Flow-Induced nanovibrations in two types of air bearing spindles

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Abstract

A new test for flow-induced vibrations is used to compare an orifice-compensated and a groove-compensated air bearing spindle. Stator motion is measured with the non-rotating spindle resting on a foam cushion.

Fig. 1: Rotors from 50,000 rpm spindles.

Air flowing through spindle bearings creates tiny vibrations measurable at zero speed with an accelerometer. Naturally, as the flow rate increases, vibrations increase and we have coined the term “AUC value” to describe the Area Under the Curve as measured through the range of frequencies of interest. We use AUC testing during the assembly process because an excess amount indicates a problem with clearances, alignment, or geometry.

In general, a high AUC value relates to high asynchronous error motion. [1] Knapp et al. also describe the effect of pressure variation on AUC. [1]

Spindle design is an orchestration process aimed at balancing heat vs. stiffness, cost vs. performance, load capacity vs. maximum speed, and a host of other spindle properties. In this paper—in addition to AUC—we compare flow rate and dynamic compliance for two similar-sized spindles having different design philosophies. (Figure 1)

The orifice-compensated spindle has more clearance, higher flow, lower dynamic stiffness, higher AUC, and lower self-heating.

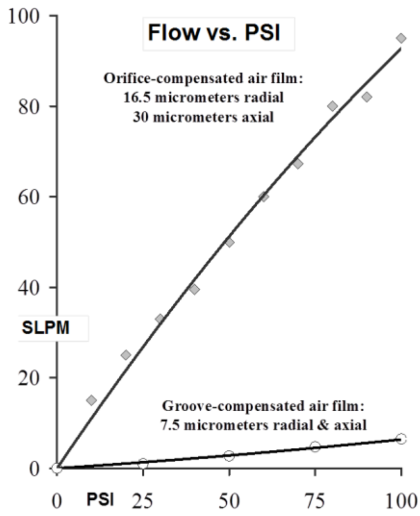

Fig 2: Comparison of flow rates as air pressure increases.

The groove-compensated spindle has similar load capacity but its air films are thinner, requiring more motor power and putting more heat into the rotor. It also has a lower flow rate, lower AUC, and higher dynamic stiffness.

In Figure 2, the difference in flow rates is because the 50,000 rpm orifice-compensated drilling spindle has high clearance for cool-running whereas the 50,000 rpm groove-compensated flycutting spindle is set up tight for maximum stiffness.

Figure 3 shows the consequences of "thick" vs. "thin" air films as they relate to axial compliance.

(Drilling does not require high axial stiffness but diamond flycutting does, so these different results are compatible with the different requirements.)

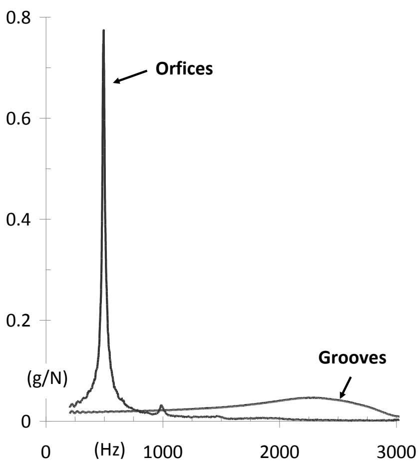

Fig. 3: Compare axial dynamic compliance.

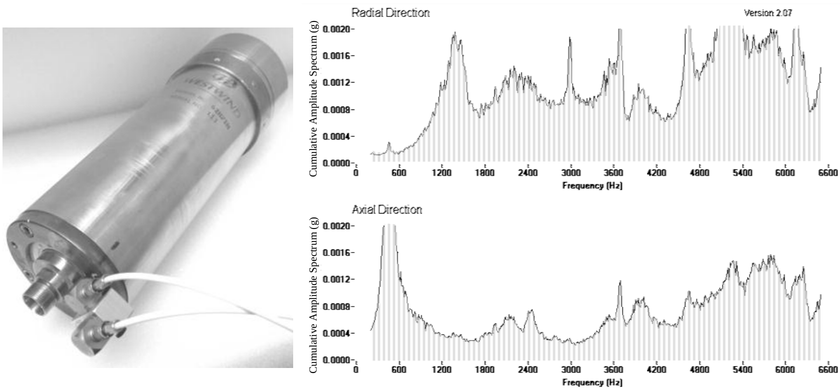

Fig. 4: Test results of an orifice-compensated spindle at 80 psi.

