Upgrade of Miniature Outrunner Brushless DC Motors

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Abstract:
Miniature Brushless DC motors (less than 5gr) offer some challenges both in the design and the manufacturing. They are used in several mass volume applications, such as hard disk drive, gyroscopes, and more recently in some unnamed aircraft vehicles (UAVs), where Cedrat is involved. For this last application, the efficiency is of upmost importance. Cedrat has used its Flux software solution to optimize the Brushless motor design: Some materials and dimensions have been changed in the motor to improve its efficiency. A gain is obtained by using some high magnetic saturation materials, such as FeCo and an appropriate thermal treatment. The experimental results have been obtained on a test bench including an magnetic encoder and an hysteresis brake. Further improvements in the optimization of the motor are linked to the drive. The paper will present the test results and FLUX fem results and a comparison between those results.

Keywords: Brushless motor, modeling, optimization, tests characterization

Introduction

Miniature Brushless DC motors offer some challenges both in the design and the manufacturing. They are used several mass volume application, such as hard disk drive, gyroscopes, and more recently in some unnamed aircraft vehicles (UAVs). For this last application, the efficiency improvement is of up most importance. CEDRAT has been using its software solution to optimize the Brushless motor design. The optimization was carried out using the Flux software solution and its Brushless Permanent Magnet Motor overlay [1]. BPM overlay is a customization of Flux 2D finite element software which makes the finite element use quicker and easier for the designer. It offers well-known topologies of rotor, stator, winding, and methods of analysis.

The modeling results have been compared to experimental results, which have been obtained on a test bench including an magnetic encoder and an hysteresis brake. The paper will describe this comparison. Some slight differences are noticed and may be attributed to the 2 dimensional assumption of the FEM analysis. However, the whole motor behavior is correctly modeled and allows an optimization process.

In a second step, some materials and dimensions have been changed in the motor to improve the efficiency of the motor. Some efficiency gain is effectively obtained by using some high magnetic saturation materials, such as FeCo and an appropriate thermal treatment. A second technological aspect remains the coil winding that requires some know-how to obtain an improved filling factor. CEDRAT is able to retrofit such motors for specific environments, such as vacuum.

Further improvements in the optimization of the motor are linked to the drive electronics. Due to the small size of the motor, a sensorless approach is used for the drive control. The future system modeling of the motor and its drive and control electronics will help optimizing the drive and controls electronics.

Motor construction

The BLDC miniature motor is typically used in UAV's and consists in a stack of laminated magnetic material and a set of miniature coils (Figure 1). The outrunner rotor is an assembly aof powerful magnet (Figure 2). The winding is called a Separated Phase sectors (SPS) [4] and the combination of poles and magnets allows a large reduction of pole pitch and speed.

Figure 1: View of the BLDC parts

FEM modeling

The first step is the Finite Element Analysis of the motor with a 2-Dimensional assumption. The FLUX® software has been used to look at the flux saturation level (Figure 3).

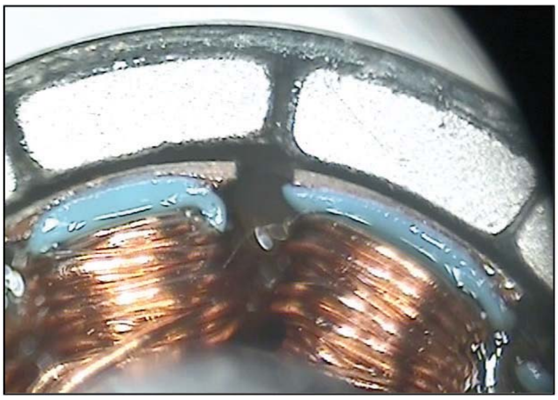

Figure 2: Detailed view of the air gap

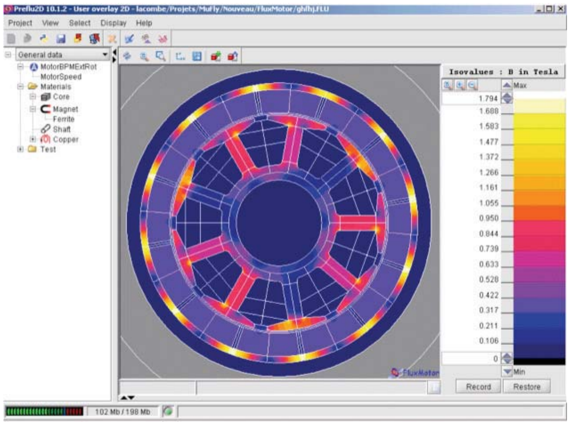

Figure 3: Flux modelling of the BLDC

A BLDC engineering-focused software has been developed based on the capabilities of the general simulation software Flux [2]. It allows managing 41 internal rotor topologies and 18 external stator topologies and is easily extensible. This dedicated tool generates automatically the geometry, the winding (lap, concentric, fractional-slot or customized) as well as rotor and stator eccentricities, motor periodicities ... A general mesh density factor is also included to control all the mesh of the motor. All these parameters allow the user to define easily and quickly his motor in the general purpose simulation software. A coupling with SPEED software is provided. The same tool has been developed for induction machines. In the future, we are planning to extend our approach to provide classical tests, design processes and optimization tools.

Lumped circuit approach

The SPEED software has been used to compare the influence of several materials of the stator (Figure 4).

It can shown that a better load characteristics can be obtained by the use of a laminated FeCo material in the stator that allows a high magnetic induction saturation field.

