Dynamical Investigation of a Wrap-around Gas Bearing Design in a Vacuum Environment

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Abstract

Ultra precision positioning stages often use gas bearings to realize the sophisticated demands of positioning accuracy and repeatability which are required for tasks like wafer processing and inspection, e.g. for EUV lithography. One common method of realizing a linear guided structure with high stiffness is a wrap-around design of two or more thrust gas bearing pads. Since some of the processes have to be performed in a high vacuum environment, dynamic tests are carried out inside of a vacuum chamber. The influences of different input parameters (supply pressure, velocity) on the stability of the wrap-around design are investigated. The first results show that no self-excited vibrations occur at supply pressures up to 400 kPa and a maximum velocity of 80 mm/s.

1 Introduction

A number of challenges have to be faced in order to operate a gas bearing stage such as the preloading of the gas bearing pads or the exhaustion of the supplied gas when operating in a high vacuum environment. A common method to exhaust the gas is to surround the gas bearing pads with differential pumped exhaustion structures. Hence, the surrounding pressure of the gas bearing pads is a low or medium vacuum what causes a reduced stiffness of the gas bearing pads compared to the usage at atmospheric pressure [1].

The result of a reduced dynamic stiffness is the higher risk of creating self-excited vibrations. Especially the possible occurrence of the so-called air hammer shall be determined in the vacuum environment. This effect describes an instability where the bearing surface and the counterpart collide and therefore wear and friction occurs. That may lead to the loss of guiding ability and even to structural failure.

2 Setup

The experiments were performed inside of a vacuum chamber, which simulates the low to medium vacuum environment surrounding the gas bearing pads. The simplified arrangement of the wrap-around configuration is shown in Fig. 1.

A ceramic plate with two highly flat (0.8 µm peak-to-valley) and parallel (< 2 µm) surfaces as well as a very low roughness (arithmetic average Ra = 0.2 µm) was used as a movable bearing counterpart. Two fixed porous gas bearing pads arranged on each side performed the wrap-around design to guide the plate. A driven ball bearing stage performed the motion of the ceramic plate itself. The stage and the ceramic plate were connected by two flat springs in order to realize a parallel alignment of the ceramic plate with respect to the gas bearing pads. They were adjusted parallel to each other and with a µm-accurate gap height in between. Different load carrying capacities of the gas bearing pads cause a non-parallel displacement of the ceramic plate with final gap heights between 4 µm and 5 µm.

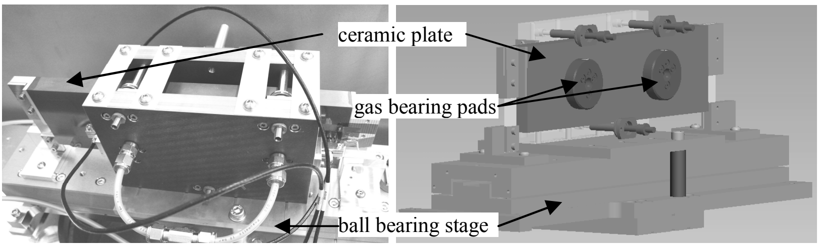

Figure 1: experimental setup (left: picture; right: CAD view with removed side plate)

3 Investigations

The varied input parameters are the supply pressure of the gas bearing pads (200, 300 and 400 kPa), the maximum velocity of the ceramic plate (0, 20, 40 and 80 mm/s) and the surrounding pressure (ambient conditions: 100 kPa, vacuum conditions: 400 Pa).

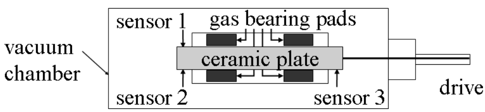

Figure 2: schematic setup with position of sensors

The gap height deviation between the ceramic plate and the gas bearing pads is measured during the oscillating movement of the ceramic plate. For this purpose, three capacitive sensors are fixed at the same level as the gas bearing pads. The location of the sensors can be seen in Fig. 2. The moving range is approx. 40 mm.

4 Results

The following results are extracts of the different parameters. All shown graphs are obtained with a supply pressure of 300 kPa relative to the surrounding pressure and all signals are measured with sensor 1. The FFT-spectra in Fig. 3 show the frequency range between 7 Hz and 500 Hz in order to cut off the disturbing lower frequencies (e.g. the fundamental mode of the building). In the expected frequency range of self-excited vibrations (several 100 Hz), no higher amplitudes are measured.

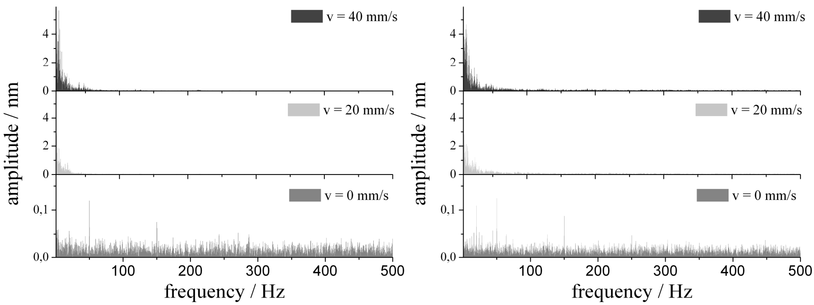

Figure 3: FFT spectra of plate motion (left: ambient conditions; right: vacuum conditions)

Additional information can be derived from the corresponding time signals in Fig. 4, which are obtained with the same parameters. The straight sections in the left graph represent the time of stopped movement between the inversions of the moving direction.

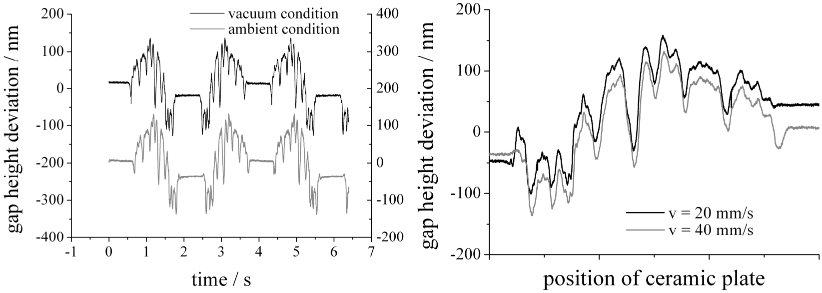

Figure 4: time signal during motion (left: 40 mm/s; right: ambient condition)

The right graph in Fig. 4 shows one single movement with different velocities. Both movements are similar compared to the position of the ceramic plate, having a standard deviation of ± 10 % over the range of constant velocity.

Based on the repeatable and highly symmetrical curves, it can be assumed that the form deviations of the ceramic plate mainly affect the run of the curve. Higher amplitudes at low frequencies (below 100 Hz, see Fig. 3) are mainly caused by position depended vibrations of the ball bearing stage or the friction drive. Therefore, the analysis of the actual gas bearing pad caused vibrations (noise) can not be performed with the used setup since the disturbing amplitudes exceed the bearing pad caused amplitudes. However, all results show no occurrence of instabilities or air hammer effects.

5 Conclusion

The wrap-around design is a suitable method for preloading gas bearing pads in a vacuum environment. No self-excited vibrations and no air hammer effect have been detected, even for the limit parameters of 400 kPa supply pressure and a velocity of 80 mm/s.

References:

[1] Schenk C, Buschmann S, Risse S. et al.; *Comparison between flat aerostatic gas-bearing pads with orifice and porous feedings at high-vacuum conditions.*; Precision Engineering 2008; Vol. 32: 319–328.