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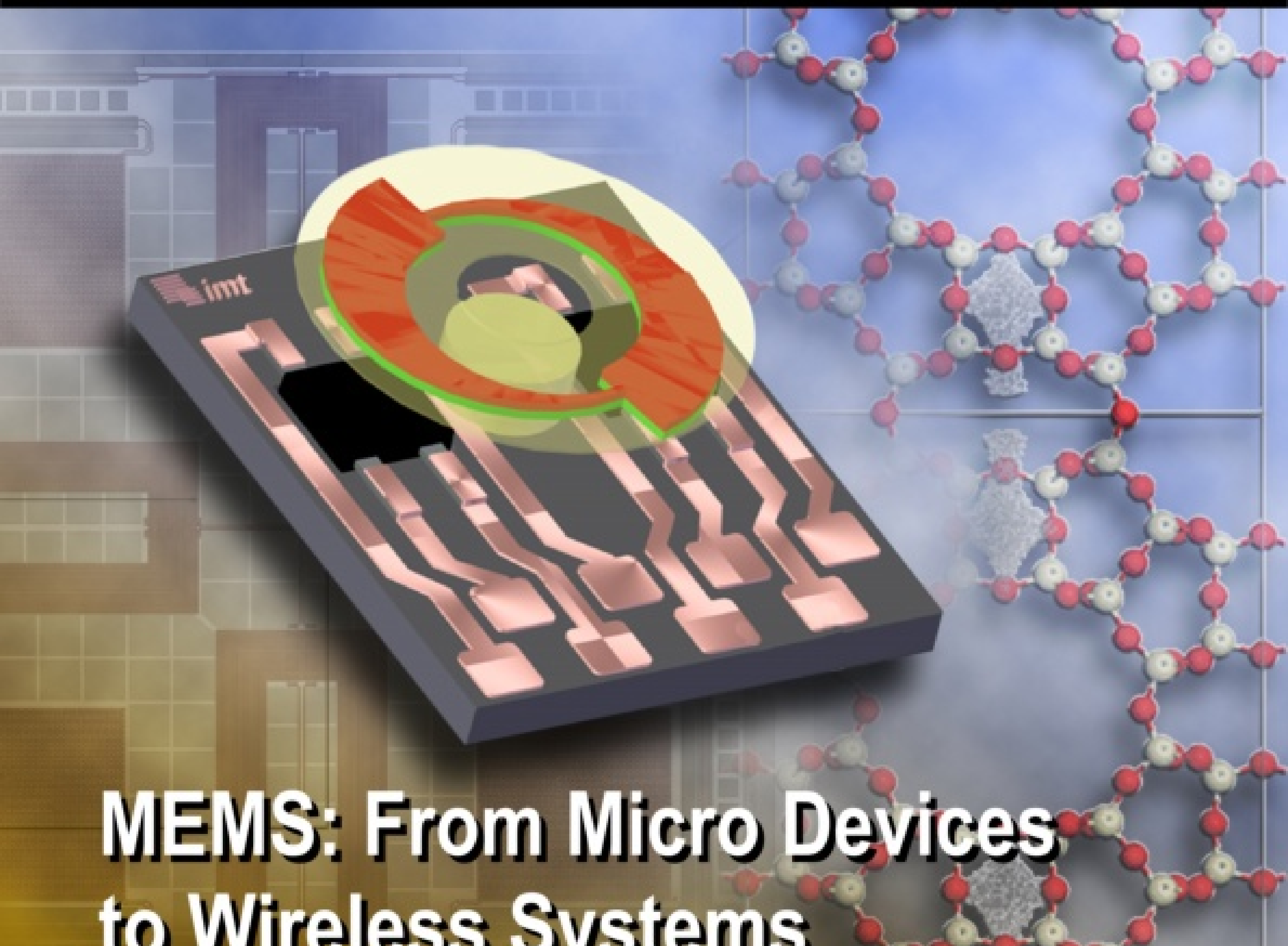

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Development and Test of a Contactless Position and Angular Sensor Device for the Application in Synchronous Micro Motors

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Abstract: In this work, we present a contactless micro position and angular sensor system which consists of fixed commercial magnetic sensor elements, 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. *Copyright © 2009 IFSA.*

Keywords: Synchronous micro motors, Micro coils, UV depth lithography, Polymer magnets, Position sensor

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 (Fig. 1) [1-3]. 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.

