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Contact-free exhaust system for vacuum compatible gas bearing guides

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ABSTRACT

Using linear gas bearing guides in a high vacuum environment, the common method to keep the vacuum quality is to exhaust the gas emitted by the bearing pads before leaking into the vacuum chamber. Thereby the exhaust tubes between the guide and the exhaust pumps should interfere with the guide as little as possible while maintaining a flexible connection and a highly effective exhaustion rate. A novel exhaust system that implements these requirements is described within this paper. The major achievement was the realization of two exhaust tubes slidable into one another combined with the known method of non-contact clearance seals, thus enabling an highly efficient and yet disturbance free exhaustion. This setup was developed and characterized at static and dynamic conditions. An analytical model for dimensioning the non-contact seal was worked out and experimentally verified. The number of seal stages and the clearance height were identified as the major impact factors on the leakage rate of the setup. It is concluded that the investigated approach is very suitable for vacuum compatible gas bearing guides since a vacuum level in the order of 10^{-4} Pa was maintained during the experiments.

1. Introduction

The outstanding qualities of linear gas bearing guides, such as positioning and guiding accuracy, can be used for many positioning tasks in vacuum environments, e.g. for lithographic processes and interferometric measurements. To cope with the gas load, the gas bearing pads have to be enclosed by exhaust stages which consists of exhaust grooves followed by sealing areas realizing a high flow resistance. The exhaust grooves are connected to vacuum pumps via exhaust tubes in order to discharge the supplied gas before leaking into the vacuum chamber [1–3]. An efficient exhaustion rate can be realized by using exhaust tubes with a high conductance. This requires that the length of the tubes is made as short as possible and the cross-section as large as possible. In addition, it is essential to evacuate the gas from the exhaust grooves without generating disturbing forces or moments and therefore without affecting the precision of the guide adversely. Particularly for guides which are fully integrated in a vacuum environment and have non-stationary bearing pads and exhaust systems, suitable designs have to be found.

Metal hoses and tubes which are typically used for vacuum technologies cause unwanted forces and moments which are not acceptable for this application. A possible solution is the usage of plastic exhaust tubes [4] which are – compared to metal tubes – less disturbing. However, the high permeability of these tubes is disadvantageous (permeation rate approximately 10^{-5} Pa l s^{-1} m^{-2} vs. 10^{-15} Pa l s^{-1} m^{-2}) since it causes a higher leakage rate and the plastic tubes can still affect the motion adversely.

Thus, it is advisable to use a contact-free connection type between pumps and linear guide. A known way to realize this approach is the integration of the exhaust pipes into the stationary part of the guide and to hand over the exhausted gas from the movable part to the stationary part via communication slots [5,6]. Each communication slot is connected with an exhaust or communication groove of the movable part. The length of these grooves is at least equivalent to the motion range of the guide. This results in expanded seal gaps and in a high leakage rate of the exhaust system, strongly scaling with the motion range.

The leakage rate of the exhaust system approach presented within this paper is almost independent from the motion range, while still maintaining a contact-free connection with a high exhaust efficiency [7]. Preliminary experimental results have been discussed in [8]. The purpose of this paper is the experimental and analytical characterization of the static and dynamic behavior of the developed exhaust system, as well as the determination of the major impact factors on the leakage rate.

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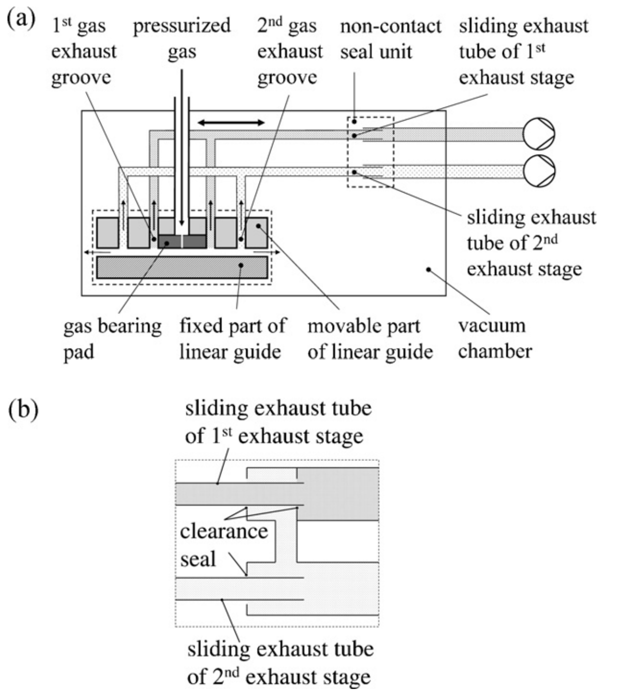

Fig. 1. Schematic, cross-section view of a vacuum compatible gas bearing guide. (a) vacuum compatible gas bearing guide with two-stage exhaust system and (b) enlarged view of the non-contact seal unit.

