High-Speed & High-Quality Laser Drilling Technology Using a Prism Rotator

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The laser head for processing or the processing stage in the conventional laser processing method is mechanically rotated for drilling. The processing speed depends upon these structures' acceleration/deceleration, which is limited by their masses and rigidities. Therefore, the laser processing method has so far had limitations in enhancing the processing speed. Since processing speed is limited, mitigation of the laser's thermal influences affecting processing quality has also been limited. In coping with the problems, a laser optical system, with a mass much smaller than that of the laser head or drilling stage was rotated quickly, thereby realizing much faster processing with processing quality maintained equal to or better than that of conventional laser processing.

1. Introduction

Laser machining is quite popular as a technology for fast processing. This was because lasers can melt and evaporate the work piece efficiently as being so directional and light-harvesting as to concentrate energy in a micro area, resulting in an increase in processing speed. On the other hand, in some cases, the high energy density prevents a sufficient processing quality from being obtained. This is because the irradiated laser's excessive heat input into the processing object causes an affected layer in the processed area under the influence of heat, and such a heat-affected layer prevents the specifications required for the work piece, including material strength, from being satisfied. In the laser processing field, therefore, heat influence-free processing, or the so-called non-thermal processing technology, is under active development.

In drilling, quick laser mobility based on factors such as the fast movement of a galvanometer mirror to increase processing speed enables processing to be faster than by the laser head's mechanical rotation, thus serving as an extremely powerful tool for drilling when no assist gas is required(1)-(4). But at present, since laser cutting requires an assist gas supply in many cases, fast processing technology using a tool such as the galvanometer mirror is sometimes applicable only to quite limited areas.

As a challenging method to make both quick laser mobility and assist gas supply compatible, this research tried to improve processing speed and quality by polarizing the optical path of the laser through prisms and then by rotating these prisms quickly, while the laser head kept fixed.

This paper reports on the verification results concerning the higher speed and better processing quality likely to be achieved by allowing a polarizing prism to rotate quickly.

2. Principle of processing

Figure 1 shows a conventional laser drilling method. In conventional laser drilling, since a laser head set is rotated (or a work piece is allowed to circulate around the laser head) for

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processing, the mechanical movement speed of the laser head (or stage) determines the processing speed, thus making it difficult to shorten processing time from the level of seconds even for a small hole with a submillimeter-order diameter.

Hence, in order to realize a processing speed comparable to that of a galvanometer mirror system, only the opposing pair of prisms was rotated with the laser head kept fixed as shown in **Figure 2** for this development, in an attempt to embody an optical system that allows laser light to revolve quickly.

