MINIATURE AIR-BEARING SPINDLES: CAN WE SCALE DOWN FROM STANDARD-SIZE BEARINGS?

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In recent years there have been efforts to make smaller and smaller, or miniature, machine tools. The reasoning is that for making smaller parts, the machine tools should be smaller, as well. For example, a standard ultra-precision air-bearing spindle lathe might be able to make a part 250 mm in diameter; however, the maximum size part needed in the miniature shop might be only 25 mm in diameter, or one-tenth that size. Why not just make a lathe one-tenth the size? A smaller machine would be much lighter and easier to move around, but would it be easier and cheaper to make? And even more important, would it be as accurate as the bigger machine? To answer these questions we can look at some of the principles involved in scaling mechanical systems.

The most straight forward approach to designing scaled or miniature mechanical systems is to simply scale all dimensions by the same number, referred to as the scale factor. For our example, the common ultra-precision lathe might have a 100 mm diameter spindle journal, so our new miniature lathe for one-tenth size parts would have only a 10 mm diameter spindle. The guide way motion, width and thickness of all components, etc. (all independent length parameters) should also be scaled by the factor of ten. The error motions of the spindle are expressed as a linear dimension (so many m of error), so the errors (and all dependent parameters with length dimensions) should be scaled by the same scale factor if the scaling is done properly. So a common ultra-precision lathe that had a spindle error motion of 50 nm, should have a error motion of only 5 nm if the scaling holds true.

This paper examines the scaling of the machine tool type air bearing spindles and investigates the concern that error motions may not scale with the overall size scaling of the spindle. If a scaled down spindle, or miniature machining spindle, does not improve in accuracy over a traditional size spindle, then there may be an optimum size for the machining spindle. Therefore, this paper speculates on how to estimate the optimum size air-bearing spindle for ultra-precision machining.

This work presented here builds on previous work presented at an ASPE spring meeting: A similitude analysis for miniature machining, R. Rhorer, ASPE Spring Topical Meeting on Micrometer-Tolerance Assembly of Macroscopic Structures, Tucson, Arizona, April 4-7, 1995, pg. 34-37.