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Development of Online Machining and Measurement System in Die and Mold Manufacturing: Concept and Fundamental Experiments

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Abstract: The corrective machining to compensate the resulting errors is usually tried at plural times based on the trial-and-error process when the machining is realized in die and mold manufacturing. This corrective machining has an influence on accuracy and efficiency and is an important factor. The measurement system for measuring the forms of die and mold at all times is essential in order to machine the die and mold with high accuracy and efficiency. However, the problems of management and operation errors are found in compensating process of die and mold machining. In this paper, an online machining and measurement system in die and mold manufacturing is developed in order to overcome these problems. In this online system, 2-axis control system is added to a surface roughness measuring instrument, and both NC machining program and measured data are linked and controlled using a same computer. Therefore, the machining and measurement can be recognized for consistent process, and can be realized on the machine. This system has the advantages such as the high accuracy, low-price, and online convenience and so on. The possibility of practical use of this online system was investigated by fundamental experiments.

Key words: Die and mold, machining, measurement, online system.

1. Introduction

The high performance and small size of the die and mold have been recently required as well as its productivity. In other words, the higher geometrical accuracy and higher efficiency of the die and mold manufacturing have been required. The precision machining of the die and mold have been tried by many researchers [1-3]. These studies involve several issues related to die and mold machining such as high-speed machining, cutting forces, chip model, tool life and tool wear, and tool passes and so on.

The corrective machining to compensate the resulting errors is usually tried at plural times based on the trial-and-error process when the machining is realized in die and mold manufacturing [4]. This corrective machining has an influence on accuracy and efficiency and is an important factor. The measurement system for measuring the forms of die and mold at all times is essential in order to machine the die and mold with high accuracy and efficiency. However, the problems of management and operation errors are found in compensating process of die and mold machining.

In this paper, an online machining and measurement system in die and mold manufacturing is developed in order to overcome these problems. In this online system, 2-axis control system is added to a surface roughness measuring instrument (SRMI), and both NC machining program and measured data are linked and controlled using a same computer. Therefore, the machining and measurement can be recognized for consistent process, and can be realized on the machine.

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This system in which task is classified clearly is composed of four units, namely, design unit, measurement unit, machining unit, and data processing unit. This system has the advantages such as the high accuracy, low-price, and online convenience and so on. The possibility of practical use of this online system is investigated by fundamental experiments.

This paper is organized as follows: Section 2 is devoted to system composition; section 3 is devoted to valuations of machining and measurement units; section 4 is devoted to fundamental experiments; section 5 summarizes conclusions.

2. System Composition

Fig. 1 shows the process flow of this system. The die and mold for lens with sphere in VCSEL (Vertical Cavity Surface Emitting Laser) is supposed in this study [5].

First, the design data such as form dimensions, geometric tolerance, and surface roughness and so on are prepared based on design specifications, and model is designed using a CAD system. Next, NC data (Machining data) in addition to model data are generated using a CAM system. This process is defined as design unit. Further, the workpiece is machined using NC data. This process is defined as machining unit. On the other hand, the machined workpiece is measured using a 3-dimensional measuring instrument. Therefore, the measured data can be obtained. In this study, 3-dimensional measuring instrument is developed in which 2-axes control system is added to a SRMI as mentioned above. A measuring axis on SRMI is *X* axis and the moving axes using 2-axis control system by stepping motor are *Y* and *Z* axes, respectively. This process is defined as measurement unit. The machining unit and measurement unit are based on a machine and measuring instrument, respectively. However, the machining unit is linked to measurement unit. Each data are held in common and reference points in machining and measurement are same. Therefore, an online machining and measurement system is realized. Finally, the measured data are compared with the design data, and the machined form is judged. The whole process is finished when the measured form is satisfied. The compensation values which means the deviation between the measured and design data are determined when the measured form is not satisfied. The design model or machining data is revised based on this result. The transfer in machining data and measured data, and control in measurement instrument