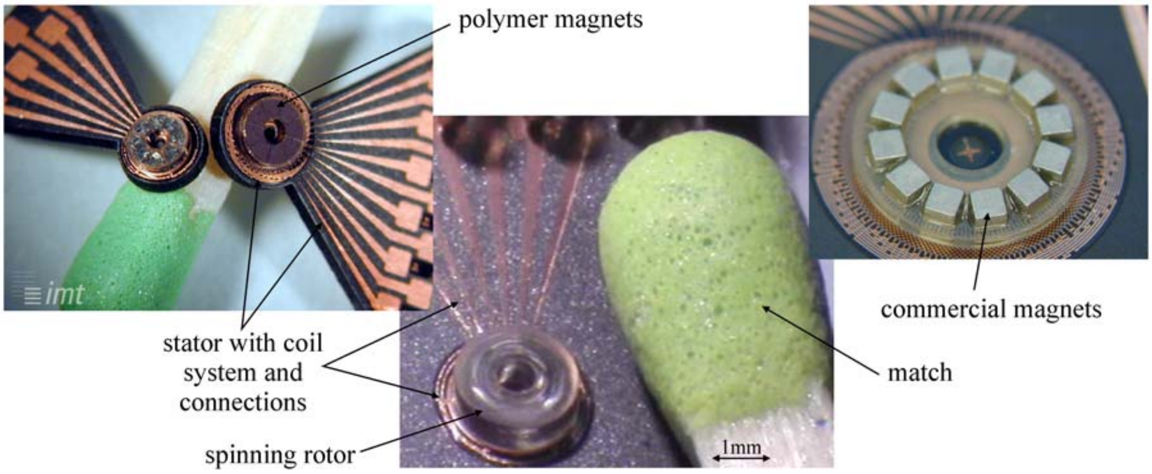


Fig. 1. Synchronous micro motors with integrated polymer magnets and commercial magnets.

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 (Fig. 2, left). 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 3.5x1.5x0.6 mm^3 and features a high linearity in the range between 0 and 300 mT.

For the first test different geometries are applied as magnetic structure in the rotor: single and double cotters, step like cotters and segmented structures (Fig. 2, right).

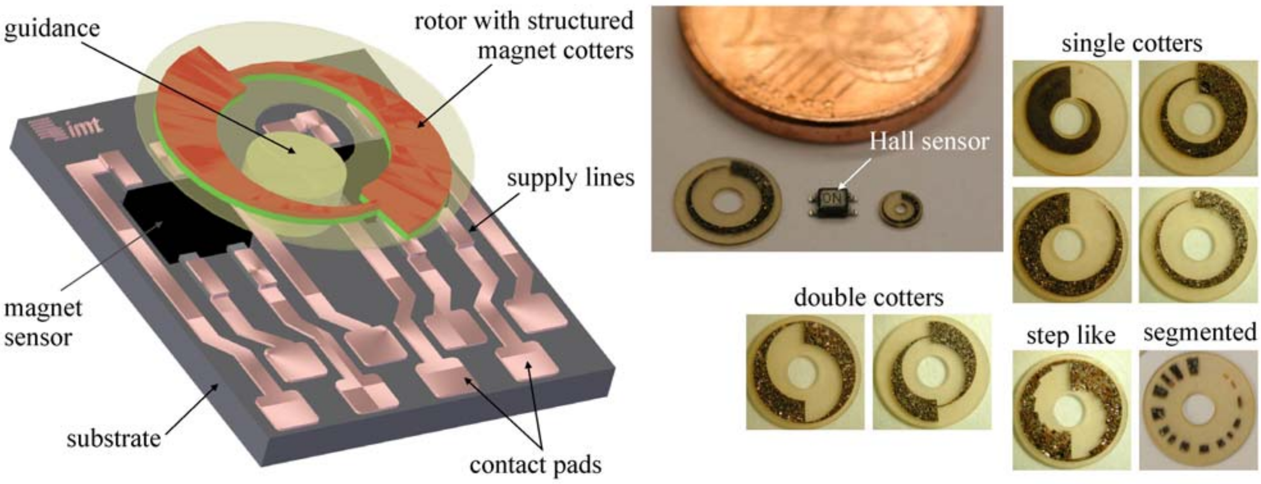


Fig. 2. Concept of the sensor device (left) and rotors with implemented magnetic structures (right).