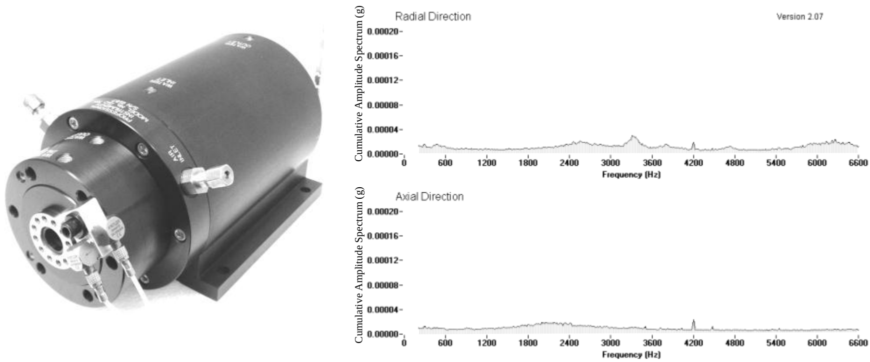

Fig. 5: Test results of a groove-compensated spindle at 80 psi.

Figures 4 and 5 show the setup and results for AUC testing an air bearing spindle for radial and axial nanovibrations. [2] "Noise" produced by flow though the bearings is detected by a stator-mounted accelerometer and shown as a series of peak magnitudes from 207.5Hz to 6 604 Hz.

The total AUC value gives us an idea of how smoothly air was flowing through the spindle bearings and this relates to asynchronous error motion of the spindle, which in turn relates to the level of attainable finish on machined parts.

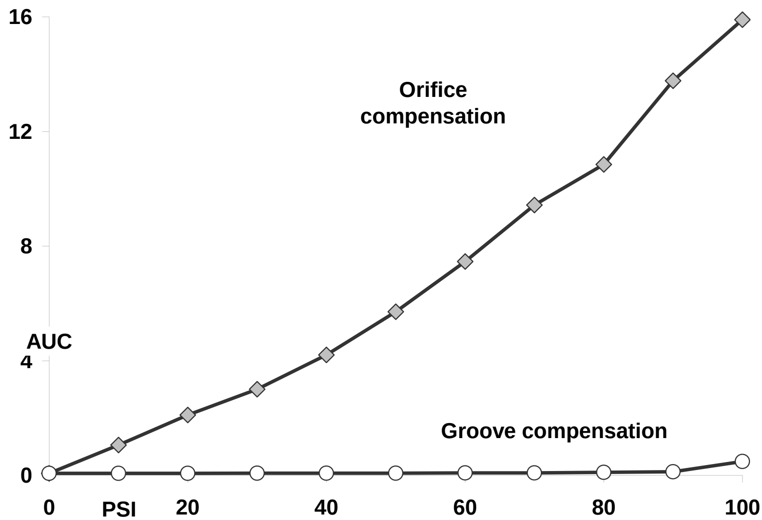

Fig 6: Compare rates of increase of AUC as air pressure rises.

Figure 6 illustrates the difference between tightly controlled flow paths vs. buffeting from multiple inlets.

Conclusions

Two similar-sized spindles with different types of compensation were found to have important differences in stiffness, flow, and nanovibrations. A simple method is shown for measuring motions due to low-amplitude disturbances in air films passing through the bearing surfaces.

References

[1] Knapp, BR et al. "Vibration Spectra and Asynchronous Error Motion of Ultra-Precision Air Bearing Spindles." Proceedings of the ASPE Topical Meeting: Precision Engineering and Mechatronics Supporting the Semiconductor Industry. 2012.

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