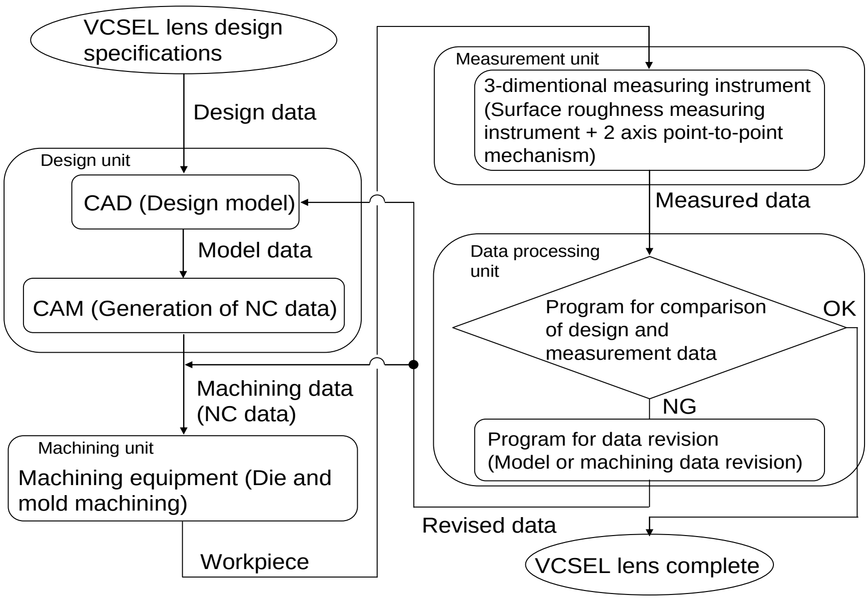


Fig. 1 Flow of online machining and measurement system.

are processed using a same computer. This process is defined as data processing unit. The functions of units were distributed to design, machining, and measurement in conventional system and data processing depended on machine and instrument. The concept of the units can be regarded as the mass of both hardware and software in developed system. The design unit and data processing unit are based on the software through serial communication between machining unit and measurement unit.

3. Evaluations of Machining and Measurement Units

The form accuracy of CAD and machining data of CAM are evaluated in the design unit. The model data in CAD is replaced by plural planes that approximate the curved surface. The approximated plane is called patch. This patch is used for data processing of measurement in addition to CAD. The number of partitions of the patch has an influence on the accuracy of model data from the design data, namely, the form accuracy of CAD. Therefore, the relation between the number of partitions and the accuracy of model data was investigated. As a result, in the case of sphere of diameter of 10 mm, the maximum error between the polyhedron that was formed by the surface of partitions of patch and real sphere was 0.099 μm when the number of partitions was indicated as 250,000. This maximum error means the maximum distance from perpendicular line to the surface of partitions of patch. This value was small enough comparing with the positioning accuracy of 1 μm of multi-tasking machine. In reverse, the number of partitions of patch was small enough 25,600 when the maximum error was indicated as 1 μm.

On the other hand, the CAM generates the machining data that shift offset corresponding to the tool radius when the form is curved surface. The machining data was generated based on the design data of cylinder model. The ball end mill with tool diameter of 3 mm was utilized. As a result, the deviation between theoretical tool setting and that in machining data was -0.2 μm using the output of 0.1 μm units. Further, a fan formed by arbitrary tool positions in cross section of cylinder model and center positions of cylinder was noticed. The maximum distance between arc and chord of the fan was calculated and consequently it was 0.39 μm. This value was also small enough comparing with the positioning accuracy of 1 μm of multi-tasking machine.

4. Fundamental Experiments

Table 1 shows the specifications of measurement unit. The range of measurement in *Z* axis is 0.8 mm because it is 0.8 mm in SRMI. The range is small for die and mold. However, the range can be extended when a 3-axis positioning stage with the moving range of *Z* axis is linked to SRMI.