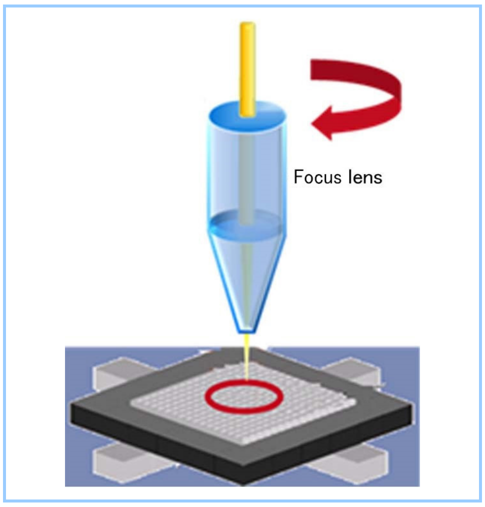


Figure 1 Conventional drilling method

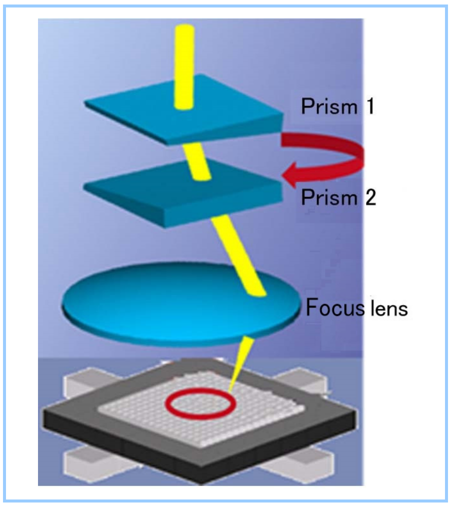
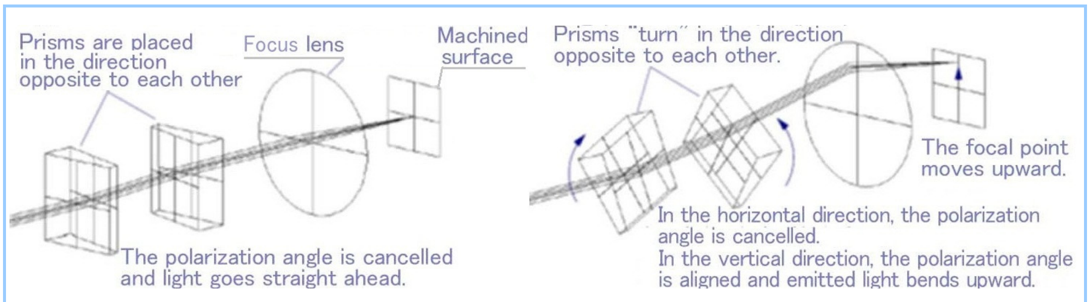


Figure 2 Conceptual diagram of machining head for fast drilling

This embodies a quick motion approximate to that of the galvanometer mirror optical system by using the prism's polarization angle with the optical axis to adjust the processing diameter and allowing the polarizing optical system including prisms to turn quickly. In addition, by keeping the prism's turning radius equal to or shorter than the inside diameter of the nozzle outlet, assist gas could always be fed in the direction vertical to the drilling axis and one of the defects due to fast processing by the galvanometer mirror system was thus successfully compensated for.

Figure 3 shows the principle of polarization through a prism. When two prisms of the same shape are placed so as to oppose each other as shown in Figure 3 (a), each prism's polarization angle is offset by the other's and the laser goes straight ahead through the center of the condenser lens to be directly placed on the work as if it were not passing through any prisms. On the other hand, if these prisms are rotated in the direction opposite to each other as shown in Figure 3 (b), the horizontal polarization angle is cancelled and the vertical one is aligned, permitting emitted light to curve upward as in the figure, and as a result, the focal point on the work also moves upward from the center. If the prisms are rotated with their polarization angles sustained, a hole is drilled along the locus of a circle with a radius equal to the length of travel by the focal point from the work center.



(a) When prisms were placed in the direction opposite to each other

(b) When prisms are rotated in the direction opposite to each other

Figure 3 Principle of polarization through prisms

Figure 4 shows the laser intensity distribution in the image formation area obtained from optical tracking simulation for different prism polarization angles. Even if a prism causes the image formation position to move on the work, the laser intensity distribution is found to remain unchanged.

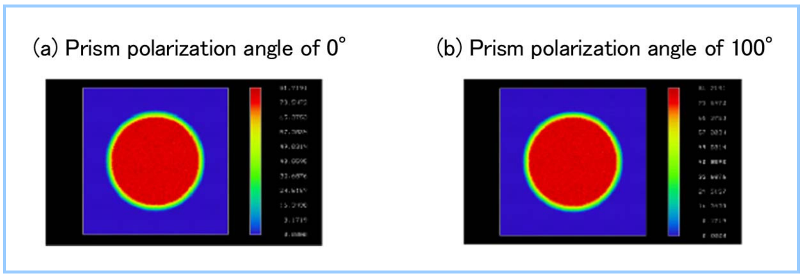


Figure 4 Simulation results of image formation

3. Processing work verification

Metal processing conditions for drilling (material: Inconel, plate thickness: 1 mm, hole diameter: 0.7 mm), were optimized, aiming to achieve an improvement in both processing quality and processing speed by using fiber laser.

Figure 5 is the photographed surface of a hole drilled under optimized laser processing conditions and **Figure 6** is a cross-sectional photo of the same. **Table 1** compares the present studied drilling method with a conventional one for the relative difference in processing time and quality. As shown in Figures 5, 6 and Table 1, although even conventional methods have met the specified processing quality, further prospective improvement of processing quality was demonstrated, together with the possibility of processing speed being shortened to 1/9.

