A Study on the Output Stabilization of the Nd:YAG Laser by the Monitoring of Capacitor Charging Voltage

Ki-Kyong Noh*, Kum-Young Song, Jin-Young Choi*, Jung-Hwan Hong***, Sung-Joon Park* and Hee-Je Kim***

Abstract - The Nd:YAG laser is commonly used throughout many fields such as accurate material processing, IC marking, semiconductor annealing, medical operation devices, etc., due to the fact that it has good thermal and mechanical properties and is easy to maintain. In materials processing, it is essential to vary the laser power density for specific materials. The laser power density can be mainly controlled by the current pulse width and pulse repetition rate. It is important to control the laser energy in those fields using a pulsed laser. In this paper we propose the constant-frequency current resonant half-bridge converter and monitoring of capacitor charging voltage. This laser power supply is designed and fabricated to have less switching loss, compact size, isolation with primary and secondary transformers, and detection of capacitor charging voltage. Also, the output stabilization characteristics of this Nd:YAG laser system are investigated. The test results are described as a function of laser output energy and flashlamp arc discharging constant. At the energy storage capacitor charges constant voltage, the laser output power is 2.3% error range in 600[V].

Keywords: current resonant converter, error range, laser output power, pulsed Nd:YAG laser

1. Introduction

Solid-state lasers are more widely used in industry than any other type. The reason for this is that the solid-state laser has a better thermal quality, a better physical stability and a finer durability. Nd:YAG lasers are more frequently used among these solid-state lasers because this laser has a high pulse repetition ratio, a relatively high gain due to the narrow fluorescence line width, and small vibrations at the threshold. Furthermore, since it has superior reaction properties with the processing material, maintenance and repair tasks are convenient, such as power transmission and light concentration by normal optical facility [1-3].

This laser has been used in accurate material processing with high hardness levels and high melting points. Now it is used in the fields which need greater accuracy and a high degree of stability such as medical operating equipment as well as IC markings, IC productions, manufacturing of surface alloy and semiconductor annealing [4-6].

In connection with these, a single pulse beam energy of Nd:YAG is a significant element of laser manufacturing. However, when we establish laser pulse repetition ratio, the change rate of the single pulse beam energy becomes worse as the repetition ratio increases [8-11].

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Received December 1, 2003 ; Accepted March 8, 2004

Consequently, it is necessary that the energy fluctuation should be minimized by controlling the capacitor charging voltage. In this study, we propose a new method of Nd:YAG laser output stabilization by the monitoring of capacitor charging voltage[12-14].

2. Equipment Settings

2.1 The Laser System

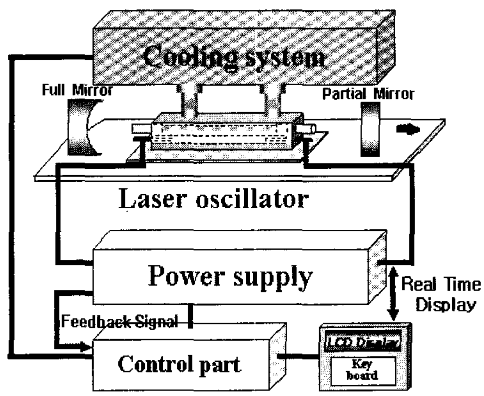

Fig. 1 Schematic diagram of a pulsed Nd:YAG laser system

Fig. 1 shows the schematic diagram of a pulsed Nd:YAG laser system. The laser head consists of a single elliptical type, which has two mirrors along the optical axis for laser vibration on both sides. The full mirror is concave and has a curvature radius of 2m and reflection ratio of not less than 99.5%. The partial mirror is a flat mirror of 80% reflection ratio. A stable resonance system is made of these two mirrors.

The Nd:YAG rod and lamp are located at the focus. The inner reflection surface with gold coating after surface cutting has a good reflection with a wavelength range that excites laser mediums in the lamp reflection light.

Heating by laser mediums as well as by lamps due to long laser operations, effects the temperature distribution of a medium, gives spatial changes of reflective index, changes the output pulse type and severely damages the medium. To prevent these results, the laser, rod, and lamp should be cooled down with cooling water.

