XVI IMEKO World Congress

Measurement - Supports Science - Improves Technology - Protects Environment ... and Provides Employment - Now and in the Future

Vienna, AUSTRIA, 2000, September 25-28

ERROR SEPARATION METHOD FOR ROUNDNESS MEASUREMENT

J.-C. Zhang and Y.-X. Cheng

Academy of Machinery Science and Technology, Beijing, P.R. China

Abstract: This paper describes a new error separation method for roundness measurement. It can be used in precision roundness measurement instrument. The spindle rotary error and work-piece roundness error can be separated by this method. This method using one sensor and one indexing of the workpiece for each measurement. Compared with other error separation methods the measuring efficiency and uncertainty can be improved.

Keywords: error separation roundness measurement

1   INTRODUCTION

With the development of science and technology, the nanometer level measurement technique has gained an ever increasing importance in modern high techniques. For high accuracy roundness measurement the error motion of the spindle of the measuring instrument can not be neglected. For solving this problem several error separation techniques were developed. Currently, the commonly usable separation techniques in roundness measuring instruments are in three kinds: (1) Three sensor error separation technique, it needs more sensors so errors will be resulted from non-uniformity of the characteristics of the sensor [1]. (2) Multi-step error separation method, the deficiency of this method is its inability to separate completely the spindle rotary errors from the roundness errors of the work-piece [2]. (3) Reversal method, this method is used only in turntable type roundness measuring instruments to separate the radial error of the spindle [3]. To overcome the deficiency of the above methods, a new method of error separation is presented in this paper. It needs only one sensor and one indexing.

2   WORKING PRINCIPLE

This method is suitable for the rotary sensor type of roundness measuring instrument. An indexing turntable and a set of date processing software are included in the system. Fig 1 shows the principle of this new error separation method. Put the indexing turntable on the worktable of the roundness measuring instrument. The work-piece for measuring is put on the indexing turntable. Firstly, the sensor turns around the work-piece in anti-clockwise direction with the spindle from a original position. If the roundness error of the work-piece can be expressed as $g(q)$ and the spindle rotary error are $z(q)$ then the error signal picked up by the sensor will be:
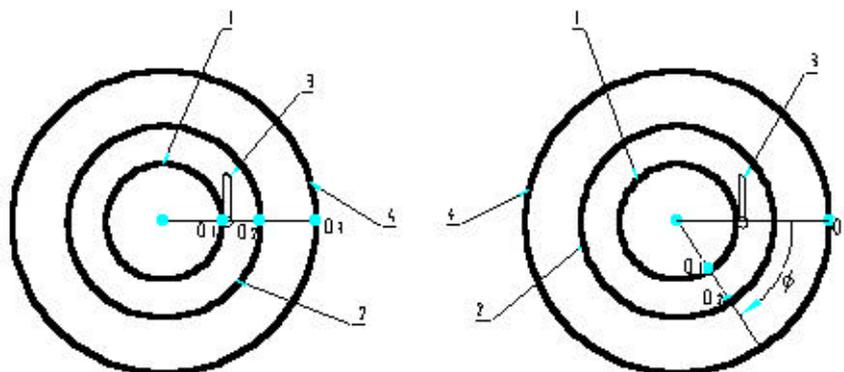
$$a(q) = g(q) - z(q) \tag{1}$$

Figure 1. The schematic chart of the error separation principle
1: workpiece, 2: turntable, 3: sensor, 4: worktable of the instrument

XVI IMEKO World Congress

Measurement - Supports Science - Improves Technology - Protects Environment ... and Provides Employment - Now and in the Future
Vienna, AUSTRIA, 2000, September 25-28

Then the indexing table bring the work-piece turn a angle f in clockwise direction. Make the sensor take the second around measurement. Its output will be

$$b(q) = g(q + j) - z(q) \tag{2}$$

The discrete forms of equation (1) and equation (2) are

$$a(n) = g(n) - z(n) \tag{3}$$

$$b(n) = g(n + p) - z(n) \tag{4}$$

Define N as the total number of the points sampling at the whole circle in equiangular interval, then

$$p = (j / 2p)N \tag{5}$$

Subtracting equation (4) from equation (3), z(n) can be eliminated.

$$s(n) = a(n) - b(n) = g(n) - g(n + p) \tag{6}$$

Employing the shifting characteristic of Fourier transform, make discrete Fourier transform for both sides of equation (6) to obtain the following equation

$$S(k) = G(k)W(k) \tag{7}$$

In this equation $\quad W(k) = 1 - \exp(j 2p\, pk / N)$
If $W(k) \neq 0$, we can obtain

$$G(k) = S(k) / W(k) \tag{8}$$

By discrete inverse Fourier transform, we can get the discrete series of the work-piece roundness error

$$g(n) = F[G(k)] \tag{9}$$

By equation (3) we can also get the rotary error of the instrument spindle:

$$z(n) = g(n) - a(n) \tag{10}$$

In equation (8), to ensure $W(k) \neq 0 \quad (k = 0,1,2,...,N)$, N/P must not be whole number. That can be done. So we can separate all harmonics of the spindle rotary error from the roundness error of the work-piece, overcome the main problem of the multi-step error separation technique. Compared with the multi-step method another advantage is that because it needs only one indexing its measuring time is much shorter, so the measuring efficiency and measuring uncertainty can be improved.

