IDENTIFICATION OF THE INFLUENCE OF THE DIFFERENT AIR BEARINGS COMPRISED IN AN AXIS OF ROTATION SYSTEM ON THE RADIAL ERROR MOTION

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PROBLEM STATEMENT
The large-scale application of gas lubrication remains restricted only to a few domains. The reason is twofold: firstly because of the disadvantages and/or limitations of an improperly designed air-bearing system and secondly because of the limited awareness of engineers of the existence of practical and reliable gas bearing solutions. However, air bearings, whether they are rotary or linear, are very well suited for high-precision applications such as roundness measurement machines, diamond turning machines, nano- CT scanners and wafer-steppers. The absence of friction and wear makes air bearings most suitable for these applications. The running accuracy of a well-designed air bearing will be mainly determined by the machining accuracy of the bearing surfaces because the clearances of air bearings should be made as small as possible in order to obtain high stiffness. When production capabilities reach their limitations, and so threaten to limit the attainable running accuracy of air bearings, other solutions have to be devised in order to ensure that air bearings can still reach the accuracy needed for ultra-precision applications in an affordable way.

In a previous work [1,2], the influence of the journal air bearing was studied and optimized. In this work, the influence and the interaction are studied of the different air bearings of an axis of rotation system on the radial error motion with the objective to increase the running accuracy.

GOAL
The general objective of this work is to find ways to reduce the radial error motion, i.e. the deviation from perfectly centric motion, of an air-bearing rotary system to a nanometer level (< 5 nm). This may be achieved by mitigating and/or compensating for the influence of the form errors of the component parts by optimizing the design parameters of an aerostatic bearing.

APPROACH
An axis of rotation system comprises typically a journal bearing and two thrust bearings, which all have an influence on the radial error motion, being coupled through the geometrical imperfection of the rotor. Therefore, in this study, a coupled air-film model is developed that can account for the minutest details affecting the error motion and the dynamic film forces. Such detailed models are indispensable to optimize the air bearing design.

THEORETICAL MODELLING
An in-house developed finite-difference model of gas film behaviour is adapted in order to analyse the influence of various manufacturing errors and feedhole configurations on the radial error motion of an aerostatic journal bearing [1]. The influence of several bearing parameters on the running accuracy is analysed with the aid of this reliable numerical model [2]. Results show that the radial error motion of an aerostatic journal bearing can be reduced most effectively by increasing the number of feedholes (Nf) as illustrated in figure 1.

FIGURE 1. The radial error motion as function of the feed number (Af) evaluated for a various number of feedholes (Nf).

However, the number of feedholes of an air bearing rotary system is restricted, from practical point of view. A porous material on the other
hand has an infinite number of feed holes. For this purpose, the finite difference model was adapted and validated in order to analyse the radial error motion of a porous aerostatic journal bearing. The first results were very encouraging. Further analyses showed a radial error motion smaller than 1 nanometer for the journal bearing.

EXPERIMENTAL RESULTS
The radial error motion of a fully porous aerostatic journal bearing is measured 133 mm above stator centre at a rotational speed of 60 rpm. The thrust bearings of the rotary table were made up of eight inherent restrictors. The measurement setup, used to remove the artifact form error, is depicted in figure 2.

![Measurement Setup](image)

**FIGURE 2.** Measurement setup used for separating the artifact form error from the radial error motion.

The least-squares synchronous radial error motion of the rotary table turns out to be 8 nm as shown in figure 3. However, this result clearly differs from our model. Further analysis showed that this difference can be attributed to the tilt error originating from the eight inherent restrictors of the two thrust bearings. This is clearly visible in the spectrum of the radial error motion shown in figure 3. The amplitude of the harmonics $n = k \cdot N_f \pm 1$ with $k \in \mathbb{N}^*$ (red colored) is remarkably higher than the amplitude of the remaining harmonic components (black colored). It can also be shown experimentally that these high amplitudes originate from the thrust bearings by reducing their influence while measuring the radial error motion. To this end, the top-thrust bearing was removed from the test setup, while the clearance between the rotor and the bottom-thrust bearing was increased by increasing the supply pressure. The result of this test is depicted in figure 4. It is clear that the overall amplitude of the harmonics $n$ decreases as the clearance (h) increases. This result indicates once more that the high amplitudes of the harmonics $n$ originate from the tilt error of the thrust bearings. As a result, the influence of the thrust bearings cannot be ignored during the analysis. Therefore, the air film model will be extended to a coupled model in order to optimize the integrated air bearing design. The outcome will be validated experimentally in the coming months and the results will be reported in the final paper.

![Spectrum](image)

**FIGURE 3.** Polar plot (left) and spectrum (right) of the measured synchronous radial error motion of the rotary table made up of a fully porous aerostatic journal bearing.

**FIGURE 4.** Spectrum of the radial error motion measured at different clearances (h) proving the influence of the thrust bearing on the radial error motion. Remark: these measurements include the artifact form error.

REFERENCES