A fast and accurate non-contact profiling instrument for assessing areal surface texture and flatness

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1. Introduction

Surface texture and surface form deviation of industrial products are significant geometrical specifications. Practical measuring instruments to measure and evaluate those specifications are expected to come onto the market. The surface form data is generally composed of discrete sampling points and so it is needed to trace a point- or spot-type displacement sensor relatively over an object surface. Although ISO/TC213 (Technical committee on dimensional and geometrical product specifications and verification) has discussed about the assessments of straightness, flatness and so on, the final agreements have not been attained due to the difficulties to guarantee their consistency. As to the areal surface texture, the official discussion has been just started.

In this study, the novel measurement principle for evaluating both flatness and surface texture of machined products is proposed. Their extraction and filtration procedures are developed in due consideration of utilized displacement sensors.

2. Measurement principle of developed instrument

The developed instrument is based on scanning method using a point-type displacement sensor. Its schematic view is shown in Figure 1. An object surface is set on the X-Y table and laterally moved by orthogonal linear motors. The displacement sensor for measuring geometrical deviation is attached to the bridge-type column made of granite. A super smooth optical flat of 140 mm diameter is attached to the backside of the X-Y table as the plane datum and the vertical motion error can be detected using an electric capacitance displacement sensor located below the optical flat.

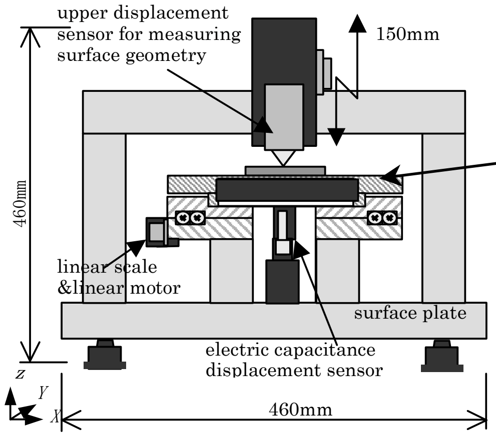


Fig.1 Schematic view of developed instrument

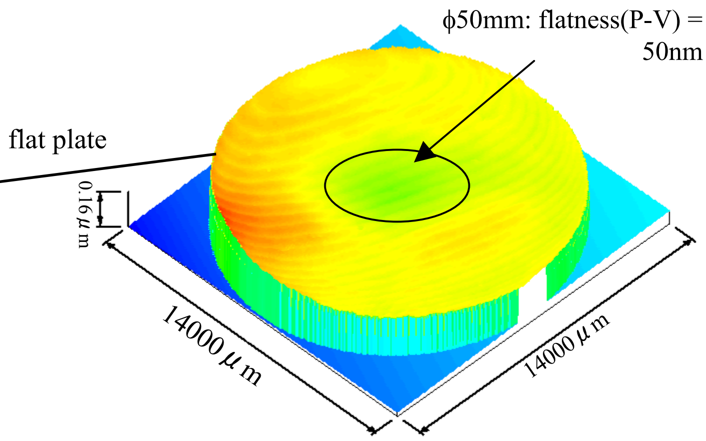


Fig.2 Flat plate

The principal specifications of the instrument are tabulated in Table 1. Its measurable area is limited to that of the plane datum. The measuring range and resolving power for surface form deviation depend on the upper sensor utilized.

Table 1 Principal specifications

External size (D x W x H)	460 x 460 x 370mm
Measurement area and height (X x Y x Z)	100 x 100 x 150mm
Positioning resolution in the X-Y plane (with linear scale)	0.1μm
Tracing speed	~30mm/s

3. Analytical model of measurement error

Measurement error of the instrument can be caused by location and orientation of its composing elements. Supposing that the work surface, X-Y motion plane and optical flat surface are ideally parallel to each other and the pitching motion center *O* of the X-Y table is below the work surface by h_1 and just on the displacement measuring axis of the upper sensor as shown in Figure 3, the measurement errors δ_{zh} and δ_x caused by rotational angle ϕ can be approximated by the following equations.

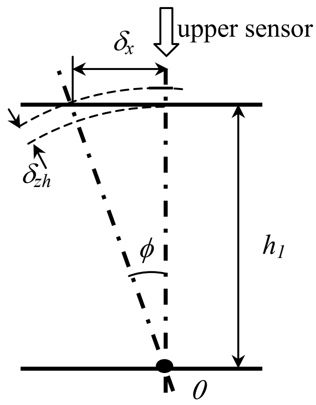


Fig. 3 Measurement error caused by table pitching

$$\delta_{zh} = h_1\left(\frac{1-\cos\phi}{\cos\phi}\right) \qquad (1)$$

$$\delta_x = (h_1 + \delta_{zh})\phi \approx h_1\phi \qquad (2)$$

There exists some misalignment *a* between measuring axes of the two sensors as shown in Figure 4. The measured displacement by the lower sensor is slightly changed due to the rotational angle ϕ and its radius of curvature h_2 in accordance with *a*. The vertical error for the lower sensor δ_{za} is expressed by equation (3)

$$\delta_{za} = a\tan\phi + \left(\frac{1-\cos\phi}{\cos\phi}\right)h_2 \qquad (3)$$

