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Development of vibration reduction mechanism for precision stage of UV-laser drilling process with on-the-fly control scheme

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Abstract
In order to compensate the vibration from laser machining head's step motion in FPCB (flexible printed circuit board) drilling system, a vibration reduction mechanism is proposed. The mechanism has accelerometers as vibration sensors and piezoelectric transducers (PZT) as compensating actuators. The sensors are mounted on the leaser head to measure the vibration. The PZTs are assembled between the gantry and the laser head to generate the compensating force and push the head against the vibration. The compensating force i.e., the control force is calculated from a feedback controller by using the sensor data. And then the enhanced vibration characteristics are verified by measuring the head using Laser Doppler Vibrometer (LDV) form outside of the equipment.

Keywords : Vibration reduction, Piezoelectric transducers, Accelerometers, Laser drilling

1. Introduction

According to the recent requirements of high productivity in FPCB manufacturing, a drilling system with "on-the-fly" control scheme has been developed. When accelerating or decelerating the laser head in the scheme, the head and work-pieces on granite surface are vibrated each other by the reaction force between them. If the residual vibration is not rejected quickly, it makes lower the productivity because defect can be caused by the vibration.

The undesirable vibration of laser head is generally in the range of 3 ~ 20 Hz. Because a passive vibration isolator is not effective for the frequency range, an active vibration isolator is needed to compensate reaction force. However, the commercial active vibration isolator is expensive, heavy and large to be mounted on the equipment [1].

In this paper, a vibration reduction mechanism for precision stage of laser drilling process is proposed, controlled and verified. This mechanism has sensors, actuators and controller. The sensors are miniaturized and light-weighted accelerometer to measure the vibration. The actuators are piezoelectric transducers (PZT) to generate the compensating force which pushes the laser head to an opposite direction of the vibration. The controller is a real time processor which calculates the compensating force signal to PZT.

2. Vibration by laser head motion

After a series of preliminary tests, it was found that the laser head's step motion is the main source of the residual vibration during laser drilling process. In the experiments, the LDV was setup on the granite and its laser probe focused on the head to measure the relative vibration.

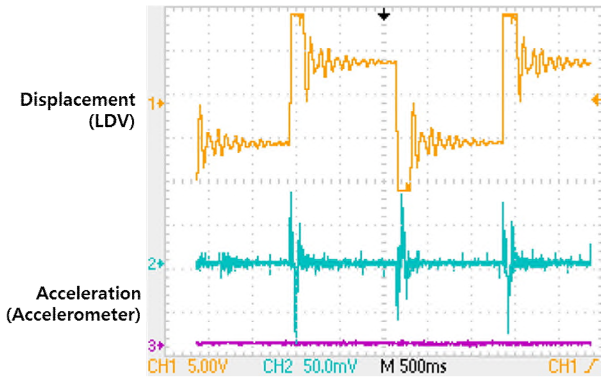


Figure 1. Typical vibration of laser head during process

The accelerometer was mounted on the head to measure the head's vibration itself. The typical vibration signals are in Figure 1.

The resonant frequency of the vibration was 12.5 Hz for the motion. Considering acceleration, the two signals were familiar except the LDV signal was truncated by its range limit. This is because the main source of vibration is not from ground but from the head mechanism's resonance. The signal from accelerometers is better to read without truncation. From this experiment, the accelerometer is selected for the feedback sensor to control the vibration [2].

3. Design of vibration reduction mechanism

Figure 2 is a schematic diagram to describe 2-DOF motion by PZT Actuators. The newly developed bracket in Figure 3(b) has a leaf spring for precision motion by PZTs. In contrast, the old bracket in Figure 3(a) is fixed on the head. The vibration reduction mechanism is presented in Figure 4

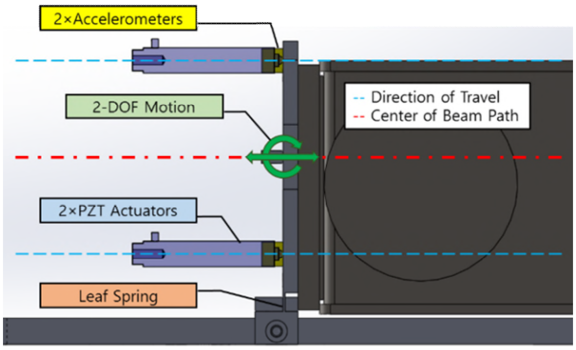
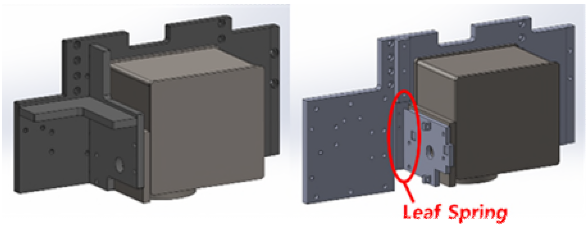