3. Characterization of Polymer Magnets

Polymer magnets are micro composite materials which are fabricated by embedding powdery, magnetically hard materials in a polymer matrix. Three different fabrication techniques were developed for micro scale structuring of these composites: direct structuring, lift-off process and soft lithographic molding [5]. Different qualities and properties can be obtained depending on the used technique. In comparison to electroplated or sputtered layers the lift-off process provides magnetically hard structures with high thicknesses of some 100 µm combined with high edge quality and high aspect ratios. The advantage of this integration technique is the possibility to fabricate structures with arbitrary shapes and thicknesses.

Various magnet powders were used and characterized for applications as polymer magnets, like rare earth materials (neodymium-iron-boron, samarium-cobalt) and ferrites (barium-, strontium-ferrites). The fabricated polymer magnet structures were characterized regarding their magnetic properties with a vibrating sample magnetometer (LakeShore Inc.). In Fig. 3 (left) the magnetization curves are shown for various used polymer magnets with 80 %wt powder ratio and structure heights of 320 µm.

For the implementation different geometries of polymer magnet structures were previously fabricated to determine the magnetic properties in dependence of the dimensions. The magnetization characteristics of different square polymer magnet structures made of neodymium-iron-boron are shown in Fig. 3 (right). Maximal remanences between 230 mT and 345 mT were obtained with neodymium-iron-boron powder.

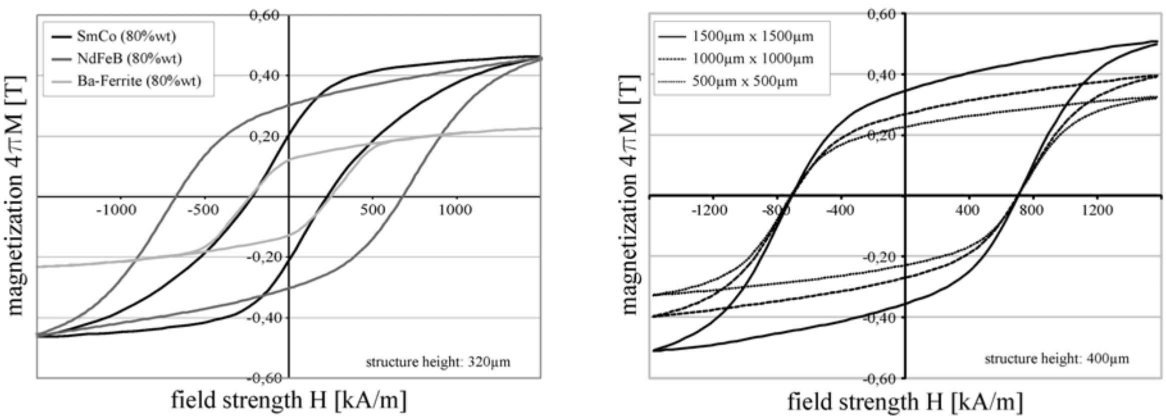


Fig. 3. Magnetization characteristics of polymer magnets made of different materials (left) and different dimensions made of neodymium-iron-boron (right).

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 Fig. 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 µm 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 like AZ9260. After that, the liquid magnetic composite is inserted in the mould and baked out. Subsequently, 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.