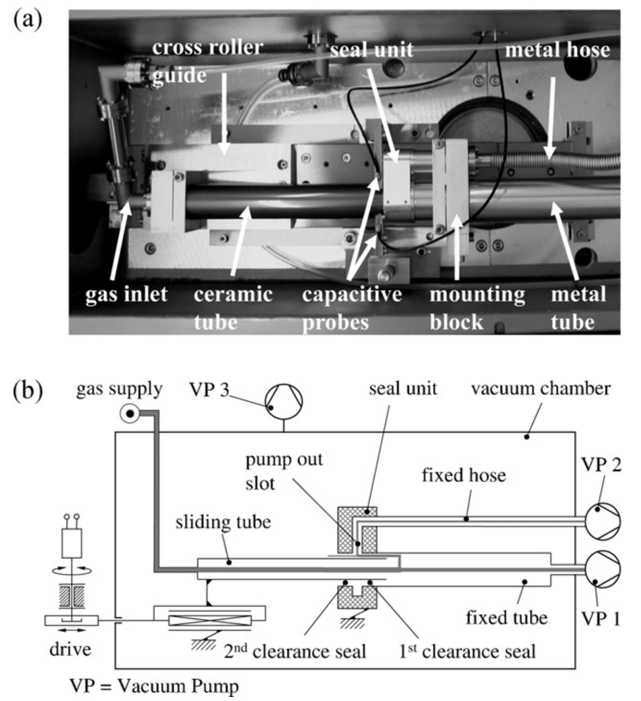

Fig. 2. Experimental setup (configuration 1): (a) view on top of the setup inside the vacuum chamber and (b) schematic view of the setup.

2. Design of the exhaust system

A schematic setup of a two-stage exhaust system including a seal unit is shown in Fig. 1(b). The exhaust pipe of each exhaust stage is comprised of two tubes which can slide into one another, separated by a non-contact, ringlike clearance seal (further refered to as clearance seal) located at the vacuum-sided end of the ringlike spacing between the tubes.

The gap height of the clearance seal has to be small to ensure a high efficiency of the seal unit. Therefore, the geometrical error and the bending, caused by the gravitational force of the single-side clamped sliding tube have to be minimized. A high specific stiffness of the used material and a small wall thickness are highly favorable.

The pressure within the exhaust tubes depends on the order of the exhaust stage. The first exhaust stage which is closest to the bearing pads (see Fig. 1(a)), discharges the largest amount of gas. This results in a pressure inside the evacuated exhaust tube in the order of 1 Pa up to 100 Pa. The smaller amount of gas discharged by the second exhaust stage yields a pressure typically in the order of 0.1 Pa up to 1 Pa. These pressure ranges were theoretically calculated according to the layout of an actual planned stage. They are comparable with the pressure ranges of the according exhaust grooves in [9]. Consequently, seal systems with different complexity are required for the particular exhaust stages.

Regarding the gas bearing guide in Fig. 1(a), the fixed and the sliding tube of the second exhaust stage are sealed up by a single clearance seal, leading to a low leakage rate due to the comparatively small pressure inside the tubes. The tubes of the first exhaust stage are sealed up by two clearance seals with a circumferential slot in between which has a connection to the exhaust pipe of the second exhaust stage within the seal unit (see Fig. 1(b)). Thus, the major part of gas passing the first of the two clearance seals is exhausted by the second exhaust stage and only a significantly reduced amount of gas passes the second clearance seal and leaks into the vacuum chamber.

This newly developed design allows for a small width[1] and a length of the seal gap that are independent from the motion range of a guide.

3. Experimental setup

The investigations were performed on an exhaust system separated from the gas bearing guide in order to achieve a setup with a reduced complexity and to enable the characterization of the system for a widespread set of input parameters. The structure of the setup is shown in Fig. 2(a) and (b).

The sliding tube of the exhaust pipe is mounted on a cross roller guide that is fixed inside a vacuum chamber. This tube slides through the non-contact seal unit into a fixed exhaust tube that is connected to a vacuum pump (VP1, see Fig. 2(b)). Via a PTFE hose, nitrogen[2] can be supplied to the sliding tube forming the required pressure distribution.

The axis of the sliding tube is aligned parallel to the movement axis of the cross roller guide in preliminary experimental settings. Therefore adjustment elements that are integrated in the mounting of the tube and two capacitive displacement sensors that are fixed on the base plate (see Fig. 2(a)) are used. The sensors are placed perpendicular to each other and to the axis of the sliding tube. The adjusted and fixed position between the sliding tube and the sealing surfaces is not assured to be ideally concentric because the distance measuring setup used cannot provide the real distance between these surfaces. To secure an accurate position of the sliding tube, the shift during the fixing process is measured.

The applied seal units are comprised of two coaxial sealing surfaces with a length of 10 mm and a circumferential pump-out slot of 10 mm in between, see Fig. 3. The sealing surface has a roughness

[1] Approximately the perimeter of the sliding tube.

[2] Nitrogen is favorable for gas bearing applications since it is easy to produce and widely available in a moisture- and oil-free state and it can be evacuated more effective than compressed air.