Step Pulse Shaping Technique for Nd:YAG Laser Using a Multi-Switching Method

Su-Young Kwak*, Jin-Young Choi, Su-Weon Kim***, Byoung-dae Min****, Hyun-ju Chung** and Hee-je Kim****

Abstract - Throughout manufacturing processes, pulse shaping is required for material processing and it is regarded as an important factor according to the specific characteristics of materials. Therefore, this study suggests a highly appropriate pulse shaping technique using a multi-switching method. This is a pulse superposition method in which one flash lamp can consecutively turn on by the double switching of the discharging system. It is possible to construct a variety of pulse shapes and pulse widths by the consecutive trigger of the silicon-controlled rectifiers (SCR) of a PIC (program integrated circuit) one-chip microprocessor. The use of this technique can provide a number of advantages to people who require suitable pulse shaping for particular applications such as welding, cutting, and drilling.

Keywords: multi-discharge, PIC one-chip microprocessor, pulse shaping

1. Introduction

The pulsed Nd:YAG laser holds a variety of advantages over the continuous laser as it has a greater efficiency and a higher peak power. Moreover, the function to vary the laser pulse shapes makes it possible to process even special areas whose processing has previously been impossible with the conventional pulsed Nd: YAG laser. [1]

The classical laser output pulse shape usually takes on a rectangular form in a two-dimensional structure having output strength and output pulse width. At this time, the variation of the pulse shape refers to the variation of the output strength and the output pulse width within a single output pulse. Therefore, rather than the standard rectangular form, the shapes of the output pulse can assume very complicated forms depending upon processing materials. [2, 3]

The laser output pulse variation involves two parameters of the output strength and the pulse width. When the laser is condensed and applied to a workpiece, the workpiece absorbs the laser light, causing the temperature to rise locally. At this point, the required temperature rise differs according to the applied laser strength, the material characteristics of the workpiece, and the processing method. Accordingly, more delicate processing is possible by accurate control of the temperature rise through the adjustment of the output pulse strength. With respect to the variation of the laser output pulse width, lengthy pulses (around 2~20msec) are needed to ensure sufficient welding in the case of laser welding while pulses ranging from 0.1~3msec are required for hole drilling. Thus, the pulse strength and width vary depending upon the types of processing materials and therefore the traditional rectangular laser pulse shape has limitations in carrying out various processing needs. These rectangular pulse shape limitations can be overcome if the laser output strength and the pulse width can be varied freely. [4, 5]

There are two traditional pulse variation methods in existence: variation of capacitance or inductance and change in the switching time of the switching element [IGBT (insulated gate bipolar transistor), SCR (silicon -controlled rectifiers), FET (field effect transistor), etc.] In these methods, the variation of the pulse shape and width is limited. Furthermore, the switching element control system is complicated and its operation is somewhat difficult. [6, 7]

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2. Design

2.1 Laser system unit

Fig. 1 shows the schematic diagram of the Nd:YAG laser system. There is a circular-type laser head in the center of the oscillator and there are two mirrors for laser oscillation on both sides of the head: a total reflector (a concave mirror with a reflectivity of over 99.5% and a curvature radius of 2m) and a partial reflector (a plane mirror with a reflectivity of 85% and a curvature radius of infinity) that constitutes a stable resonator. The laser cavity formed by optical pumping was made in a round formation with use of optical glass causing diffused reflection in order to deliver the light radiated from the lamp efficiently to the rod.

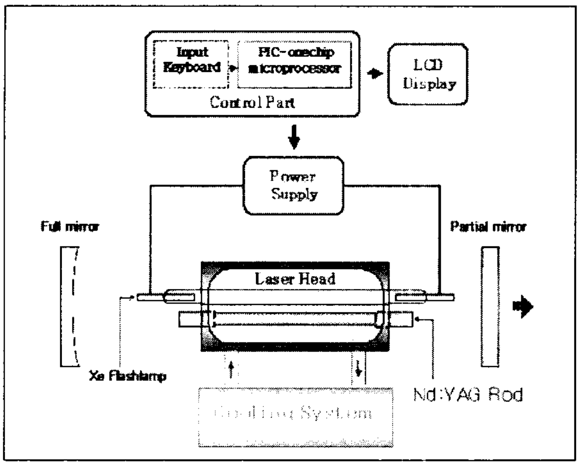

Fig. 1 Typical pulse shapes

2.2 Power supply

This study proposes an innovative multi-switching method that can vary the pulse width in accordance with the consecutive turn-on of the SCR. Using a real time one-chip microprocessor, this method consecutively turns on the flash lamp with a delay time from 0μs to 100μs, thus creating a variable pulse (Fig. 2).

