LINEAR MAGNETIC ACTUATORS FOR FINE POSITIONNING

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1. INTRODUCTION

Linear Magnetic Actuators and Limited Angle Torque Actuators are attractive technologies for designing space pointing applications. They are preferable to piezo actuators when the displacement reaches 1 mm or the angular range reaches 1°. Although those technologies have been already used in space mechanisms [1-4], there are very few european companies that produce those actuators for the space market.

For a new accurate pointing application based on a gimbals assembly, a new Limited angle Torque (LAT) actuator has been designed and tested [5]. Moreover, the Limited Angle Torque actuator was submitted to thermal shocks and a thermal vacuum burn-in test. This paper introduces the design and test activities around this actuator.

The Limited Angle Torque actuator uses the Lorentz force to produce a smooth cog less torque. The coils have been redunded; an intensive effort was performed to optimize the LAT with the help of magnetic flux finite element computation using FLUX®. The coils have been over-molded with a space compatible potting resin.

In a second step, the LAT has been assembled on a test bench including flexible pivots. The LAT was driven by a linear amplifier LA24 from CEDRAT TECHNOLOGIES SA. The high signal to noise ratio of the amplifier (90 dB) allows us reaching a torque resolution of 25 µN.m, limited by the angular position sensor resolution.

A discussion is provided on the difference between the as-designed and as-measured configurations.

The Parts, Materials and Processes have been assessed and the technology is available for building a family of LAT or linear Moving Coil [6].

2. ACTUATOR SELECTION & BASIC PRINCIPLE OF OPERATION

An actuator has to be selected for a fine pointing application, given the following set of requirements:

- creation of a pure torque,
- coils preferably at the stator side to evacuate the Joule's losses,
- redunded actuations at the actuator level,
- constant torque over the limited angle,
- low electrical constant,
- linear torque versus the driving current.

To comply with these requirements, the use of the Lorentz force is mandatory, since in alternative designs (variable reluctant actuator [6], moving magnet actuator [7]) the reluctant force would create some cogging forces. The last alternative consists in Conventional design, which is based on a regular Permanent Magnet BLDC motor, in which a laminated stack of the Armature Assembly consists of the slots, teeth and the back iron. Those solutions have their pros and cons (Table 1).

BLDC motor	LAT	Angular VCM
Small air gap	Larger air gap	Larger air gap
High torque	Lower torque	Lowest torque
High motor constant	Lower motor constant	Lowest motor constant
High hysteresis and eddy current losses	Lower hysteresis and eddy current losses	No hysteresis and eddy current losses
High cogging torque	No cogging torque	No cogging torque
High electrical constant time	Lower electrical constant time	Lowest electrical constant time
Best heat dissipation	Good heat dissipation	Heat dissipation may be a problem
Large sensitivity to rotor out-centering	Medium sensitivity to rotor out-centering	No sensitivity to rotor out-centering
No moving connectic	No moving connectic	Moving connectic

Table 1 : Technologies trade-off

The Limited Angle Torque (LAT) is composed of a conducting rotor supporting the permanent magnets. The stator is based on a conducting torus, supporting two toroidal wounded coils. Those coils

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are driven opposite in phase to force the flux passing through the magnets. A Lorentz force is generated within a part of the coil in the inner diameter of the torus, creating a pure torque (Figure 1).

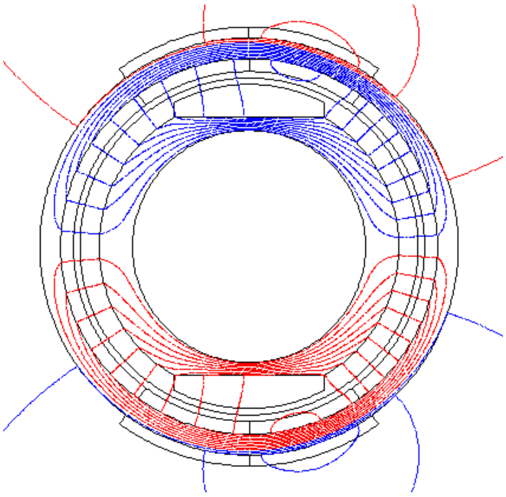

Figure 1: View of the Flux line created by the coils

Two angular Voice Coil Motors [8] driven opposite in phase would be needed to cancel the parasitic forces produced by such design. Moreover, a moving connectic is a source of risks, if a long lifetime and low disturbance torque are wished.

It was concluded that the toroidally wounded LAT represents the best compromise.

