

# A STUDY ON SURFACE MATERIAL MEASURES FOR AREAL SURFACE TEXTURE MEASURING INSTRUMENTS

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## INTRODUCTION

Various surface texture measuring instruments such as contact stylus type, optical probing type and interferometer system have appeared on the market. Subsequently, the sampling length and evaluation length by liner profiling method can be expanded to sampling area and evaluation area by areal measuring method. However, the identical surface texture data can not always be obtained due to different measuring principle of each instrument. So, all the instruments should be calibrated properly. Needed is the areal surface texture standard to cross check the overall performances of surface texture measuring instruments. Nowadays, only the surface material measures for conventional 2D stylus instruments are standardized. As to the 3D surface texture measuring instruments, their calibration method and uncertainty analysis procedure have not been established. So the performance test of the instruments may be carried out using arbitral calibration tools at each manufacturer.

In this study, a surface material measure with the irregular surface topography which can be used for various measuring instruments is proposed. And the surface material measure was manufactured using a super 5-axis nano machine. The optimal measuring conditions are clarified under the software gauge data. The evaluation results using the manufactured surface material measure are discussed.

## GENERATION OF SOFTWARE GAUGE DATA

In the ISO, the measurement standards for 2D surface texture measurement are five kinds of types, A ~ E [1]. Their dimensions and roughness parameters are defined for evaluating overall performances of stylus type surface texture measuring instruments. The measurement standard which can verify overall performances of the measuring instruments

equipped with analysis software on these measurement standards is a roughness standard of Type D. The roughness standard has irregular surface topography, and is characterized by the arithmetical mean deviation ( $R_a$ ) and the maximum height of profile ( $R_z$ ). And measuring instruments can be evaluated by comparing measurement values with nominal values.

About areal surface texture evaluation, calibration method and measurement standards for the instrument have been discussed in ISO/TC213. There, seven kinds of measurement standards such as triangle groove, hemisphere, plane and crossed grating are proposed as measurement standards similar to the 2D measurement standards. However,  $x$ ,  $y$  and  $z$  coordinate values for measuring instruments can be calibrated by the proposed measurement standards. Therefore, the proposal of the measurement standards for verifying overall performance of measuring instruments like the roughness measurement standard is required. Then, the surface material measure with the irregular surface topography for 3D roughness calibration is determined. So, the software gauge data for surface texture standard was generated by using the non-causal 2D autoregressive model (2D A-R model) [2] from the following two reasons.

1. Possible to generate periodical irregular surface topography data.
2. Possible to generate surface topography data from specified feature index.

The 2D A-R model is shown by the equation (1) and equation (2).

$$z(x, y) = \sum_{(i, j) \in D} d(i, j) \{z(x-i, y-j) + z(x+i, y+j)\} + \alpha(x, y), \quad (1)$$

$$D = \{(i, j) | (1 \leq i \leq m, j = 0) \cup (-m \leq i \leq m, 1 \leq j \leq n)\} \quad (2)$$

where,  $z(x, y)$  is height at the position  $x$  and  $y$ . The weight function  $\varphi(i, j)$  is AR parameter.  $\alpha(x, y)$  is random noise components.  $D$  is the area of the linear weighted summation.  $m$  and  $n$  are AR orders in  $x$  and  $y$  directions. Thereby,  $z(x, y)$  is related to the surrounded data in the whole directions. The software gauge generation parameters needed for generating irregular surface topography data using this 2D A-R model are 6 kinds, i.e. correlation length ( $\beta_x$  and  $\beta_y$ ), power index  $w$ , root mean square height  $Sq$ , skewness  $Ssk$  and kurtosis  $Sku$ .  $\beta_x, \beta_y$  and  $w$  are auto-correlation coefficient (ACC), and  $Sq, Ssk$  and  $Sku$  are height probability density function (HPDF). The values of the generation parameters under test are calculated shown in Table 1. And generated software gauge for the unit sampling area is depicted in Fig. 1 (a).

TABLE 1. Generation parameters of software gauge data for surface texture standard.

