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MINUTE FORM MEASURING SYSTEM

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Abstract: According to the progress of industrial products, high-accuracy and minute parts are increasing rapidly. As one of the desired measuring systems for accurately and efficiently evaluating the 3D form of these mass-production minute form parts, an evaluation system constructed by combining “a high-accuracy stage,” “minute probes” and “an optical unit” is described.

Keywords: Measuring instrument, Minute form measurement, Probe, Low measuring force

1. INTRODUCTION

Nowadays making industrial products minuter and more accurate is essential to improve the performance and achieve high accuracy. Therefore, minute form machining is becoming a general technology in the modern industry.

However, there are few measuring systems for evaluating the 3D form of these minute-formed parts. Therefore, there are strong demands for measuring systems for evaluating the 3D form of minute parts from the technology development aspect and from the quality control aspect. [1], [2]

To satisfy these demands, we have struggled to develop a “minute form measuring system” for performing general minute-form measurements with 3D coordinate measuring functions. In this paper, we describe the structure and evaluation results of the stage and the driving mechanism for realizing high accuracy of coordinate measuring functions, and also describe the structure and evaluation results of the probe system with features of ultra-low measuring force and minute stylus tip.

2. REQUESTS FOR MINUTE FORM MEASUREMENT

There are the following issues for measuring minute-form parts.

1) Minute stylus tip of probe

   The size of the stylus tip directly influences the measurement resolution. A micro stylus tip is required to grasp the detailed form of the workpiece.

2) Low measuring force

   When measuring minute workpieces, scratches caused by the measurement form non-negligible measurement errors. To prevent the workpiece from being scratched or damaged, ultra-low measuring force is required.

3) High and stable accuracy

   Generally speaking, the form accuracy of minute workpieces is an order of sub-micrometer. The coordinate measuring accuracy of the measuring system should be an order of sub-micrometer.

4) High operational efficiency

   When measuring minute forms, there are many occasions that it is difficult to check the measuring position visually.
   To enhance the measuring accuracy, it is essential to reduce the measuring time and to correctly measure the necessary portions.

3. OUTLINE OF MEASURING SYSTEM

To satisfy these requests, we have developed a minute form measuring system, whose specifications are shown in Table 1.

Table 1 Specifications of main unit system

Item		Specification
Main unit structure	XY plane	XY-plane guide
	Z axis	Moving carriage
Guide		Air bearing
Driving mechanism		Friction drive
Scale unit		Laser Holo Scale
Minimum resolution		1 nm
Measuring range		300 (X) × 200 (Y) × 100 (Z)
Optical unit		Three-step change type tube lenses
Indicating accuracy		(0.2 + L / 1000) µm
Mountable sensors		Ultrasonic touch trigger probe (See Section 4.) (Other non-contact type sensors can be also mounted.)

Figure 1 shows the appearance of the minute form measuring system.

Fig. 1 Appearance of minute form measuring system

To achieve high-accuracy measurement, we have realized the following technical features.

1) Stage unit by friction drive method

   The stage unit has a one-plane guide structure and is driven by the push-rod type friction drive method. Thus the orientation variations caused by the driving force and the thermal variations are greatly reduced. [3]

2) Measuring sensors with ultra-low measuring force and minute stylus tip

   In this measuring system, an appropriate probe can be selected according to your usage purpose. Especially, we have provided probes with ultra-low measuring force, which have detection principles using ultrasonic vibration and are optimum to measure the 3D form of minute parts.

3) Including vision measuring system

   The vision measuring unit is arranged adjacent to the measuring sensor. The approach process of the measuring sensor is automated by the vision measuring system, so that the high-sensitivity sensor and the workpiece are prevented from being damaged and the measurement throughput is enhanced.

4. STRUCTURE OF MEASURING SYSTEM

The structure of the minute form measuring system is described.

Stage System

As shown in Fig. 2, the stage system has a one-plane guide structure using the air bearing. Furthermore, this stage system has a wide measuring range, namely the X-axis stroke is longer than 300 mm. Therefore, to avoid the unstableness caused by the extension of the optical path of a laser interferometer, we adopt a laser hologram linear encoder using low-CTE (Coefficient of Thermal Expansion) glass as the position sensor.