3. DETAILED DESIGN

Various designs of Limited Angle Torque actuators, including redundant coils have been studied (Figure 2). Space qualified materials have been selected. Because the coils are located on the outer diameter, it was preferred to over mould the coil through a dedicated potting. SmCo magnets have been selected for their very stable behaviour over a large temperature range, despite their lower intrinsic energy. Finally, two redundant coils were wounded and separated through a polyester segregation.

The FLUX® software has been used to estimate the actuator's behaviour. Various sensitivity analyses have been performed. Also, the effects of a non centered rotor have been estimated.

The FLUX® software was also used to evaluate the thermal worst case assuming radiative and conductive thermal paths (Figure 3). The self heating of the coil is around 30 ℃, assuming one third of the thermal dissipation is evacuated by conduction.

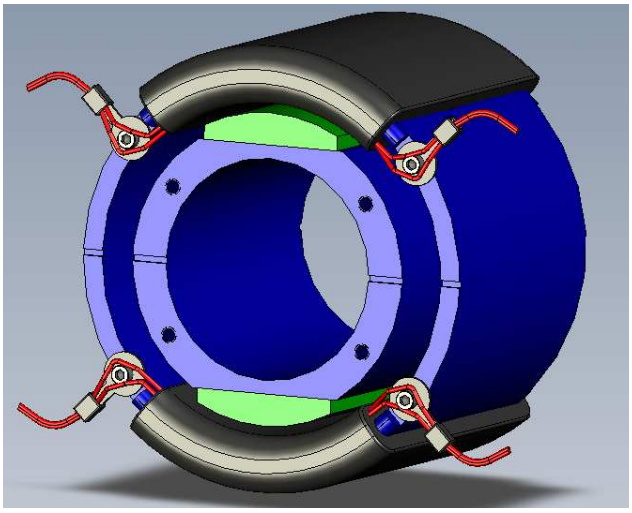

Figure 2: CAD View of the LAT100

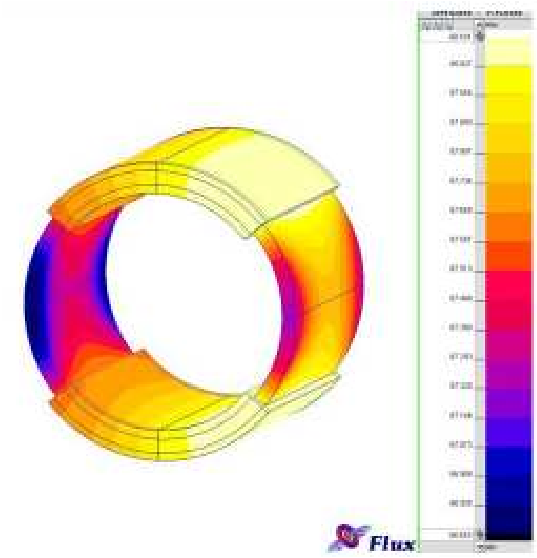

Figure 3: FLUX® thermal computation

The breadboard is designed to comply to the Class F (155 ℃) according to the ESCC 3201 standard. The coils are procured according to MIL-STD-981 Class S.

4. EVALUATION CAMPAIGN

The Limited Angle Torque actuator LAT100 (Figure 4) has been integrated. The LAT was tested on a dedicated test bench (Figure 5). This test bench includes:

- 2 flexible pivots,
- a differential eddy current sensor reading the angular position,
- a force sensor able to read the torque.

The acceptance functional cycles shows that the behaviour is linear until 200 mN.m (Figure 6). The measurement on both the nominal and redundant windings, of the produced torque versus the angular position requires some particular care (Figure 7).

The actuator was then subjected to an evaluation campaign including:

- functional tests,
- 50 thermal shocks (to evaluate the robustness of the over-moulding,
- a thermal-vacuum test including 2 storage cycles and 6 functional cycles.

No particular change in the actuator's behaviour was noticed. The electrical impedance is dependant on the temperature as expected.

