Dynamic characterization of an air bearing spindle as a tool to predict asynchronous error

B. Knapp[1], D. Oss[1], D. Arneson[1], M. Liebers[1], and E. Marsh[2]
[1]*Professional Instruments Company, Hopkins, Minnesota, USA*
[2]*The Pennsylvania State University, University Park, Pennsylvania, USA*
bknapp@airbearings.com

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Abstract

Aerostatic bearings are used in precision metrology and manufacturing because of their low error motions. Currently, the data storage industry demands spindles with nanometer-level asynchronous radial error (defined by the IDEMA T17-91 standard as non-repeatable runout or NRRO). Achieving this level of accuracy requires refinement of the spindle design with feedback from performance measurements. Efforts to achieve reduced asynchronous error motion led to our implementation of a dynamic test regimen using the self-excited power spectrum combined with spindle metrology. This paper demonstrates a method of vibration measurement as a predictor of asynchronous spindle error motion.

1. Introduction

One important consideration in air bearing spindle design is the stability of the pressurized air film. Large amplitude instability (pneumatic hammer) has been addressed in the literature [2] and is largely solved in practice. However, nanometer-level vibration remains a concern in the most demanding applications. Previous work demonstrated the measurement of these vibrations [3]. These tests have been a useful tool in developing a new air bearing spindle for the disk drive industry with minimal asynchronous error. The spindle is shown in Figure 1 and has a 4 096-count rotary encoder (MicroE) and a brushless, frameless servo motor and linear amplifier (MCS). The groove compensated axial bearing uses exhaust air scavenged from the porous radial bearings. This compensation scheme results in improved vibration spectra and lower asynchronous errors.

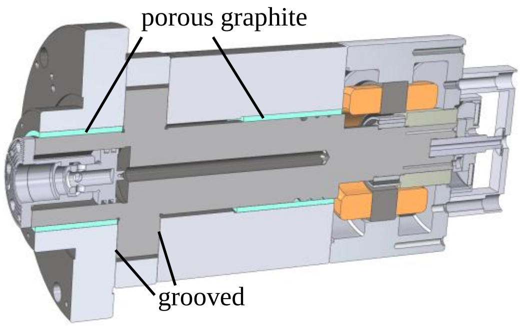


Figure 1: Spindle designed specifically to minimize asynchronous error.

2. Approach

Vibration power spectra are measured as a function of pressure and supply gas for the stationary spindle supported with compliant foam as shown in Figure 2. A high sensitivity accelerometer (1 V/g Kistler PiezoBEAM) is mounted on the spindle rotor in the radial direction. A dynamic signal analyzer (HP 35670A) is used to acquire power spectra at supply pressures from 0.6 MPa to 0.9 MPa. Total average power obtained by numerical integration from 300 Hz to 6 400 Hz provides a convenient single value for comparison.

In a separate test, asynchronous error is measured at 10 000 RPM as a function of supply pressure and gas. For these tests, an 18-bit data acquisition system (NI 6281) is triggered by the encoder (critical for nanometer-level asynchronous error motion) at 512 points per revolution. The average asynchronous error is reported for data acquired over 45 tests with each consisting of 100 revolutions. Near real-time analysis and display software (Lion Precision SEA) is used with a newly developed ultra-low noise capacitive sensor with integrated electronics and 15 kHz bandwidth (Lion Precision 2G-C8-1.2 probe with CPL490 driver). The capped-probe noise floor is 0.4 nm which is four times better than our previous sensor. The new probe and DAQ allow us to resolve the differences in asynchronous that were previously buried in the noise.