Parameter	Symbol	Value
Correlation length	$\beta_x, \beta_y$	$40\mu\text{m}$
Power index	$w$	0.9
Root mean square height	$Sq$	$1.0\mu\text{m}$
Skewness	$Ssk$	0
Kurtosis	$Sku$	3

## EVALUATION CONDITIONS

### Evaluation area

In order to evaluate parameter values in 2D roughness measurement, it is necessary to measure 5 times of sampling length which is identical to the evaluation length [3]. When this method is applied to 3D roughness measurement, it is necessary to take 5 times the evaluation length in  $x$  and  $y$  directions for the sampling area corresponding to 2D sampling length. Therefore, the evaluation area will be 25 times the sampling area. Its measuring time by a conventional instrument can be too long. And the measurement data points also exceed 100,000 points. In this surface material measure, the area ( $768\mu\text{m} \times 768\mu\text{m}$ ) of the unit sampling area shown in Fig. 1 (a) is proposed as an evaluation area. And the area of Fig. 1 (b) which combined four of the unit sampling area shown in Fig. 1 (a) is proposed as one surface material measure ( $1,536\mu\text{m} \times 1,536\mu\text{m}$ ). Constant roughness parameter values should be obtained by measuring the evaluation area. Here, when changing a measurement area to the evaluation area, the obtained roughness parameter values with the area are shown in Fig. 2.

As a result, when measurement area is composed of about 16 times or more on the correlation length, the difference between evaluation value and design value becomes 5% ( $400\text{nm}$ ) or less.

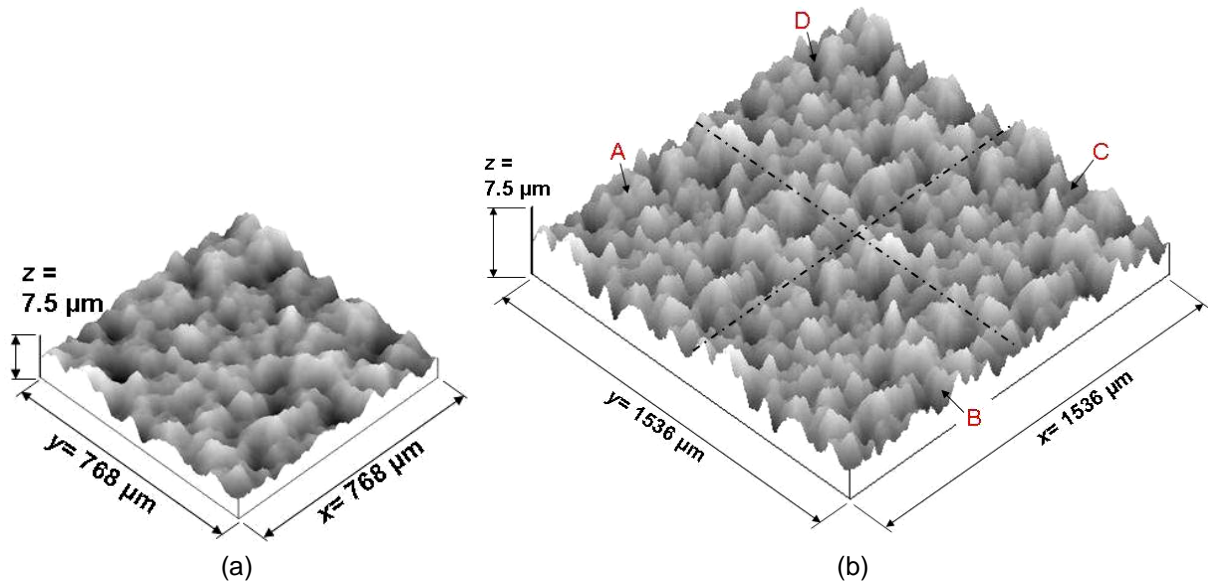


FIGURE 1. Composition of software gauge data. (a) is an unit sampling area. And (b) is multiple sampling area.

