106 Journal of Electrical Engineering & Technology, Vol. 2, No. 1, pp. 106~111, 2007

Deduction of Optimal Conditions for Acrylic Etching Technique by using CO_2 Laser

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Abstract - Laser cutting with the micro-control technique has great potential to be employed for acrylic machining. In this paper, the optimal conditions of acrylic etching have been investigated. The three parameters such as laser power, moving velocity, and thickness of acrylic are experimented to find out optimal conditions. From these experimental results, we have known that it is very important to control accurate power by the TRIAC switching technique. The best condition of acrylic etching is performed 10 W and 72 mm/sec at the plastic thickness of 1.33 mm. The other case is performed 10 W and 48 mm/sec, and 12 W and 56 mm/sec at the acrylic thickness of 2.00mm, respectively.

Keywords: Acrylic etching, CO_2 laser, Laser power, Moving velocity, TRIAC

1. Introduction

Since the first laser made by Maiman in 1960, various laser machining techniques have been developed [1]. Especially, material processing and surface treatment based on laser technology has improved remarkably. Laser power density for material processing is controlled through a focal lens. The temperature of the target point is highly increased by the use of incident laser beams and the energy is concentrated in a small area (HAZ: Heat affected zone).

The laser cutting technique with controlled fracture proposed by Lumley [2] is very important in the processing industry. The applied laser energy produces a mechanical stress that causes the substrate to separate along the moving path of the laser beam. This material separation is similar to a crack extension with controllable fracture growth. Lumley successfully used this technique to cut brittle materials such as alumina ceramic substrate and glass using a CO_2 laser. The required laser power is less than that for conventional laser evaporative cutting, or laser scribing, and the cutting speed is much higher.

Lambert et al. originally developed the laser cutting technique for several glass or vitro-crystalline bodies. There are two lasers used in this process, the one has a wavelength such that at least 50% of the laser energy is used in the melting of a 0.2 mm deep groove-crack. The other generates thermal stress at the crack tip to make the material separate controllably [3].

A study on the capability of the low power laser performs tasks other than marking. A theoretical model is developed to estimate the depth of cut and the cutting speed and laser power for different materials is proposed [4].

Grove et al. [5] proposed a related controlled fracture method for glass cutting with higher cutting speed. In recent years, Kondratenko [6], Unger, and Wittenbecher [7] further investigated using a low power laser to separate glass with an additional coolant, water, which produced tensile stress along the cutting path. This improvement in the controlled fracture method has been recognized as providing good prospects for future laser cutting applications.

The results of an experimental investigation show the main parameters. Namely, sample thickness, laser power, cutting speed, type, pressure, and flow rate of the covering gas have on overall process efficiency [8].

According to the above researches, the wavelength (10.6μm) of the CO_2 laser beam is absorbed well in plastic materials [9]. Therefore, the CO_2 laser is the best choice to perform our goal for acrylic etching.

In this study, we have investigated to find out the optimal conditions for acrylic etching by using the CO_2 laser. It was found that TRIAC switching technique played an important role in controlling the accurate CO_2 laser beam intensity, for deducing three parameters such as laser power, moving velocity and thickness of acrylic.

2. Performance of acrylic etching

The laser etching system is shown in Fig. 1. Its photograph is presented in Fig. 2.

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Received 28 February 2006 ; Accepted 15 November, 2006

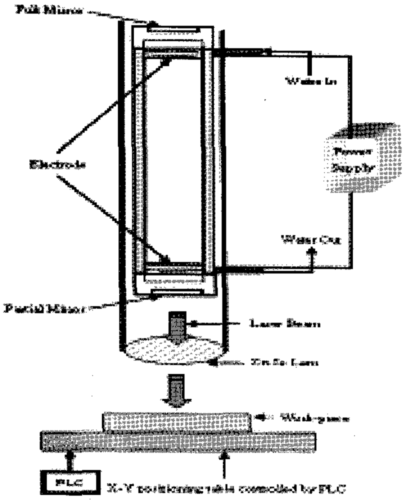

Fig. 1. Schematic showing the set up used for laser cut processing of plastic.

