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Insufficiency of the SPAM test for spindle error motion measurement

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Abstract

Single-point asynchronous motion, or SPAM, is often used to describe the error motion of a precision spindle. However, a typical SPAM test with a physical fiducial cannot be used for synchronous, rotating sensitive direction, or axial error and is only an estimate of the fixed sensitive direction asynchronous error. A typical SPAM test is limited to a single angle of rotation of the rotor but there can be large differences in asynchronous error at different locations. The full correct definition of spindle error includes radial, axial, and tilt synchronous and asynchronous error for fixed or rotating sensitive direction applications. The insufficient specification of spindle error motion using only a single SPAM result compared to a spindle specification using the error components defined by ASME B89.3.4 and ISO 230-7 is explored. Spindle measurements are shown that highlight the inaccuracy of the SPAM estimate compared to complete spindle error motion metrology using a modern spindle analyzer.

SPAM, asynchronous, spindle error, spindle metrology

1. Introduction

The ASME B89.3.4 Standard *Axes of Rotation* provided a comprehensive description of modern spindle error motion terms [1] since 1985 which served as the basis for the more recently published ISO 230-7 [2]. Marsh describes the experimental procedures needed to accurately capture error motion of a spindle according to both of these standards [3].

Before these resources existed or advances in computers, data acquisition, capacitive sensors and encoders enabled the development of modern spindle error analyzers, error motion measurements were costly and time consuming. As a result, in 1978 when William Bryan was developing a diamond turning machine for his Senior Thesis at CalPoly, he described a simple method to estimate asynchronous without a proper spindle analyzer [3]. This procedure became known as the grease pencil test (a grease pencil used to create the fiducial) and later named the single-point asynchronous motion (SPAM) test.

However, a SPAM test using a physical fiducial cannot be used for axial error and provides no information about synchronous error. Hence, for ultra-precision machine tools, a SPAM test cannot predict workpiece form errors. Since the SPAM estimate of the asynchronous error motion applies at a single angle of rotation this can lead to significant underestimates due to variation of asynchronous as a function of angle. This work demonstrates the insufficiency of using SPAM when complete spindle error measurement is required.

2. Methodology

To perform a typical SPAM test a fiducial mark is made on the spindle rotor with a marker or grease pencil. The variation in the height of the fiducial over several revolutions is an estimate of the asynchronous at a single angle of rotation. An example of the measurement result for a Professional Instruments model 4R Blockhead air bearing spindle at 150 RPM is shown in Figure 1. At one angular orientation, the asynchronous face error is less than 1.0 nm.

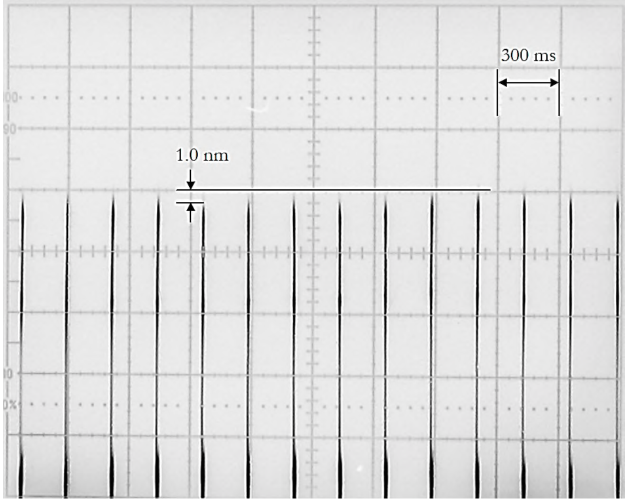


Figure 1. An example SPAM result to estimate asynchronous face error motion [4]. Spindle speed is 150 RPM and asynchronous face error is less than 1.0 nm for the 4R Blockhead air bearing spindle.

To avoid aliasing, it is required that the sampling rate is high enough so that the fiducial mark contains at least ten samples [1]. Different values for the asynchronous may be observed depending on the location of the fiducial. Improved estimates of the maximum asynchronous require performing the SPAM test at more than one rotational angle.

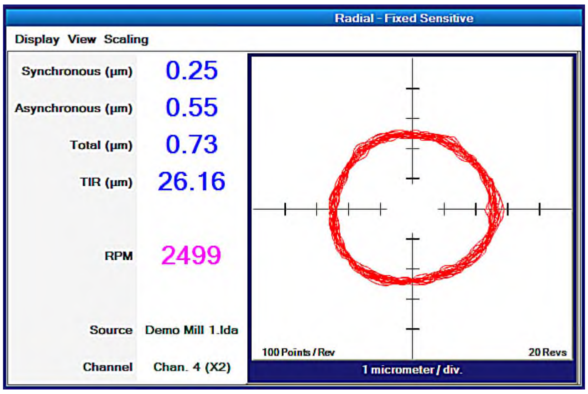
An alternate version of the SPAM test can be performed when the error motion measurements are triggered using the output of an encoder reference or index mark [5]. The encoder output acts as an electronic fiducial mark designating a specific angular position of the spindle. The physical fiducial mark is no longer necessary so the alternate SPAM test is used in this work.