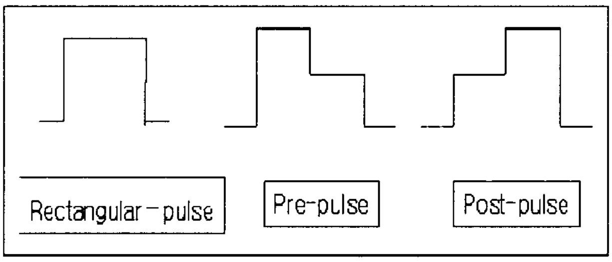

Fig. 2 Schematic diagram of Nd:YAG laser system

Fig. 3 shows a power supply that consists of two independent sources and pulse forming network (PFN). PFN is comprised of a 4-step mesh, causing the laser output pulse to take on a rectangular form. In the experiment, the value of the capacitance C and inductance L were set at 240 μF, 450μH. As well, in order to vary the charging voltage of the capacitance, they were set at 500 and 700V, respectively. At this time, the input energy was respectively calculated at 30J(PFN A) and 59J(PFN B) and the FWHM (full width at half maximum) was approximately 1ms from formulas (1) and (2).

$$E_0 = \frac{1}{2} CV^2_0 \tag{1}$$

$$t_d = 3\sqrt{LC} \tag{2}$$

The circuit operation is as follows.

(1) DC 1[kV] is applied to both ends of the flash lamp with the simmer power supply. Once the trigger pulse circuit switch is turned on, the streamer discharge is sustained in the flash lamp.

(2) When SCR S1 and S2 are turned on, the energy is respectively charged in the capacitance of the PFN, and then SCR S3 and S4 are turned on consecutively. At this time, the energy stored in the capacitance of the PFN is transferred and the flash lamp is turned on.

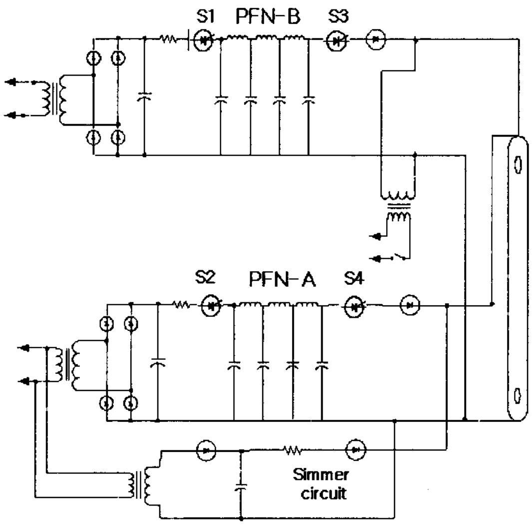

Fig. 3 Schematic diagram of Nd:YAG laser power supply

2.3 Control circuit

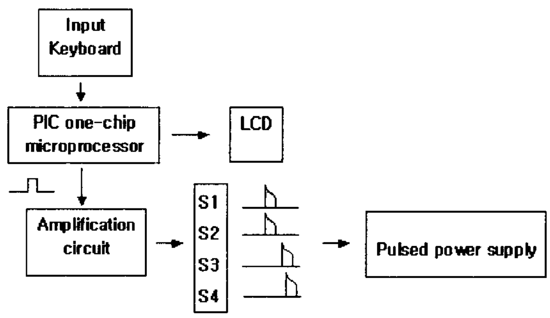

Fig. 4 Schematic diagram of Nd:YAG laser control circuit

Fig. 4 shows a control circuit that is composed of a keyboard, LCD (liquid crystal display), PIC one-chip microprocessor and an amplification circuit to turn on the SCR. In this control circuit, delay time is entered via the keyboard, and this input information is transferred to the PIC. The PIC generates four different signals (S1and S2 are used as charging part switches and S3 and S4 are used as discharging part switches). However, these signals are too weak to turn on the SCR and therefore the current and the voltage are amplified by use of a transistor for high-speed switching.

2.4 Virtual test

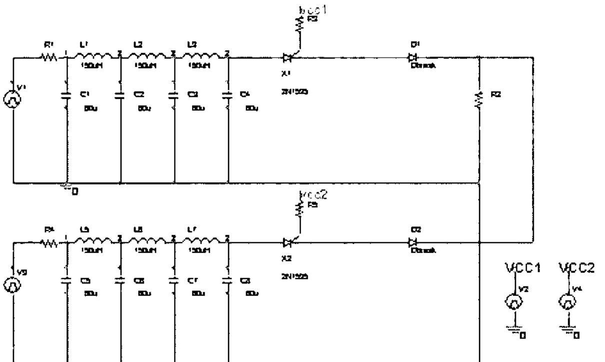

Fig. 5 P-spice schematic of two independent parallel input sources

In this study, we conducted a virtual experiment using a p-spice. Fig. 5 is p-spice schematic. We substituted pulse source for input source and we set flash lamp resistance as R=5Ω, L_T=450μH and C_T=240μF. Fig. 6-(a) shows a current pulse waveform of resistance when the charging voltage of PFN-A is 500V and PFN-B is 700V with the delay time of signals S3 and S4 at 200 μs. Fig. 6-(b) is a current pulse waveform of resistance when the charging voltage of PFN-A is 700V and PFN-B is 500V with the delay time of signals S3 and S4 at 200μs.