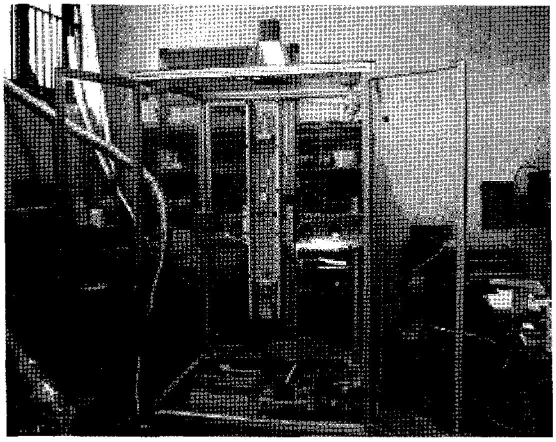

Fig. 2. Photograph of the CO_2 laser cutting system.

It was comprised of a Pulsed CO_2 laser, an XY-table and a TRIAC switching part. The laser beam was moved across the surface of the work piece which is mounted on a platform. The etching experiments were performed with a 50W CO_2 laser. The laser beam was focused on the center position of the target acrylic. The focusing lens with a focal length of 100 mm was used, and the spot size of 86.21μm was calculated as equation (1).

$$R = 1.22\frac{\lambda}{D}f \tag{1}$$

(R: spot size [μm], λ: wavelength of input beam [μm], D: diameter of condensing lens [cm])

The aim of this investigation was to determine the optimum acrylic etching parameters with two different thicknesses. There are six important parameters between focusing lens and work piece, focusing lens, thickness of plastic, laser power, and moving velocity of platform. In consideration of these six parameters depended on etching process, etching edge quality, and operating speeds, we first decided to keep three parameters constant: focusing lens, distance between focusing lens, and work piece. Laser power level was adjusted from 8 up to 24W. Acrylic etching was performed from 40 to 122 mm/sec with the incremental speed of 4 or 8 mm/sec [11].

The X-Y table was controlled by PLC (MITSUBISHI ELECTRIC MR-C Servo system). It was possible to move at the high precision of 1μm with loading the AC-servo motor. Also the stage speed is varied from 0.5 to 200μm/sec.

The control part for the CO_2 laser was comprised of a ZCS, a PIC16F877A one-chip microprocessor, an amplification circuit of the TRIAC signal, and a switching technique. (Fig. 3)

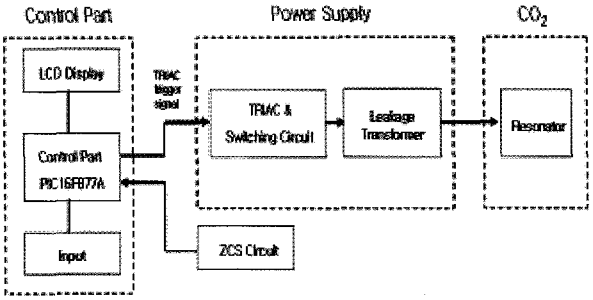

Fig. 3. Schematic diagram of the experiment.

The ZCS circuit detected the zero voltage of the AC line and then transferred the signal to the PIC one-chip microprocessor. As shown in Fig. 4, the ZCS circuit makes 60 pulses per second at the zero voltage of the AC power line. 60 pulse signals per second from Tr3 in ZCS were applied to pin 6 called RTCC (Real Time Clock Count) in PIC16F877A. The desirable trigger pulse repetition rate of the TRIAC gate was given by the ratio of input pulses to output pulses. The PIC also controlled the firing angle of a TRIAC from 45° to 135° in order to investigate the influence of the initial value of the input voltage on the laser output power.

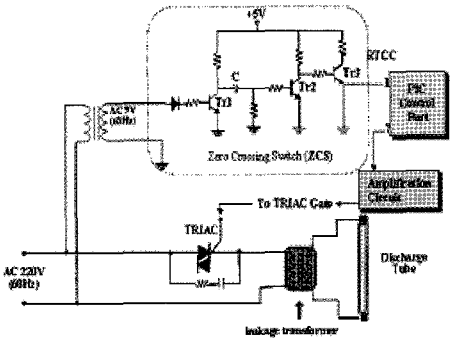

Fig. 4. The electrical circuit consisting of three major components: A ZCS circuit, a PIC one-chip microprocessor, and a discharge circuit.

