Laser Scanner Stage On-The-Fly Method for ultrafast and wide Area Fabrication

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Abstract

This paper presents an on-the-fly method to synchronize a laser galvanometer scanner and a linear stage for fast and wide area fabrication. The location and velocity information of a linear stage is transferred to the galvanometer scanner control board by the encoder signal. The scanner control board calculates amount of laser beam movement subtracting from original CAD data to linear stage movement. On-the-fly method is different from existing step & scanning method that it ensures continuous stage movement and real time signal transfer between the linear stage and the galvanometer scanner.

Keywords: On-the-fly; Galvanometer scanner; Linear stage; Synchronization

1. Motivation / State of the Art

The advanced technology of short-pulsed lasers now provides the opportunity for material fabrication of ultra-precision lasers, such as via-hole drilling [1], FPCB cutting [2], and surface texturing [3]. The trend of laser fabrication requires high-speed, wide-area, and high speed process. A galvanometer scanner has been widely used as a marking tool [4]. The on-the-fly technique initiates in marking field. The laser marking head engraves like serial numbers, weight, date or barcodes on the product which usually is moved by a conveyor belt. Recently, application of galvanometer scanner expands to many laser material fabrication area [5]. However, the working field size of this scanner is limited by the focal length of the f-theta objective lens, measured from the scanner head to a sample. With an increase in the focal length, the working field size of the scanner becomes wider but the resolution of the scanning field decreases, which can be a drawback for precise fabrication. To overcome this problem, recently the hybrid method that involves the use of both a linear stage and a scanner has been developed. The manufacturers of the scanner-stage synchronization processing equipment include ESI, LPKF, and AEROTECH. The ESI (Electro Scientific Industries) has applied on-the-fly equipment to micro via-hole drilling and FPCB cutting. The ESI UV laser drilling system, HDI 5330 is capable of on-the-fly processing with a $533 \text{mm} \times 635 \text{mm}$ working area, which system can guarantee 20 μm accuracy with a 500 mm/s fabrication speed. The German company, LPKF’s recently releases the MicroLine 6000 model for coverlayer cutting of PCB or FPCB. The company provides software known as the LPKFCAM, which profiles the stage path and scanner working path and reduces the 20% fabrication time. In

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recent years, AEROTECH in the United States develops similar on-the-fly equipments with a pre-processing path optimization software whose name is Automation 3200. Some examples of on-the-fly equipments are shown in Figure 1. Some commercial scanner control board provides the on-the-fly application with an option such as RTC 5 board of SCANLAB and MOTF (Marking on-the-fly) Add-On board of RAYLASE. However, the main application of MOTF board is limited to the marking application. In present paper, we mainly focus application of FPCP coverlayer cutting application.

Figure 1. Photos of on-the-fly equipments of several companies: ESI (Left), LPKF (Middle), and AEROTECH (Right)

2. On the fly system set up and algorithm

2.1. System configuration

Figure 2 shows the configuration of the on-the-fly system. The on-the-fly device mainly consists of the stage part, laser scanner header part, and the control part. The stage moves with a one axis and the 2 axis galvanometer scanner is used. The stage position information transmitted to the MOTF (Marking on the Fly) board by a multi-function pulse modulator. In the MOTF board, direction of scanner movement is pre-calculated and provides interface between a scan control board and a motion control board. The scanner board commands movements of 2 axis galvanometer by tilting the mirrors in the scanner header.

Figure 2. One axis stage – Two axis galvanometer on-the-fly system configuration
To synchronize a galvanometer scanner and a linear stage, the scanner and MOTF board control the system. Figure 3 shows a system block diagram. Initially, the AutoCAD data is input to the scanner control board by size scaling and coordinate transformation. For the synchronization method, the zero offset algorithm is employed. Purpose of this algorithm is to maintain zero-distance between scanner center position and laser fabrication point by changing the stage location. If distance from scanner center position to laser fabrication point, the stage moves to scanner center point and makes zero offset distance. Information of position and velocity of linear stage is then transferred to the scanner control board. In the scanner control board, the scanner movement with certain velocity is determined by subtracting or adding from drawing data to information of stage location and velocity.

Figure 3. Control block diagram of the on-the-fly method

3. Experiment

3.1. Method comparison between step & scanning and on-the-fly

The on-the-fly system is build up as shown in Figure 4. With a laser source, the IPF fiber laser with a 30 ns pulse width, 12 W maximum power, and 1064 nm wavelength is adopted. The scanner head made in CTI company is used whose beam aperture is 10 mm and focal length is 100 mm. The linear stage is selected locally made in DASAROBOT of which stroke is 400 mm, maximum speed is 500 mm/s, precision is about 5 μm.