3 COMPUTER SIMULATION TEST

3.1 Accuracy analysis
Suppose the roundness error of work-piece and the spindle rotation error can be expressed by the following equations:

$$g(n) = Ag\cos(2p\, Kg\, n / N) \tag{11}$$

$$z(n) = Az\cos(2p\, Kz\, n / N) \tag{12}$$

In the equations:

g(n) is the roundness error of work-piece.
z(n) is the spindle rotation error.
Ag is the amplitude of g(n).
Az is the amplitude of z(n).
Kg is the harmonic of g(n).
Kz is the harmonic of z(n).
n is the sampling point.
N is the total number of the points on one measuring round.

At the first measuring round we can get the composed error

$$a(n) = g(n) - z(n) = Ag\cos(2p\, Kg\, n/N) - Az\cos(2p\, Kz\, n/N) \qquad (13)$$

After the indexing table bring the work-piece turn an angle, $j = 2p/N$ the second measuring round is taken and another composed error is got

$$b(n) = g(n+p) - z(n) = Ag\cos(2p\, Kg\, n/N) - Az\cos(2p\, Kz\, n/N) \qquad (14)$$

Use a(n) and b(n) as the input, through the error separation process we can get the roundness error of work-piece and the spindle rotation error. Table 1 and Table 2 show the processing results of the roundness error of work-piece. From the results Table 1 and Table 2 show it can be find that the deviations are lager especially for the smaller error the relative deviations must be consider. To improve the separation accuracy we change the data length of the computing process from 4 bytes to 8bytes. By this way the separation accuracy is improved clearly. Table 3 shows the results. It can be known that if the data length of computing process is longer enough the accuracy of this method is high.

Table 1. Processing results of roundness error of work-piece(μm)(Ag=2 μm, Az=1 μm, Kg=2, Kz=3)

Value of p	3	30	100	300	600
Processing Results of roundness error	4.00082	3.99987	4.00042	4.00049	4.00025
Real value of roundness error	4.00000	4.00000	4.00000	4.00000	4.00000
Deviation	0.00082	-0.00013	0.00042	0.00049	0.00025

Table 2. Processing results of roundness error of work-piece (μm) (Ag=0.002 μm, Az=0.02 μm, Kg=2, Kz=3)

Value of p	3	30	100	300	600
Processing Results of roundness error	0.00474	0.00477	0.00440	0.00455	0.00457
Real value of roundness error	0.00400	0.00400	0.00400	0.00400	0.00400
Deviation	0.00072	0.00077	0.00040	0.00055	0.00057

Table 3. Processing results of roundness error of work-piece (μm) (Ag=0.002 μm, Az=0.02 μm, Kg=2, Kz=3,Data length=8 Bytes)

Value of p	3	30	100	300	600
Processing Results of roundness error	0.004000	0.003999	0.004000	0.004000	0.004000
Real value of roundness error	0.004000	0.004000	0.004000	0.004000	0.004000
Deviation	0.000000	-0.000001	0.000000	0.000000	0.000000

XVI IMEKO World Congress

Measurement - Supports Science - Improves Technology - Protects Environment ... and Provides Employment - Now and in the Future
Vienna, AUSTRIA, 2000, September 25-28

3.2 Turning angle selection

In part 2 we have known that to ensure W(k) 0 (k=0,1,2, …, N), N/P must not be whole number. So it is easy to think that we can select p as a non-whole number to ensure W(k) 0 (k=0,1,2, …, N). We do this and find if the FFT is used, when p is not a whole number the computing deviation is much lager. Table 4 shows the results. So for the separation system which use FFT the indexing angle must be in high accuracy to ensure the parameter p is a whole number.

4   EXPERIMENT VERFICATION

We have performed experiments of this method with a Talyrond73 rotary sensor type roundness measuring instrument for a glass hemisphere. The experiments were performed with the filter set at 1-50 UPR, magnification x20000, and the number of sampling points N=1024.

The measuring results of the roundness error of the glass hemisphere have a good repeatability, but are not same with the result give by Talyrond73 by a multi-step error separation method. The further studies and experiments are needed to detect the reasons for that.

Table 4. Processing results of roundness error of work-piece for different p (µm) (Ag=2 µm, Az=1 µm, Kg=4, Kz=3, Data length=4 bytes, N=2048)

Value of p	200	486.6847
Processing Results of roundness error	4.00009	4.02795
Real value of roundness error	4.00000	4.00000
Deviation	0.00009	0.02795

5   CONCLUSION

The one sensor and one indexing error separation present by this paper is a good method for high accuracy roundness measurement. One sensor, the errors resulting from nonuniformity of sensors are avoided. One indexing shorted the measuring time. Selecting the suitable turning angle the errors of all harmonics can be separated, this can not be done by the multi-step method. The separation accuracy of this method can get to be 1nm.

REFERENCES

[1] Cao wei, tadatoshi nomura and satoshi kiyono, 1994,measurement with soft ware datum method -- comparison between mixed method and three point method by computer simulation--, J.oftheJSPE,60(1),106-110.
[2] Cao Linxiang, 1989,The measuring accuracy of the multistep method in the error separation technique, J. Phys. E: Sc. Instrum. 22(11),903-906.
[3] Reere, C.P.,1979,Calibration of a roundness standard, Nat. bur. Standard (U.S.A) NBSIR 79-1758,1-8

AUTHORS: Jing-Cai ZHANG and Yue-Xiang CHENG, Academy of Machinery Science and Technology, Beijing, P.R. China