Fig. 5 indicates the voltage waveform of the AC line, pulse signals generated from the ZCS circuit, and the gate trigger signals with a trigger pulse delay angle of 90° at 60Hz [12].

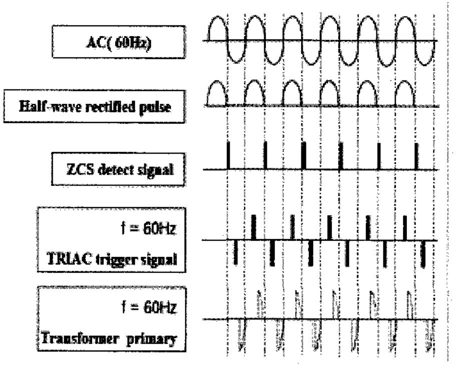

Fig. 5. The voltage waveform of the AC line, pulse signals generated from the ZCS circuit, and the gate trigger signals with trigger pulse delay angle of 90° at 60Hz.

The switching part was comprised of a TRIAC, a high voltage leakage transformer, a capacitor, and a resistor. The TRIAC (Sanrex: TG25C60) was used for switching of rectified pulses. And a leakage transformer (also called a neon transformer) was employed in the power supply. The transformer produced a peak voltage pulse of up to 25 kV and its rating capacity was 300 VA.

Fig. 6 is the amplification circuit for the TRIAC switch driving. In this experiment, the PIC signal controller and power source part were separated with 1:1 transformer and photo-coupler. This isolation provided protection to the control part when the switching circuit is malfunctioned.

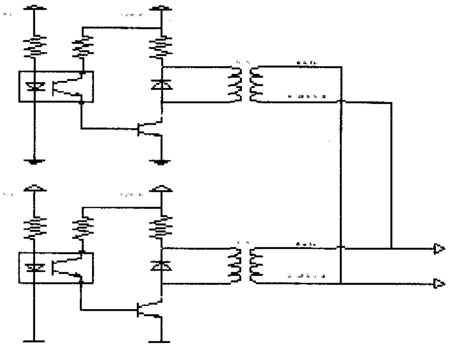

Fig. 6. The amplification circuit of TRIAC trigger signals.

3. Results and Discussion

By Zhou [13], plastic materials, such as acrylic, HDPE (High Density Polyethylene), PP (Polypropylene), and PC (Polycarbonate) were cut with several power levels. In his experiments, he rarely used plastic materials.

Table 1-(A) and 1-(B) indicate the relationship between laser power and moving velocity of platform (arcylic thickness: 1.33mm and 2.00mm). The higher laser power increased, the larger etching width was. The faster moving velocity was, the more narrow etching width was.

Table 1-(A). The etching width according to laser power and moving velocity at acrylic thickness of 1.33mm (x: not cutting).

Laser power[W] / velocity [mm/s]	8	10	12	14	16	18	20	22	24
40	0.224	0.247	0.301	0.359	0.427	0.501	0.572	0.61	0.656
48	0.212	0.231	0.274	0.31	0.399	0.489	0.564	0.597	0.641
56	0.195	0.217	0.254	0.271	0.378	0.476	0.533	0.577	0.629
64	0.167	0.186	0.224	0.249	0.351	0.411	0.512	0.551	0.611
72	0.111	0.154	0.195	0.221	0.301	0.395	0.487	0.539	0.577
80	x	0.097	0.124	0.187	0.269	0.357	0.459	0.509	0.543
88	x	x	0.107	0.139	0.211	0.313	0.413	0.471	0.519
96	x	x	0.098	0.12	0.186	0.275	0.361	0.409	0.451
104	x	x	x	0.101	0.155	0.232	0.281	0.357	0.411
112	x	x	x	0.077	0.142	0.194	0.239	0.301	0.361

Table 1-(B). The etching width according to laser power and moving velocity at acrylic thickness of 2mm (x: not cutting)