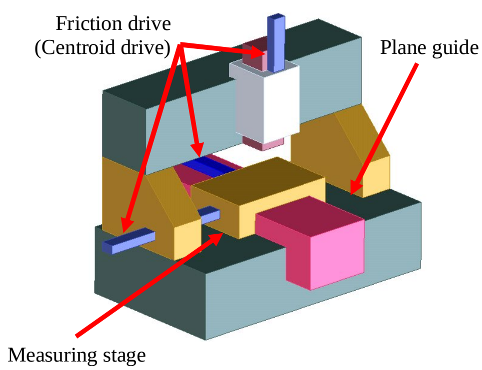

Fig. 2 Structure of stage unit

Since the force of driving the stage may cause stage orientation errors, it is necessary to pay attention about the structure and layout of the driving unit. The stage system uses a push-rod type friction drive unit to apply only the thrust-direction driving force to the centroid position.

Friction Drive Unit

Figure 3 shows the schematic drawing of the friction drive unit in the measuring system.

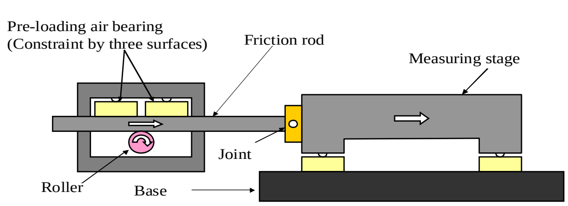

Fig. 3 Structure of friction drive unit

The friction drive unit consists of a drive shaft and a rod, and the rotational movement of the drive shaft is transformed into the translational movement of the rod.

In the ordinary friction drive, the contact force of the driving roller is generated by the opposing back roller. However, this friction drive unit uses air bearings to reduce the skewing errors at the contact portion. [4]

Only the thrust component of the motive power generated by the friction drive unit is transmitted to the stage via the joint having four degrees of freedom. [4]

This friction drive unit has the following advantages. Namely, the heat sources such as the motor can be arranged at a position far from the stage system, and the degree of freedom of arranging the driving rod is high so that the point of application of the driving force can be arranged at the optimum position.

Accuracy of Stage

Figure 4 shows the evaluation results of indicating error and straight motion error of the stage system.

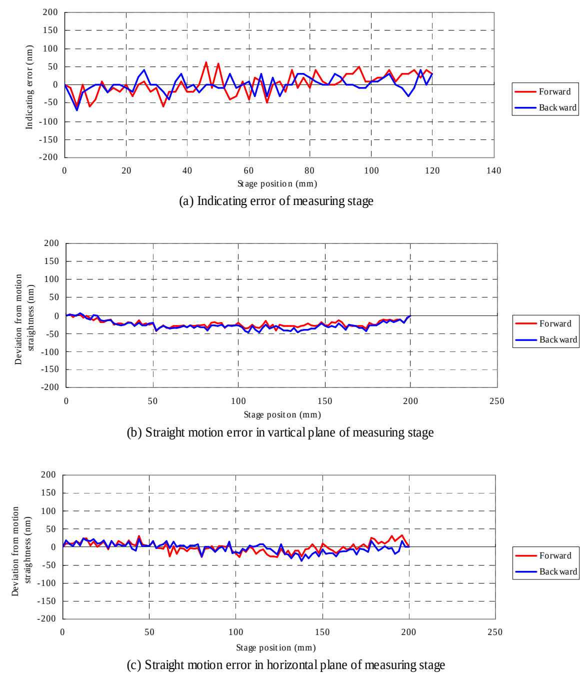

Fig. 4 Evaluation result of stage accuracy

As shown in Fig. 4, the indicating error of the stage is less than 100 nm / 200 mm including the hysteresis, and the straight motion error is less than 50 nm / 200 mm both in the horizontal plane and in the vertical plane including the hysteresis.

Probe System

In this minute form measuring system, one of the probe systems shown in Table 1 can be mounted.

In this paper, a newly developed contact-type probes having excellent measuring principles are described.

Ultrasonic-Vibration Touch Trigger Probe

We have developed a minute probe utilizing ultrasonic vibration to realize the touch triggering detection with ultra-low measuring force. As shown in Table 2, this probe has four types of stylus tip diameters, namely 300 µm, 100 µm, 30 µm and 15 µm.

Table 2 Specifications of ultrasonic touch trigger probe

Model	101	103	110	130
Repeatability [µm]	σ ≤ 0.1	σ ≤ 0.1	σ ≤ 0.15	σ ≤ 0.18
Tip diameter: D [µm]	ϕ15	ϕ30	ϕ100	ϕ300
Stylus length: L [mm]	0.2	2	10	16
Aspect ratio: L/D	13.3	66.7	100	53
Measuring force (Theoretical value) [µN]	25	1	1	10

Measuring Principle of Ultrasonic-Vibration Touch Trigger Probe

Figure 5 shows the measuring principle of the ultrasonic-vibration touch trigger probe.