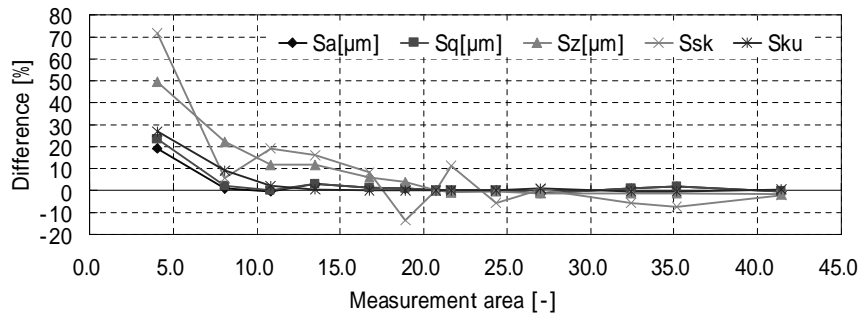


FIGURE 2. Variation of roughness parameter values against the size of measurement area. The horizontal axis shows a length of one side of the measurement area normalized by correlation length. And the vertical axis shows the difference between evaluation value and design value.

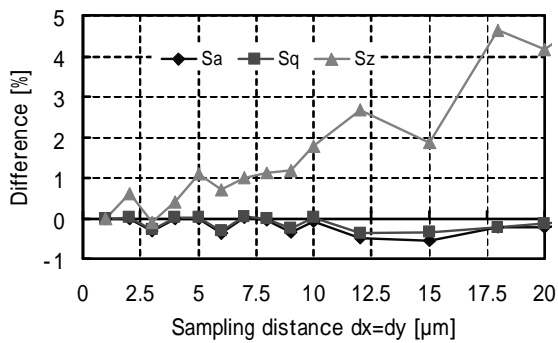


FIGURE 3. Variation of roughness parameter values against sampling distances in both directions.

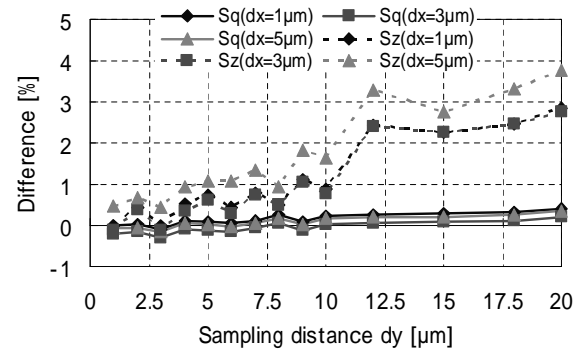


FIGURE 4. Variation of roughness parameter values against sampling distance in y direction.

### Sampling distance

The sampling distances in  $x$  and  $y$  directions are defined as  $dx$  and  $dy$ , respectively. The sampling distance for 2D roughness evaluation is determined by the cutoff wavelength ( $\lambda_s$ ,  $\lambda_c$ ) of the filter for evaluation roughness parameter values, and tip radius ( $R_{tip}$ ) of stylus. From these conditions, when the sampling distance of this surface material measure is calculated, the maximum sampling distance ( $dx$ ) is set to  $0.5\mu\text{m}$ . And the data points of the evaluation area exceed 2 million points.

So, the optimal sampling distance with this surface material measure is discussed in this section. The result under constant sampling distance ( $dx = dy$ ) is shown in Fig.3. And the result when changing the sampling distance in  $y$  direction is shown in Fig.4. When the sampling distance is  $10\mu\text{m}$ , the difference between evaluation value and design value becomes 2% (about  $150\text{nm}$ ) from these results. And, when the sampling distance is  $5\mu\text{m}$ , the difference between evaluation value and design value becomes 1% (about  $70\text{nm}$ ).

### Generation of machining data

The machining data for manufacturing a material measure is generated from the software gauge data. The value of  $w$  was set to 0.9 in order to decrease the short wavelength component which is not manufacturable with a ball end-mill. However, 2D A-R model cannot remove a specific wavelength band, in order to generate the irregular surface texture. Then the Morphological filter (closing) was used for removing the short wavelength component which is not manufacturable with a ball end-mill. Since the nominal value of the tip radius of the ball end-mill used for machining was  $50\mu\text{m}$ , closing processing was carried out with the ball diameter  $100\mu\text{m}$ . The surface profile after this filter processing is shown in Fig. 6. As shown in Fig. 6, the short wavelength component was removed by this filter processing. And as shown in Table 2, surface texture parameter values are not changing before and after filter processing.

