DYNAMICAL NON-CONTACT EXHAUSTION PIPE FOR VACUUM COMPATIBLE AIR GUIDED STAGES

Nils Heidler¹,², Christoph Schenk², Gerd Harnisch², Stefan Risse², Gerhard Schubert³, Ramona Eberhardt² and Andreas Tünnermann¹,²

¹ Institute of Applied Physics, Friedrich-Schiller-University, Germany
² Fraunhofer Institute for Applied Optics and Precision Engineering IOF, Germany
³ Vistec Electron Beam GmbH, Jena, Germany

ABSTRACT
The exhaust tubes of high vacuum compatible gas bearing guides should interfere as little as possible with the guide while maintaining a flexible connection and a highly effective exhaustion rate. Within this paper, a novel exhaust system is described that implements these requirements. The major achievement is the realization of a non-contact sealing between two exhaust tubes slideable into one another. This setup is characterized at static and dynamic conditions. The number of seal stages and the clearance height are identified as major impact factors on the leakage rate of the setup. It is concluded that the investigated approach is very suitable for the guides, allowing for an efficient exhaust and avoiding mechanical disturbing forces.

INTRODUCTION
The outstanding qualities of linear gas bearing guides like positioning and guiding accuracy can be used for many positioning tasks in a vacuum environment. The common method to keep the vacuum quality is to exhaust the supplied gas after leaving the bearing area and before reaching the vacuum chamber [1]. Therefore, the gas bearing pads have to be enclosed by exhaust grooves which are separated by sealing areas. The exhaust grooves are connected to atmospheric pressure or to vacuum pumps [2].

An efficient exhaustion rate can be realized by using exhaust tubes with a high conductance which requires that the length of the tube is made as short as possible and the cross-section as large as possible. In addition, it is essential to exhaust the gas from the exhaust grooves without generating disturbing forces or moments to maintain the precision of the guide. Thus, it is advisable to use a contact-free connection type between the vacuum pumps and the linear guide.

A known way to realize that approach is the integration of the exhaust pipes into the stationary part of the guide [3]. A disadvantageous aspect of this approach is the limited potential of increasing the conductance of the integrated exhaust pipes and the effect of a rising gas leakage with an increasing motion range.

Within this paper, a novel approach is presented for an exhaust system using a contact-free connection with a high exhaust efficiency and a gas leakage that is almost independent from the motion range. The objective of the paper is the characterization of the static and dynamic behavior of the developed exhaust system. Impact factors on the leakage rate of the sealing are analyzed.

SETUP
The contact-free connection between the exhaust groove and the vacuum pump was accomplished by two exhaust tubes which are slideable into one another, separated by a non-contact seal unit. A clearance seal located at the vacuum-sided end of the ringlike gap between the tubes realizes the performance of the seal unit, see fig. 1.

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

The sliding tube was made of ceramics whereby
the high specific stiffness minimizes the gravitational deflection and allows for the realization of a small clearance height of the seal gap. This tube was mounted on a linear rolling guide that was fixed inside a vacuum chamber and could slide through the seal unit into a fixed metal exhaust tube that was connected to a vacuum pump. Via a PTFE hose, nitrogen could be supplied to the sliding tube. The wide range of the mass flow rate and the pressure respectively occurring in the exhaust tubes of a gas bearing guide was the reason for using two different setups. Setup 1 was used to simulate the higher mass flow rate of the first exhaust stage. Therefore, the seal unit consisted of two sealing surfaces with a connection to an additional vacuum pump in between that could be used to discharge the major part of the gas escaping from the first seal gap (see fig. 2). When the smaller amount of gas of the second exhaust stage had to be discharged, the metal hose and the additional vacuum pump were removed for setup 2.

The first step of the preliminary experimental settings was the alignment of the ceramic tube with the axis of movement of the linear rolling guide. Afterwards, the seal unit was adjusted and fixed by an adjustment bonding process in order to achieve a non-contact movement. During the investigations three different seal units were analyzed. Seal units 1 and 2 were configured to realize a mean gap height of 50 µm and seal unit 3 of 35 µm.

**EXPERIMENT**

The described setup was used to perform stationary and dynamical tests. Six different mass flow rates for each setup simulated the range of pressure within the exhaust pipe of a real linear gas bearing guide (see tab. 1).

**TABLE 1. Mass flow rate.**

<table>
<thead>
<tr>
<th>Mass flow rate / kg s⁻¹</th>
<th>( \dot{m}_1 )</th>
<th>( \dot{m}_2 )</th>
<th>( \dot{m}_3 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>setup 1</td>
<td>( 3 \cdot 10^{-7} )</td>
<td>( 1 \cdot 10^{-6} )</td>
<td>( 4 \cdot 10^{-6} )</td>
</tr>
<tr>
<td>setup 2</td>
<td>( 3 \cdot 10^{-8} )</td>
<td>( 7 \cdot 10^{-8} )</td>
<td>( 2 \cdot 10^{-7} )</td>
</tr>
<tr>
<td>( \dot{m}_4 )</td>
<td>( 9 \cdot 10^{-6} )</td>
<td>( 2 \cdot 10^{-5} )</td>
<td>( 6 \cdot 10^{-5} )</td>
</tr>
<tr>
<td>setup 1</td>
<td>( 3 \cdot 10^{-7} )</td>
<td>( 6 \cdot 10^{-7} )</td>
<td>( 1 \cdot 10^{-6} )</td>
</tr>
</tbody>
</table>

For the stationary tests, the length of the traverse path (190 mm) was divided equally by five measuring points. The ceramic tube was stopped at these points and the pressure inside the vacuum chamber was recorded after reaching a quasistationary status.