2.2 Power circuit

In this research, we have adopted a double power circuit by using voltage division capacitors as shown in Fig. 2 and made it operate as half bridge type by adding a resonance circuit. At this time, an on-and-off operation of the switch occurs when the current in the switch is zero. So the power loss by operating the switch is almost zero. Switch S_1, S_2 come into the serial action of On and Off.

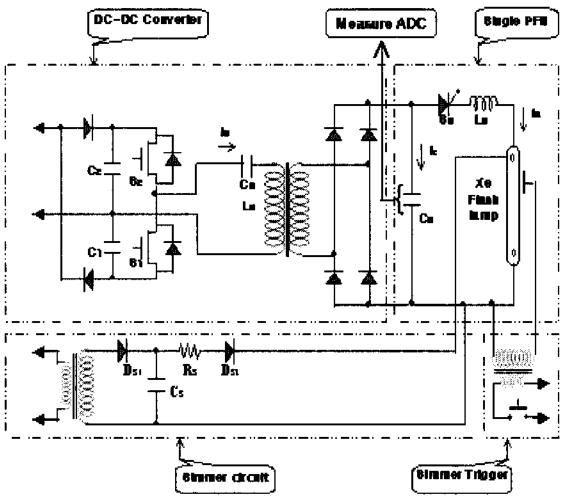

Fig. 2 Laser power supply

IGBT (BSM75GB120DN2), which operates from 1 kHz to tens of kHz, is used in the switching element. It is a half bridge package type, which has 1200V of regular voltage and 105A of regular current. IGBT is a hybrid semiconductor element, which has a rapid MOSFET switching of power and electrification of BJT. Also, it is more convenient to use than BJT, due to its voltage control element with high impedance between the Gate and Emitter of MOSFET. Furthermore, it has a low and steady on-drop regardless of current over BJT, which produces more current than MOSFET.

C_R is used as a blocking capacitor. When input capacitors C_1 and C_2 do not divide input voltage V_i exactly in two parts, or on-time of switches S_1 and S_2 do not accord together exactly, there is a risk of the transformer being saturated by the transformer's magnetic flux changes. To prevent these occurrences, we dismiss the DC elements that produce a lack of balance in flux change by adding a blocking capacitor between input voltage and transformer.

2.3 Control circuit

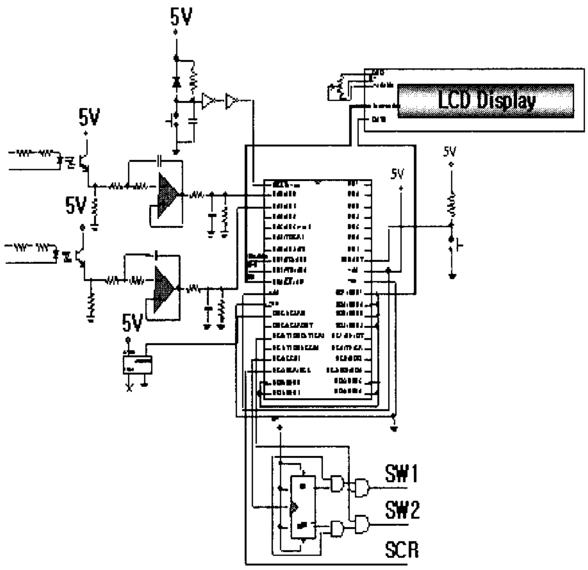

Fig. 3 PIC16F877 control circuit.

The control circuit uses PIC16FB77 as shown in Fig. 3. The voltage charged in the capacitor should be maintained uniformly for laser output. First, we put on SW1 and SW2 signals. Then, we read capacitor and charging voltage and put these values in PIC through LPF (Low Pass Filter). After that, these values are expressed in letter LCD instantly, and are loaded into SCR signals through PIC treatments. The signals in Fig. 4 and Fig. 5 are IGBT and SCR operating signals.

