

Development of a Cylindricity Measurement System for Parallel Rollers Based on a V-Block Method

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Introduction

Cross section roundness profile and cylindricity measurement is generally considered a significant procedure in the processing of parallel rollers requiring the highest quality in dimensional accuracy. This becomes a difficult procedure due to the fact that such rollers show extremely small dimensional error, resulting in expensive and time consuming measuring methods or, in most cases, the ignorance of the procedure itself. Such rollers are incorporated into precision stages for ultra-precision machining tools or measuring instruments, and thus we believe it is important to realize a practical method to evaluate such dimensional error precisely.

In this report, we attempt to evaluate the dimensional error of high-precision parallel rollers with a newly developed cylindricity measurement device based on a V-block three point method. The roller was supported at two points by two independent V-blocks, and measurements are simultaneously taken at three points; namely the two cross-sections supported by the V-blocks and a third cross-section. These results were analyzed to determine the roundness and average radius of the respective cross-sections, while the centers of the cross-sections were calculated and used to determine coaxiality. Furthermore, these results were combined to provide the cylindricity of the measured roller.

We started off with a device designed to support the roller at both ends. Experiments proved that this configuration provided high repeatability for the two cross-sections supported by the V-block, while the third cross-section in between showed rather lower performance.

Experimental results matched well with results from a commercially available high accuracy roundness measuring instrument, thus proving the validity of the proposed device. Repeatability of average radius, roundness and cylindricity measurement was approximately 20 nm. Furthermore, more than 300 parallel rollers of a uniform standard were measured to analyze the distribution of average radius, roundness, and cylindricity.

Measuring principle

We have already reported about the principle, hardware system configuration and basic experimental results of roundness profile measurement method based on a V-block three point method [1]. Figure 1 illustrates the cross-section of a cylindrical workpiece placed in a V-block with a taper angle of α . The cross-section of a cylindrical workpiece can be looked upon as a periodic function with a period of 2π and thus its radius $r(\theta)$ can be expressed in a Fourier series as shown in equation (1).

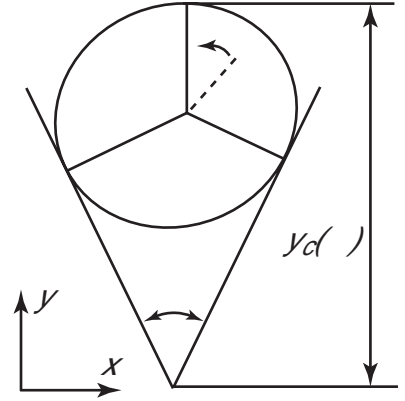


Fig.1 V-block method

$$r(\theta) = r_0 + \sum_{k=1}^{\infty} (A_k \cos k\theta + B_k \sin k\theta) \quad (1)$$

By arranging the measured $y_c(\theta)$ values into a Fourier series, the resultant Fourier coefficients, A_k and B_k can be easily calculated using equation (2).

$$y_c(\theta) = \left\{ 1 + \frac{1}{\sin(\alpha/2)} \right\} r_0 + \sum_{k=2}^{\infty} \left\{ 1 + \frac{\cos k(\pi/2 + \alpha/2)}{\sin(\alpha/2)} \right\} (A_k \cos k\theta + B_k \sin k\theta) \quad (2)$$

If section L, M and R are the measuring points on a parallel roller, we can express cross-section roundness profiles of section L and R as eq.3 and 4.

$$y_L(\theta) = \hat{r}_{L0} + \sum_{k=1}^{\infty} (\hat{A}_{Lk} \cos k\theta + \hat{B}_{Lk} \sin k\theta) \quad (3)$$

$$y_R(\theta) = \hat{r}_{R0} + \sum_{k=1}^{\infty} (\hat{A}_{Rk} \cos k\theta + \hat{B}_{Rk} \sin k\theta) \quad (4)$$

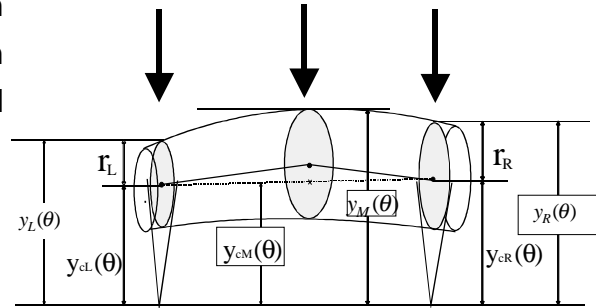


Fig.2 Cylindricity measuring method

In contrast, section M is not supported by V-block. Roundness profile of section M is now calculated by $y_L(\theta)$ and $y_R(\theta)$. Central points at section L and R are given by eq. 5 and 6.

