz, and a SCR gate firing angle of 90° . In addition, the resulting laser pulse width is approximately 3ms(FWHM). This is a relatively long pulse width, compared with other repetitively pulsed CO_2 lasers.

Keywords: pulsed CO_2 laser, PIC controller, ZCS (Zero Crossing Switch)

1. Introduction

High voltage pulsed power supplies for a pulsed CO_2 laser are classified into three principal circuits: RSG (rotating spark gap)[1], thyratron switched[3/5], and thyristor switched pulsed power supplies[6].

TEA (transversely excited atmosphere) pulsed CO_2 lasers reported earlier have very short pulse duration below a few hundred nanoseconds, and longitudinally pulsed CO_2 lasers using a pulse transformer have pulse width below 100 microseconds and a peak power of 1 kilowatt[2/5,7]. These lasers can be used in applications such as range-finders, remote sensing of gases, and nonlinear spectroscopy. On the other hand, millisecond long pulses are used in surgery and medicine such as skin rejuvenation and tissue ablation[7,8].

In these supplies, the circuit elements such as a rectifier bridge, a current-limiting resistor, energy storage capacitors, a high voltage switch, and a high-voltage transformer are necessary. Consequently, those supplies are expensive and complicate to fabricate.

The transformer and the rectified bridge provide DC voltage for an energy storage capacitor. The stored energy in the capacitor is converted to pulse energy by controlling the switch, and glow discharges are generated by the pulse energy. The charging of the capacitor presents a problem as the discharged capacitor constitutes a short circuit. Without a current-limiting device in the power supply, the short circuit current is only limited by the resistance of the transformer windings. To protect the rectifier diodes and other components in the circuit, current-limiting circuits are required[12].

In this study, we propose a simple power supply to run a repetitively pulsed CO_2 laser with a pulse duration on the order of a millisecond. This power supply switches the AC line (60Hz) voltage on the primary of a leakage transformer and it uses a SCR to generate input pulses to the transformer at a peak voltage of only 220V.

It also controls the laser output power by varying the number of pulses of the AC line voltage switched on the transformer. This power supply requires no circuit elements such as a rectifier bridge, an energy-storage capacitor, or a current-limiting resistor in the discharge circuit because of the direct use of the AC (60Hz) line and the inner impedance of the leakage transformer. Also, in our laser system, the pumping discharges last a few milliseconds because a half cycle voltage pulse in the AC power line has a pulse duration of about 8ms.

Therefore, our laser system requires few of the above devices and makes it possible to generate long millisecond long pulses, which can be used in surgery and medicine.

* Dept. of Electrical Engineering, Pusan University, Korea (shrlrud@hanmail.net., shock707@hanmail.net, hyunju30@hanmail.net, huntermin@hanmail.net, kjsong@kepco.co.kr, heeje@pusan.ac.kr)
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2. Design

2.1 Laser Tube

The type of lasers that we are investigating are sealed water-cooled devices made of pyrex glass. The experiment is equipped with a plano-concave resonator in a longitudinally pulsed CO_2 laser system. The optical resonator is formed by a totally reflecting Mo mirror with a radius of curvature of 10m and a 90% reflecting ZnSe flat output coupler separated by 95cm. The discharge length is about 80cm.

2.2 Discharge Circuit

As shown in Fig. 1, a power supply for exciting the gas molecules is composed of two main circuits, a SCR control circuit and a discharge circuit. The former includes a ZCS circuit and a PIC one-chip microprocessor. The latter includes a SCR(Sanrex:SG25AA60), a leakage transformer, a diode, and a resistor.

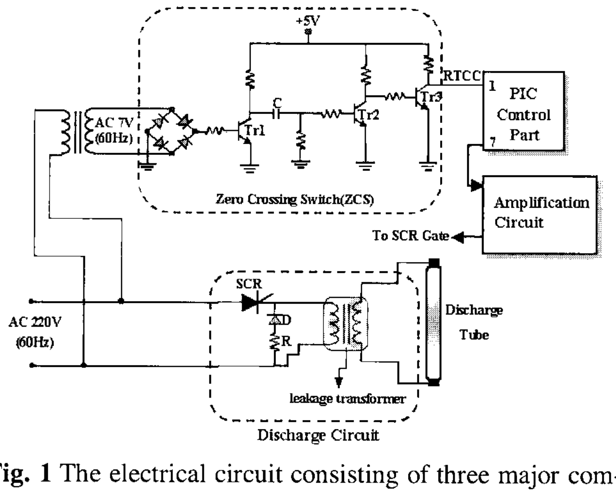

Fig. 1 The electrical circuit consisting of three major components: a ZCS circuit, a PIC one-chip microprocessor, and a discharge circuit.