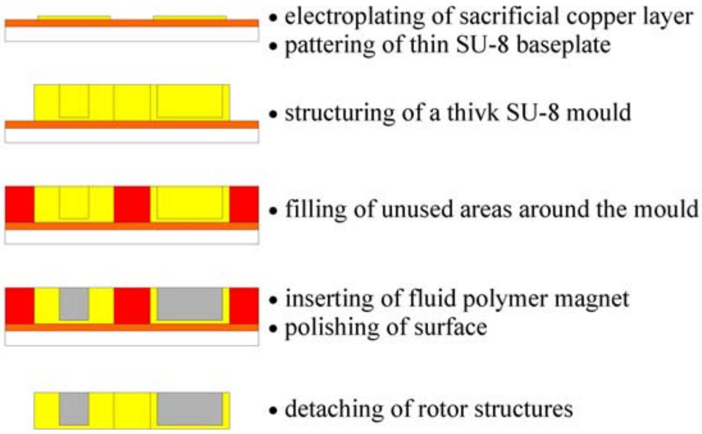


Fig. 4. Process sequence for the rotor fabrication.

For the magnetization of the polymer magnet cotter structures, 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 (Fig. 5). A flat coil with 445 windings wound around the core serves for generating the magnetic flux. With the equipment a magnetic flux density of nearly 2.1 T is reached in the air gap or polymer magnet respectively what is adequate for a permanent axial magnetization.

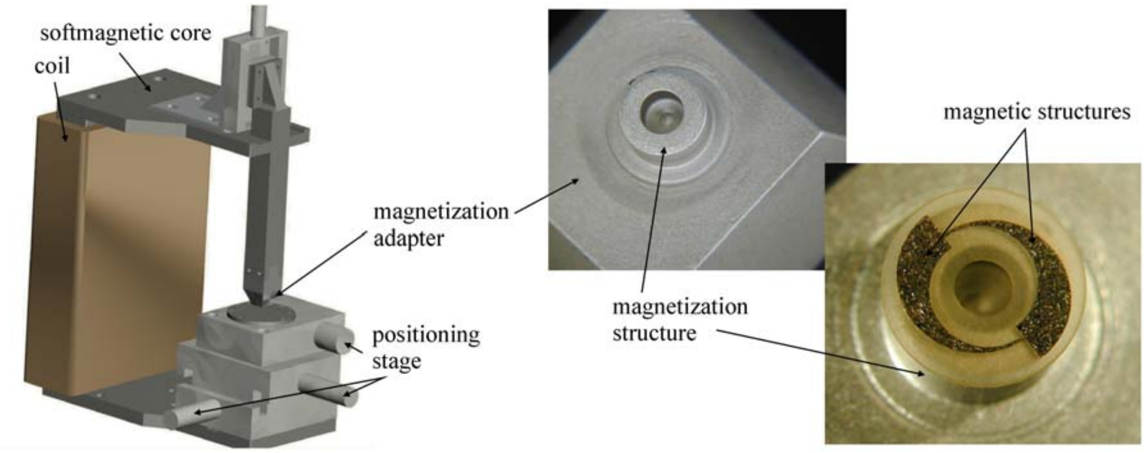


Fig. 5. Magnetization equipment (left) and adapter (right).

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 (Fig. 6, left). Therewith a detailed parameter study can be run to optimize the sensor device.

To improve the sensor device performance, different magnetic structures were tested, which differ in the number and the shape of cotters. One static measurement of a complete rotation of a double cotter over one hall sensor is shown in Fig. 6 (right). 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 12 mV measured by an input current of 5 A.