$$y_{cL}(\theta) = y_L(\theta) - r_L(\theta) \quad (5) \quad y_{cR}(\theta) = y_R(\theta) - r_R(\theta) \quad (6)$$

Tentative center of section M is given by eq. 7 with central points at section L and R ($y_{cL}(\theta)$ and $y_{cR}(\theta)$).

$$y_{cM}(\theta) = \frac{1}{2} \{ y_{cL}(\theta) + y_{cR}(\theta) \} \quad (7)$$

Roundness profile of section M, $r_M(\theta)$ is expressed as eq. 8.

$$r_M(\theta) = y_M(\theta) - y_{cM}(\theta) \quad (8)$$

Measuring instrument

Figure 3 shows the test stand based on above theory for precision parallel rollers. The instrument consists of two V-blocks, three measuring bars, capacitance type displacement sensors with a sensitivity of $0.01\mu\text{m}$, and a miniature DC motor to rotate roller.

Our proposed device possesses double enlargement mechanism, where parallel roller is enlarged first by a V-block, and furthermore by a measuring bar which act as a lever. The former gives an enlargement rate which is a function of V-block angle α and lump order k . Enlargement due to the measuring bar is a constant which is determined by the distances from the supporting point of the bar to the V-block position and measuring position. In our device, the measuring bars at section L and R enlarge the y_c value to 5 times and middle bar enlarges 6 times.

The V-block was cut out of a SUJ2 steel composite block, with the contacting planes lap processed to a roughness of $R_a=0.01\mu\text{m}$. The contacting plane of the measuring bar, also lap processed. Contact length of V-block and roller is 3 mm. The measuring bars contact the roller at a width of 1 mm on section L and R and 0.8 mm on middle bar as shown in Fig. 4. Figure 5 shows photograph of the measuring

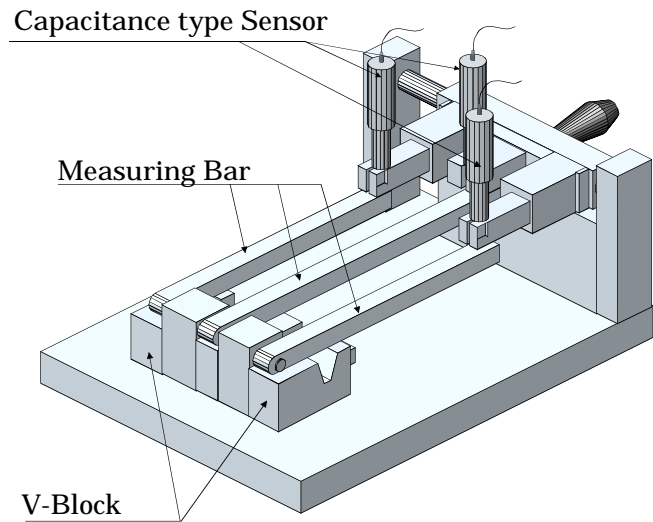


Fig.3 Conceptual design of the measuring system

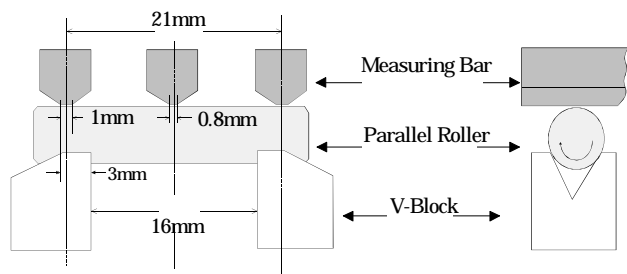


Fig.4 Enlargement of V-block

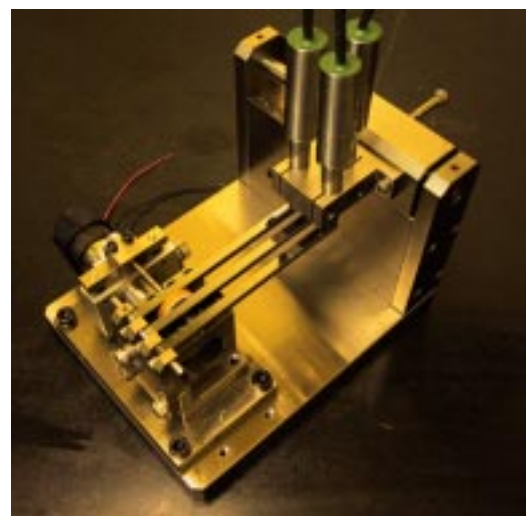


Fig.5 Photograph of the device

system.

