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Rotational error motion of a large rotary table with hydrostatic thrust bearing and roundness measurement of hard-turned part

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Abstract
In this paper the methods for measuring the roundness of a large bearing part are presented. The large volume multi-tasking vertical lathe has been developed for machining the bearing parts of wind power generators. During and after the part machining it is very important to measure the roundness of the part and the measured result can be used for correction machining. Therefore, the measurement should be performed in the machine right after the machining process. A simple in-process roundness measurement method and experimental results for the bearing part with high accuracy with the rotational error motion investigation of the table are presented.

Keywords: Roundness Measurement, Large Bearing Parts, Rotary Table, Rotational Error Motion

1. Introduction

Recently the wind power systems (WPS) become much larger and can generate more than 5 MW energy. The rotor diameter of 10 MW system is about 150 m and the height is more than 200 m [1]. Therefore the WPS requires large mechanical components and in order to increase the WPS's life the higher dimensional accuracy of the component part is required.

The large volume multi-tasking vertical lathe has been developed for machining the bearing parts for wind power generators. Although the machined part is large in size the high precision tolerance is required recently. One of the most important system components to achieve this mission is the rotating table which holds and rotate the part to be machined. The oil hydrostatic bearing is adopted for the thrust bearing and the rolling bearing for the radial bearing. During and after the part machining it is very important to measure the roundness of the part and the measured result can be used for correction machining. Therefore, the measurement should be performed in the machine right after the machining process.

2. Roundness measurement methods and calculation algorithm with table error motion data

Figure 1 shows the previous experimental setup for roundness measurement. The rotary table, a bearing race workpiece, a master bar and two dial gauges are shown. The master bar is located at the center of the table and with the dial gauge the radial error motion of the table is measured. The height values from the top of the table are the same for both dial gauges which are contacting the master bar and the workpiece respectively. The workpiece is an inner ring part(3 000 mm diameter) with a bearing race for the pitch bearing of WPS. The workpiece is machined and finished by a hard-turning process. And the measurement is performed in the same machine(in-process) and by the same workpiece setup.

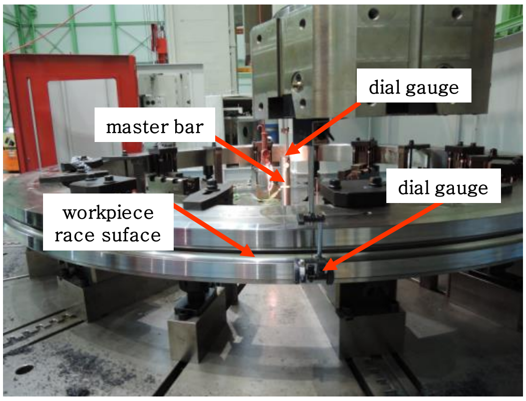


Figure 1. Previous experimental setup for the error subtraction method

The roundness measuring experiment need to rotate the workpiece by 360 degrees and record the gauge values simultaneously. The simple method for measuring the roundness is to subtract the table's radial error motion from the measured data of workpiece gauge. The table center gauge is used for the subtracting error motion data. Due to the same height from the table surface the contribution of the table's tilt error motion to the workpiece gauge is small enough to be ignored (error subtraction method). By using this experimental configuration and error subtraction method the roundness measurement result is shown in Fig. 2 which has twenty data points. The roundness value is 7.4 ㎛.

However the error subtraction method has some drawbacks. The one thing is from the experiment configuration. If the part's size is large the difficulty issue arises in the holding the gauge (or displacement sensor) at the table center. And there can be vibration problems for a gauge holding structure. The second thing is the effect of the tilting motion of the rotating

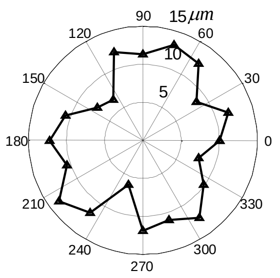


Figure 2. Roundness measurement result by the error subtraction method with dial gauges

table especially when measuring the bearing race roundness. Because the race surface has curved profile in the vertical direction the tilting motion can affect the measurement result especially when the part's size is large enough.

