MICROMOTOR BASED ON FILM PERMANENT MAGNETS

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Abstract:
A design of a single phase step micro motor is presented. The rotor has been optimised to induce the greatest magnetic energy using film permanent magnets. A special study has been performed to select the most advantageous magnetisation direction and the structure has been chosen taking into account micro technologies characteristics and the present know-how available for realisation of prototypes. A scale 2 prototype has already been realised. Its special air gap tuning for film magnet test is presented, as well as first torque measurements.

Keywords: Micro motor, Film permanent magnet, micro-technology, Single phase stepper motor,

Introduction

The development of micro systems includes magnetic devices like sensor, actuators and motors. These kinds of device use the magnetic field for coupling relevant physical values. As for macro system, the corresponding magnetic energy may be established mainly by two kinds of original sources: currents or permanent magnets. Whereas current has for long been mastered in any chip, integration of magnets in silicon chip remains an up to date topic. It is all the more relevant to develop magnets for micro systems as the scale factor properties tends to favours magnet versus coil while the device size is decreasing [1].

Improvement of magnet-on-chip technologies is the main objective of the M²EMS EC 5^{th} FP project, in the framework of witch these works have been performed [2]. In this project Cedrat Technologies is in charge of the design of the micro motor subject of the article.

In order to benefit of the development of micro-systems fabrication technologies which is the only way to render affordable the realisation of new kinds of micro device, the design of device parts need to be adapted consequently. For permanent magnets, it means being able to produce films and being able to adapt [3] the design of the device that use them like the micro motor which is presented here.

Parallel or perpendicular film magnets ?

Once permanent magnets in film have got characterised by one small dimension versus at least one other, the first issue is to decide in which direction should be magnetised film magnets. We have dealt with this issue in order to determine which kind of magnetisation is the best for our application.

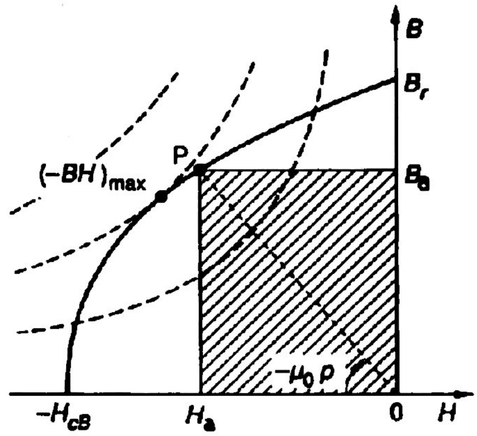

***Fig. 1:** Magnet characteristic and charge line*

Devices using bulk magnet are designed to have a working point near the $(BH)_{max}$ of the material. It allows to optimise the amount of magnet material for the application.
The particularity of film magnets is their shape tends to render more difficult their use near this ideal working point. Parallel magnetised materials present no problem to size the magnet length in order to adapt the charge line (see Fig. 1) of the magnetic circuit. But then the flux generated is very low as depends directly on the thickness of the magnet layer. Therefore, to obtain a given flux, the designer will have the possibility to increase easily the magnet length. Inversely, perpendicular magnetisation often forbid to work at the (BH)max due to the fact that the magnet thickness is limited by the manufacture of the film and the air gap is generally fixed by the application and technology constraints.

In order to choose between parallel or perpendicular magnetisation, we have decided to maximise the ratio of useful magnetic energy induced by the magnet. The reluctant torque of the stepper motor corresponds to the differential of the total magnetic energy versus the angular position of the rotor [4].

$$\Gamma = \frac{\partial W_s}{\partial \theta} \qquad (1)$$

Integrating these values, we obtain a relationship between the ability to produce torque and the maximum variation of energy.

$$\int \Gamma d\theta = W_s^{max} - W_s^{min} \quad (2)$$

Thus we get a criterion to compare the interest of both configurations parallel or perpendicular magnetisation. We will choose the configuration which is the most able to generate torque.

However, the conclusion is not so easily obtainable as the variation of magnetic energy depends both on the magnet shape and its charge line. The last one takes into account the whole magnetic circuit of the device. Thus actually it should be computable only for each optimised device, and no general conclusion might be taken.

To overpass the difficulty, we have made a model of the magnetic circuit for the kind of device we are working on: i.e. single phase step micro-motor. Generalising the concept, it is possible to define other models of magnetic circuit for other kinds of device.

To define the model of the magnetic circuit, we need to set up some variables to be able to compare configurations. First variable to set up is obviously the magnet characteristic. Remanent induction has been fixed to 1T. The second constant parameter for configuration comparison is the magnet volume. A third parameter is the air gap that has been set up to 50 µm, which is an adapted value for our micro-systems.

