Precision grinding components of a watt balance using a novel step-compensated conical hydrostatic work spindle

Dave Arneson, Mel Liebers, Byron Knapp
Professional Instruments Company, Hopkins, Minnesota, USA
darneson@airbearings.com

Abstract

For over 125 years, the standard for mass has been a platinum iridium cylinder, known as Le Grand K. As measurements have become more precise, the limitations of this approach have become impossible to ignore. To address the problems inherent in having a physical artifact for such an important unit of measurement, a new watt balance is being built to link the kilogram to absolute physical constants. Professional Instruments was contracted by the Fraunhofer Institute on behalf of BIPM to grind some of the precise components required for the design. The project is complicated by the extremely tight tolerances needed and by the large size and weight of the individual components. Professional Instruments is uniquely qualified for this type of project because the precision required for this project are quite similar to the precision required to manufacture the air bearing spindles we are known for.

This paper details tooling and procedures we employed to grind the core of the new watt balance. Because of its weight we needed to replace the standard air bearing work head spindle in our cylindrical grinder with a conical oil hydrostatic spindle that uses step-compensation instead of traditional pockets.

1. Motivation

Normally we would grind a part with such tight tolerances mounted on one of our air bearing spindles. But in this case, the weight greatly exceeds the air bearing's load capacity. Fortunately, we have recently been developing a new dual-cone step-compensated hydrostatic spindle with identical mounting to our standard 4R Block Head air bearing spindle.

Table 1: Component weight and spindle radial load capacities.

BIPM Core	360 Newtons
Fixture	90 Newtons
Total	450 Newtons
4R (air bearing) working capacity	200 Newtons
4R-H (hydrostatic) Working load capacity	1600 Newtons

2. Core

The core is a cylinder of Supra 50 iron-nickel soft magnetic alloy, 110 mm tall and 240 mm in diameter. The design of the watt balance requires it to be cylindrical to better than 1 micron. It weighs 360 Newtons, which exceeds the load capacity of most air bearing spindles.

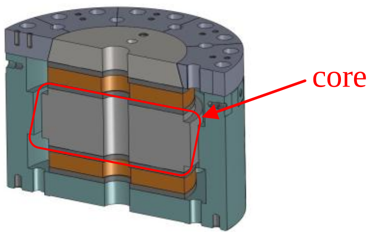

Figure 1: Cross-section of a portion of the watt balance showing the core.

3. Grinding

Grinding was done with a conventional aluminum oxide wheel running 1800 rpm on an air bearing wheel spindle. Workhead spindle oil pressure was 41 bar and specially designed in-process gaging was used to monitor part geometry during the grind.

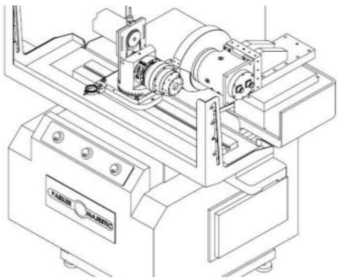

Figure 2: Parker Liberty One CNC cylindrical grinder retrofitted with an air bearing wheel spindle and hydrostatic work spindle.

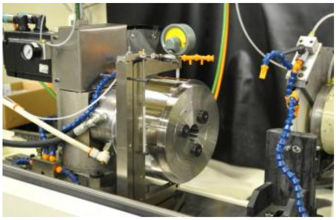

Figure 3: In-process inspection of the core using a CEJ Mikrokator, mounted in a C-frame supported on parallel reeds.

4. Hydrostatic Spindle

The model 4R-H hydrostatic spindle was designed to fit in place of our air bearing spindle, using the exact same mounting pilots and bolt circles. Hydrostatic spindles have big advantages over air bearings in load capacity, crash resistance and dynamics but they are generally large and cumbersome.

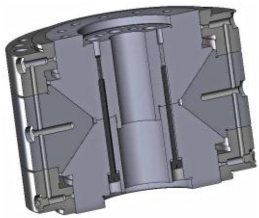

Figure 4: Cross-section of the 4R-H step-compensated hydrostatic spindle.

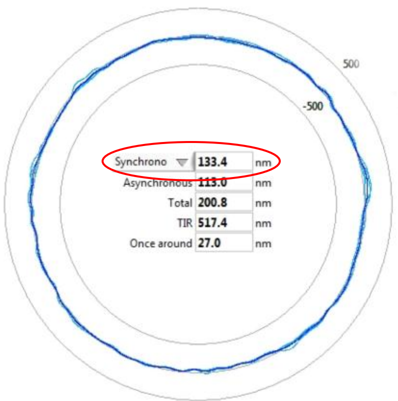

Figure 5: Roundness measurement results (0.13 micron).

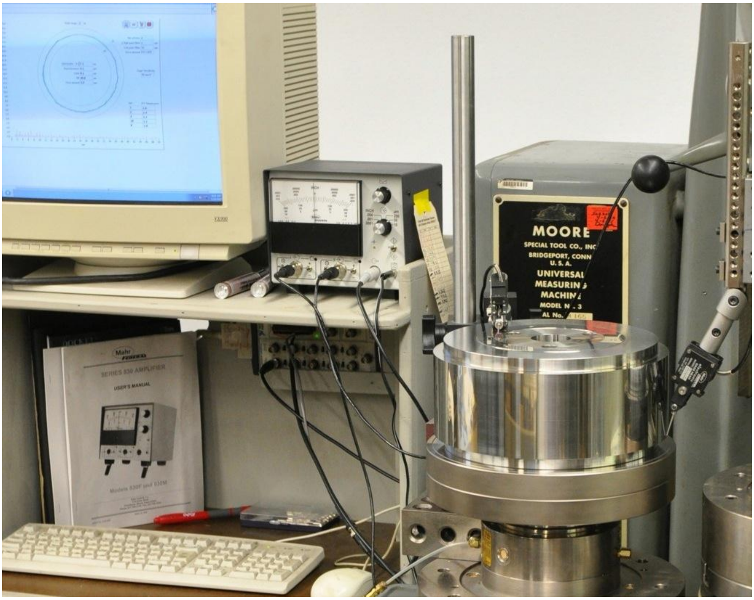

Figure 6: Inspecting the core using a 4R Block Head air bearing spindle and software developed at PSU by Professor Eric Marsh.

5. Conclusions

The tolerance allowed for cylindricity of this part is only 1 micron; our final result ended up being 0.6 micron, well within the required accuracy. The unique compact, modular design of the 4R-H spindle allowed us to grind large very precise parts in a compact and relatively inexpensive machine.

References:

[1] R Courtland. (May 2012). The Kilogram, Reinvented. In *http://spectrum.ieee.org/consumer-electronics/standards/the-kilogram-reinvented/0.*

[2] N Kane, J Sihler and A Slocum. A hydrostatic rotary bearing with angled surface self-compensation. Precision Engineering, 27(2):125–139, 2003.

[3] B Knapp, D Arneson, M Liebers, D Oss, and E Marsh. Design and testing of a step compensated bi-conic hydrostatic spindle. Proceedings of the 24th Annual ASPE Meeting: Monterey, CA. October 2009.