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Measuring central stiffness of an air bearing spindle

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Abstract
We describe a test for stiffness and load capacity for the radial bearings of an air bearing spindle. A feature of interest is the ability to measure "central stiffness", which is important for precision machining because it is needed to resist drive influence, unbalance, and tool forces. Central stiffness also comes into play on the final light cut, especially with interrupted surfaces. We define central stiffness as the ability to respond to small increases in force, particularly when the rotor is centered.

Central stiffness, spindle metrology, compliance testing, balanced radial load capacity, ultimate load capacity, Blockhead air bearing spindle

1. Motivation

The first Blockhead spindles [1] were tested for load capacity with dead weights, but while low-cost, this method does not measure the spring rate of the air films, a crucial factor for spindles used in machining applications. Thus an apparatus was designed to apply a frictionless variable force while measuring displacement (and without risking damage to the bearing surfaces at touch-down). A desired bearing property is a linear spring rate – which is achieved by fine tuning the groove compensation relative to the air film thickness. (Without spring rate information, a spindle might inadvertently be optimized for load capacity at the expense of central stiffness. *"You can expect what you inspect."* W. Edwards Deming)

2. Discussion

The test is done with the axis vertical so that measurements begin with no gravitational load on the radial bearings. Equal loads are applied on both ends of the spindle to produce pure radial displacement (without tilt), Figure 1. It is desired to measure not just average stiffness but also the central region where the bearings are lightly loaded. It is also desired to detect any deviation in linearity of the spring rate; from on-center to metal-to-metal contact. Test results are charted in terms of compliance for convenience of analysis.

3. Requirements

- Smoothly apply over 1800 newtons of balanced radial force, starting with the rotor on-center.
- Frictionless rotation under load (applied by means of external air bearings attached to the spindle).
- Air bearing load cells with a known piston area for setting the radial force by adjusting air pressure.
- Indicators mounted with short, stiff structural loops for accurate stator-to-rotor displacement measurement. [2] (Displacements are measured without rotation whereas load capacity is defined as the last point at which a full revolution can occur without metal-to-metal contact.)
- Fine-grained sampling rate of 10 or more increments in order to reveal any non-linearity.
- Adaptable to round and square stator Blockheads and for testing radial, axial, and tilt properties. [3]
- Because air bearings are sensitive to subtle changes in geometry and clearances, the tester must be able to detect small variations in spindle performance.

4. Representative results

Figure 2 plots radial displacement vs. load so that the compliance line can be examined for linearity and for where it falls within the large shaded triangle delineating the specification zone. (The dashed line is the slope of maximum allowable compliance.) The star beyond the zone indicates that the measured load capacity exceeded the specified minimum "ultimate" load capacity. The smaller triangle delineates the specified "working" zone, which is based on a safety factor limiting rotor de-centering to 50% of the metal-to-metal displacement. Charts and numerical values are used to demonstrate conformance to specifications and for production control. Test data was first used to optimize compensation on early spindles and is now used to ensure that established procedures are followed for quality control of production spindles.

5. Conclusions

Accurate measurement is the key to optimizing spindle properties and this requires special gear such as shown here.

References

[1] Patent 3472565 (Describing the Blockhead structure)
[2]ASME B89.3.4-2010 Axes of Rotation: Methods for Specifying and Testing (For definitions and basic principles.) [3] www.airbearings.com (For specifications)