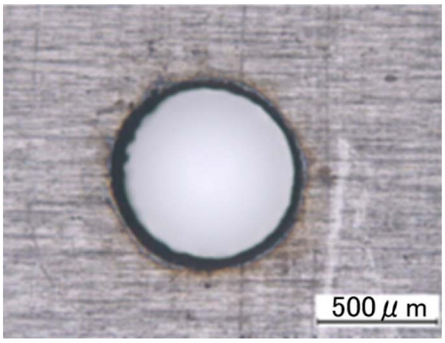


Figure 5 Processed surface view after being made appropriate

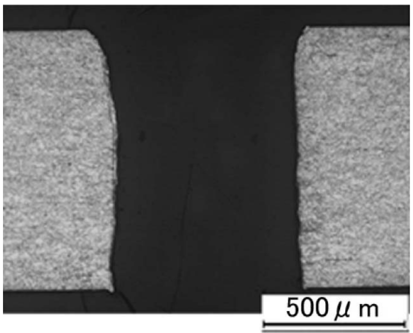


Figure 6 Cross-sectional view of processed hole after being made appropriate

Table 1 Comparison with conventional method for processing time/quality

	Drilling time	Processing quality
Conventional method	1	Good
The present reported development	Up to 1/9	Excellent

4. Equipment composition

The equipment composition used for recent demonstration experiments is as follows (see **Figure 7**): For first allowing an arbitrary diameter to be drilled and then realizing fast processing, it was necessary to rotate two opposing prisms quickly and change phases without steps. Hence, each of the two prisms (Prism 1 and Prism 2) was controlled by either of two independent direct-drive servo motors (Motor 1 and Motor 2). If these two prisms are synchronized and kept turning continuously, the acceleration/deceleration time of prism rotation can be reduced to zero when identical hole diameters are processed, thus enabling processing time to be further shortened. In addition, a laser-interferometric measurement sensor and a drilling point checking camera were incorporated into a single optical system to precisely measure the focal position and shorten the nozzle's center location setup time.

Furthermore, by installing a curved-axis motor to tilt the nozzle and a swiveling table on the side of the work, it became possible to drill a three-dimensional shape with a laser.

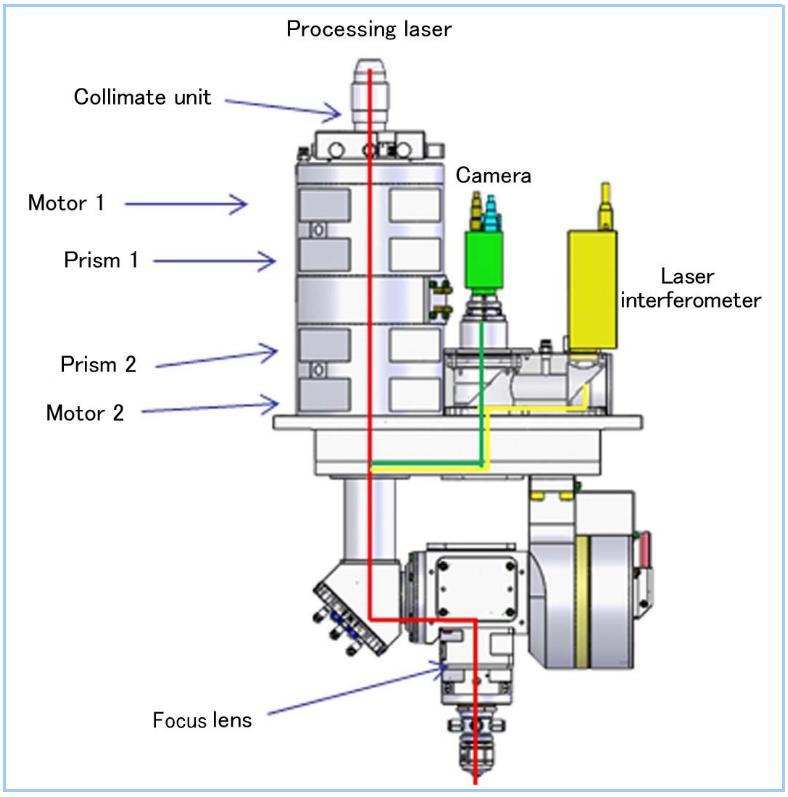


Figure 7 Machining head composition

5. Conclusion

By allowing a prism unit to turn alone to polarize laser light with the laser head fixed, an optical system capable of turning quickly was developed. The laser drilling technology using a prism rotator was demonstrated to improve processing quality and shorten processing time to 1/9 compared with conventional methods.

Reference

1. Miyamoto, Journal of The Japan Society for Precision Engineering, Vol. 75 No.1 (2009) p. 66.