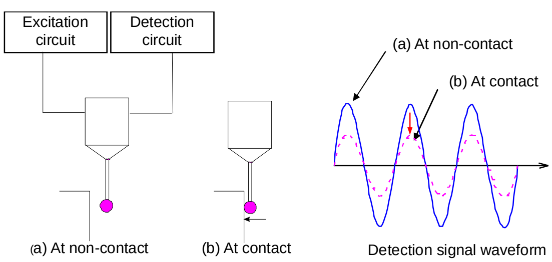

Fig. 5 Measuring principle of ultrasonic touch trigger probe

In this probe, the stylus is vibrated at an ultrasonic frequency by a piezoelectric element, and when the stylus touches the workpiece, the amplitude of the ultrasonic vibration is reduced by the restraint force (friction force) so that a trigger signal is generated. Since the touch trigger signal is generated based on extremely fine self-excited vibration of the stylus, a touch phenomenon with the workpiece can be detected with an extremely low measuring force.

Since this probe has the minimum stylus tip diameter of ϕ15 µm, this probe makes it possible to measure and evaluate the wall surface of ferrule holes and so on, which were difficult to measure by the conventional contact-type probes.

Verification of Probing Capability

Figure 6 shows the measurement result of three cycles of measuring a ϕ1-mm ruby ball by the ultrasonic-vibration touch trigger probe. As shown in Fig. 6, unlike normal mechanical electric-contact type probes, this probe does not have dependency on measuring directions.

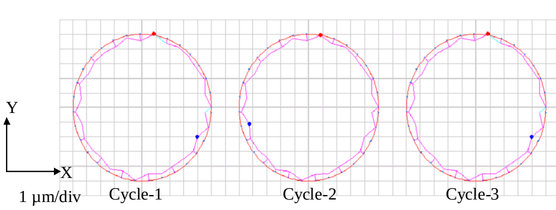

Fig. 6 Measurement result of ϕ1 ruby ball

Figure 7 shows the measurement result of a micro impeller with a diameter of 5 mm.

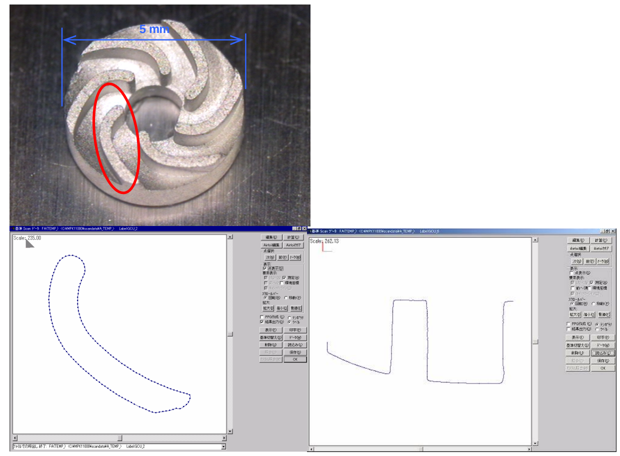

Fig. 7 Measurement result of micro impeller

Ultrasonic-Vibration Contact-Type Scanning Probe

This probe is a contact-type scanning probe obtained by progressing the above-mentioned ultrasonic-vibration touch trigger probe. Table 3 shows the basic specifications of the ultrasonic-vibration contact-type scanning probe.

Table 3 Specifications of ultrasonic scanning probe

Item	Specification	
Measuring range	20 mm	
Scale resolution	0.25 nm	
Indicating error	(0.05+0.05H/20) µm, H: height [mm]	
Measuring force	10 ~ 750 µN	
Following angle	Scanning mode	Ruby ball: Max. 80 deg Diamond stylus: Max. 50 deg
	Touch trigger mode	Max. 90 deg Note: Ruby ball is used.
Stylus	Standard: Ruby ball, ϕ0.3 mm Optional: Diamond stylus, R: 2 µm	

As mentioned before, when the stylus vibrated at an ultrasonic frequency touches the workpiece, the amplitude of the ultrasonic vibration is changed. In the ultrasonic-vibration contact-type scanning probe, the change of the vibration amplitude is detected by the force sensor, and the stylus height is automatically controlled by the active control in such a manner that the ratio between the input amplitude and the output amplitude keeps a constant value.

Figure 8 shows the internal structure of this probe.

