Large stroke Rotary Voice Coil Motor for cryogenic application

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Abstract

CTEC is developing and testing Rotary Voice Coil Motors (RVCM) for new cryogenic space scan mechanisms applications, based on former MTG space program heritage. The RVCM is an electromagnetic motor based on Laplace force. The motor is composed of coils at the rotor part (mobile) and magnets at the stator part (fixed). The Laplace motor generates a pure torque, without cogging or parasitic force drawback, which makes it specifically relevant for scan mechanisms.

For the expected next generation of scan mechanisms, CTEC has been asked to extend the angular stroke of RVCM technology up to ± 90 deg, and to make a specific design for cryogenic temperature condition at -140 °C. The design and test results are presented, up to a torque of 1.2 N.m. The functional tests are presented at ambient temperature and pressure, as well as in the operational temperature range [105 to -140°C to °C] under vacuum.

The goal of this paper is to present the motor that meets these requirements. The first part will focus on the approach that leads to the selection of the architecture and magnetic materials. It will point out on the main issues that are the torque characteristic and the power consumption. Then, the actuator by itself will be presented, associated with the expected performances. To conclude, the test results of the prototype will be summed up.

1 Introduction

Several actuation solutions are available for the space market. Several actuation technologies are available for the scanning application. The electromagnetic technologies are the adapted solution for a large angular stroke. The Laplace force is a mandatory solution to comply with all motor requirements, since the alternative solution brings some limitations and none conformances. The cogging torque and parasitic force are the main drawback of permanent magnet BLDC (Brushless direct current) motor. The LAT (Limited Angel Torque) motors are adapted to generate a pure torque with a large angle stroke [1]. The LAT motors are based on the toroidal coil wounded upon the cylindrical stator. The rotor is installed inside the stator. So, only half of the coil contributes to the torque generation. The voice coil motor technology has no hysteresis, no cogging and no eddy current. These properties are suitable for scanning application. Nevertheless, the heat dissipation may be a problem because the coil is located at the mobile part level.

The voice coil motors are well known for linear actuation solution. But, there are also adapted for angular displacement (Figure 1). The picture show two different coils at the stator level to be compliant with the redundancy constrain. This solution has been already qualified in a former MTG project.

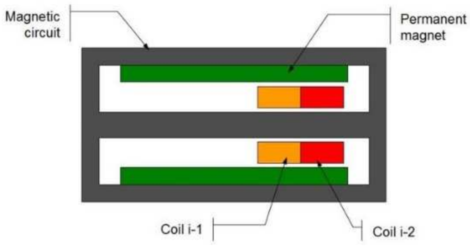

Figure 1 : 2D cut view of RVCM

2 Background

For the ESA / MTG project two motors have been designed and qualified by CTEC. These motors are used for the scan mechanism of the MTG satellite. Depending on the location, the motors have ± 12 deg or ± 6.5 deg angular strokes [2]. Both motors are in push-pull configuration to avoid force generation at the guiding level.

The generated torque is based on the combination of the Laplace force and a level arm with axes of rotation. To avoid parasitic force, a mechanism based on two RVCM motor is proposed.

Figure 2 : The RVCM – MTG scan mechanism

3 The specification

For the expected next generation of scan mechanisms, the RVCM-180 motor is designed for a large angular stroke (±90 deg), and large temperature constrain (from 105 to -150 °C) in order to achieve compatibility with cryogenic cold conditions and space vacuum.

4 Justification for cryogenic application

The performances of the RVCM-180 actuator are evaluated from the electromagnetic point of view, and from the mechanical and thermo-mechanical side.

4.1 Electromagnetic

The first simulations have been done with a 2D model. A parametric study has been conducted with the aim of having a geometry corresponding to the optimal required motor constant (K_M) and the nominal torque (T_N):

$$K_M = \text{Torque} / \sqrt{\text{consumed power}}$$

$$T_N = \text{Torque} / \text{Current}$$

The optimisation process has been performed with some constraint linked to the rotor mass, actuator mass and the available volume. From the material point of view, the comparison has been done between the NdFeB and SmCo magnet. The diameter of the electrical wire has been selected regarding the electrical impedance requirement.