The SCR trigger control is achieved by counting the number of zero voltage signal from the AC line (60Hz). The ZCS circuit detects the zero voltage of the AC line and then transfers the information to the PIC one-chip microprocessor.

As shown in Fig. 1, a leakage transformer [9/10] also called a neon transformer, is employed in the power supply. The transformer produces a peak voltage pulse of up to 25kV and its rating capacity is 300VA.

The leakage transformers are built to have a large leakage reactance that serves to limit the current in the secondary circuit even if the impedance of the load drops to a low value. This prevents the glow to arc transition to occur in the neon-sign tubes. In this manner, the use of a costly and energy dissipating ballast resistor is avoided. The same benefit is obtained when using this type of transformer to drive low-pressure CO_2 laser discharges that have impedance characteristics similar to that of neon-sign tubes.

In addition, an energy-storage element like a capacitor is unnecessary because the voltage pulse switched from the AC line is applied to the discharge tube through the leakage transformer directly in our laser system.

A free wheeling diode, D, and a resistor, R, are connected with the primary winding. Without these elements in the discharge circuit, input energy would be trapped in the inductor for an appreciable period and might be further increased by the subsequent closing of the SCR. The inductor of the transformer might be saturated by the energy stored in the transformer. This prevents the SCR from subsequently switching until the energy stored in it is discharged. However, when a free wheeling diode and a resistor is present as shown in the circuit, the inductor discharges its energy through the free wheeling diode and the resistor.

Thus, this circuit requires the resistor and diode to dissipate trapped energy in the transformer. The value of the resistor is 10 kΩ, and PIV (Peak Inverse Voltage) of the diode is 600V in this circuit.

2.3 Control Circuit

As shown in Fig. 2, the ZCS circuit makes 120 square pulses per second at the zero voltage of the AC line. 120 pulse signals per second from Tr3 in ZCS are applied to pin 1 called RTCC(Real Time Clock Counter) in the PIC one-chip microprocessor(PIC16C55).

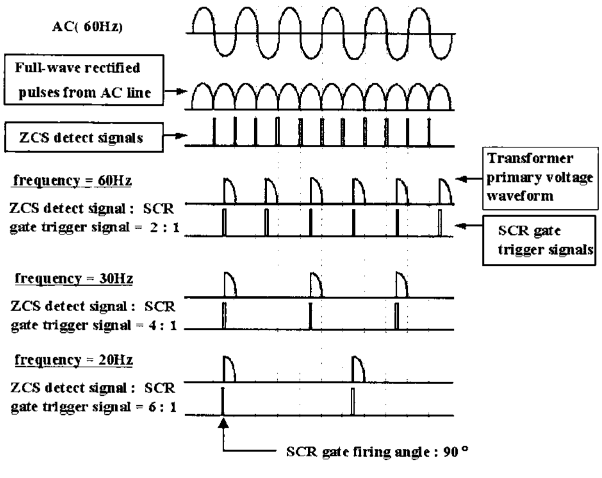

Fig. 2 Voltage waveforms of the ZCS output signals, SCR gate trigger signals, and HV leakage transformer primary as pulse repetition rate at SCR gate firing angle of 90.

The signals from ZCS circuit are divided into the desirable frequency for variable laser power as shown in Table 1. The desirable trigger pulse repetition rate of the SCR gate is given by the ratio of input pulses in pin 1 to output pulses in pin 7 of the PIC as shown in Fig. 2.

Table 1 Comparison between the number of input pulses and output pulses in PIC corresponding to different pulse repetition rates of 10, 20, 30, and 60 Hz.

Pulse repetition rate [Hz]	The ratio of PIC input/output signals	
5Hz	24	1
10Hz	12	1
20Hz	6	1
30Hz	4	1
60Hz	2	1

PIC also controls the SCR gate firing angle from 30° to 150° to investigate an influence of the initial voltage of the input voltage on the laser beam profile and the laser output power. Fig. 2 shows the voltage waveform of the AC line, pulse signals generated from the ZCS circuit, and the gate trigger signals with trigger pulse delay angle of 90° at each working frequency.

3. Output Performance

The experiment has been conducted with a 1/9/15 $CO_2/N_2/He$ gas mix. We measured the average output power using an energy meter (Gentec:PS-1k).