Laser power[W] / velocity [mm/s]	8	10	12	14	16	18	20	22	24
40	x	0.198	0.29	0.337	0.349	0.356	0.378	0.397	0.401
44	x	0.151	0.217	0.285	0.301	0.312	0.32	0.341	0.359
48	x	0.109	0.185	0.216	0.251	0.259	0.264	0.271	0.291
52	x	x	0.171	0.207	0.234	0.241	0.253	0.259	0.265
56	x	x	0.159	0.197	0.228	0.231	0.245	0.249	0.255
60	x	x	x	x	x	x	x	x	x
64	x	x	x	x	x	x	x	x	x
68	x	x	x	x	x	x	x	x	x
72	x	x	x	x	x	x	x	x	x
76	x	x	x	x	x	x	x	x	x

Fig. 7 indicates that the etching width is directly proportional to laser power at acrylic thickness of 1.33mm.

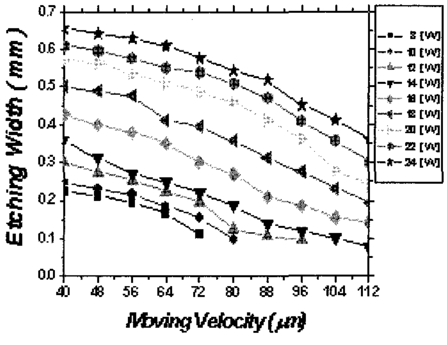

Fig. 7. The etching width is directly proportional to laser power at acrylic thickness of 1.33mm.

Fig. 8 illustrated that the etching width is inversely proportional to moving velocity at acrylic thickness of 1.33mm.

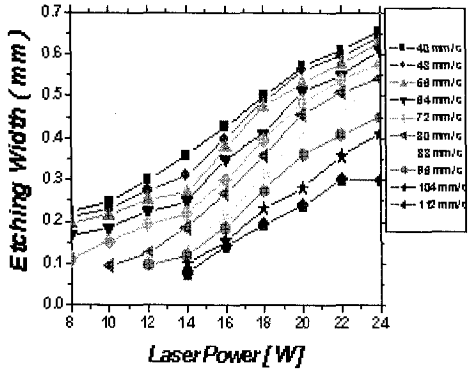

Fig. 8. The etching width is inversely proportional to moving velocity at acrylic thickness of 1.33mm.

Fig. 9 demonstrated that the etching width is directly proportional to laser power at acrylic thickness of 2.00mm.

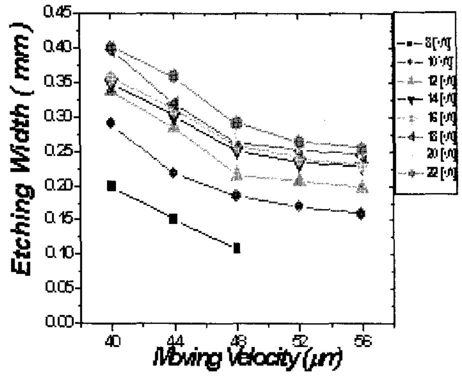

Fig. 9. The etching width is directly proportional to laser power at acrylic thickness of 2mm.

Fig. 10 shows that the etching width is inversely proportional to moving velocity at acrylic thickness of 2.00mm.

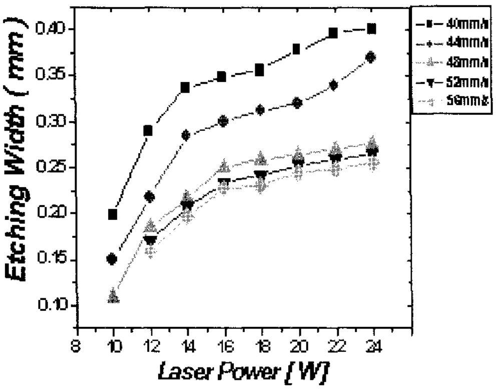

Fig. 10. The etching width is inversely proportional to moving velocity at acrylic thickness of 2mm.

That is, the etching width was directly proportional to laser power but was inversely proportional to the moving velocity of the platform.

