Turning hardened steel with an oil hydrostatic spindle

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Abstract

For precision turning of hardened steels, air bearing spindles may lack the ability to withstand sudden overloads. A high pressure oil hydrostatic spindle is a logical alternative due to its greater load capacity with nanometer-level error motions. The squeeze film effects of the oil help to prevent damage to the bearing surfaces during an overload. An oil hydrostatic spindle was retrofitted into a conventional CNC lathe to explore its effectiveness in precision turning of hardened A2 tool steel. Spindle metrology tests demonstrate that this spindle has radial and axial error motion less than 12 nanometers. Cutting tests showed roundness errors better than 0.25 micrometers and surface finishes better than 0.12 micrometers Ra.

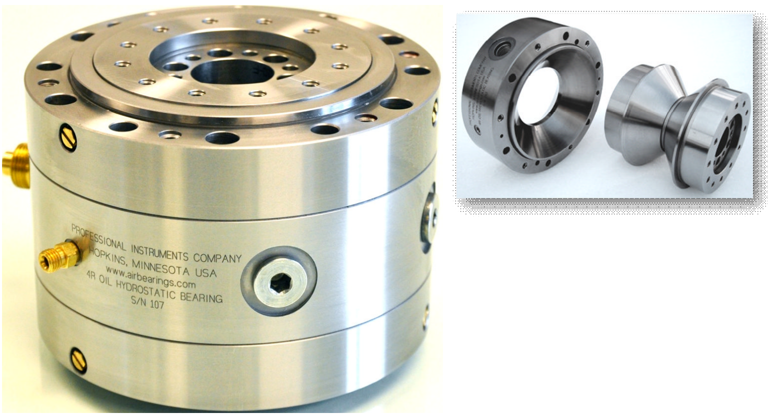

Figure 1: 4R oil hydrostatic spindle with inset view showing bi-conic bearing.

1 Design

The compact size and simple construction of the bi-conic shown in Figure 1 allows for this spindle to be used in a variety of situations. It is ideally suited to be retrofitted into existing machines. The squeeze film effects and lubricating properties of the oil help to prevent damage to the bearing surfaces during the inevitable overloads. Furthermore, spindle metrology results shown in Figure 2 demonstrate that this spindle has radial and axial error motion less than 12 nanometers. In this work, the oil hydrostatic spindle was retrofitted into a conventional CNC lathe using the lathe spindle to drive it through a non-influencing collet coupling as shown in Figure 3.

Radial Axial

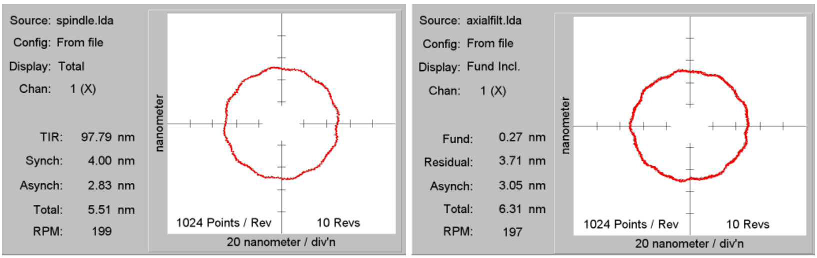

Figure 2: Spindle error motion measurements of the oil hydrostatic spindle. For this test, total radial error is 5.5 nm and total axial error is 6.3 nm.

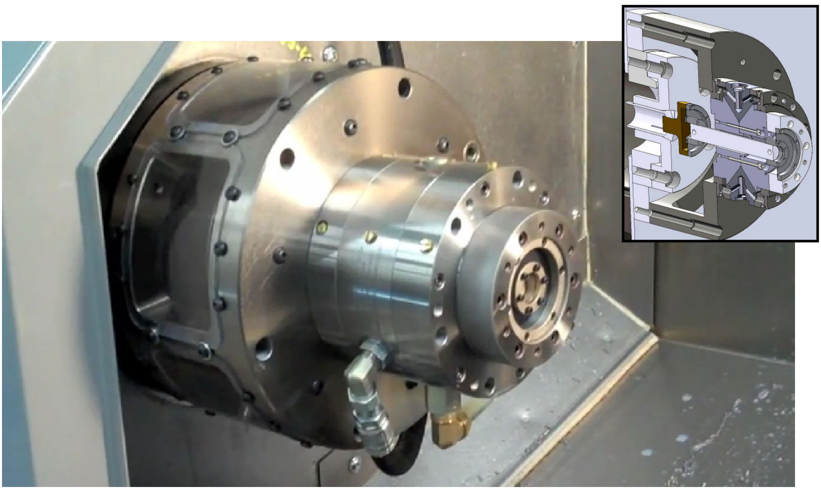

Figure 3: The hydrostatic workhead is driven by the lathe spindle through a non-influencing collet-drive.

