Design of a nanometer-accurate air bearing rotary stage for the next generation nano-CT scanners

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Abstract

Micro- and nano-CT scanners are increasingly used in precision engineering. Proper selection of the key components of these devices allows elimination of most artifacts already during data acquisition. Typical nano-CT scanners contain an air bearing rotary stage for object manipulation due to their rotational accuracy compared with conventional bearings. In this work, the radial error motion of such an air bearing rotary stage is reduced to 3 nm by optimising the feeding system, leading to a new state of the art record for passive aerostatic bearings to our knowledge.

1 Introduction

Today, nano-CT scanners have a resolution as fine as 50 nm and are used in several applications like life science studies, semiconductor industry and advanced material analysis. They contain three main components: an X-ray source, an object positioning system and an X-ray detector. However, the key parts are not ideal and in most cases designed as a compromise between performance and price. Performance limitations in the key components lead to artifacts in the acquired angular projections and reconstructed slices. Most studies in the field have focussed on increasing the accuracy of the X-ray source/detector and by compensating the artifacts through acquisition and reconstruction software. However, there is still much room for improvement by increasing the performance of the positioning system. This is the objective of this work.

2 Air bearing design

The axis-of-rotation error motion of a well-designed aerostatic rotary stage is mainly determined by the machining accuracy of the bearing surfaces as the clearances should be as small as possible in order to obtain a high stiffness. The influence of various manufacturing errors and bearing parameters on the radial error motion of an aerostatic journal bearing is analysed in [1,2]. The results of this study show that the running accuracy can be improved most effectively by increasing the number of feedholes N_f of an air bearing system. As a result, the pressure profile between rotor and stator is more uniform, which ultimately reduces the influence of irregularities in the bearing surfaces.

However, the number of feedholes of an air bearing system is restricted from practical point of view. A porous material, on the other hand, has an infinite number of feedholes (ideally). As a result, a 2-DOF orbit model is developed to analyse the radial error motion of a porous aerostatic journal bearing. The results were very encouraging: 3 nm radial error motion.

3 Experimental validation

An existing air bearing rotary stage with inherent restrictors was adapted to a porous type air bearing in order to validate the theoretical results. However, the thrust bearings, each made up of eight inherent restrictors (N_f = 8), were not adapted. The radial error motion is measured with the use of a novel reversal technique [3], separating the artifact form error from the error motion. The measurement setup is shown in Fig. 1.

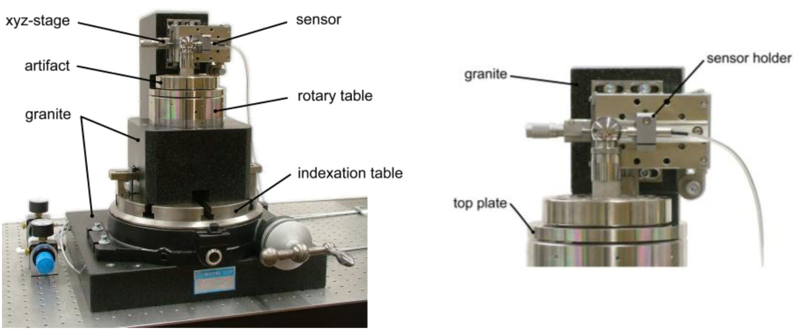

Figure 1: Measurement setup.

The radial error motion of the rotary table, partially mounted in a granite block which is placed on a high-precision indexation table, is measured at a rotational speed of 60 rpm and a supply pressure of 5 bar. The rotor is manually driven as an electrical drive system can have a significant influence on the performance. The rotary table is equipped with a rotary encoder triggering the data sampling at evenly spaced angular increments. In this way, the effect of spindle speed fluctuations is eliminated.

The least squares synchronous radial error motion of the rotary table under test is 9 nm, as illustrated in the polar plot of Fig. 2. This result differs slightly from the 3 nm calculated by the orbit model. From Fig. 3 it can be seen that the harmonics at $n = k \cdot N_f \pm 1$ with $k \in N_0$ (grey) are remarkably higher than the remaining harmonic components (black). This can be attributed to the tilt error originating from the thrust bearings, which were not taken into account in the orbit model.

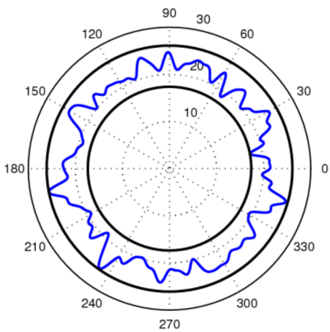

Figure 2: Radial error motion of the rotary table under test (9 nm).

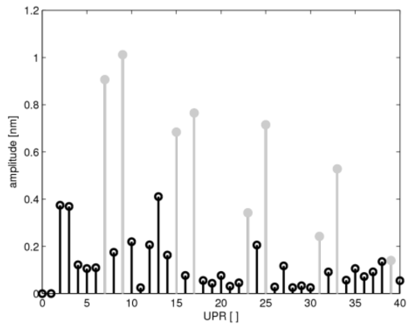

Figure 3: Frequency spectrum of the synchronous radial error motion.

From the data in Fig. 3, it is apparent that the influence of the thrust bearings cannot be ignored. As a result, a new rotary table, with the journal and thrust bearings each made up of a porous feeding system, was designed and validated.

The synchronous and asynchronous radial error motion of this new design (full porous) is compared with the first rotary table (journal: porous – thrust: restrictors) for several supply pressures P_s in Fig. 4. It is apparent from this figure that both the synchronous and asynchronous radial error motion is reduced to 3 nm and 2 nm, respectively, by using a porous feeding system instead of inherent feedholes for the thrust bearings. These results nearly equal the noise level of the Elite Series capacitive sensors of Lion precision used for the tests (1-2 nm).

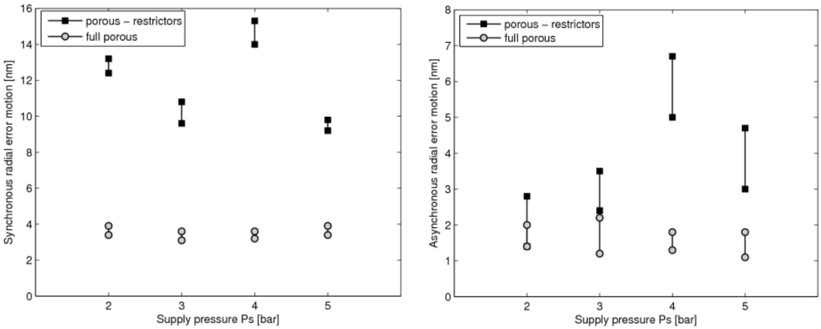

Figure 4: Comparison of the synchronous and asynchronous radial error motion of a full porous and partially porous aerostatic rotary table.

4 Conclusions

In this work, the radial error motion of an aerostatic rotary table is reduced to the noise level of the capacitive sensor, i.e. 3 nm. This is a new state of the art record for passive aerostatic bearings to our knowledge. To achieve this, the supply geometry of the air bearing rotary system was optimised by increasing the number of feedholes by the use of a porous feeding system.

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References:

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