Figure 2. Schematic diagram of vibration reduction mechanism



(a) (b)

Figure 3. (a) Fixed bracket, (b) flexible bracket with leaf spring

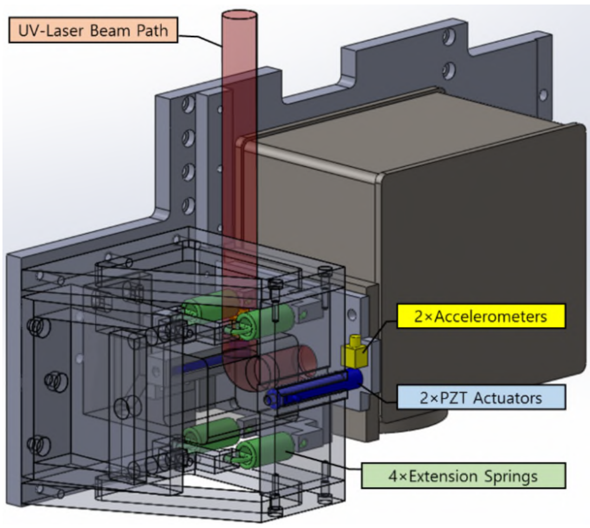


Figure 4. Schematic design of vibration reduction mechanism

The red cylinder is a laser beam path. The rectangular parallelepiped on the right is optics for laser machining. It has two PZTs in blue and two accelerometers in yellow.

The PZTs are linear actuators to push the laser head. The simultaneous pushing of the two actuators will give a translational motion of the laser head. The asynchronous actuation of the PZTs will cause a rotational motion of the laser head. The two accelerometers will sense the translational and rotational vibration. The very back structure is gantry. Between the gantry and the optics there is a connecting plate. In the plate, there are flexures to guide the translation and rotation.

4. Control of vibration reduction mechanism

The PZTs are P-841.38 from PI. The accelerometers are 333B50 from PCB Piezotronics. The real time controller is Power PMAC from Delta Tau Data Systems. The vibration data from the sensors is feed-backed to controller, the controller generates control signal, the signal is amplified by a high voltage PZT amplifier, the amplified voltage engaged to PZTs and then the compensating force is exerted on the laser head.

If the laser head vibrates by disturbance, the acceleration is proportional to the vibration in the specific range of frequency. Therefore, the disturbance can be rejected by a control algorithm in Figure 5 and Equation (1). The controller, $G(s)$ is a PID controller.

$$\frac{A(s)}{D(s)} = \frac{P(s)}{1+R(s)G(s)} \tag{1}$$

MATLAB Simulink is used to implement feedback algorithm with PID controller and band pass filter. The filter has range of 6 Hz ~ 14 Hz to cut-off undesirable signal from accelerometer.

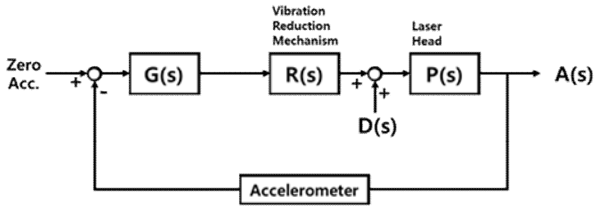
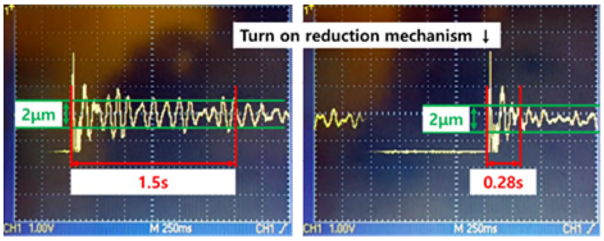


Figure 5. Control algorithm to reduce residual vibration: Zero acceleration is reference and disturbance vibration is to be rejected.

5. Results



(a) (b)

Figure 6. Performances of vibration reduction: (a) the one without the mechanism, (b) the one with the mechanism.

The results of vibration reduction are illustrated in Figure 6. From the industry's requirements, the settling time is to be shorter than 0.3 s. The minimum residual vibration amplitude is to be smaller than 2 μm. From the results, the settling time was reduced to 0.28 s from 1.5 s.

6. Conclusion

A vibration reduction mechanism was proposed and verified. It can reject the residual vibration during laser drilling process. The vibration reduction capability was efficient despites the simple and light structure.

If the simple and inexpensive vibration reduction mechanism is adapted to laser machining process, it will helpful to the industry. Also, this mechanism can be applied to laser direct imaging, semiconductor fabrication and display manufacturing.

7. Acknowledgement

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