Table 1. Stiffness and load capacity of the 4R oil hydrostatic spindle using oil pressure of 4 MPa (600 psi). These values are approximately linear with oil pressure.

	Axial	Radial	Tilt
Stiffness	350 N/μm	130 N/μm	1.1 N•m/μrad
Load capacity	9,000 N	3,000 N	300 N•m

2 Approach

A cone of A2 tool steel hardened to 63 Rc was chosen as a representative material for test cuts. The cone tapers from a 63 mm diameter to point and is 75 mm long. Sumitomo BN 350 grade 0.4 mm radius CBN inserts were used with flood coolant. The cone was cut at a constant spindle speed of 1,000 RPM. A depth of cut of 125 micrometers was used with a feed rate of 15 micrometers per revolution.

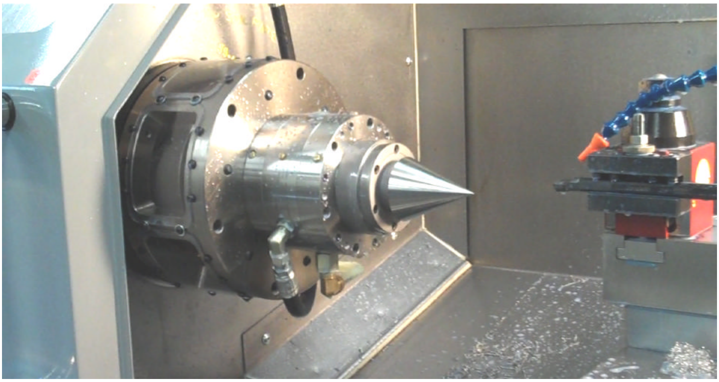

Figure 4: Setup showing the hardened A2 tool steel cone testpiece.

3 Results

Benefits of using the oil hydrostatic spindle are shown in surface finish and in form errors. A Mitutoyo SJ-400 surface profilometer was used to measure a surface roughness better than 0.12 micrometers perpendicular to the feed lines.

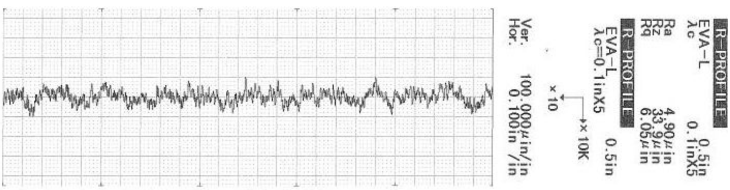

Figure 5: Surface profilometry demonstrates better than 0.12 micrometer Ra.

Roundness of the cone is measured using a 4R Blockhead® air bearing spindle with encoder for rotation. The analogue signal from a high resolution Mitutoyo 519 LVDT with a diamond tip is processed by custom roundness software. The out-of-roundness measurement of the cone is shown in Figure 6. The typical out-of-roundness is better than 0.25 micrometers.

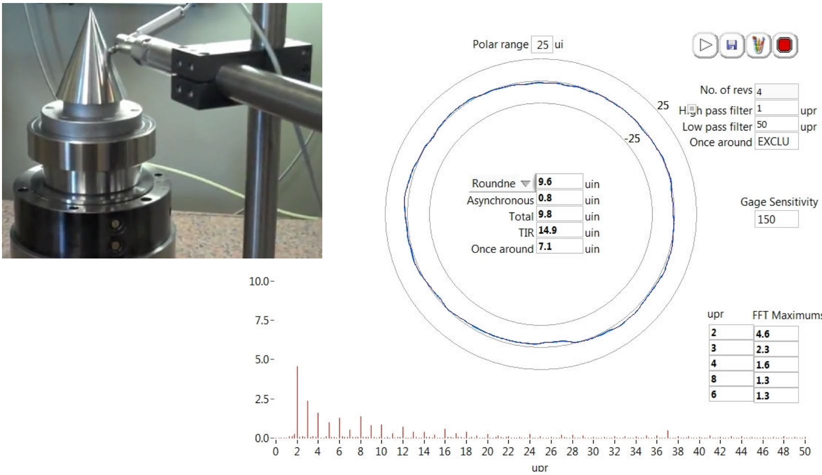

Figure 5: Roundness measurement setup and result. Out-of-roundness of the hardened A2 tool steel cone is better than 0.25 micrometer.

Conclusion

In precision industrial machining applications, an oil hydrostatic bearing can provide high load capacity with nanometer-level error motions. The precision spindle enabled superior form and finish for hard turning despite using an inexpensive toolroom lathe as the testbed [1-3].

References:

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[3] J. Lai, FE prediction of cutting error from thermal expansion of workpiece and tool in hard turning. SKF Engineering and Research Centre, The Netherlands, 2001.