For a low pulse repetition rate of 1 kHz, the marking precision between the step and scanning method and the on-the-fly method is compared. The marking speed is 300 mm/s, and the scanner working area is 50 mm × 50 mm. In the step and scanning method, the stage is stopped during the scanner working. After the scanner operates within the working area, the stage shifts to 50 mm in the right direction to begin with the next process. The scanning and step movement processes are repeated for marking the entire area. However, in the case of the on-the-fly system, the stage and the scanner move and work together. Various marking directions from 0° to 90° are tested, as shown in Figure 4. Three areas are selected to compare the marking qualities between the two methods.
Comparisons in the marked spots between the two methods are shown in Figure 6. In the scanner working area of both the methods, the distances between the marking spots are almost constant in all directions. In the step and scanning method, irregular spots are observed in the boundary of the scanner working area. This is because the exact marking positions cannot be controlled owing to the irregular start and stop movements of the stage. However, the on-the-fly method shows an almost constant marking distance between spots in the boundary region and the working area. This is a critical advantage of the on-the-fly system over the step the scanning method.
In Figure 7, the marking spots of the comparison experiment are magnified by a microscope. For the step & scanning case, aggregation of two marking spots is observed and the distance of spots is not controlled. However, distance of marking spots is generally conserved with on-the-fly method. The error may be happened with a irregular and large beam size. If smaller beam spot is used, the result can be improved.

Figure 7. (a) Microscope image of marking with the step & scanning method

Figure 7. (b) Microscope image of marking with the on-the-fly method

3.2. Precision test of the on-the-fly system

The precision of the on-the-fly system is evaluated with the help of a drawing experiment. A triangle and rectangle whose sizes are larger than the scanner working area are first drawn. Then, the length of each side of the drawn figures is measured and compared with the original CAD data. Three drawing speeds—100, 200, and 300 mm/s—are selected to test the influence of speed. The size difference in the triangle drawing is approximately 60 um, which is measured at three different drawing speeds. The drawing accuracy of the rectangle drawing shows almost constant values. In addition, the different drawing speeds do not affect the precision of the drawing. This result may indicate that the precision in this case is conserved with various fabrication speeds of the on-the-fly system.

Table 1. Measurement data for triangle drawing

<table>
<thead>
<tr>
<th>Triangle Side</th>
<th>Length difference with CAD data(um)</th>
<th>Fabrication speed(mm/s)</th>
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<td></td>
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<tr>
<td>Bottom</td>
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<tr>
<td>Hypotenuse</td>
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<tr>
<td>Average</td>
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<td>63</td>
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</tbody>
</table>
3.3. FPCB sample experiment

The marking test with the FPCB sample is performed. Sample size is over the scanning area. The CAD drawing and test result is shown in Figure 8. The linear stage moves only x axial direction and the stage moving speed is changing by the zero offset algorithm. Simply speaking, the linear stage follows center point of scanner head. The marking test successfully is conducted with a good agreement of CAD drawing. The marking speed should be faster than step & scanning method, too.

<table>
<thead>
<tr>
<th>Rectangle Side</th>
<th>Length difference with CAD data(µm)</th>
<th>Fabrication speed (mm/s)</th>
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</thead>
<tbody>
<tr>
<td></td>
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<td>200</td>
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<td>Bottom</td>
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<tr>
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<tr>
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<tr>
<td>Average</td>
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4. Result and conclusion

The on-the-fly system of one-axis stage and two-axis scanner was built up by synchronization two control boards. Information of position and velocity of linear stage was transferred to the MOTF board by encoder signal. The role of MOTF is interfacing between the stage motion board and the scanner control board and calculating of some portion of the scanner board. By the zero offset algorithm, the location and speed of the linear stage was determined. The step & scanning method and the on-the-fly were compared with a marking experiment. The irregular spot distance was observed for the step & scanning method because it is difficult to control of stage motion frequent stop and start. However, test result with the on-the-fly method showed consistent distance between marking spots. The
accuracy of the on-the-fly system was tested by drawing triangle and rectangle. The size accuracy was measured as about 60 μm, which accuracy was conserved with various fabrication speeds. Finally, the FPCP sample marking was conducted with over scanning area. Test result showed a good agreement with CAD drawing. Proposed on-the-fly method was well validated that it showed good fabrication quality and fast fabrication speed.

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References