

# Contactless Micro Position and Angular Sensor Device Based on Micro Structured Polymer Magnets

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## ABSTRACT

In this work, we present a contactless micro position and angular sensor system which consists of fixed commercial magnetic sensors, such as hall sensors and a movable part with integrated micro structured polymer magnets. This system serves particularly for linear and rotatory synchronous micro motors which we have developed and successfully tested. In order to achieve high precision and control of these motors an integration of the special micro position and angular sensors is pursued to increase the resolution and accuracy of the devices.

**Keywords:** Synchronous micro motors, linear actuators, micro coils, UV depth lithography, polymer magnets

## 1 INTRODUCTION

Due to the development of several electromagnetic micro actuators and motors, like linear and rotatory reluctance micro steppers as well as a special “Lorentz force actuators”, the demand of suitable position detection systems has increased. In the last years, we have developed and fabricated linear and rotatory synchronous motors with axially magnetized polymer magnets or commercial magnets in disc shape rotor design (see Figure 1) [1-3].

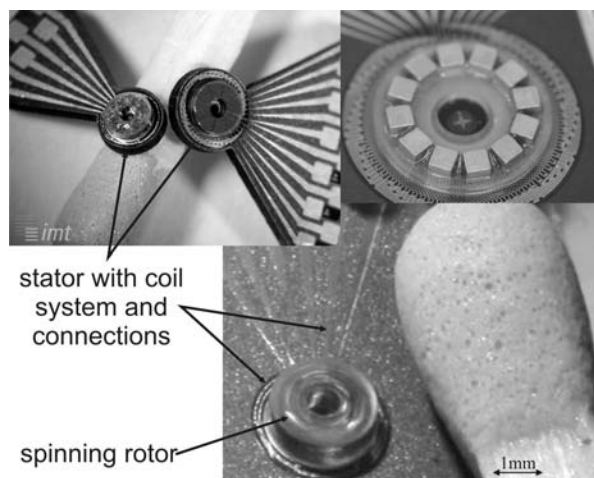


Figure 1: Synchronous micro motors with integrated polymer magnets and commercial magnets.

Their basic design consists of electrical conductors and coil systems as well as of magnetic materials that were fabricated in additive technology via UV-depth lithography and electroplating. Furthermore, special micro composites were developed. This allowed the fabrication of micro magnets with arbitrary shape and properties, ensuring complete compatibility to existing process chains [4]. Thereby the integration of the position detection system into these synchronous motors by already used technologies is possible.

## 2 CONCEPT AND DESIGN

The sensor device consists of a Hall sensor element and a magnetic structure implemented in a rotor disc which is adjusted above the sensor (see Figure 2). The Hall sensor detects the strength of axial magnetic field generated by the magnetic structure. Due to the varying geometry of the magnetic structure, the strength of the magnetic field can be altered by moving it over the magnetic sensor. This results in the detection of the geometric structures as well as the measurement of their corresponding angle.

The Hall sensor is purchased from ‘Chen Yang Technologies’. This component has an overall size of  $3.5 \times 1.5 \times 0.6 \text{ mm}^3$  and features a high linearity.

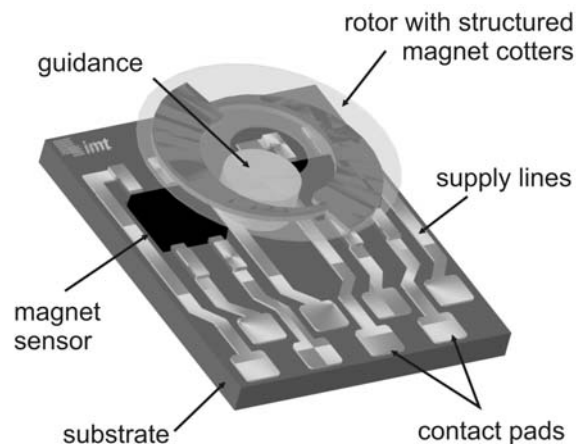


Figure 2: Concept of the sensor device.

Different geometries are applied as magnetic structure in the rotor: single and double cotters, step like cotters and segmented structures (see Figure 3). These structures are made of polymer magnets – a composite material which consists of magnetic powder integrated in a polymer matrix. For the test, powder of rare earth metals like neodymium-iron-boron and ferrites like strontium-barium-ferrite are used.

