한국기계가공학회지, 제17권, 제6호, pp.111～116(2018.12) ISSN 1598-6721(Print)
Journal of the Korean Society of Manufacturing Process Engineers, Vol. 17, No. 6, pp.111~116(2018.12) ISSN 2288-0771(Online)

https://doi.org/10.14775/ksmpe.2018.17.6.111

Development of Optical Leveling System using Quarter Photodetector

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4분할 위치검출소자를 활용한 광학식 레벨링 개발

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(Received 9 November 2018; received in revised form 13 November 2018; accepted 15 November 2018)

ABSTRACT

Recently, shape manufacturing method has been changed to a 3D printer. Since lamination type manufacturing method is the basis for forming a three-dimensional shape by repeated lamination, the horizontal accuracy of the lamination layer is very important. In the current paper, we have proposed a new leveling system to be installed in a large 3D printer. The light source was reflected from the water surface contained in the measuring device, and the inclination of the measuring device was measured from the light that entered into four regions of a quarter photodetector. The electrical signals generated differently according to the position of the beam spot incident on the quarter photodetector was acquired and compensated to be horizontal by using a motor mounted at the corner. Compared to a digital leveler, the newly developed leveling system gave errors of only 2 to 3%. This new device can be applied to various fields including the 3D printer in future.

Key Words : Leveling System(레벨링), Optical Devices(광학식 장치), Quarter Photodetector(4분할 위치검출소자)

1. Introduction

Horizontal and vertical measurements have been largely recognized as significant items in civil engineering and construction work. This is because architecture generally proceeds with the assumption that the underlying laminate is horizontal since the materials are generally stacked to form a structure. If the lower laminate is not horizontal, it will cause unexpected process problems. In order to maintain the accuracy of the work process, various methods for measuring the horizontality of members have been proposed. In general, a horizontal measuring apparatus for measuring the horizontal state of a specific member is referred to as leveler. To visually check whether the equipment is horizontal, a leveler is used which measures the degree of movement of bubbles or the degree of separation between a horizontal member and a specific member using a bubble or a horizontal blob.

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In recent years, horizontal problems have also been raised in the field of ultra-precision machining. For example, in order to maintain the high-concentration and high-reliability of a semiconductor device, it is necessary to maintain the level of the semiconductor manufacturing facilities. For example, in case of ion implantation process for implanting ions onto a semiconductor wafer, it is essential to maintain the horizontal position of the mounting table on which the semiconductor wafer is mounted. Therefore, the user of the semiconductor facility has to examine the level of the equipment from time to time to maintain the level and take necessary measures if any abnormality occurs. As additive manufacturing (AM) method became popular, the paradigm of the manufacturing method also changed. Since the AM method involves repeated lamination to produce three-dimensional shapes, the horizontal accuracy of the laminated layer is related to the manufacturing precision. Till now, the leveling method applied to 3D printers is manual and semi-automatic method using gap sensor. As shown in Fig. 1, in the manual method the slope of the bed is adjusted by using a driver or a hexagon wrench at four corners before the operation. The semi-automatic method uses a gab sensor to measure the distance of 9 points on the bed.

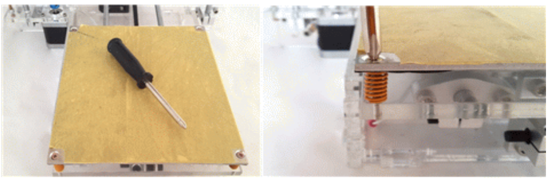


Fig. 1 Manual leveling method

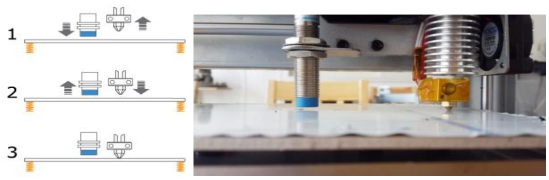


Fig. 2 Semi-automatic leveling method

In this method the distance is measured automatically but the bed is tilted manually.

Generally manual and semi-automatic methods are very time-consuming and the disadvantage is that the leveling can not be compensated in real time during the manufacturing process by performing the test once before the start of manufacturing.

