A SIX MAGNETIC ACTUATORS INTEGRATED MICROMOTOR

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ABSTRACT
A contact free actively controlled micromotor bearing structure of a very flat aspect ratio is presented. The system combines contact free suspension and rotation with six magnetic actuators and a minimum of three inductive sensors. The principle of combined suspension and drive could meet price, reliability and performance requirements for integrated micromotors in the field of optical choppers, gyroscopes, hard disk drives and many more. An experimental setup was manufactured with a combination of micromachining techniques such as etching and electroplating.

INTRODUCTION
Active magnetic bearings (AMBs) offer a very good solution for rotating micromachines of which speed and lifetime are limited by friction and wear [1]. AMBs have no wear and no need for lubrication. Others advantages include the possibility to change their stiffness and their damping depending on the application.
Video heads, medical instruments, hard disk drives and optical scanning are new potential applications of AMBs. The micromotor which has been developed allows active control of three degrees of freedom (axial translation and two tilts) of the rotor. Radial translations are passively stabilized.
The final aim of this project is the integration of the sensors and driving electronics on a single chip placed on a stator.

CONFIGURATION OF THE SYSTEM
The bearing consists of two identical stators and a chemically etched rotor, which is suspended in between. The air gap is 30 µm. Each stator (fig.1) has three actuators. Each of them consists of a triple of cores, surrounded by monolithically electroplated coils.

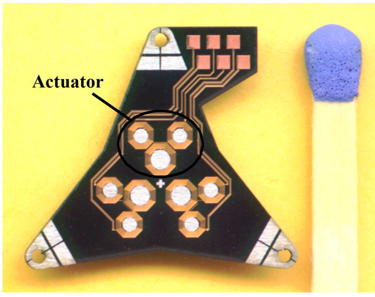

FIGURE 1: The stator with three actuators

The sensor coils are placed on a PCB under one stator (fig. 2 and 3). The overall thickness of this integrated system is around 2 mm.

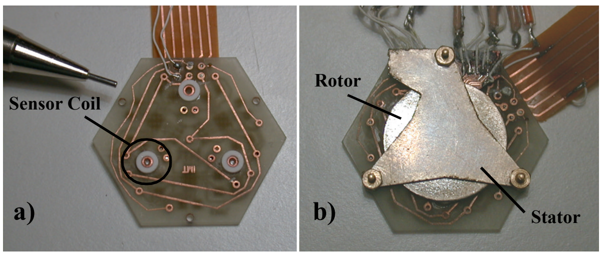

FIGURE 2: **a)** Top View of the sensor PCB and the three sensing coils; **b)** View of the micromotor showing the sensor PCB, the rotor and the stators

Suspension and rotation are achieved with the same actuators. The control currents are a superposition of levitation control current and torque control current. Radial displacements are passively stabilized by a particular design of the rotor with concentric rings.

Stator
A ferromagnetic FeSi steel sheet is used as base substrate and back-iron for the electromagnetic actuators [2]. The two layer spiral (fig. 3) shaped copper have 36 turns per pole shoe and the pole shoes of the actuator are electroplated out of FeNi50. The copper track section is 8 µm x 6 µm.

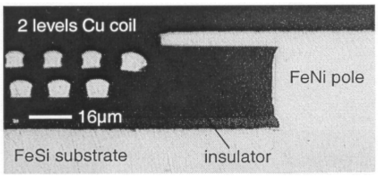

FIGURE 3: Cut through actuator pole and actuator coil

Rotor
A set of different rotor designs was produced by chemical etching (fig. 4). All rotors have a diameter of 15 mm, a minimum thickness of 150 µm and a maximum of 340 µm. A standard non grain oriented V300-35A silicon steel was used for their production. The total mass of such rotors is between 266 and 286 mg.

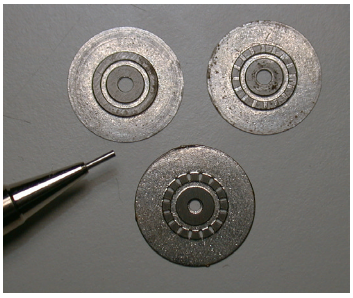

FIGURE 4: Different designs of the rotors

The rotor is a flat disk with two concentric rings. The outer ring is partially slotted in order to create a torque on the rotor. The inner ring is used for centering the rotor.

Sensors
A variety of contact free position sensing principles can be used for AMBs. Among these are optical, capacitive and inductive sensors. Regarding a future integration of the complete motor with means of thin film technology, inductive sensors were chosen. A first non differential setup was designed to have a minimum gap between the sensor and the rotor (fig. 5).

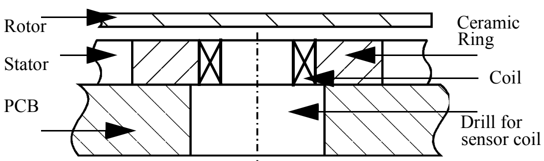

FIGURE 5: Cut through the sensing coil with ceramic carrier

Unfortunately, the heat produced by the actuator coils leads to a drift of the sensor signal (fig. 6). Since the sensors are not operated in a differential way, this temperature sensitivity has to be compensated.

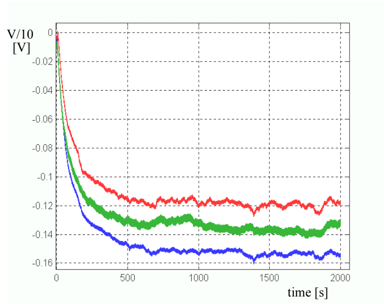

FIGURE 6: Offset drift with temperature of the three sensors

Motor
The torque creation is based on the principle of a reluctance motor [3]. The angular displacement of the rotor is created by modifying the bias currents in the axially opposed actuators. Sinusoidal currents with a phase shift of 120° are added to the control currents of the three pairs of actuators to create the rotating magnetic field. This rotating magnetic field acts on the partially slotted ring on the rotor. One complete rotor turn is composed of 36 steps. Angular position feedback is not yet implemented.