The study aims at comparing configuration of the magnets and its associated air gap. The return magnetic circuit has been over dimensioned to minimise its impact (which is not directly related to magnet configuration but to device topology). We get then models presented hereunder (see Fig. 2a & 2b)

The evaluation of the ability of the configuration to generate reluctant torque is done computing the variation of stored magnetic energy between two extreme conditions: in front of a stator tooth and between two stator teeth. The presence of the tooth is modelled by the presence of the return circuit, whereas its absence is modelled with the magnet alone.

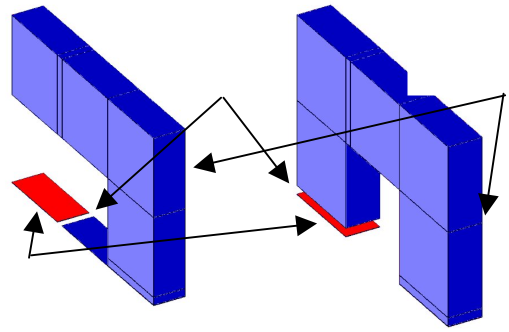

Fig. 2a: *Parallel magnet model* ***Fig. 2b:*** *Perpendicular magnet model*

The model is 3D with two symmetries (here only one quarter of the whole geometry is represented). The 3D model enable to get a good evaluation of the magnetic energy inherent to flux leakage.

Finally width and length of the magnet have been fixed also to micro-motor adapted values. The concerned micro motor would be a 4mm radius 60 poles device. It is expected that the impact of the configuration (parallel or perpendicular) increases with the ratio thickness dimension versus main dimension of the magnet. So the evaluation has been parameterised through magnet film thickness from 1µm up to 1mm.

The figure 3 shows clearly that the variation of stored magnetic energy is significantly greater with perpendicular magnetisation, which means that the torque potentially obtainable with perpendicular magnets is greater. Consequently, the micro motor we have designed uses perpendicular magnetisation to optimise the use of the film magnets.

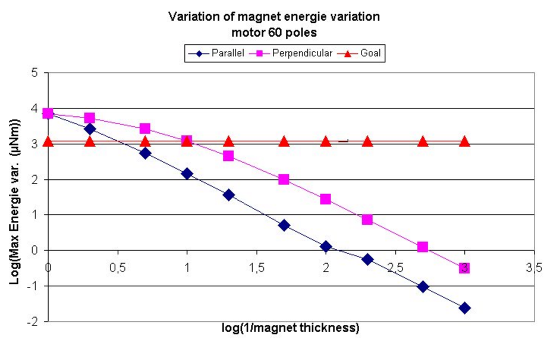

Fig. 3: *Comparison of the torque generation ability between parallel and perpendicular magnetisation of film magnets*

Motor structure for film magnets

Once chosen the configuration of film magnetisation, one needs to adapt the design of the micro motor for the achievable micro technologies. Two issues are concerned: air gap and coil configurations.

Due to the process complexity of the realisation of film magnet, it is not yet affordable to realise complex structure of soft material leading the magnetic flux. So perpendicular magnet have been directly exposed to the air gap.

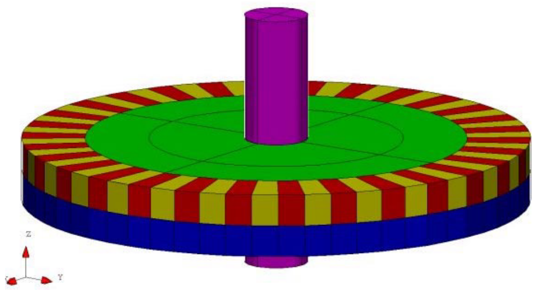

Fig. 4: *Structure for a 60 poles rotor*

Consequently, we have opted for an axial air gap which is from the precedent consideration the right air gap configuration for the optimisation of film magnet use (see Fig. 4).

About the micro motor coils, we have taken into account two considerations, which give the same conclusion.
First, as we previously said, scale factor tends to favour magnet use when the device is miniaturised. The consequence is the difficulty to generate equivalent magnetic energy with micro coils. One well known aspect is the micro coils are limited to small number of turns. Hence the interest to limit the number of coils in the device. We have selected a single coil motor. This means also a single phase motor, which is casier to command even if such a kind of system is more tricky to design.
Our second consideration is about the market of micro motors. Today, one important market for micro motors is the watch industry. The established motor structure for this industry is the Lavet motor which is a single phase step motor.

Principle of the single phase step micro motor

Single phase motor are particular for their functioning way. For two, three or multiple phases step motors, the principle the rotation is based on the same scheme. One phase allows the rotation of the rotor until a balance position. Then another phase takes the relay so to move further. Current phase of most devices are controlled in order to smooth torque and speed, else they are called step motor. Single phase motors are particular in the way there is no other phase to shift the balance position and thus turn the rotor. Thus single phase motor need to use some trick, like Lavet motor, to transform it into an actual rotating device. The reluctant torque is used to replace a second phase. But then, the reluctant torque needs to be designed with care as its balance positions should have angular dephasing with thoses of the coil torque.