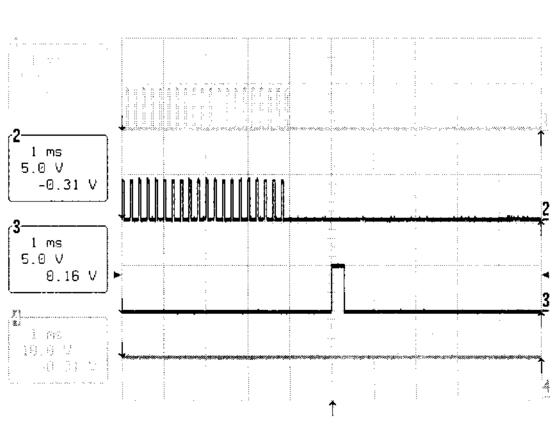

Fig. 4 PIC and IGBT drive signal

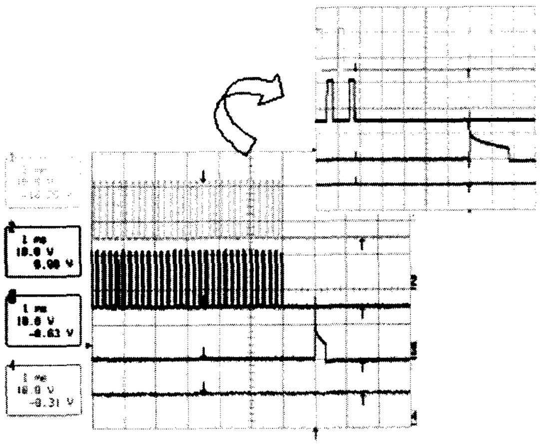

Fig. 5 IGBT and SCR drive signal

3. Experimental results

In this experiment, load capacitors and control equipments are insulated by photo couplers, and are used as input. These input signals are read by letter LCD, and then instantly managed by PIC. The current pulse is measured by ES300C of ABB Co.

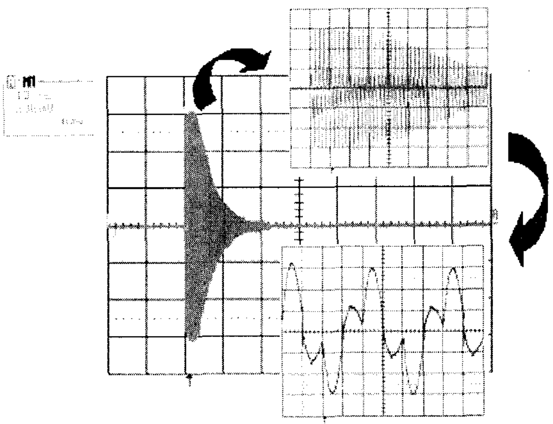

Fig. 6 The resonator current i_r waveform

Fig. 6 shows a wave current i_r that is generated by resonance between C_r and L_r, when IGBT is operated by a signal occurring from PIC. A large amount of resonant currents flow initially because the load capacitor voltage is zero. Recently, we have found that resonant current reduces when the capacitor is gradually charged. Then, when the set point is reached, the current reduces and becomes zero. After that, IGBT operating ends, and the mode changes from capacitor charging mode to capacitor discharging mode as the trigger signal of SCR in the second side is subjoined. At this time, the time delay of 1ms is given in order to complete the task. When the task of half bridge converter ends, the discharge mode of the second side starts.

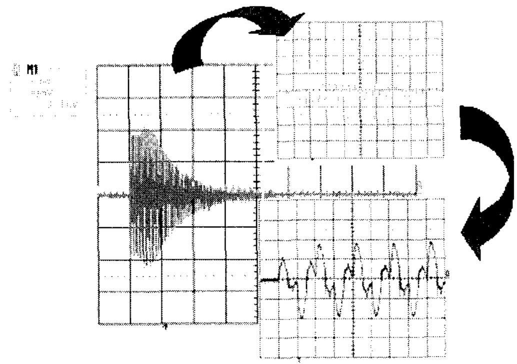

Fig. 7 The current waveform of pulse transformer secondary

Fig. 7 represents the current waveform of the transformer created by crossing paths with magnetic flux of the primary current. The shape is similar to primary resonance current waveform. It shows the uniform waveform, but the amplitudes gradually reduce as the charge ceases. The charging capacitor frequency operates at 5kHz as the IGBT On-Off cycle is 50 μs.

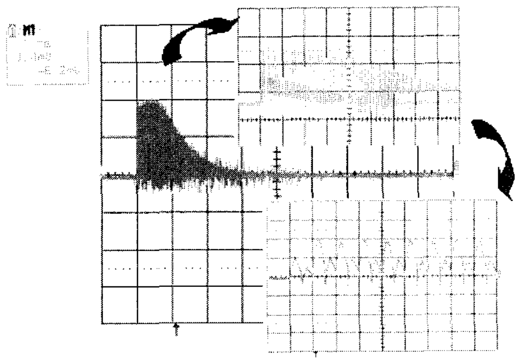

Fig. 8 The charging current waveform of the secondary part load capacitor

Fig. 8 shows another example of Fig. 7 rectified by diode. These shapes only have (+) magnitude waveforms due to the rectified waveforms. If it shows only (+) magnitude, then its frequency is 10 kHz.