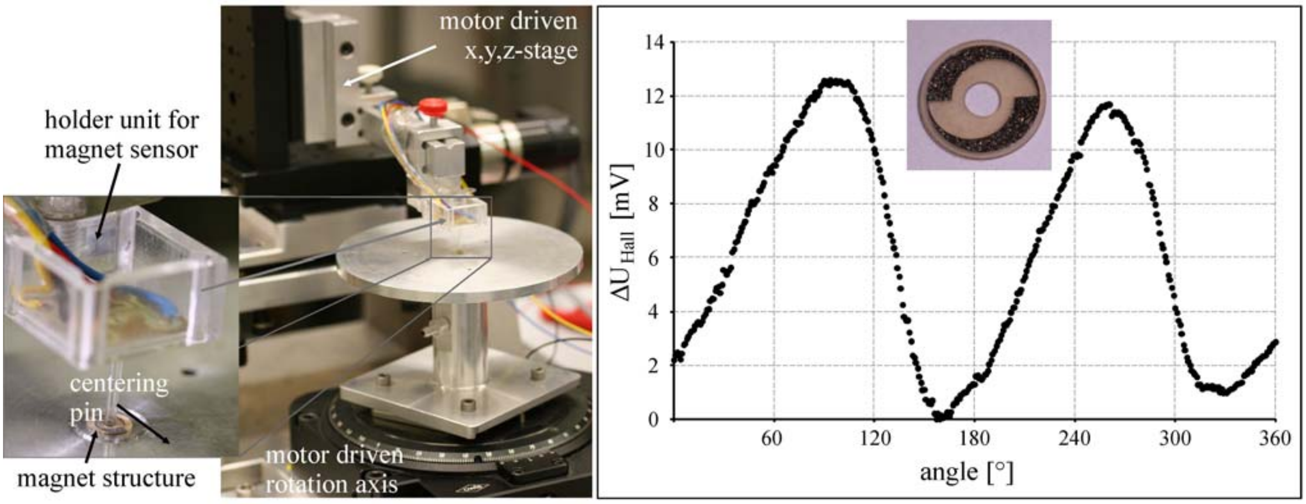


Fig. 6. Measurement setup with motorized stage and automated control for static measurements (left); and characteristic of a double cotter for a rotation of 360° (right).

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 (Fig 7, left). 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.

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 µm to the rotor. The characteristics of Hall voltage were recorded for different rotational speeds. The results for a double cotter are shown in Fig. 8 (right). In the area between low and high level, the voltage proceeds almost linearly independent of the rotational speed.

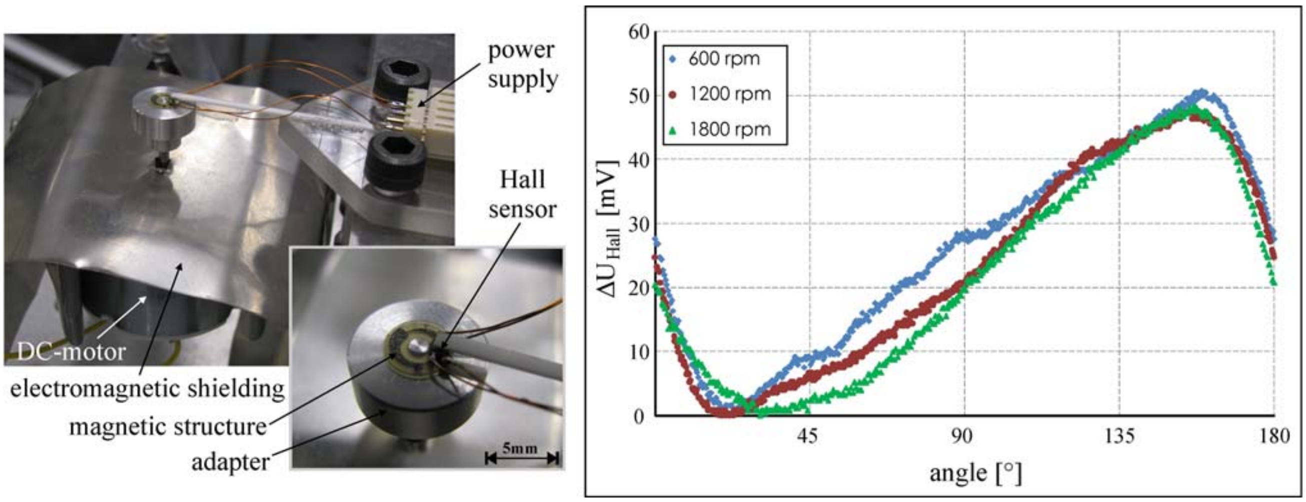


Fig. 7. Set up for dynamic measurements (left); and measurement results of a double cotter for different rotational speeds (right).

A comparison between single and double cotter rotor is shown in Fig. 8 (left). 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 µm) or unequal distribution of the NdFeB powder. The likewise tested ferrite powder possesses a finer grain size (<1.5 µm). In Fig. 8 (right) a comparison between ferrite and NdFeB magnet double cotter structures is depicted. 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.