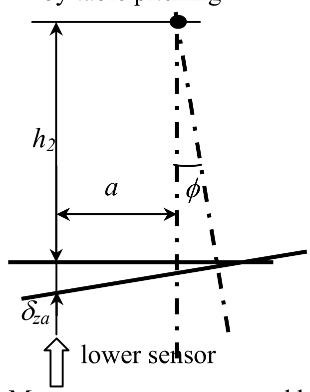
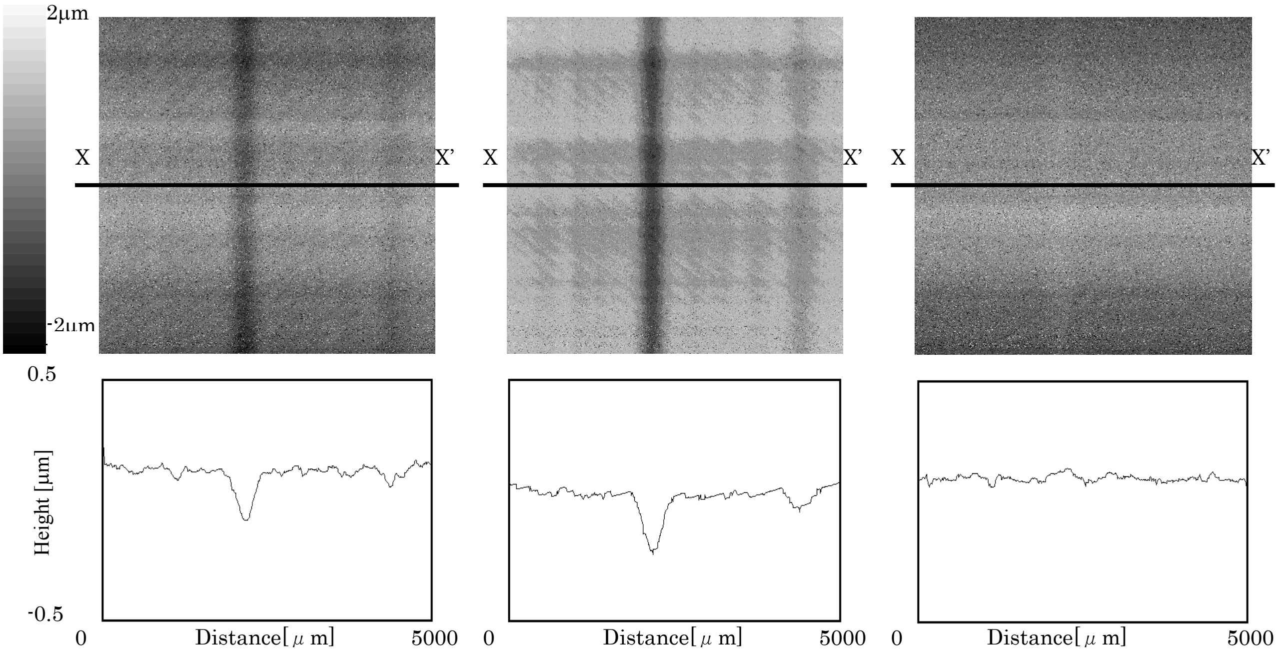


Fig. 4 Measurement error caused by misalignment of the two sensors

The total measurement error in the vertical direction δ_z becomes $\delta_{zh} + \delta_{za}$. In the case that h_1=50mm, h_2=20mm, *a*=1mm and ϕ=0.01°, δ_z can be roughly estimated at 0.18μm.

4. Fundamental performance test

One of the advantages of the developed instrument was experimentally verified using a smooth flat plate as a work surface. Figure 5 shows the measured profiles by following raster scan method for lower sensor as well as upper sensor. From the concaved hollow portion of the profiles for the two sensors, a certain motion error of the X-Y table can be identified. And it was made clear that the motion error was thoroughly corrected by the proposed measurement principle. This means that the compensated or subtracted final profile does not include any significant motion errors.



(a) Originally measured profile of the specimen(X-X')   (b) Profile of reference plate (Motion error)   (c) Corrected profile

Fig.5 Measurement result by using raster scanning method

5. Sampling conditions for flatness evaluation

ISO/TC213 has discussed about specification operators to evaluate flatness deviation and proposed the default measuring conditions shown in Table 2 when using a ball probe[1]. The ball radius tends to dominate the cut-off values λc and so the evaluation length ℓn. As an extraction method for the flatness evaluation, orthogonal grid sampling shown in Figure 7 is generally used. In that case, any adjacent sampling points have to be well correlated from a statistical point of view. Consequently it is necessary to select a reasonable displacement sensor in accordance with the work surface geometry. An auto-correlation curve for a real surface is suddenly attenuated as depicted in Figure 8 when short wavelength components are superimposed on the surface. In order to evaluate the flatness deviation, relatively shorter wavelength components have to be excluded to make the sampling distance much longer. The auto-correlation curve derived from a profile measured by either large ball probe or non-contact displacement sensor can be gently-sloping as shown in Figure 8.