As a method of measuring the inclination of the plane, methods of acquiring images of the pattern engraved on the bed and image processing have been proposed. Before measuring the horizontal state of the wafer prior to lithography process, Chen et al. obtained an image of a specific pattern etched on the edge of the wafer and checked whether the pattern of the edge was within the DOF (Depth of Focus).[1-3] Kim et al. quantitatively measured the tilt of the bed by acquiring the image of the circular pattern etched on the bed and interpreting the shape of the deformed circle according to the inclination of the bed.[4-6] In the present paper, we have proposed a method to measure independent absolute equilibrium of a coordinate system using a light source and a photosensor and the results have been discussed.

2. Development of the leveling device

Equilibrium is defined as the degree of parallelism with respect to a reference plane existing in the relative coordinate system, as shown in Fig. 3, while the leveling surface is defined in the absolute coordinate system. Since all the existing measurement systems have a relative coordinate system, implementation of a leveling surface defined in the absolute coordinate system is a difficult attempt. The reference plane that is always constant within the Earth's absolute coordinate system is the water surface, and the normal vector of the water surface always faces the earth's center.

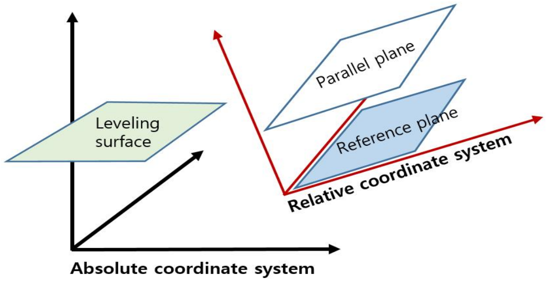


Fig. 3 Definition of leveling surface by coordinate system

2.1 Working principle

If the Earth's gravitational field is set as the absolute coordinate reference, the radial direction from the ground to the center of the Earth can be set as the reference for the developed measurement system. The vector of the gravity direction which was set as the reference of the absolute coordinate system can be commonly used over a considerably wide area on the earth surface. The physical phenomenon that maintained a constant direction in the absolute coordinate system set above was the normal direction of the surface formed by the liquid with flowing characteristics. When the measurement system to be developed contained liquid as shown in Fig. 4, the normal direction of the liquid surface remained directed toward the center of the earth regardless of the position and attitude of the measurement system.

As shown in Fig. 5, the slope of the measuring device including the liquid can be measured by using the characteristics of the liquid which always maintained a constant direction with respect to the gravity and the laws of reflection of light. When the measurement device was horizontal, as shown in Fig. 5(a), the light from the light source was reflected on the surface of the liquid following the laws of reflection law and entered the light receiving part. As shown in Fig. 5(b), even when the measuring device was tilted at a certain angle, the normal vector to the surface of the liquid did not change. This led to an increase in the incident angle and the reflection angle, which in turn led the reflected light to reach another position of the light receiving unit.

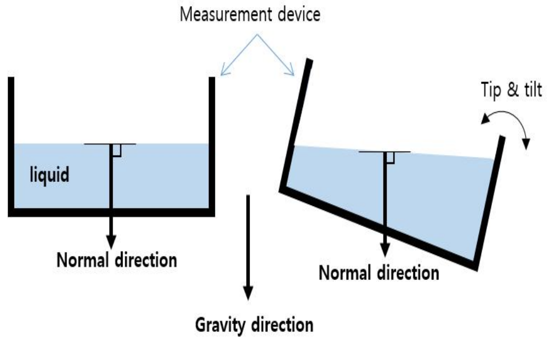
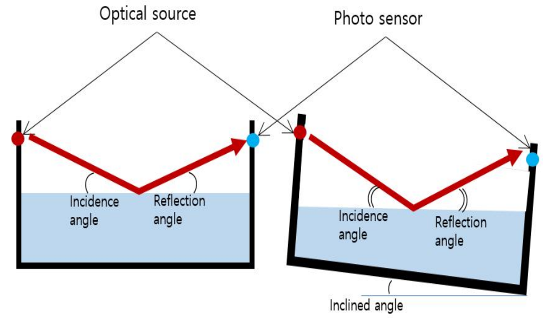