The filtered irregular surface topography data is converted into the NC program by using CAM system. In this study, the FUNAC super 5-axis nano machine was utilized.

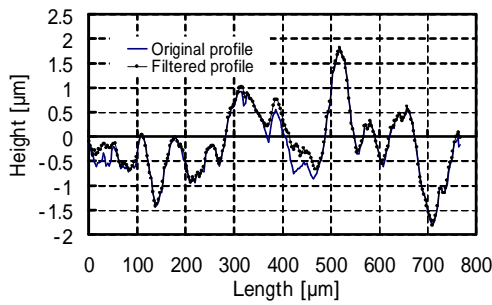


FIGURE 6. Comparison of surface profile between original data and filtered one.

TABLE 2. Comparison of roughness parameter values between original data and filtered one.

parameter	Sa [μm]	Sq [μm]	Sz [μm]	Sku
Original	0.788	1.000	7.253	3.188
Filtered	0.784	0.995	7.169	3.175

## MANUFACTURING OF THE MATERIAL MEASURE

### Machining conditions

Material measure has been manufactured with micro size ball end-mill. Machining conditions are shown in Table 3. Cutting edge radius of the ball end-mill is  $50\mu\text{m}$  and center of rotation and knife point have  $3\mu\text{m}$  offset. To prevent machining near center of rotation, where circumferential velocity 0, the tool should be leaned by about 20 degrees.

A short pick feed distance reduces the influence of the cusp on the surface form. However, a short pick feed distance makes machining time increase. Then, influence of pick feed distance on the surface texture parameter values was analyzed. As a result, influence of the cusp on the surface texture parameter values can be made smaller down to 0.5% or less by setting the pick feed distance to  $3\mu\text{m}$ . Therefore, pick feed was set to  $3\mu\text{m}$ .

In addition, tool rotation speed is assumed to be 37,000rpm in consideration of the resonance.

### Manufactured material measure

Manufactured material measure was measured by contact stylus type and optical probing type surface texture measuring instruments. Measurement results are shown in Table 4. The sampling distance was obtained from the software gauge data. As a result, the obtained roughness parameter values are almost the same regardless of each measuring principle.

TABLE 3. Machining conditions for manufacturing material measure.

Pick feed	3 μm
Tool rotation speed	37,000 rpm
Depth of cut	Crude 4 μm
	Finish 2 μm
Feed speed	Crude 50 mm/s
	Finish 20 mm/s
Tool angle	20 degrees

TABLE 4. Measurement results of manufactured material measure ( $dx=1\mu\text{m}$ ,  $dy=10\mu\text{m}$ ).

parameter	Sa [μm]	Sq [μm]	Sz [μm]	Sku
Original	0.788	1.000	7.253	3.188
Contact stylus	0.761	0.968	6.787	3.221
Optical probe	0.746	0.950	6.893	3.217

## CONCLUSIONS

We applied the 2D A-R model to the generation of software gauge data for the surface material measure which can be used to verify the overall performances of 3D surface texture measuring instruments. And material measure was manufactured using a super 5-axis nano machine. The following concluding remarks were obtained.

- (1) The evaluation area is defined as  $768\mu\text{m} \times 768\mu\text{m}$ . And the area which combined four evaluation areas is defined as multiple sampling areas ( $1,536\mu\text{m} \times 1,536\mu\text{m}$ ).
- (2) By measuring the area of 16 times or more on the correlation length, the influence of measurement area on the roughness parameters becomes 5% or less. And the optimal sampling distance is  $10\mu\text{m}$  or less.
- (3) The material measure with  $Sa:0.788\mu\text{m}$  was manufactured. This material measure can be used for various 3D surface texture measuring instruments.

## REFERENCES

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- [3] ISO 12179: 2000, Geometrical Product Specifications (GPS) - Surface texture: Profile method - Calibration of contact (stylus) instruments