Active Guides for Precision Micro-systems

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Abstract

In order to enable high precision motion in micro-systems, the application of active aerostatic as well as electromagnetic guides is presented in this paper. Both concepts have in common, that they prevent contact between the moving slide and the system's frame and allow precision movements at drive forces below 1 mN. In order to compensate for tilting and vertical displacement of the slide, an accurate air gap measurement system has to be developed and integrated in a highly limited installation space.

1 Active aerostatic linear guides for micro-systems

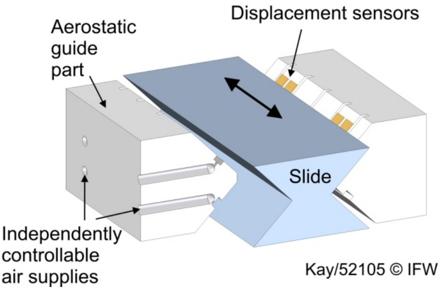


Figure 1: Principle of a miniaturized active aerostatic linear guide

It is state of the art to use aerostatic guides in high precision applications like measurement machines or precision machine tools. In those macroscopic applications the air supply hoses are often connected to the slide. In applications where high positioning accuracy at low drive forces and low travel ranges is required, a concept is proposed, that uses a longer slide and equips the shorter stator with aerostatic guides (Fig.1). Disturbing connections to the slide are avoided in this way.

In this design, a static pressure supply of the guide bearings would lead to tilting of the slide due to varying location of the centre of mass. A tilting itself reduces the bearing forces. That can lead to unwanted contact.

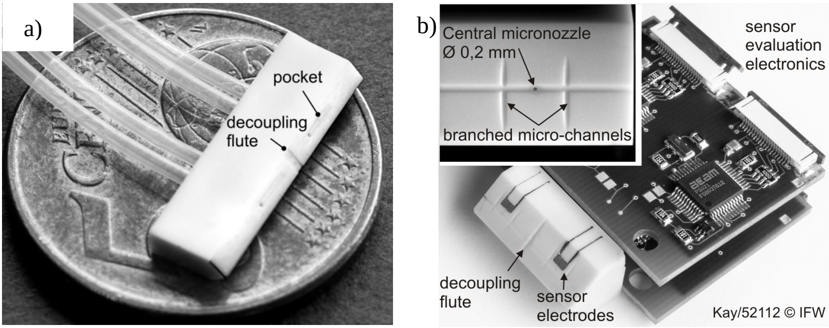
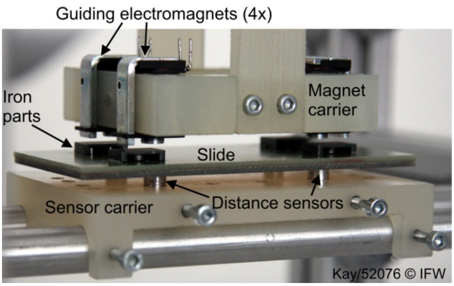


Figure 2a) Aerostatic micro-guide with rectangular pockets and decoupling flute; b) Aerostatic micro-guide with air gap measurement system

In order to overcome this challenge, an air gap control is proposed that compensates for tilting and vertical displacement errors. Micro-displacement sensors that are directly deposited on the guides' surfaces are observing the air gaps at eight locations. A controller unit sets the independent bearing pressures using proportional pressure valves. To reduce the order of the controller, the system's inputs and outputs are decoupled into its five degrees of freedom (all except for the travel direction).
In order to obtain high bearing forces, damping and low air consumption, particular attention has to be paid to the design of the bearings' nozzles and surfaces. Computational fluid dynamics proved to be an adequate tool for the design support.
In earlier works, the IFW presented the development of aerostatic micro-guides based on porous ceramics [1] and multiple micronozzles [2]. In order to increase the cost efficiency in manufacturing, a design with micro-channels is proposed (Fig. 2). In this approach, a single nozzle is sufficient to supply the pressure distributing channels.
Comparing with a rectangular pocket bearing with the same dead volume, 80% more stiffness and 20% more bearing force is achieved. Considering the complicated manufacturing and assembly efforts of micro-systems, the proposed monolithic concept has proved to be an acceptable choice.

2 Planar electromagnetic guides for micro-systems

Electromagnetic guides are reasonable alternatives if contactless guiding is required in micro-systems. In contrast to aerostatic guides, magnetic guides based on reluctance forces need a powerful closed-loop control to become stable.



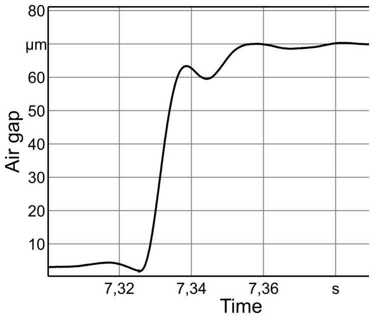
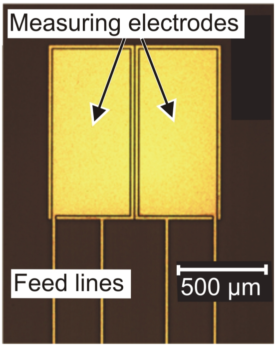


Figure 3: Prototypical micro-magnetic guide and its step response to a step of 70 µm

In order to develop and validate an adequate control, a prototypical setup has been built, that uses four magnets on the upper side of the slide and four capacitive displacement sensors on the underside to measure the levitation height (Fig. 3). The control [3] is able to lift up the slide autonomously whereas the standard deviation at the operating point is about 25 nm. The main properties like the carrying force, stiffness and damping can be defined by the controller's parameters and are restricted by the electrical power limitation, magnetic saturation and sensor noise.

3 Capacitive air gap sensor

In both guides a miniaturized gap measurement system is mandatory. According to the requirements of the micro-guides concerning the available space, the travel range, the gap measurement range, the resolution and the dynamics, a capacitive displacement sensor has been developed that needs no electrical connection to the target [4]. The electrodes' dimension is 1 x 1 mm² (Fig. 4a). The capacitance evaluation unit is able to resolve the gap with standard deviation of 23 nm at a reference gap of 5 µm and 5 kHz sampling rate. Measurement results of a given trajectory of micro-steps can be seen in Fig. 4b.

a) 

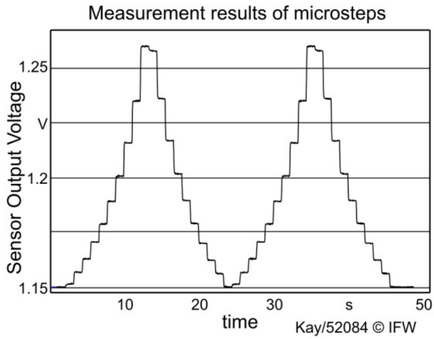
b) 

Figure 4: (a) Fabricated sensor electrodes; (b) Measurement results of micro-steps

4 Conclusion

The two guiding principles are suitable for use in miniaturized systems. The main challenges in using aerostatic guides are the manufacturing of micro-structures and the adjustment efforts. In the electromagnetic guide heat generation and a sufficient sample rate should be considered particularly if the slider mass is low.

Acknowledgement

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