Our single phase, single coil stator is equipped with teeth to lead the flux efficiently up to the rotor. The reluctant torque of these teeth has a spatial frequency which is the double of the one generated by the coil. However the balance position of reluctant torque is also a balance position for the current torque. We have then added reluctant teeth independent from the magnetic circuit of the coil so to shift the total reluctant torque. The total motor torque is then the sum of a reluctant torque plus the spatially dephased stator torque parameterised by the supplied current. By this way, different balance positions are obtained according to the presence or not of the current (see Fig. 6).

Motor numeric model

The micro motor has been designed with FLUX FEM software [6]. Here, we present the first model of the 4 poles version that has been designed with a scale of 2 factor on the diameter for the realisation of the first prototype (see Fig. 5).

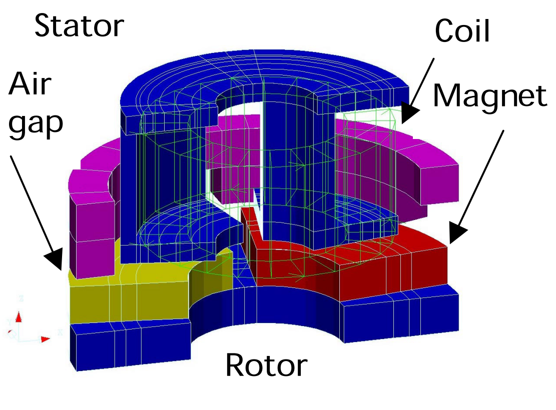

Fig. 5: *Structure of the single phase step motor*

The rotor has 10 mm in diameter and the computed torque of the prototype is given hereunder (see Fig. 6).

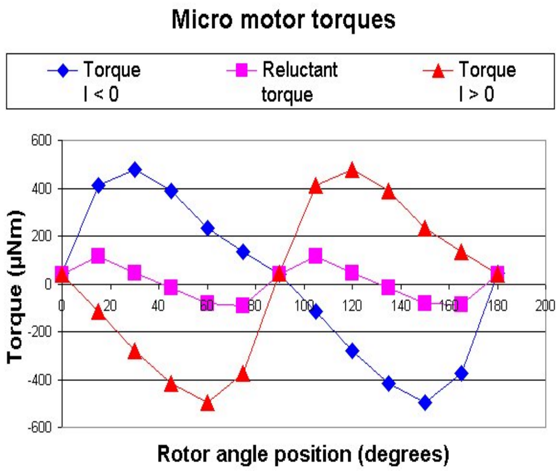

Fig. 6: *Flux Computed torque of the scale 2 motor*

Prototype

A prototype of the scale 2 motor has been realised in the laboratories of Cedrat Technologies (see Fig. 8). It uses artificial ruby stones supplied by ETA and 1mm thick bulk SmCo magnets (see Fig. 7).

Air gap tuning

The design of the motor comprises a tuning device for the air gap of the rotor. The air gap is adjustable from several tens of micro meter up to 1mm and is prepared to receive rotor made of film permanent magnets.

Measurements

The maximum reluctant torque of the motor has been measured to 220 µNm for a stator air gap of 400µm. More accurate characterisations of the different device torque will soon be done.

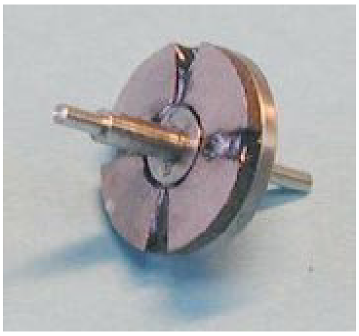

Fig. 7: *Rotor with 4 magnets*

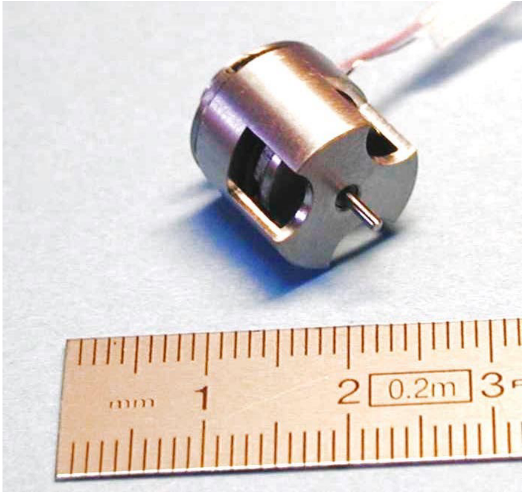

Fig. 8: *Scale 2 motor*

Conclusion

The single phase step motor has been designed to be compatible with the micro system technologies. The structure of the rotor is adapted to film permanent magnet deposition. A scale 2 prototype with tuneable air gap and using bulk magnets has already been realised and it shows an adequate torque.

Acknowledgement
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