The measurement process is as follows: (1) The measured workpiece is positioned at the stylus of the SRMI using the 3-axis positioning stage; (2) One direction of the workpiece is measured using remote measurement mode on SRMI; (3) The direction of *Z*

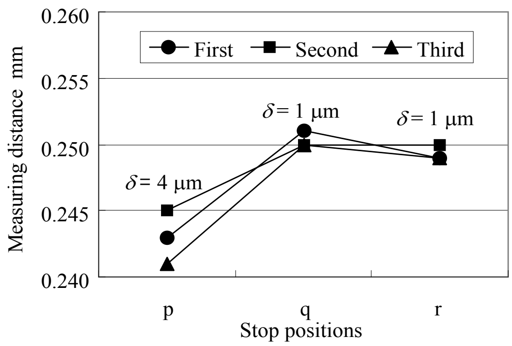
Table 1 Specifications of measurement unit.

Items	Specifications
Measurement method	Surface roughness and form measurement by stylus method
Detector	Indenter, Tip radius: 2 μm, Measuring force: 0.75 mN
Measuring range	*X* axis: 40 mm, *Y* axis: 20 mm, *Z* axis: 0.8 mm
Measurement accuracy	*Z* axis:10 nm
Straightness in measuring direction	0.5 μm/50 mm
Positioning drive system	*X* axis, *Y* axis, *Z* axis: stepping motor control
Positioning accuracy	*X* axis, *Y* axis, *Z* axis: ±1 μm

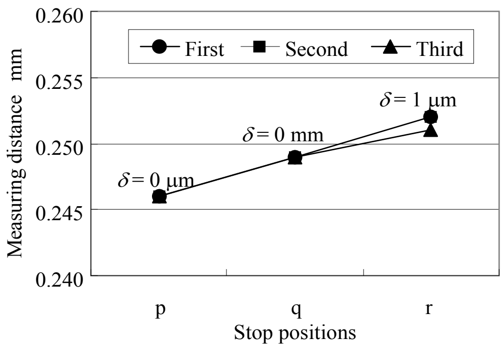
axis on 3-axis positioning stage is driven and the stylus of the SRMI is released from the workpiece. Further, it is returned to the position of the start of measurement using remote measurement recovery mode on SRMI. Afterwards, *Y* and *Z* axes on 3-axis positioning stage are driven and the next workpiece is positioned.

The operation for positioning two points was confirmed at 0.25 mm intervals from arbitrary position in the direction of *Z* axis of 3-axis positioning instrument in order to evaluate the positioning accuracy of the developed instrument. In this method, a dial gauge is set in parallel to *Z* axis and the interval at the moment of positioning was measured. In this case, the stopping position was decided beforehand and the error of the positioning was measured using the dial gauge. The position was compensated at the moment of measurement. Fig. 2 shows the obtained results under each condition. δ means the positioning error. The compensation coefficient was applied to the moving setting pulse. As a result, the repeatability of positioning accuracy was 1 μm.

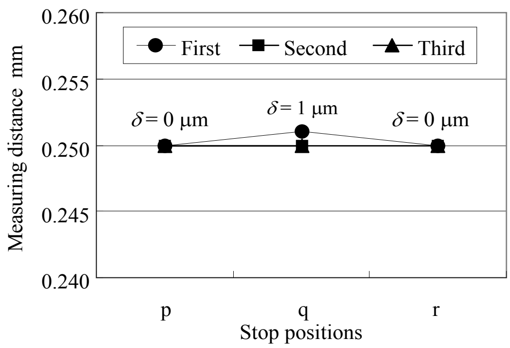
The diameter is 2.65 mm and maximum height of concave side is 0.549 mm for the die and mold of VCSEL lens. The range of measurement of 3 mm, the number of partitions of 20, and the number of partition area of 400 were set and then a plane glass was measured. The interpolation of the range that does not contain measured data was done by straight line. The interpolation polynomial was estimated so that the measured data on 1 line and two points before and behind data by the method of least squares. Fig. 3 shows 3-dimensional displays of the measured data. Figs. 3a-3c show the data right after measurement, the data after inclination compensation using a data transfer program by interpolation, and the data after the optimization of magnification for measurement, respectively. From these results, it was shown that the form accuracy could be measured. As a result, the validity of measurement unit was confirmed.