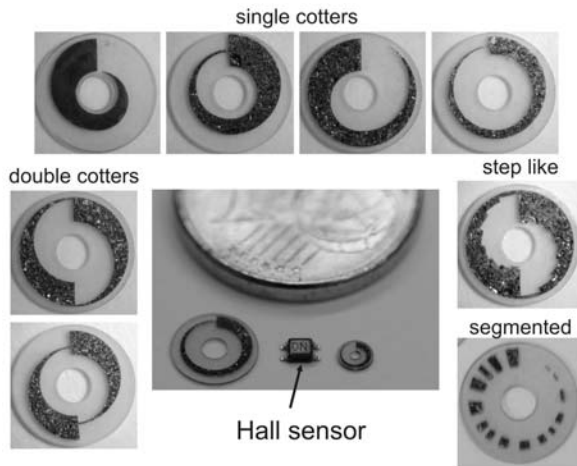


Figure 3: Rotors with implemented magnetic structures.

### 3 FABRICATION

For fabrication of the sensor system the hall sensor is assembled on the substrate and integrated into the micro fabrication process chain; thereby allowing high precision adjustment and electrical contacting through the combination of UV-depth lithography and copper electroplating. The rotor is made in a separate process.

The process sequence for the fabrication of the rotor element is shown in Figure 4. It starts with electroplating of a sacrificial copper layer. On this a thin SU-8 layer is patterned serving as a base plate. A following SU-8 layer with thickness of about 300  $\mu\text{m}$  is structured to create a high precision form with an arbitrary geometry, which is only limited by the lithography step. The unused areas around the mould and the guidance structure are filled with a soluble resist. After that the liquid magnetic composite is inserted in the mould and baked out. After that, a polishing process follows to level the compound structure and to remove waste residues. Finally, the sacrificial copper layer is etched and the rotors are detached from substrate. In doing so several magnetic structures were fabricated.

For magnetization of the polymer magnet cotter structures, a special magnetization equipment was designed. It consists of a ferromagnetic core with a yoke, in which a magnetization adapter with a ring structure can be placed. A flat coil with 445 windings wound around the core serves for generating magnetic flux. With the equipment a magnetic flux density of nearly 2.1 T is

reached in the yoke what is adequate for the axial magnetization.

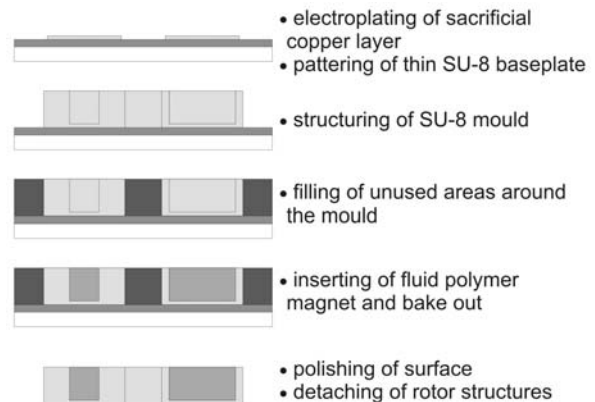


Figure 4: Process sequence for the rotor fabrication.

## 4 MEASUREMENTS

### 4.1 Static Measurements

For the first tests an automatic measuring system was developed. This system allows the positioning of the magnet sensor to the polymer magnet and controls all measurement parameters (see Figure 5). Therewith a detailed parameter study can be run to optimize the sensor device.

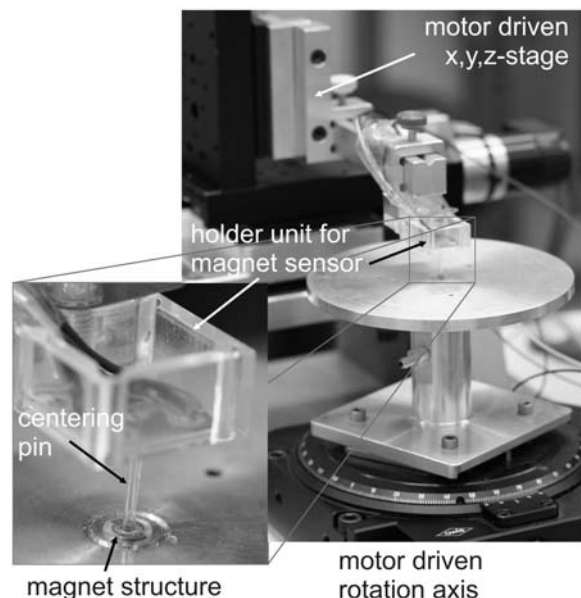


Figure 5: Measurement setup with motorized stage and automated control for static measurements.