Fig. 4 gravity direction and normal direction of liquid surface



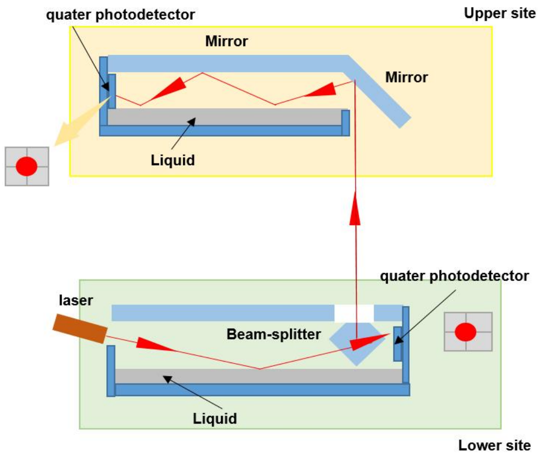
(a) horizontal state **(b) inclined state**

Fig. 5 Principle of measurement using reflection law of light

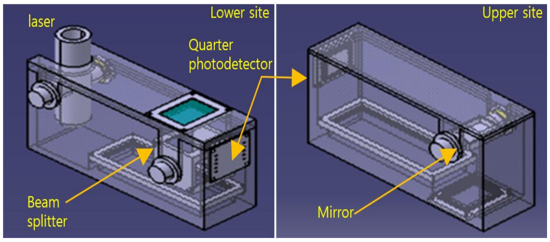
By analyzing the position of the light reaching the light receiving part, the tilted angle of the measuring device was measured.

2.2 System configuration

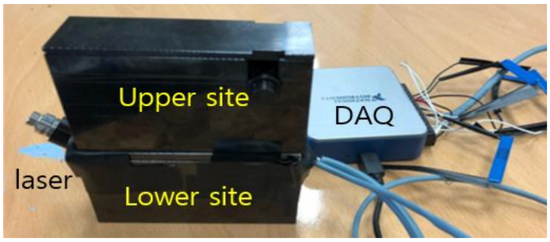
To detect the position of the reflected light, a light receiving unit was constructed by using a quarter photodetector, as shown in Fig. 6. A light ray from the laser was reflected at the surface of the liquid contained in the measuring device and entered the four elements.



(a) configuration of upper and lower site



(b) 3D drawing of device



(c) Photograph of device

Fig. 6 Configuration of optical leveler

When the circular light was incident on the central part of the quarter photodetector composed of four pixels, same charge was generated in the four pixels. However, when the light came out of the center, a charge difference was created between the center and the pixel where the light reaches the maximum. By comparing the amount of charge generated in each pixel, the tilted angle of the

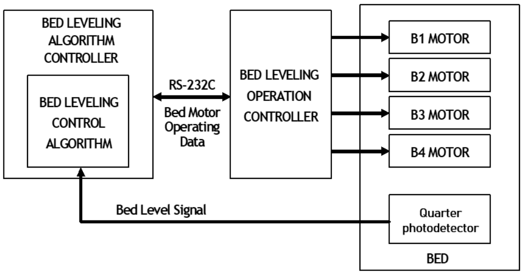


Fig. 7 Process of tilt compensation

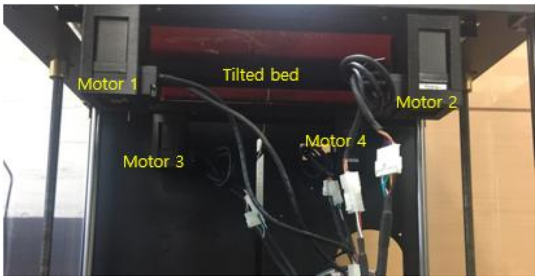


Fig. 8 Configuration of tilt compensation system

measuring device could be quantitatively calculated. Furthermore, the mechanical system to measure horizontal level was divided into a lower part and ae upper part, as shown in Fig. 6. Due to such division, the light source used in the lower part could be transmitted to the upper part using a beam splitter, and the upper part was measured in the same manner as the lower part. Moreover, one light source was able to measure simultaneously both the top and bottom of the target system. Fig. 6(b) shows the implemented 3D drawing and Fig. 6(c) shows the leveler photo.