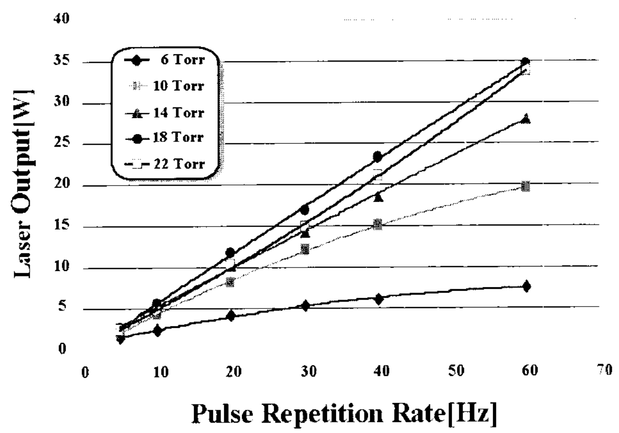

Fig. 3 Laser output power versus pulse repetition rate for various static pressures for an SCR gate firing angle of 90° .

In Fig. 3, the laser output power versus the pulse repetition rate is plotted for various filling pressures for an SCR gate firing angle of 90°. As can be seen in Fig.3, the laser output power increases linearly with the pulse repetition rate for a fixed input voltage because power is deposited more often in the tube and more laser pulses occur as the pulse repetition rate increases.

Output energy per pulse is about 600mJ. In this experiment, the pulse repetition rate is restricted to 60Hz due to the limited number of voltage pulses of the AC (60Hz) power line.

In addition, considering the relationship between the laser output power and the filling pressure, the laser output increases with increasing total pressure up to 18 Torr. The saturation of laser power is observed at pressure higher than 18 Torr. This is due to a transition of the glow mode discharge into the arc mode, which is accompanied by a drastic reduction of the laser power when the gas pressure or the discharge current increases. This instability of the glow discharge is accompanied by a substantial drop in the electron energy, well below 1eV, which results in a drastic lowering of the population inversion and the lasing[11].

The effect of the firing angle of the SCR gate on the laser power is described in Fig. 4. The SCR trigger pulse is delayed from 30° to 150° by the PIC program to investigate an influence of the initial values of the input voltage on the laser output power. From these experimental data, it is found that the maximum laser power is obtained when the trigger pulse is applied to SCR gate with a firing angle close to 90°, which is at the time of the peak voltage of the AC line.

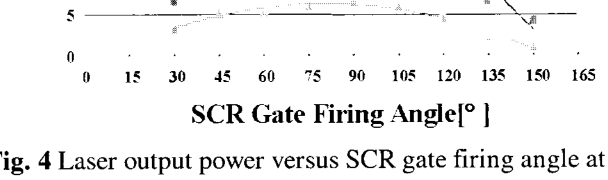

Fig. 4 Laser output power versus SCR gate firing angle at a total pressure of 18 Torr and a pulse repetition rate of 15Hz, 30Hz, and 60Hz.

As a result, we might expect that the magnitude of the input peak voltage is a more dominant factor than the discharge time length.

Fig. 5 shows the voltage waveforms of the AC line, the ZCS detecting pulse, the SCR triggering pulse, and the laser beam pulse shape for firing delay angles of 90° on an oscilloscope. In this figure, it is found that a laser beam formation time of about 1ms exist after the SCR trigger pulse is applied.

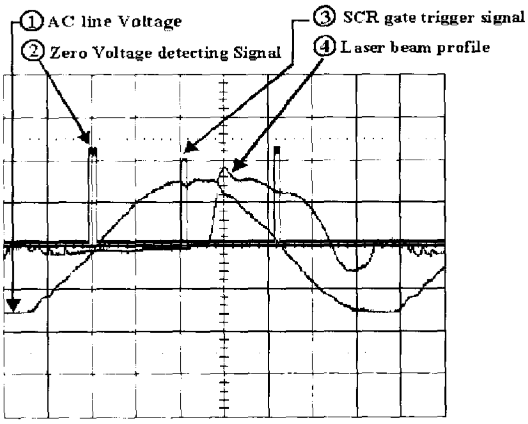

Fig. 5 Voltage waveform of the AC power line, ZCS detecting pulse, SCR triggering pulse, and laser pulse shape for a firing angle of 90 degrees as seen on an oscilloscope (Time scale: 2ms/div).