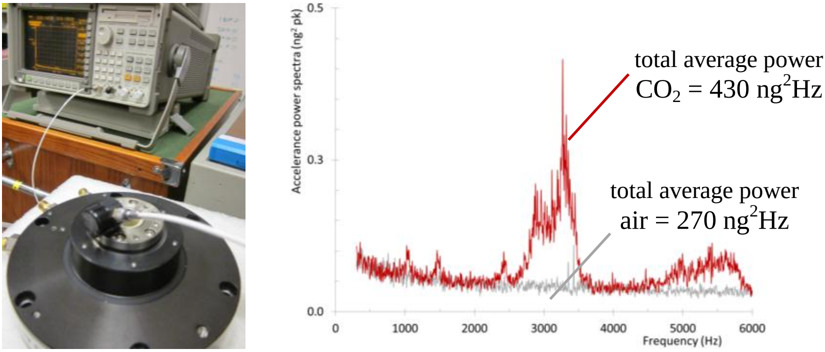
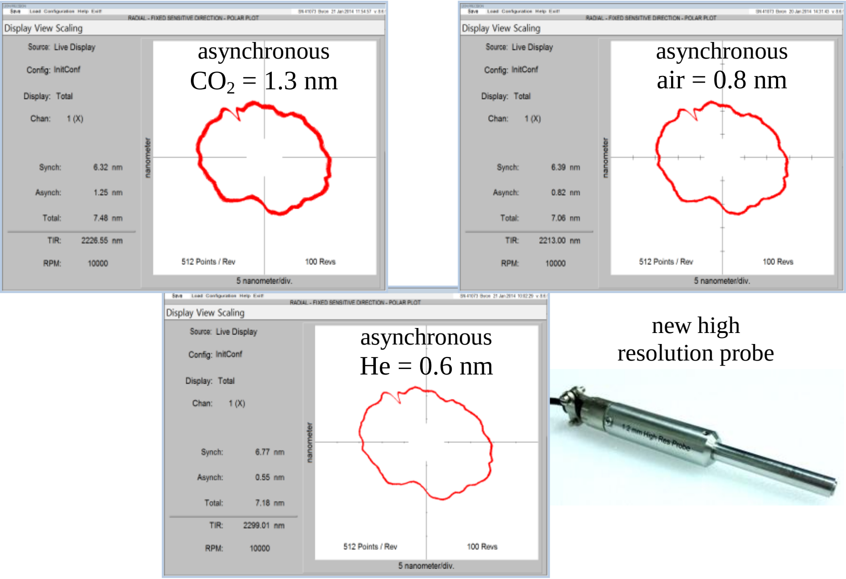


Figure 2: Spectral measurement showing the difference between air and carbon dioxide as the supply gas (at 0.9 MPa).



Source: Live Display
Config: InitConf
Display: Total
Chan: 1 (X)
Synch: 6.32 nm
Asynch: 1.25 nm
Total: 7.48 nm
TIR: 2226.55 nm
RPM: 10000

Source: Live Display
Config: InitConf
Display: Total
Chan: 1 (X)
Synch: 6.39 nm
Asynch: 0.82 nm
Total: 7.06 nm
TIR: 2213.00 nm
RPM: 10000

Source: Live Display
Config: InitConf
Display: Total
Chan: 1 (X)
Synch: 6.77 nm
Asynch: 0.55 nm
Total: 7.18 nm
TIR: 2299.01 nm
RPM: 10000

Figure 3: The new sensor allows us to see differences in the asynchronous that were previously lost in the noise floor.

3. Results

The measurement results are summarized in Tables 1-3. Air results in lower asynchronous than carbon dioxide but helium provides even lower asynchronous. With the spindle used in this paper, helium is only 20% less than air at 0.6 MPa. This indicates that flow paths and compensation scheme are nearly ideal.

Table 1. Summary of measurements using **air** as the supply gas.

Pressure (MPa)	Noise floor	0.6	0.7	0.8	0.9
Total average power (ng^2 Hz)	270	260	260	270	270
Asynchronous error (nm)	0.4	1.0	1.0	1.0	1.0

Table 2. Summary of measurements using **helium** as the supply gas.

Pressure (MPa)	Noise floor	0.6	0.7	0.8	0.9
Total average power (ng^2 Hz)	270	260	260	260	270
Asynchronous error (nm)	0.4	0.8	0.8	0.6	0.6

Table 3. Summary of measurements using **carbon dioxide** as the supply gas.

Pressure (MPa)	Noise floor	0.6	0.7	0.8	0.9
Total average power (ng^2 Hz)	270	260	270	360	430
Asynchronous error (nm)	0.4	1.5	1.5	1.8	1.9

4. Conclusion

Nanometer-level vibration levels of ultra-precision spindles translate into asynchronous error motion. This phenomenon is present in all types of air bearings to varying degrees depending on design, compensation, and dynamic stiffness. This paper demonstrates the measurement and characterization of these errors using an accelerometer and a new high-resolution capacitive sensor.

References:

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