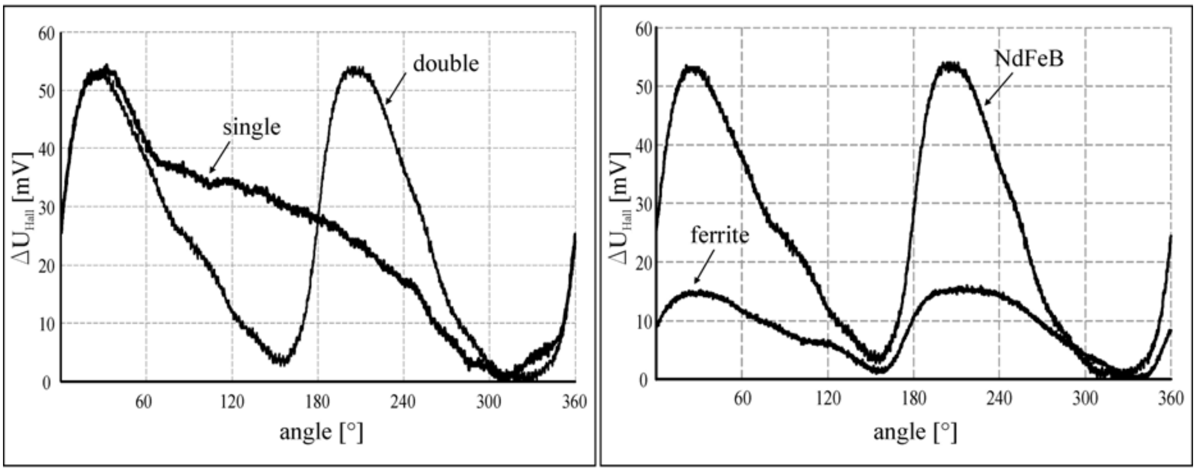
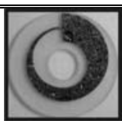
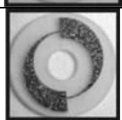


Fig. 8. Comparison of single and double cotter made of NdFeB-polymer magnet (left); and comparison of double cotters with different polymer magnet materials.

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

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

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 (Fig. 9). Due to a convenient combination of measured Hall voltages of both sensor elements the sensitivity could be increased and therewith more precise position detection could be provided.

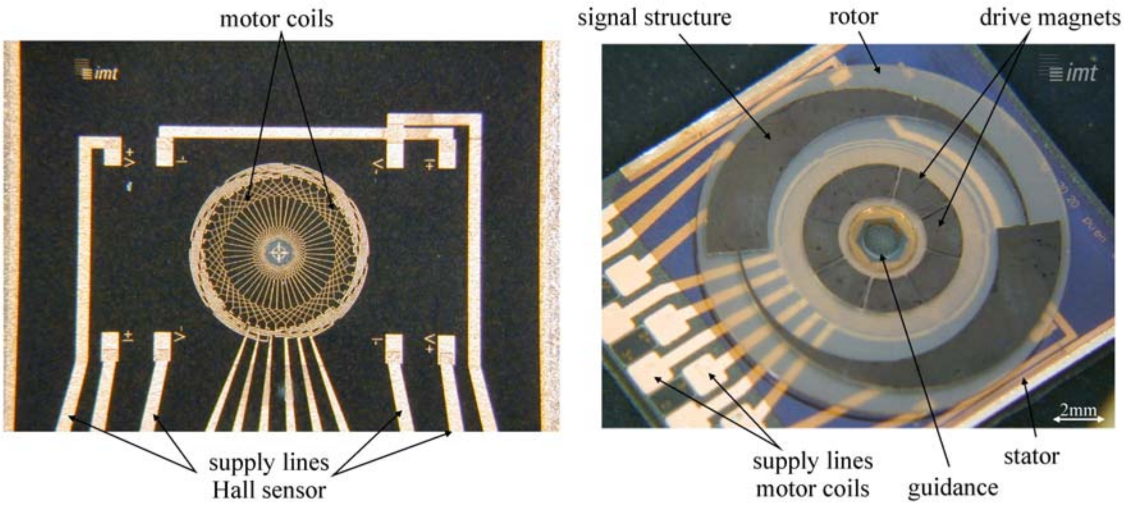


Fig. 9. Synchronous motor with integrated sensor structure for position detection.

Acknowledgements

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Aims and Scope

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