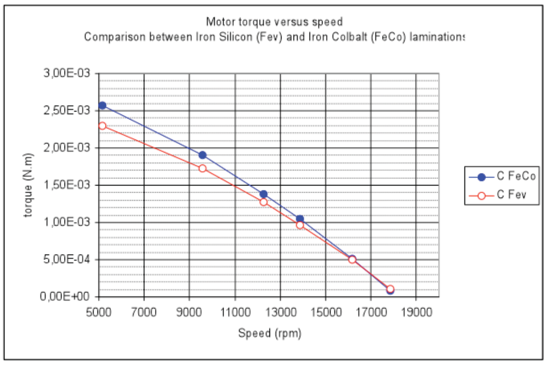

Figure 4 : SPEED results: load characteristics of the BLDC

Drive and control electronic

However, the design of the drive and control electronic of the BLDC comes with the need of an external controller as it is required to switch the phases, which is done internally by the commutator on the classical DC machine. The role of the external controller is to create a rotating magnetic field, such that the magnets on the rotor will be able to follow it. This means that the controller should rotate the magnetic field at the exact same frequency as the permanent magnets are rotating, which is why a good knowledge of the angle of the rotor is required. The angle can be measured by using sensors placed on the motor such as an encoder or Hall Effect sensors. Back-EMF technique and observers are sensorless methods to estimate the angle. They are called sensorless methods as there are no sensors placed on the motor.

The commonly used back-EMF (Electro-Motive Force) sensing technique is chosen for controlling the BLDC. The back-EMF technique is based on a property of the BLDC that when the rotor is perpendicular to the inactive phase (angle between the magnets of the rotor and the inactive coil is 90°), the voltage drop through this phase is zero. The voltage drop through a phase is $v_X=V_X-V_N$, where V_X is the potential of the phase X (which can be measured directly on the BLDC), V_N is the potential at the neutral node, that is the potential at the star connection for all three phases of the motor (which is inside the motor and is more difficult to measure, cf Figure 1). The property can be realized from the electrical dynamics of the BLDC, which are represented by the following equation.

$$\mathbf{v}_{abcs} = \underbrace{\mathbf{L}_s \frac{d}{dt}\mathbf{i}_{abcs}}_{Inductance} + \underbrace{\mathbf{R}_s \mathbf{i}_{abcs}}_{Resistance} + \underbrace{\left(\frac{d}{d\theta_e}\boldsymbol{\lambda}'_m\right)\omega_e}_{Back-EMF}$$

A miniature board has been used to control two motors (Figure 5).

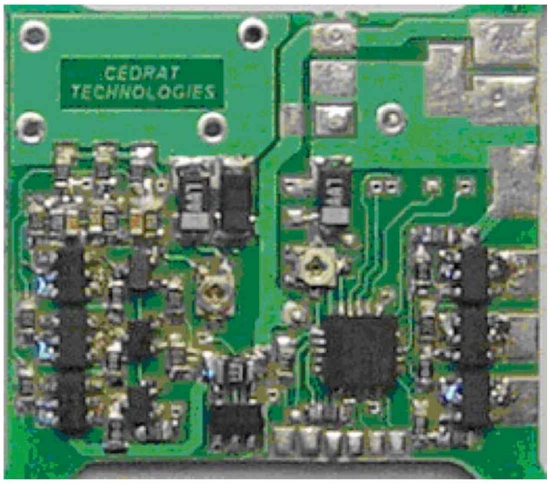

Figure 5 : View of the BLDC control board

Tests characterization

A test bench (Figure 6) including a hysteresis brake, a speed encoder has been prepared to characterize the BLDC and its electronic. Several configurations have been measured:
- initial configuration of the motor,
- influencing parameters of the driver,
- motors with improved stator materials.

For instance, the measurements are found repeatable. Several controllers have been also tested on a reference motor to study the parameter setting in the real time controller and their influence on the efficiency (Figure 7).

Optimization routes

Miniature BLDCs have been considered, modelled and tested for their use in UAV's. Optimization routes have been identified mainly in the stator. Another possibility could consist in using miniature Hall effect sensors to monitor the rotating magnetic field.

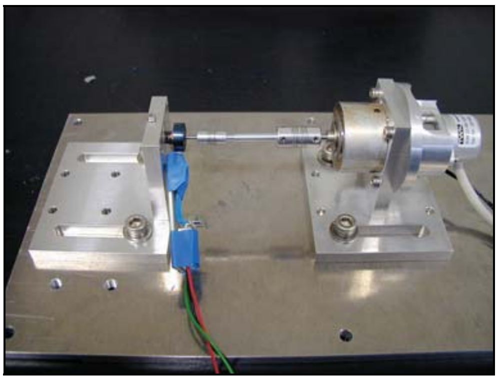

Figure 6 : Tests characterization bench

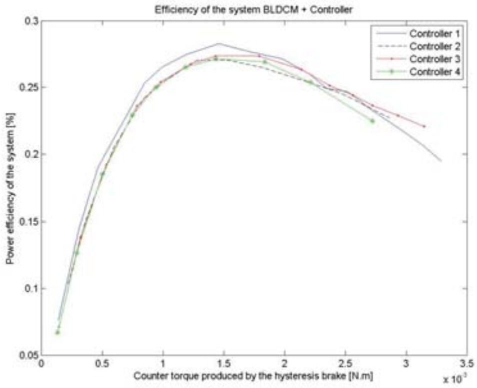

Figure 7: Comparison of the efficiency of the motor + drive electronic

Conclusion

A gain is obtained by using some high magnetic saturation materials, such as FeCo and an appropriate thermal treatment.

Acknowledgement
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