For reference, amplitude transmission characteristics of electric capacitance sensors are shown in Figure 9. It is clearly seen that the shorter surface wavelength components can be excluded with such a sensor depending upon its probe diameter. The reasonable sampling distance for the electric capacitance sensor would be less than 1/6 of its diameter.

Table 2 ISO proposal for measuring flatness deviation [1]

dimensions in millimeters

L		λc	*R*
from	up to and including		ball radius
0.4	1.25	0.08	0.05
1.25	4	0.25	0.15
4	-	0.8	0.5

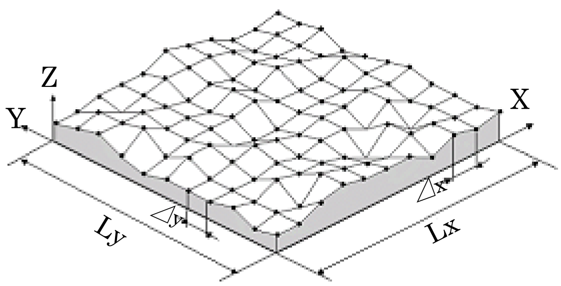


Fig. 7 Orthogonal grid sampling for flatness evaluation

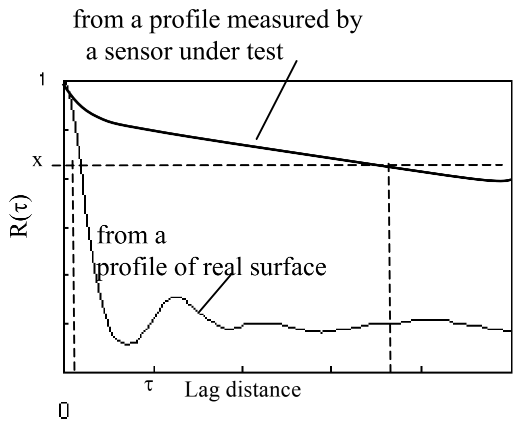


Fig. 8 Auto-correlation curves

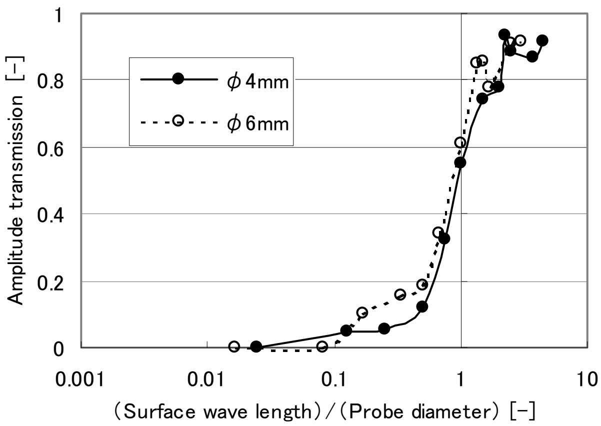


Fig.9 Amplitude transmission of the electric capacitance sensor

6. Areal surface texture measurement

As far as surface texture measurement using stylus instrument is concerned, the profile data is to be measured in accordance with the conditions shown in Table 3[2]. It should be noted that the evaluation length is five times of the cut-off length λc in the default case. However, actual sampling distance is likely to be taken much less than the values shown in Table 3 because of filtration at λs. In the case of areal 3D surface texture, extremely short sampling distance is inconvenient because the repetitive measurements in the orthogonal direction would become almost impossible. It is also to be desired that the cut-off values λs for the areal case should be much greater than those of the 2D case so that the maximum sampling distance could be nearly stylus tip radius or spot radius of optical stylus. In addition to that, measuring area or evaluation area should be taken into account

Table 3 Measuring condition for the case of 2D stylus instrument [2]

λc mm	λs μm	λc/ λs	Max r_{tip} μm	Max sampling distance μm
0.08	2.5	30	2	0.5 (to be changed to 0.41)
0.25	2.5	100	2	0.5 (to be changed to 0.41)
0.8	2.5	300	2	0.5 (to be changed to 0.41)

7. Concluding remarks

The developed instrument can realize the fast and accurate assessment of both areal surface texture and flatness deviation of mechanical products. Tentative sampling conditions for evaluating those geometrical specifications using non-contact displacement sensors were proposed in compliance with the committee drafts of ISO/TC213/WG1. A further study on the amplitude transmission characteristics of non-contact displacement sensors and the sampling scheme will be needed in the near future.

Reference

[1] ISO/DIS 12781-2: Geometrical product specification (GPS)-Flatness part 2 specification operators, (1999)

[2] ISO 3274: Geometrical product specification (GPS)-surface texture :Profile method- Nominal characteristics of contact (stylus) instruments, (1996)