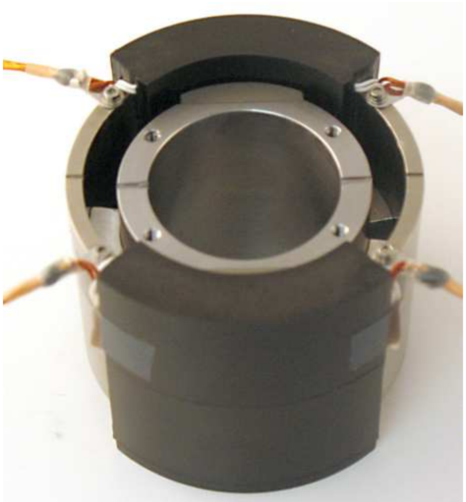

Figure 4: View of the LAT100

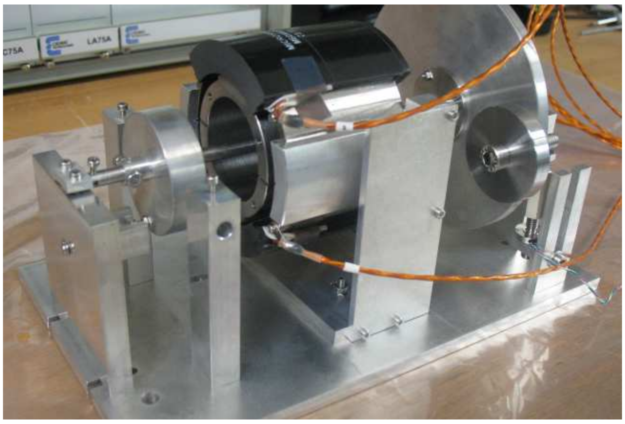

Figure 5: View of the space evaluated Limited Angle Torque actuator installed on its test bench

The obtained functional performances are compared in the Table 2. Some functional tests were performed both on the nominal and redundant coils. For instance, the actuator provides a torque of 220 mN.m with a current of 1.2A and a dissipated power of 17.5 W. The actuator starts to saturate with higher values of current. Some comparisons with the magnetic modelling have been used to explain the difference on the motor constant between the nominal and the redundant coils (Figure 7). For instance, the magnets (if non centered) can lead to a local magnetic saturation of the tore, which further provides a change of the motor constant.

		2D design	3D design	Measured
Torque constant	N.m/A	0.207	0.157	0.167
Motor constant	$N.m/W^{1/2}$	0.059	0.045	0.048
Inductance	mH	12	15	15.2
Resistance	Ohms	12.07	12.07	12.25

Table 2: Functional set of performances

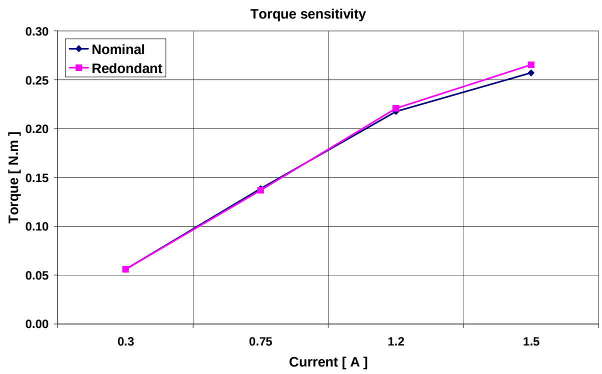

Figure 6: Torque versus the driving current

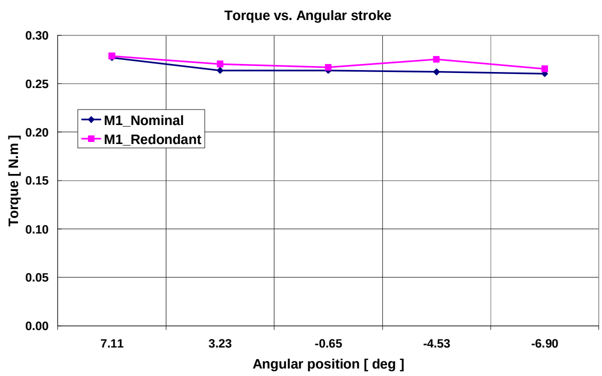

Figure 7: Torque versus the angular position (nominal and redundant winding)

Several lessons learned have been obtained from this test campaign:

- adequate tool to ensure a good centering of the rotor versus the stator and a good angular indexing,
- include some metrology check of this centering,

- follow the coil's temperature in thermal vacuum conditions though the resistance change.

5. FURTHER DEVELOPMENTS

To get an optimized design, it is interesting to compare the designed solutions though a parameter Kmw, defined as:

$$Kmw = N.m/(W^{1/2}.kg),$$

Where:

- N.m is the produced torque,
- W is the dissipated power,
- Kg is the mass.

Thus, several solutions (including the number of poles) can be compared, as this was done in [1]. This approach shows the interest to reduce the air gap.

The qualification campaign includes a lifetime test, some thermal step-stress tests and a thermal model refinement.

This technological development, especially the Parts, Materials & Processes (PMP) is available for linear Voice Coil Motors [9] that find typical applications in Fourier Transform spectrometers, or for two degrees of freedom pointing mechanisms.

6. ACKNOWLEDGEMENT

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