To improve the sensor device performance, different magnetic structures were tested, which differ in the number and shaping of cotters. One static measurement of a complete rotation of a double cotter over one hall sensor is shown in Figure 6. The characteristic of Hall voltage mirrors the form of signal structure. The rising between low and high level proceeds approximately linear with a different voltage of 12mV measured by an input current of 5A.

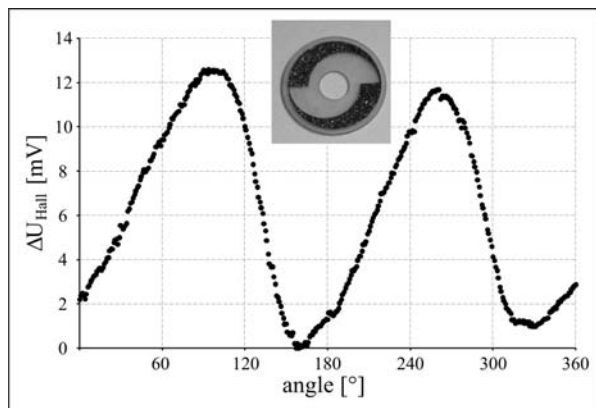


Figure 6: Static measurement of a double cotter for a rotation of 360°.

## 4.2 Dynamic Measurements

There is a requirement of high dynamic response behavior for the application in the synchronous motors. Hence, dynamic measurements were carried out with a modified set up (see Figure 7). A commercial DC-motor is used for varying the rotational speed. An additional electromagnetic shielding is fixed on the top of the motor to avoid influences on the measurements due to the magnetic field of the motor.

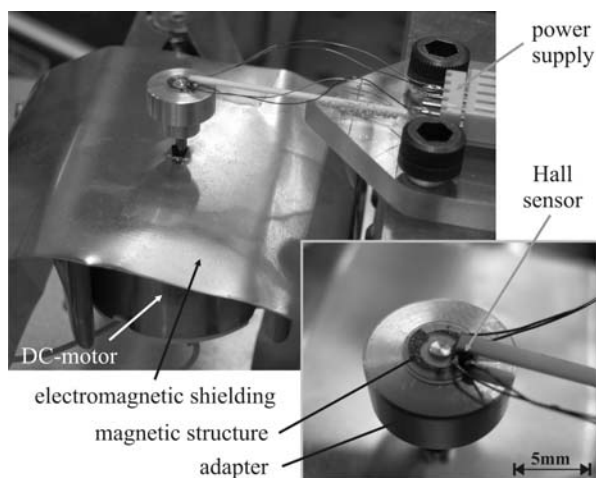


Figure 7: Set up for dynamic measurements.

The rotor is adjusted on an adapter which is form-closed mounted on the motor shaft. The Hall sensor is aligned by a three axis positioning stage. Because of this measurement set up the sensor could be placed with a height distance of 10  $\mu\text{m}$  to the rotor. The characteristics of Hall voltage were recorded for different rotational speeds. The results for a double cotter are shown in Figure 8. In the area between low and high level, the voltage proceeds almost linearly independent of the rotational speed.

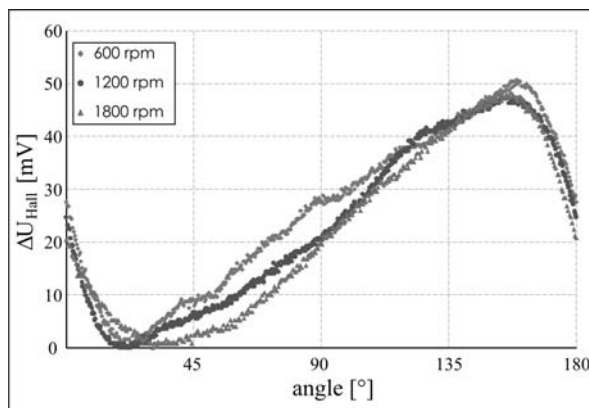


Figure 8: Dynamic measurement of a double cotter for a rotation of 180°.

A comparison between single and double cotter rotor is shown in Figure 9. The high and low voltage levels are equal. However, the double cotter features a steeper rising when compared to the single one. Furthermore, the single cotter characteristic shows some fluctuations. This is caused by a small-scale unbalance in z-direction. A major influence is given by the grain size of the constituted magnet powder. Such fluctuations could appear due to inhomogeneous grain size ( $>9 \mu\text{m}$ ) or unequal distribution of the NdFeB powder. The likewise tested ferrite powder possesses a finer grain size ( $<1.5 \mu\text{m}$ ). In Figure 10 a comparison between ferrite and NdFeB magnet double cotter structures is depicted.