During the dynamical tests the tube was moved along the traverse path with five different maximum velocities and with a different number of cycles (see tab. 2). The pressure inside the cham-
ber was recorded continuously. Every velocity was applied using all six mass flow rates.

**TABLE 2. Max. velocities and number of cycles of dynamical tests.**

<table>
<thead>
<tr>
<th>velocity / mm/s</th>
<th>v₁</th>
<th>v₂</th>
<th>v₃</th>
<th>v₄</th>
<th>v₅</th>
</tr>
</thead>
<tbody>
<tr>
<td>cycles</td>
<td>10</td>
<td>10</td>
<td>20</td>
<td>40</td>
<td>80</td>
</tr>
</tbody>
</table>

This procedure was performed using the three seal units and both setups. The seal was not replaced during the modification from setup 1 to setup 2.

With the help of the measured pressure difference $\Delta p$ inside of the vacuum chamber, the leakage rate $q_L$ was calculated using the pumping speed of the vacuum pump $S_p$.

$$q_L = S_p \cdot \Delta p$$

**RESULTS**

**Stationary tests**

The results for the stationary tests for setup 1 are shown in fig. 3a and for setup 2 in fig. 3b. The six groups of measuring points represent the six different mass flow rates that were supplied. Each group consists of five points which represent the five different positions of the ceramic tube during the tests.

The leakage rate rises almost linearly with the supplied mass flow and the calculated pressure in front of the seal unit, respectively. It is slightly influenced by changing the position of the ceramic tube as well due to the variation of the flow resistant between the two tubes. With increasing retraction depth of the ceramic tube, the leakage rate decreases.

The pressure $p_p$ at the vacuum pump that is connected to the metal tube can be calculated by

$$p_p = \frac{\dot{m} R_g T}{S_p}.$$  

Hereby $R_g$ is the specific gas constant, $T$ the temperature of the vacuum chamber and $S_p$ the pumping speed of the vacuum pump. With the known geometrical dimensions and $p_p$, the relevant pressure $p_p$ in front of the seal can be calculated using the common relationships of the flow characteristics through pipes. The fluid dynamics have to be considered during these calculations because typically all different kind of flow regimes can occur (molecular, intermediate and viscous flow).

Inside the seal gap, a molecular flow exists due to the low pressure and low clearance height. The analytical relationship between the leakage rate $q_L$ and the number of seal gaps $n$ and the gap height $h_g$ is an exponential one:

$$q_L \propto h_g^{2n}$$

Consequently, the measured leakage rate of setup 1 is approximately one order of magnitude below the leakage rate of setup 2 at comparable input conditions. The strong impact of the seal
gap height on the leakage rate is particularly clarified at setup 1. The reduction of the gap height from seal unit 2 (50 µm) to seal unit 3 (35 µm) causes a decrease of the leakage rates of about 70% (theoretical 76%).

**Dynamical tests**
The pressure inside the vacuum chamber during the dynamical tests is plotted in fig. 4. The figures show exemplarily the pressure of both setups for seal 1, velocity $v_2$ and mass flow rates $\dot{m}_1$, $\dot{m}_3$, and $\dot{m}_6$.

The run of the curves has to be read as follows: The first rise in pressure is caused by opening the gas inlet. At this point of time the tube stands still. During the movement of the tube, the pressure is oscillating. After passing the determined cycles, the movement of the tube and the oscillating of the pressure stop. The steep fall of pressure shows the closure of the gas inlet.

The change in pressure caused by the movement of the ceramic tube lies within the same range as the difference of the pressure while moving from the first to the fifth measuring point during the stationary tests.

Regarding setup 1 (fig. 4a), the change of the pressure caused by moving the tube is almost negligible compared to the total pressure rise caused by feeding the gas. On the other hand, the change of the pressure caused by the movement of the tube equals approx. 10% of the total pressure rise in setup 2. The origin of this behavior is the additional air exhaust stage used in setup 1.

If the results of the stationary and the dynamical tests are compared, a relation between the speed of the ceramic tube and the leakage rate could be observed solely for setup 2 and low mass flow rates. In this case, a slight increase of the leakage rate above the static values was detected. For all other dynamical experiments, a correlation between speed and leakage rate could not be determined.

**CONCLUSIONS**
The developed exhaust system shows tolerable leakage rates for the application in a high vacuum compatible gas bearing guide. During all experimental tests, a high vacuum level in the order of $10^{-4}$ Pa has been maintained within the vacuum chamber. The gap height of the applied clearance seal has to be as small as possible and the number of seal stages should be well chosen to minimize the additional leakage of the seal unit. A significant influence on the leakage rate caused by a dynamical movement of the sliding tube could not be detected.

**REFERENCES**