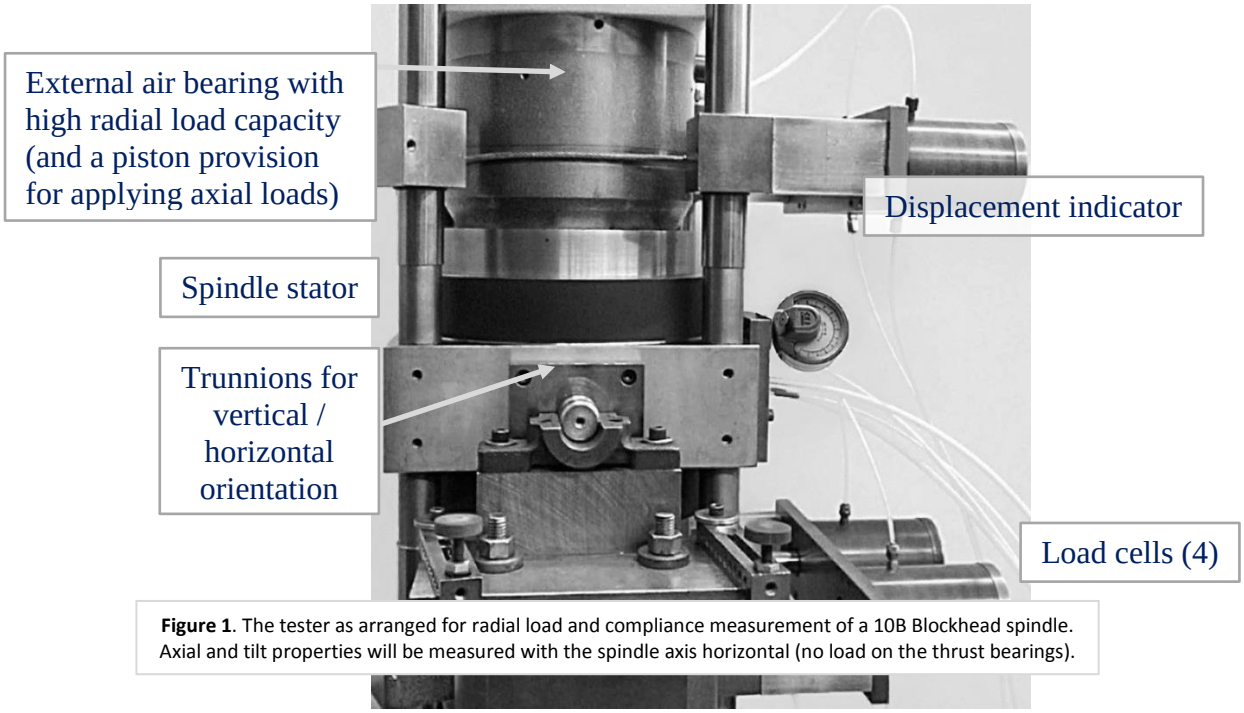

Figure 1. The tester as arranged for radial load and compliance measurement of a 10B Blockhead spindle. Axial and tilt properties will be measured with the spindle axis horizontal (no load on the thrust bearings).

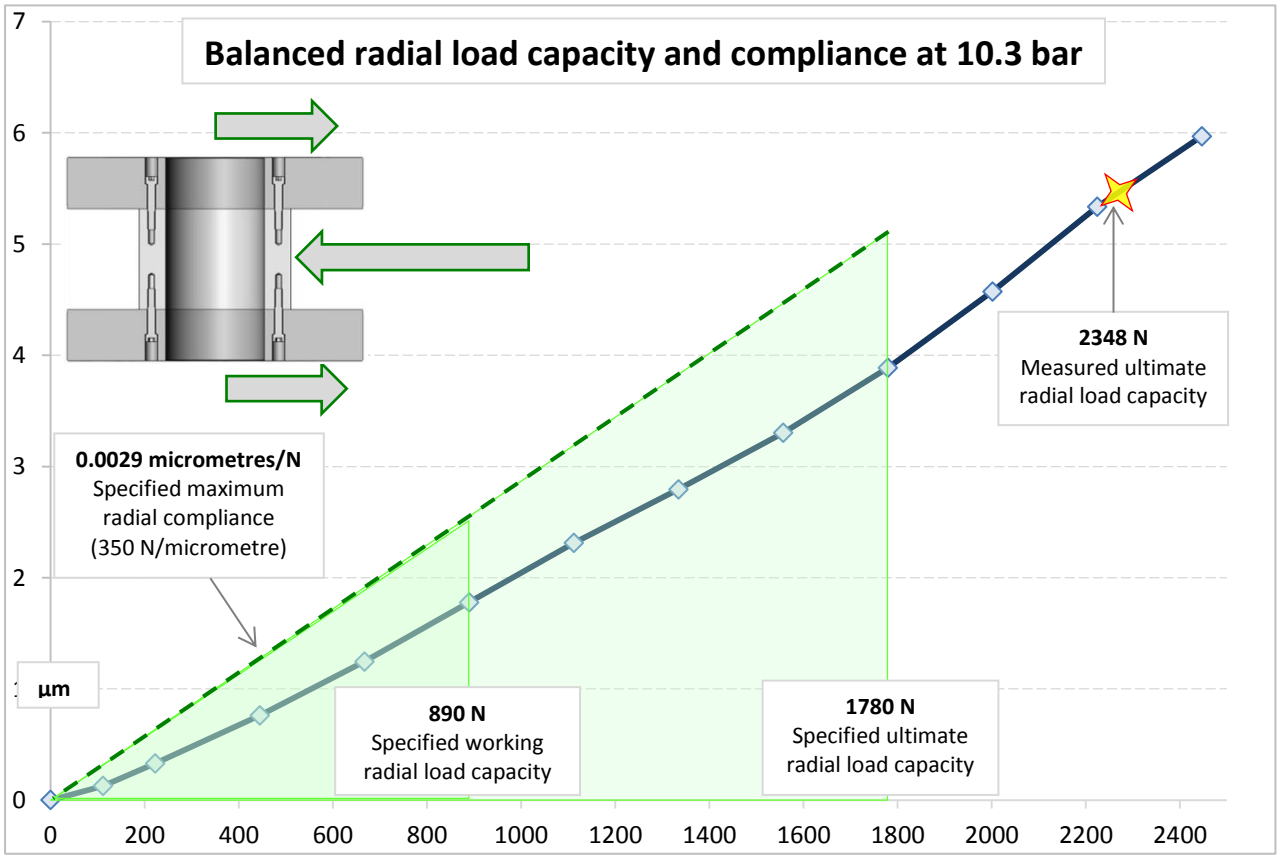

Figure 2. This annotated test report charts the radial compliance and load capacity of 10R #598.