From parameters such as etching width, moving velocity of platform, laser power and acrylic thickness. We have proposed the relationship as equation (2).

$$W = \frac{P}{V \bullet d} \tag{2}$$

(W: Etching width [mm], P: Laser power [W], V: Moving velocity [mm/s], d: Plastic thickness [mm])

The shape of the groove shown in Fig. 10 is also shown in Fig. 11 and Fig. 12. The photograph indicates the optimal shape of each groove.

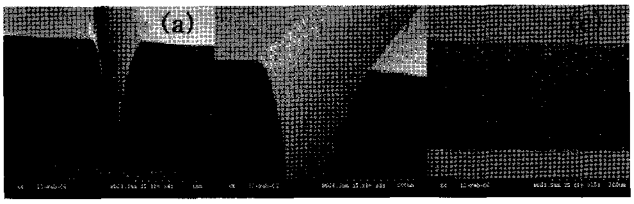

Fig. 11. Scanning Electron Microscopy showing the geometry of the cut (Acrylic thickness: 1.33[mm], moving velocity: 64[mm/s], laser power: 10[W]). **(a)** side cutting surface **(b)** cutting surface at an angle of 45 degrees **(c)** top view

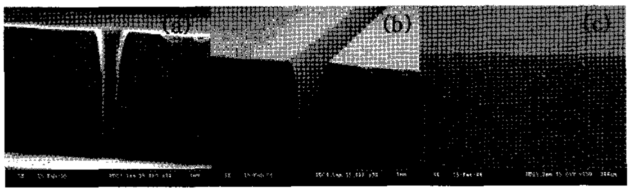

Fig. 12. Scanning Electron Microscopy showing the geometry of the cut (Acrylic thickness: 2[mm], moving velocity: 48[mm/s], laser power: 10[W]). **(a)** side cutting surface **(b)** cutting surface at an angle of 45 degrees **(c)** top view

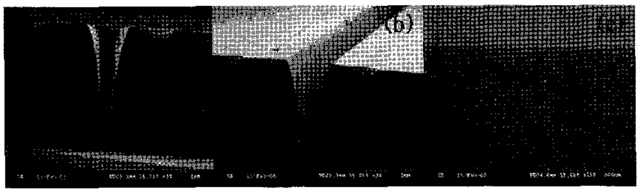

Fig. 13. Scanning Electron Microscopy showing the geometry of the cut (Acrylic thickness: 2 [mm], moving velocity: 56[mm/s], laser power: 12[W]). **(a)** side cutting surface **(b)** cutting surface at an angle of 45 degrees **(c)** top view

From the general theory, the laser beam had been normalized by Gussian distribution. Equation (3) shows the relationship between P_0 and I_0. [14]

When the laser beam has Gaussian distribution, about 85% of the laser beam was concentrated on spot size. ($2w_0$)

$$\frac{I(x,y)}{P_0} = \frac{1}{2\Pi w'} exp - \frac{(x^2+y^2)}{2w'^2} \tag{3}$$

(I: intensity, P: Laser power, w': standard deviation)

The shape of the grove was also changed like the above equation (3). It was able to penetrate deeply at the center because of its Gaussain distribution. The more distant from the center, the deeper etching depth was. From these results, the micro-control of laser power by using TRIAC was proper. The best conditions of acrylic etching were performed at 10 W and 72 mm/sec on the acrylic thickness of 1.33 mm. The other case was performed at 10 W and 48 mm/sec, and 12 W and 56 mm/sec on the acrylic thickness of 2.00mm, respectively.

4. Conclusions

The optimal conditions of acrylic etching have been investigated. The three parameters of laser power, moving velocity, and thickness of acrylic are experimented to find out optimal conditions. From these experimental results, we have known that it is very important to control accurate power by TRIAC switching technique. The best conditions of acrylic etching are performed 10 W and 72 mm/sec at the plastic thickness of 1.33 mm. The other case is performed 10 W and 48 mm/sec, and 12 W and 56 mm/sec at the acrylic thickness of 2.00mm, respectively.

Acknowledgements

This work was supported for two years by Pusan National University Research Grant.

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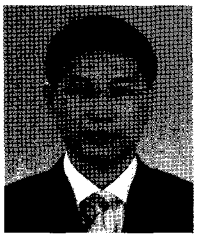

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