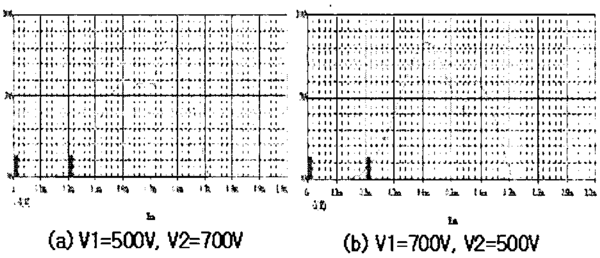

Fig. 6 Simulation results [(a) V1=500V, V2=700V, (b) V1=700V, V2=500V]

3. Experimental results

The laser beam was measured by the change in input energy of two independent input sources.

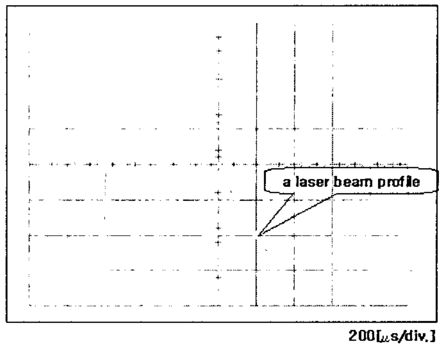

Fig. 7 Laser beam profile when only one input source was used (charging voltage Vo=500V)

Fig. 7 shows a laser beam profile when only one input source was used (the input energy E_0=30J, the charging voltage V_0=500V, and the total capacitance C_T=240μF). At this time, the FWHM (full width at half maximum) was approximately 1.0ms and we know that this is nearly equal as compared with the theoretical formulation ($t_d = 3\sqrt{LC}$).

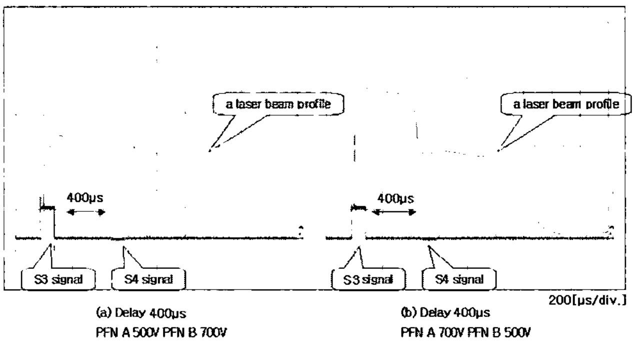

Fig. 8 Laser beam profile when the delay time of signals S3 and S4 is 400μs.

Fig. 8 demonstrates a laser beam profile when the charging voltage of PFN-A is 500V and PFN-B is 700V. Fig. 8(a) shows PFN-A at 700V and PFN-B at 500V. Fig. 8(b) shows delay time of signals S3 and S4 at 400μs. At this time, the FWHM (full width at half maximum) is approximately 1.4ms. Fig. 8 (a) and (b) have post-pulse and pre-pulse shapes respectively as indicated in Fig. 2.

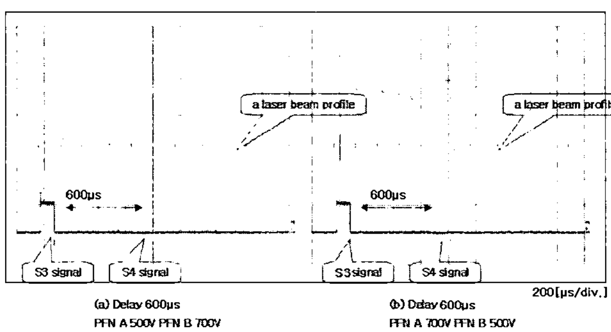

Fig. 9 Laser beam profile when delay the time of signals S3 and S4 is 600μs.

Fig. 9 shows a laser beam profile when the charging voltage of PFN-A is 500V and PFN-B is 700V(a), when PFN-A is 700V and PFN-B is 500V(b), and when the delay time of signals S3 and S4 is 600μs. At this time, the FWHM (full width at half maximum) is approximately 1.6ms. Fig. 9 (a) and (b) have post-pulse and pre-pulse shapes respectively as shown in Fig. 2.

As can been seen in the above Fig. 7~9, various pulse shapes can be made according to individual energy inputs of two independent PFN circuits. Furthermore, the FWHM (full width at half maximum) is changed by the delay time of signals S3 and S4.

4. Conclusion

Throughout a wide range of material processing systems, the variety of pulse shapes will serve to enhance processing efficiency. In this study, we have proposed a pulse superposition method in which one flash lamp consecutively turns on by the double switching of the discharging system.

This method can create an assortment of pulse shapes and lengthy pulse widths by the consecutive trigger of the SCR using a PIC one-chip microprocessor.

According to the change of input energy and values of the inductor and capacitance, we have made various pulse shapes such as rectangular-pulse, pre-pulse and post-pulse. Therefore, this method can be used in a range of applications including medical equipment and special processing needs.

Acknowledgements

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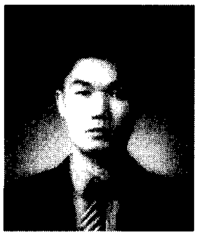

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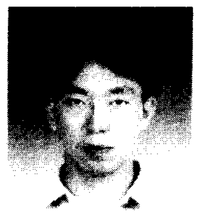

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