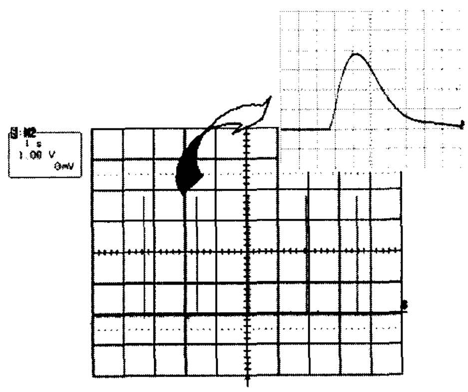

Fig. 9 A typical flashlamp discharge current waveform

Fig. 9 depicts a discharge waveform of a flashlamp measured by C.T. (Current Transformer) when the laser has been oscillated continuously. It shows the uniform waveform of the flashlamp. When we amplify it in 50 μs, its FWHM (Full Width at Half Maximum) is about 150 μs.

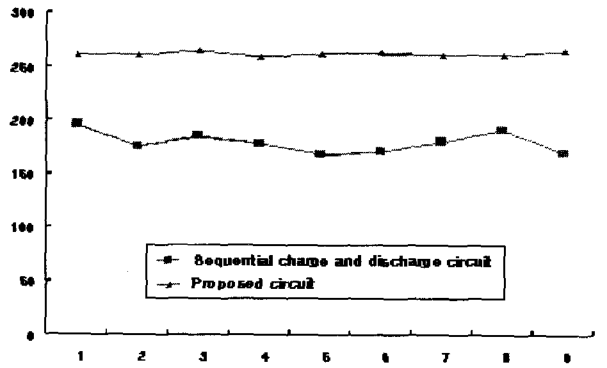

Fig. 10 Comparison results between the sequential charge and discharge circuit, and our proposed circuit

Fig. 10 shows the comparison test results between our previous sequential charge and discharge circuits [10], and our suggested circuit. In reference to the laser output, a 15% alteration ratio is revealed. That difference of output power is caused by the charging process of the load capacitor where the current originated from rectification, resistance, inductor, and SCR switch. The input energy of the load capacitor is so inaccurate that the desired energy cannot be exactly stored. However, our proposed circuit can store digitalized energy by using a feedback system, which can precisely measure the load capacitor energy. This method produces a stable output within 4% alteration ratio as compared with our previous one.

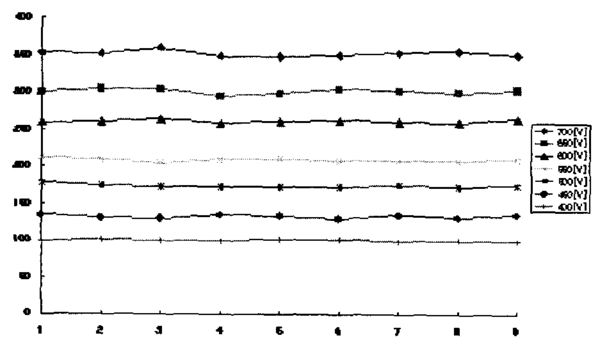

Fig. 11 The comparison results of various input voltages

Fig. 11 shows the results of individual output energy stability tests. This Fig. indicates the output energy changing ratio. The actual graph has no changes in energy levels, but it shows larger deviation in small changes as the total average output is low. In exceptional cases, as the load capacitor input voltage is 700V, some larger output change is obtained. Especially, the best output error range of the single pulse has achieved 2.3% when the charging voltage is 600V.

4. Conclusion

In this study, we have proposed a new method of Nd:YAG laser output stabilization by the monitoring of capacitor charging voltage. It was shown that our proposed method was adopted effectively in designing the stable pulsed laser output.

This method has improved the error range of laser output within 4% compared with our previous sequential charge and discharge method that has a 15% output error range. In particular, the optimal output error range of the single pulse has obtained a 2.3% improvement at the charging voltage of 600V.

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