Based on the optimisation process conclusion, a 3D modelling has been built and simulated. The elected materials for the electromagnetic simulation are given in the table below (Table 1). The SmCo magnet (RECOMA 33E) has been selected due to its stability against the temperature and durability regarding the corrosion effect.

Material	Region	μr ( )	Js / Br (T)
RECOMA 33E	Magnets	1.07	1.13
AFK502	Magnetic circuit	2000	2.35

Table 1 : The magnetic properties of the material

The level of magnetic field upon the magnetic circuit, the magnet and the coils is computed in a first step (Figure 3).The torque generated is extracted regarding the injected current.

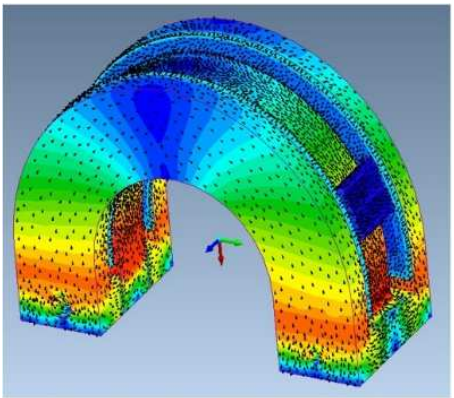

Figure 3 : 3D view of magnetic field upon the magnetic circuit and the magnet

The generated torque by the RVCM-180 actuator based on the simulation versus the angular position and the current is given in the curves below (Figure 4). The direction of the current is changed is such way to allow the rotor to turn the clockwise direction on half of stroke and in counter clockwise direction in the second half of the stroke.

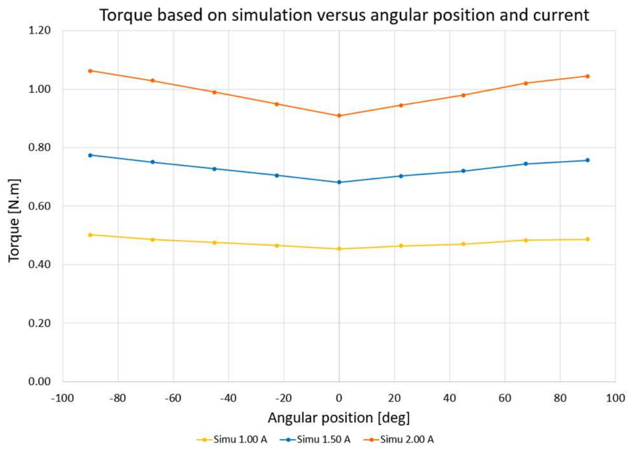

Figure 4 : The torque vs. angular position and current

The simulated current are 1, 1.5 and 2 A. The torque is not constant versus the angular position, so the minimum torque is obtained at the center angular position (o deg) and the maximal one at end position (90 deg) as given in the table below (Table 2). This is consistent with a pivot stiffness which increases as it moves away from the nominal position (0 deg).

Parameters	Value	Units
The performances		
Stroke	± 90	deg
Torque (@0 deg)	0.68	N.m
Torque (@90 deg)	0.77	N.m
T_N (@0 deg)	0.45	N.m / A
T_N (@90 deg)	0.51	N.m / A
K_M (@0 deg)	0.12	N.m / W½
K_M (@90 deg)	0.14	N.m / W½
Coil resistance at 363K	19.15	Ohm
Coil resistance at 293K	15.10	Ohm
Coil resistance at 130K	5.34	Ohm
Inductance	38.3	mH
The properties		
Stator weight	0.43	Kg
Rotor weight	9.95	Kg
Motor weight	10.38	Kg

Table 2 : The RCVM-180 performances

The dimension and the mechanical interface are given below. The mobile part of the motor is hollowed to allow a shaft to pass through.