Controller
A PID controller with an offset controller (fig.7) is used to stabilize the system and to compensate for the temperature drift.

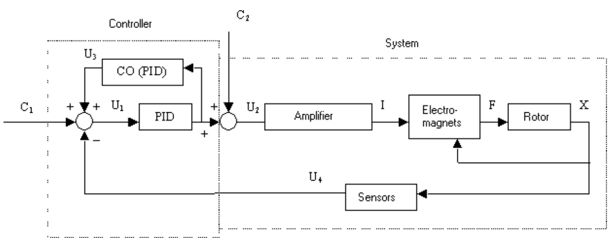

FIGURE 7: Controller scheme

The offset controller consists of a feedback of the levitation controller output, which is activated when the system is stabilized. It permits to compensate temperature variations of the sensor at the input of the controller, and the levitation of the rotor can be maintained.
This type of controller is useful to eliminate low frequency variations of the sensing system due to temperature changes.

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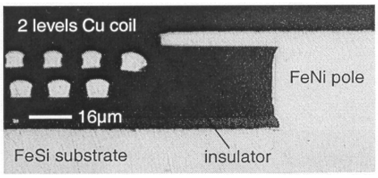

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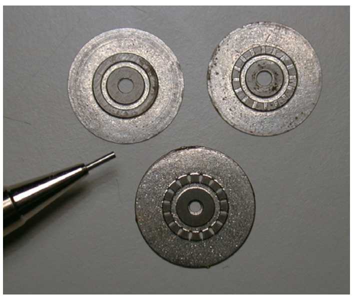

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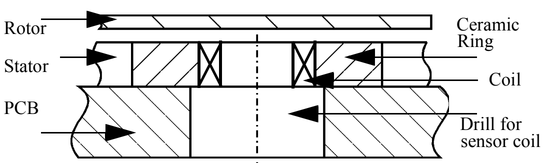

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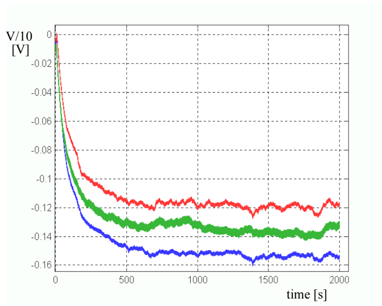

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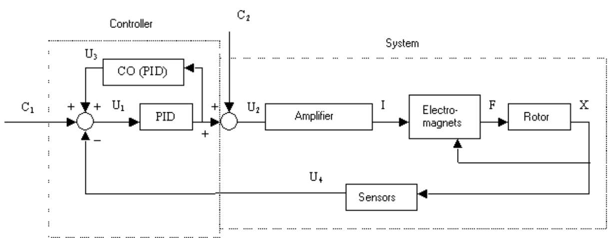

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EXPERIMENTAL RESULTS

Levitation was achieved with all type of rotors. Rotation was performed only with compressed air and at low rotation speed (< 600 rpm). The system presents weak damping of radial directions.

Step response and closed loop frequency response from one actuator to the adjacent sensor were measured and the results are shown in the next two figures (8 and 9).

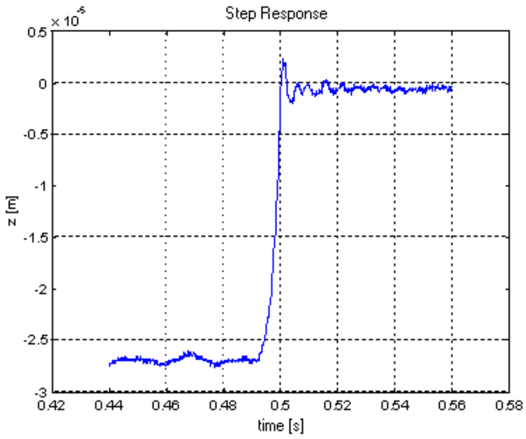

FIGURE 8: Step response

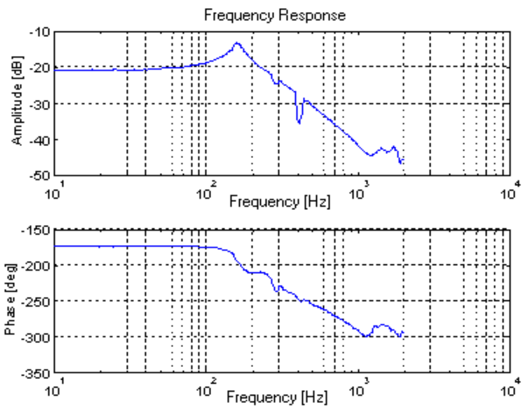

FIGURE 9: Frequency and phase response

The cut-off frequency is around 155 Hz and the oscillation in the step response is damped after 20 µs. The resolution with a non-differential sensor setup is 400 nm. This value can be lower when a differential setup is used.

CONCLUSIONS AND OUTLOOK

A contact free motor of a very flat aspect ratio has been developed and assembled. It has the potential of being manufactured with thin film batch fabrication techniques. Contact free suspension and rotation with compressed air were achieved with all rotors. The motor function is not yet controlled with angular position feedback and when the rotation is enabled a radial oscillation occurs. The radial position is centered passively with very low forces and weak damping, bringing undesirable radial oscillations.

A possible approach for increasing these forces and stabilizing the micromotor is a hybrid system, combining permanent micromagnets and AMBs. Next steps will also include redesign of the actuators, angular position feedback and integration of the sensing coils on the stator.

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