The laser pulse shapes shown in Fig. 6 correspond to different SCR gate firing angles of 45° , 90° and 135° are obtained at 60Hz. The laser pulse width is approximately 3ms (FWHM). This is a relatively long pulse compared with any other repetitively pulsed CO_2 laser. The laser beam pulse shape was recorded with a pyroelectric element (Molectron: P5-01).

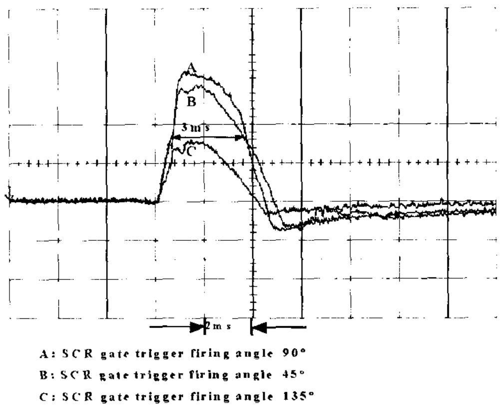

Fig. 6 Laser output pulse shape of the longitudinally pulsed CO_2 laser with a controlled switching of the leakage transformer primary at different SCR gate firing angle (Time scale: 2ms/div).

4. Conclusion

We present a simple power supply that uses a high voltage leakage transformer as a source for a pulsed CO_2 laser with long pulse width. This power supply switches the voltage of the AC power line directly with a SCR, and the switched AC line voltage is applied to the leakage transformer primary.

As a result, this power supply offers some cost and size advantages compared to a typical pulsed power supply for CO_2 laser because it requires no charging element or current-limiting device.

Moreover, it can generate a laser beam with a very long pulse duration of 3ms because of its long discharge time, making it useful for surgery and medicine, such as skin rejuvenation and tissue type ablation.

The maximum laser output is 35W at the total pressure of 18 Torr, the pulse repetition rate of 60 Hz, and the gas mixture of 1/9/15 $CO_2/N_2/He$.

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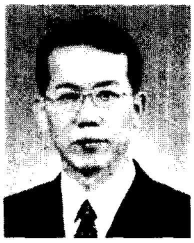
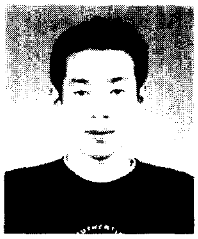


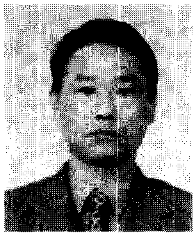
Ki-Kyung Noh
He received his B.S. and M.S. degrees in Electrical Engineering from Pusan National University, Korea, in 2000. He is currently working toward Ph. D. degree in Electrical Engineering at Pusan National University.
TEL: +82-51-510-2770
FAX: +82-51-513-0212



Geun-Yong Kim
He received his B.S. degree in Electrical Engineering from Pukyoung National University in 2001. Currently, he is working toward M.S. degree in Electrical Engineering at Pusan National University.
TEL: +82-51-510-2770
FAX : +82-51-513-0212

Hyun-Ju Chung
He received his B.S. and M.S. degrees in Electrical Engineering in 1998 and 2000, respectively, and is currently working toward a Ph.D. degree in Electrical Engineering, all from Pusan National University, Korea. His research interests are include pulsed CO2 laser, laser pulse shaping, high voltage pulsed power supply, resonant inverters and electric drive systems.
TEL: +82-51-510-2770, FAX: +82-51-513-0212

Byoung-Dae Min
He received his B.S. degree in Electrical Engineering from Pukyoung National University in 2002. Currently, he is working toward M.S. degree in Electrical Engineering at Pusan National University.
TEL: +82-51-510-2770
FAX: +82-51-513-0212



Keun-Ju Song
He received his M.S. degree in electrical engineering from Pusan National University, Korea, in 2001. He is currently working toward Ph. D. degree in Electrical Engineering at Pusan National University.
TEL: +82-51-510-2770
FAX: +82-51-513-0212

Hee-Je Kim
He received his B.S. and M.S. degrees in Electrical Engineering from Pusan National University, Korea, in 1980 and 1982 respectively. He joined the Plasma & Laser Lab of Korea Electro-Technology Institude in 1983 as a research engineer and went to Kyushu University, Hukuoka, Japan, in 1985. and he received Ph.D. degree from Kyushu University, Hukuoka, Japan in 1990. 1995-present, Professor, School of Electrical Engineering, Pusan National University, Pusan, Korea.
TEL: +82-51-510-2364, FAX: +82-51-513-0212