Complete spindle error motion measurements are compared to the SPAM result using the Lion Precision Spindle Error Analyzer (SEA) equipment system shown in Figure 2. Five capacitive sensors are used to determine error motions of a rolling element spindle in five degrees of freedom: two radial (R_X and R_Y), one axial (Z), and two tilt (α_X and α_Y).

Figure 2. Complete spindle error motion measurement using five capacitive sensors with nest, double-ball artifact, and spindle error analyzer. Photo courtesy of Lion Precision.

3. Results

A typical SEA result reporting synchronous, asynchronous, total error motion in the X-direction is shown in Figure 3. A summary of the fixed sensitive and rotating sensitive measurements is provided in Table 1 and Table 2 at 2 500 RPM.



Radial - Fixed Sensitive

Display View Scaling

Synchronous (µm) 0.25

Asynchronous (µm) 0.55

Total (µm) 0.73

TIR (µm) 26.16

RPM 2499

Source Demo Mill 1.lda

Channel Chan. 4 (X2)

Figure 3. Representative result from a modern spindle error analyzer (Lion Precision SEA).

Table 1. Fixed sensitive direction error results reported by Lion Precision SEA. †Per the definition, axial synchronous includes fundamental synchronous and residual synchronous [1,2].

Sensor	Error component	Synch	Asynch	Total
X	- (µm)	0.35	0.89	1.16
Y	- (µm)	0.67	2.83	3.17
Z	Z (µm)	0.57†	0.89	1.39
X2	R_X (µm)	0.25	0.55	0.73
Y2	R_Y (µm)	0.44	1.16	1.31
X, X2	α_X (µrad)	1.79	7.70	8.39
Y, Y2	α_Y (µrad)	3.98	30.48	36.37

Table 2. Rotating sensitive direction error results reported by SEA.

Sensor	Synch (µm)	Asynch (µm)	Total (µm)
X2, Y2	0.51	0.95	1.11
X, Y	0.51	2.60	3.12

The synchronous error, which predicts the best workpiece form error under ideal conditions [1], ranges from 0.25 µm – 0.67 µm. However, since the SPAM test provides no information about the synchronous error, it does not predict form. The asynchronous error, which predicts the lower limit for surface roughness under ideal conditions [1], ranges from 0.55 µm – 2.83 µm. The minimum asynchronous values obtained using the SPAM method are summarized in Table 3 and compared to the actual asynchronous. The actual error is over 400% larger than the SPAM estimate for this spindle. The SPAM value calculated at one hundred angles of rotation is shown in Figure 4. Variation in asynchronous as a function of rotation angle is a significant source of uncertainty when relying on SPAM.

Table 3. Minimum asynchronous error obtained using SPAM with an electronic fiducial compared to actual asynchronous per B89.3.4.

Sensor	SPAM$_{MIN}$ (µm)	Actual Asynch (µm)	% Error
X	0.33	0.89	270%
Y	1.32	2.83	215%
Z	0.52	0.89	171%
X2	0.13	0.55	435%
Y2	0.34	1.16	344%

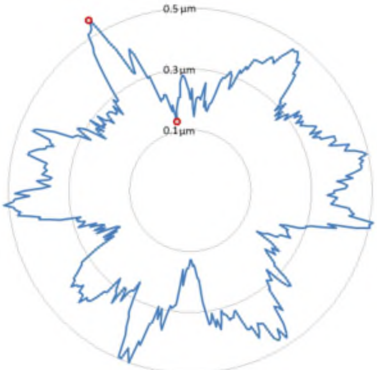


Figure 4. SPAM estimate of asynchronous error varies greatly as a function of angle of rotation. Maximum is 0.55 µm and minimum is 0.13 µm as shown above.

4. Conclusion

SPAM measurements were used before the development of modern spindle analyzers to predict asynchronous face and radial errors. SPAM does not provide information about synchronous error and the estimate it provides for asynchronous can be significantly under-reported due to large differences in the asynchronous as a function of angular orientation (more than 400% error in this work). SPAM is not an approved substitute for complete error motion metrology by the ASME B89.3.4 or ISO 230-7 standards.

References

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