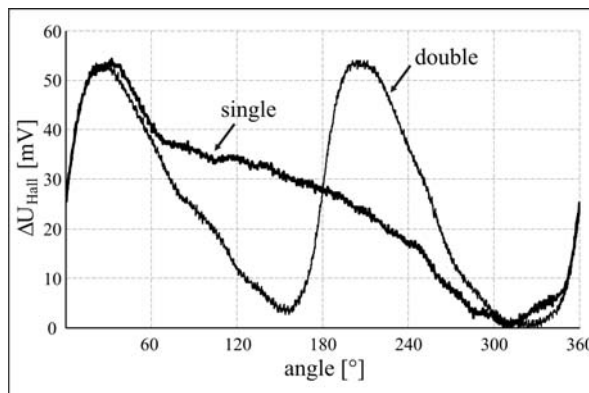


Figure 9: Comparison of single and double cotter made of NdFeB-polymer magnet.

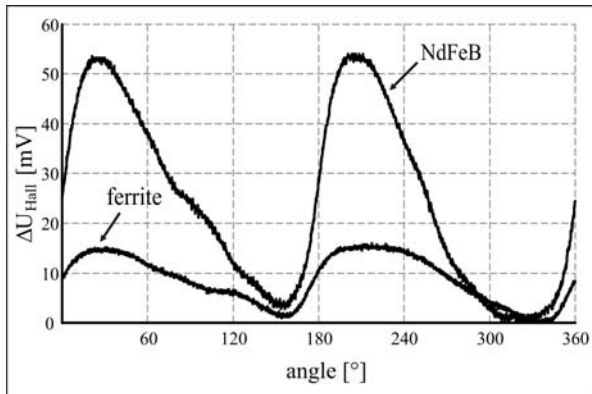


Figure 10: Comparison of double cotter with different polymer magnet materials.

The signal structure made of NdFeB indicates a three- to fourfold higher magnetization and therewith higher Hall voltage. This corresponds with a sensitivity of 0.3 mV per degree for the NdFeB structure and 0.09 mV per degree for the ferrite structure. A summary of the measured values and resultant sensitivities are listed in table 1.

signal structure	material	signal difference [mV]	sensitivity [mV/°]
	ferrite	16-20	0.04-0.06
	NdFeB	49-60	0.14-0.17
	ferrite	14-17	0.08-0.09
	NdFeB	48-54	0.27-0.30
	ferrite	16	0.09
	NdFeB	56	0.31

Table 1: Overview of measured signal differences and calculated sensitivities.

## 5 CONCLUSION AND OUTLOOK

The purpose of this work was to develop a position detection system for electromagnetic actuators. The concept of such a system based on the Hall Effect was presented and the fabrication of rotatory signal structures was identified. Furthermore, first measurements for the characterization of this system were carried out and evaluated. The results show that with NdFeB powder based structures nearly linear characteristics with good sensitivities can be achieved. In respect of the signal structures no substantial difference could be determined between step like variants and the other ones.

Two important aspects will be aimed for the further optimization and application. Thus, unpacked Hall sensor elements should be applied, which are integrated in the process chain for fabrication of the synchronous motors. Furthermore, the synchronous motor will be provided with

two Hall sensor elements. A first example has already been realized (see Figure 11). Due to a convenient combination of measured Hall voltages of both sensor elements the sensitivity could be increased and therewith a more precise position detection could be provided.

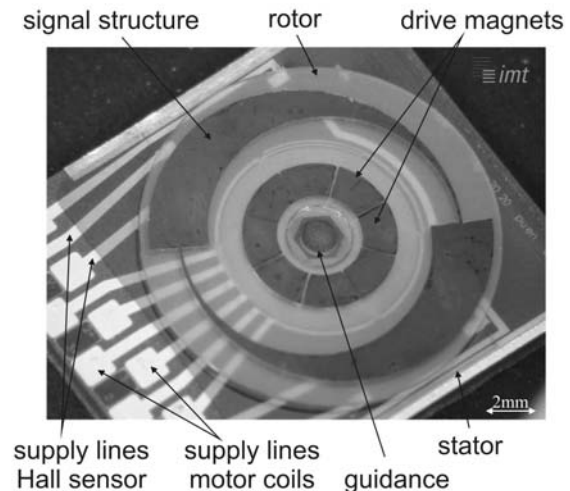


Figure 11: Synchronous motor with integrated sensor structure for position detection.

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