2.3 Tilt compensation system

Fig. 7 shows the process of tilt compensation. When the measuring device was tilted, different charges were generated in each of the four regions of the quarter photodetector, and by applying an algorithm that compensated for them, each of the four motors was driven to finally compensate the

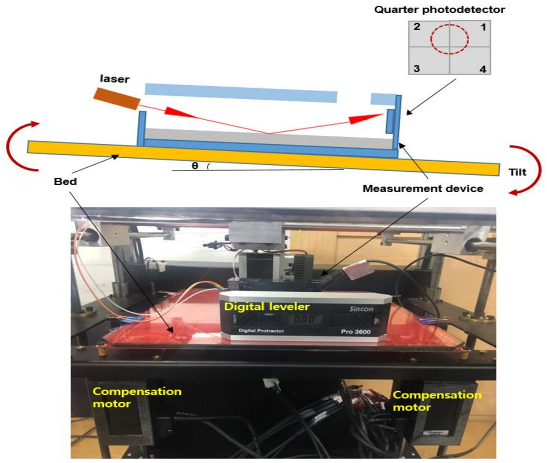


Fig. 9 System for measurement

slope of the bed. The tilt compensation system was constructed by attaching four motors to the four corners of the bed to be tilt compensated, as shown in Fig. 8. The driving data calculated by the compensation algorithm was transmitted to the motor controller via RS-232 protocol. When the tilt compensation was performed by four motors, the circular shape beam light of Fig. 6 (a) was finally positioned at the center of the four-divided element.

3. Measurement results

3.1 Measurement on tilted angle

To verify the newly developed measuring device, the system was constructed as shown in Fig. 9. The measuring device was placed on the bed that required calibration and the generated signals were carefully observed in the quarter photodetector while tilting the bed. When the bed was tilted as shown in Fig. 9, the light spot moved from the center of the pixels to the upper pixels (#1, #2), and the voltage increased at the upper pixel(#2) whereas decreased at the lower pixel (#3). To represent the signals obtained from the four pixels, a LabVIEW program was created (Fig. 10).

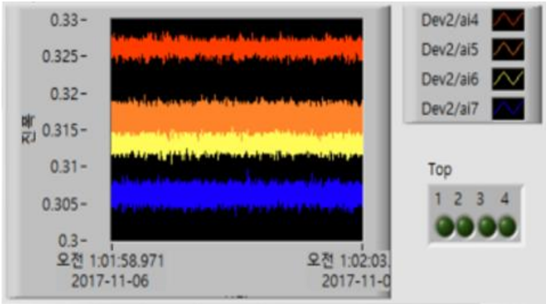


Fig. 10 Front panel of LabVIEW program

Table 1 Compensation angle range (∓2°)

Range	degree	0	+0.5	+1.0	+1.5	+2.0
Signal	mv	0.000	0.008	0.029	0.051	0.077
Range	degree	0	-0.5	-1.0	-1.5	-2.0
Signal	mv	0.000	0.004	0.023	0.057	0.078

Table 2 Signal difference between pixel#2 and pixel#3 according to tilted angle

Digital leveler	degree	0	0.1	0.2	0.3
Measurement result	degree	0.000	0.098	0.202	0.027
Error	degree	0.000 (0%)	0.002 (2%)	0.002 (2%)	0.003 (3%)

As a result of testing the maximum compensation angle of the developed measuring device, the voltage difference between pixel#2 and pixel#3 was observed to change linearly in the range of maximum 4 degrees (∓2 degrees), as shown in Table 1.

3.2 Measurement calibration

To calibrate the generated voltage with the tilt, a digital leveler was used as shown in Fig.9. In the current paper, only the calibration process for the lower measuring device has been shown. After correcting the measured signal value using a digital level meter, the errors in the measured value were obtained (see Table 2). It was confirmed that the slope value obtained using the newly developed measuring instrument corresponded to about 2 ~ 3% of the measurement slope.

4. Conclusion

To conclude, we have proposed and developed a new leveling instrument to be installed in a 1.5m size 3D printer. Using this new leveling instrument, the measurement accuracy could be confirmed. The horizontal reference defined in the absolute coordinate system was placed in the normal direction of the water surface and remained unchanged regardless of the attitude of the measuring device. A measuring device was also developed which was composed of a light source for generating parallel beam and a 4-pixels photodetector in which a reflected light ray was incident. The angle was measured using the principle that the position of the beam spot incident on the 4-pixels photodetector varied with the tilting of the measuring apparatus. A small measurement error of 2 ~ 3% in comparison with the digital level meter was obtained using the new measuring device. We believe that the optical leveling system developed in the current work can be applied not only to large 3D printers but also in various fields.

Acknowledgments

This work was supported by Kyungnam University Foundation Grant, 2017.

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