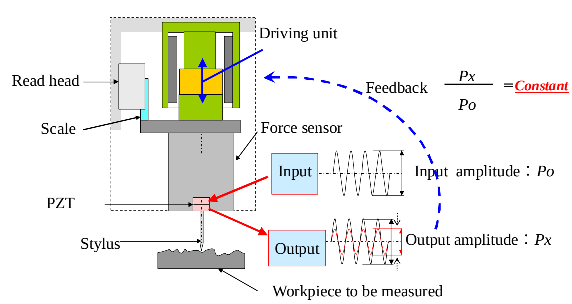

Fig. 8 Measuring principle of ultrasonic contact scanning probe

When the stylus tip vibrated at an ultrasonic frequency touches the workpiece, the amplitude of the ultrasonic vibration is reduced by the restraint force. The stylus is automatically moved upward and downward in such a manner that the ratio between the input amplitude and the output amplitude keeps a constant value, and the displacement of the stylus is read by the linear encoder. Thus the Z-axis scanning function with a constant minute force is realized.

Verification of Probing Capability

Figure 9 shows the experimental evaluation result of controlling the measuring force applied to the stylus.

As shown in Fig. 9, the measuring force can be controlled to an extremely low measuring force of 10 µN by controlling the excitation voltage of the probe.

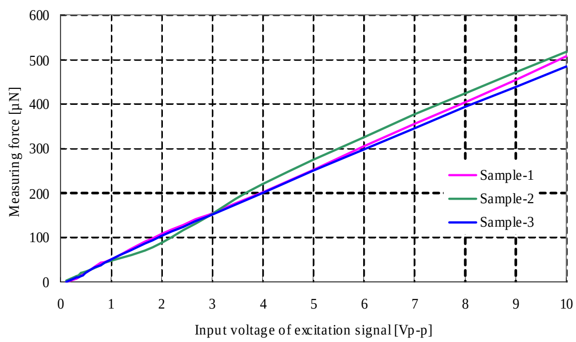

Fig. 9 Experiment result of measuring force

Figures 10 and 11 show the experimental evaluation results of the wide-range and narrow-range indicating errors of the probe only at a measuring force of 50 µN.

As shown in Figs. 10 and 11, the wide-range indicating error is less than 35 nm including the hysteresis, and the narrow-range indicating error is less than 2 nm.

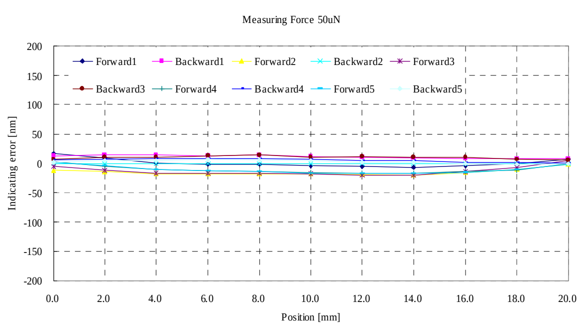

Fig. 10 Measurement result of wide-range indicating error

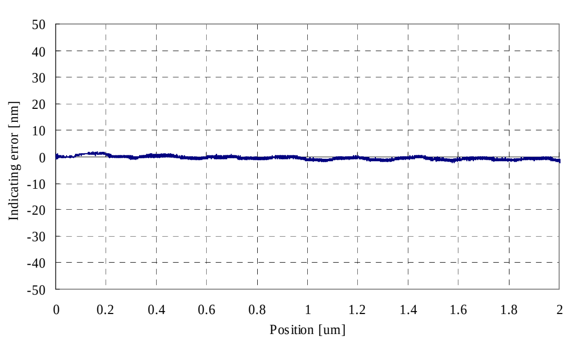

Fig. 11 Measurement result of narrow-range indicating error

5. ROLES OF VISION HEAD

The vision image processing functions included in the measuring system provide various advantages for the minute form measurement.

1) Most minute workpieces are very difficult to determine the measuring positions by human eyes. In the measuring system, it is possible to perform provisional non-contact measurement of the measuring portions by the vision probe, and then based on the provisional measurement result, it is possible to automatically position the sensor to the minute measuring position.
2) By arranging multiple workpieces on the measuring stage and performing a provisional measurement of those workpieces, it is possible to measure those workpieces in one pallet by a batch operation. Thus the man-hour for the measurement can be reduced drastically, compared with the conventional manual operations.
3) Temperature change caused by manually setting the workpiece is eliminated, so that the adverse influence to the measuring accuracy by temperature drifts can be reduced.

6. CONCLUSION

To realize accurate form evaluations of minute-formed parts, we have developed a measuring system consisting of an ultra-high-accuracy measuring stage and minute probes. Furthermore, to realize efficient measurements, the measuring system equips a vision image processing unit, so that a form evaluation system with the minimum operator's intervention has been established.

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