Figure 6 shows the measured middle cross-section profiles of a single roller. These measurements were repeated 3 times, where the roller was taken off the V-block after each measurement. The results in the figures prove high repeatability, thus demonstrating the validity of the device.

Experimental results

Measurement experiments were conducted on JIS P1 grade high-precision parallel rollers, 4 mm in nominal diameter and 25.7 mm in length and processed from SUS 440J2 bearing steel. Tolerance zone in diameter is $4^{+0}_{-0.001}$ mm. The surface of the rollers were lapped. The measurement on each roller was done by four consecutive rotations. Sampling rate of the data was 256 points in a roller rotation. Figure 7 illustrates the base radius values of the 344 sample rollers.

Conclusions

In this report, the measuring principle and the test stand for the cylindricity measurement of parallel rollers are described, followed by analyzed results of roundness and base radius deviation at three cross sections for 344 sample rollers were shown.

Reference

[1] K. Goho, K. Mitsui and A Hayashi: Development of a Roundness Profile Measurement System for Parallel Rollers Based on a V-Block Method, JSME International Journal, Series C, Vol.42, No.2(1999)410.

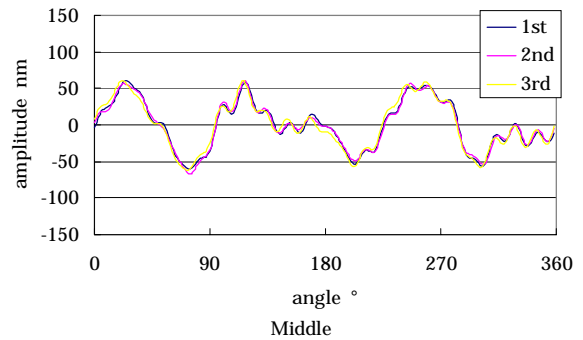
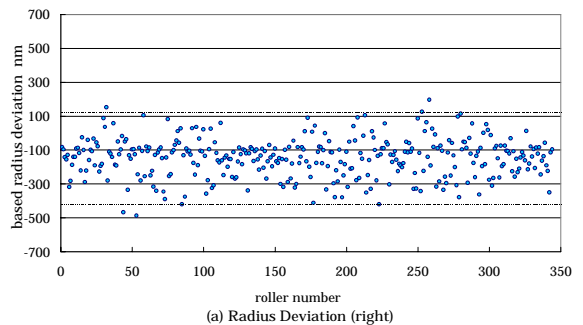
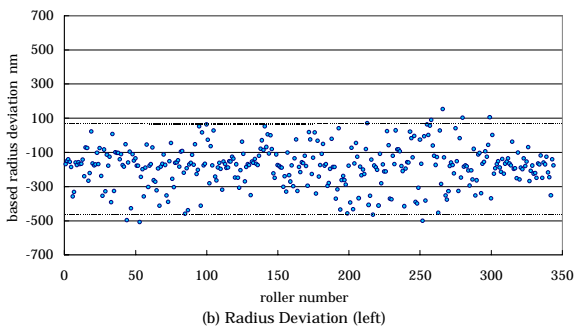


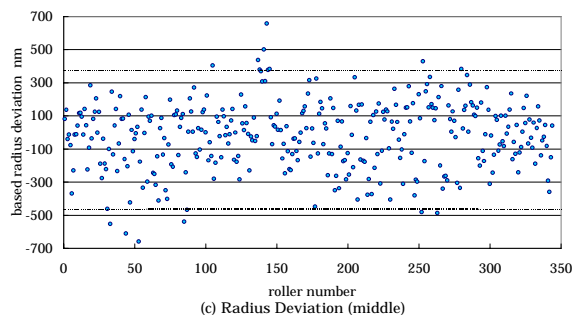
Fig.6 Repeatability



(a) Radius Deviation (right)



(b) Radius Deviation (left)



(c) Radius Deviation (middle)

Fig.7 Relative radius distribution