In order to overcome those drawbacks mentioned a new method for measuring the roundness is proposed which is similar to the two-probe differential method [2]. It uses two displacement sensors and difference equation algorithm. In Fig. 3 the measurement setup configurations are shown. S1 and S2 is two displacement sensors, R is the radius of rotary table and d is the distance between the two sensors.

$$\left\{\begin{aligned} S_1(\theta) &= e_t(\theta) + e_{tilt}(\theta) + \delta r(\theta) \\ S_2(\theta) &= e_t(\theta) + e_{tilt}(\theta) + \delta r(\theta - \theta_p) \end{aligned}\right\} \quad (1)$$

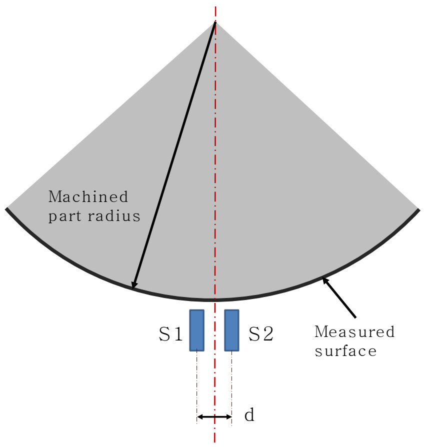


Figure 3. The measurement setup schematic for proposed two-probe differential method

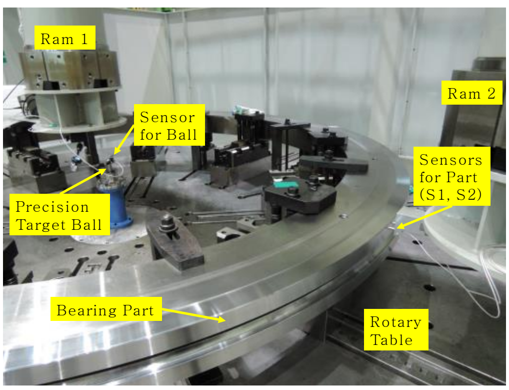
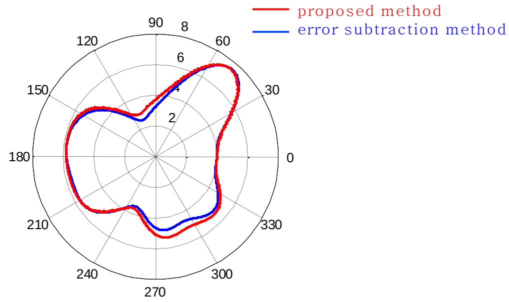
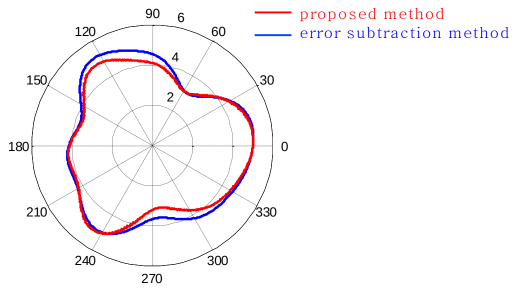


Figure 4. Experimental setup simultaneously performing both the proposed and the error subtraction methods using capacitive type displacement sensors



(a) Part roundness measurement results



(b) Rotary table radial error motion measurement results

Figure 5. Part roundness and rotary table radial error motion measured results (dimension in µm) by the two methods

In the Eq. (1) e_t is the radial error motion in the sensing direction, e_{tilt} is the tilting error motion and δr is the roundness error value.

$$\begin{aligned} e_t(\theta_{i+1}) &= e_t(\theta_i) + S_1(\theta_{i+1}) - S_2(\theta_i),\; e_t(\theta_0) = 0 \\ \delta r(\theta_{i+1}) &= \delta r(\theta_i) - S_1(\theta_i) + S_2(\theta_i),\; \delta r(\theta_0) = 0 \end{aligned} \quad (2)$$

The subscript index of the theta in the Eq. (2) indicates a data point from the experiment. The nature of the difference equation enables the algorithm to cancel out the error from the table tilt motion. And the distance d(40 mm) is small(considering the part 3 000 mm radius) enough to separate the table error motion from the measured data. In Fig. 5 the measured result difference shown between the two methods is due to the tilt motion or deformation of the table during rotation.

3. Conclusion

A simple in-process roundness measurement method for the bearing part with high accuracy is presented. The vertical lathe has a rotating table which can be used for the measurement and by measuring the radial displacement of the part (for example a bearing race surface) during rotation the machined error can be obtained. However, the measurement error value due to the error motion of the table should be identified and removed. The simple method which uses two displacement measuring probes is proposed and the experimental result with the measured roundness error is shown. The proposed measurement method does not need to know the error motion of the table with simple experimental configuration.

References

[1] Goch G, Knapp W and Hartig F 2012 CIRP Annals **61** 611-634

[2] Kiyono S and Gao W 1994 Prec. Eng. **16** 212-218