(a) Initial condition (Sudden stop)



(b) Revised condition (Speed decreasing stop)



(c) Revised condition and positioning compensation

Fig. 2 Experimental results of performance of positioning instrument.

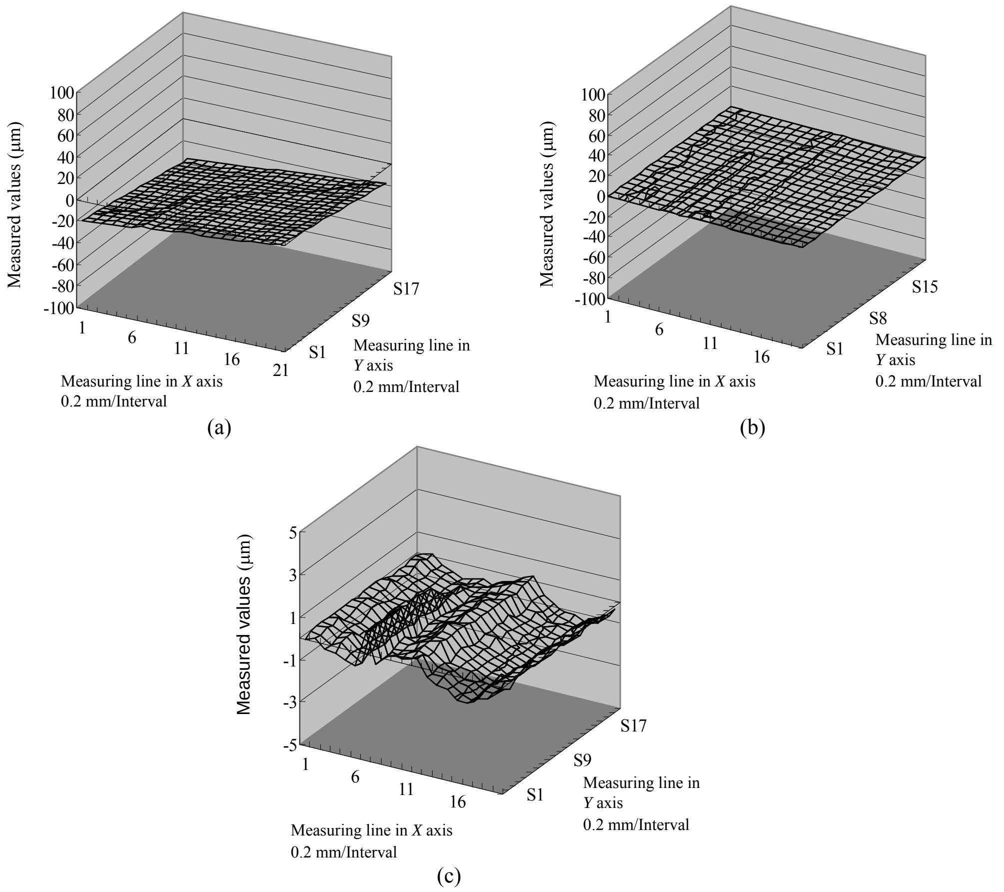


Fig. 3 3-dimensional display of measured data.

5. Conclusions

An online machining and measurement system in die and mold manufacturing was developed. In this online system, 2-axis control system was added to a SRMI, and both NC machining program and measured data are linked and controlled using a same computer. This system in which task is classified clearly is composed of four units, namely, design unit, measurement unit, machining unit, and data processing unit. This system has the advantages such as the high accuracy, low-price, and online convenience and so on. The possibility of practical use of this online system was investigated by fundamental experiments.

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