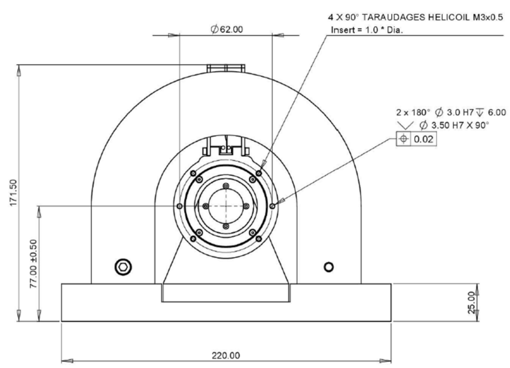

Figure 5 : The dimension of the RVCM-180

4.2 Glue reliability

The magnets are glued upon the magnetic material. The reliability of the glue has been studied due to the magnetic interaction between magnets. The magnet has been manufactured in several part due to manufacturing limitation. The magnitude of this force is computed and used to evaluate the stress generated upon the glue due to this force (Figure 6).

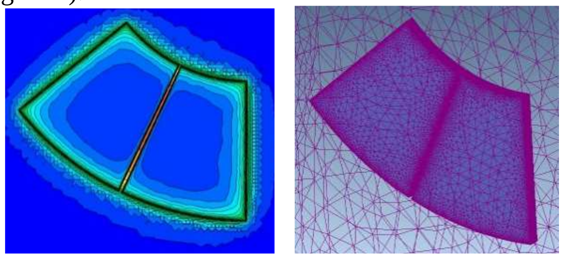

Figure 6 : The forces between magnets simulation

The stress generated on the glue is simulated and evaluated to ensure the reliability of the glue (Figure 7). Additionally, the thermal constraint [110 to -140 °C]. The magnet has been manufactured in several part du manufacturing limitation.

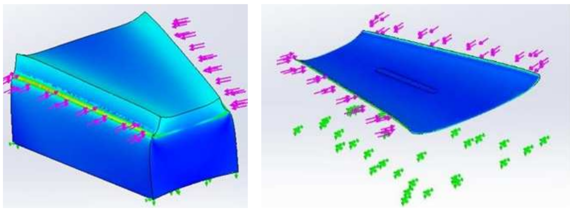

Figure 7 : The model for evaluation of stress on the glue

4.3 Ball bearing

The maintain of the preload at the ball bearing level is a major issue on the motor design. Indeed, the high variation of the temperature requirement [110 to -140 °C] and the different material used in the motor (different coef. of thermal expansion) impact the preload of the ball bearing.

So, the material of the ring, the cage and the balls have been selected in order to be compatible with cryogenic temperature. The rotor is fixed upon to ball bearing in O configuration coupled with spring washer.

5 Manufacturing

The prototype has been manufactured and mounted according. The same manufacturing process has been in the RVCM-180 as used for the MTG scan mechanism motors.

5.1 Coil overmolding

The material of coil housing (TA6V) has been selected. The electrical insulation tape (Kapton) is placed between the coil housing and the wire to avoid any risk of varnish damage during the winding process. Mechanical segregation is directly machined on the coil housing to avoid any risk of failure propagation between the nominal and the redundant coil (Figure 8).

Both coils have been overmolded for mechanical protection of wire and for thermal consideration. The potting material has been selected for its thermal conductivity (Figure 8).

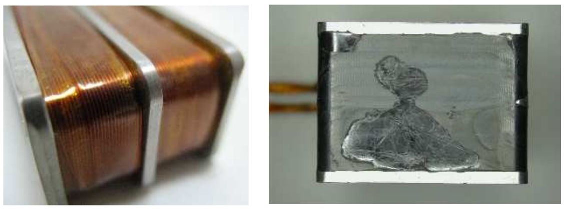

Figure 8 : The coil winding filing factor and the overmolding

5.2 Actuator

The mechanical air gap between the coils and the magnetic circuit correspond to 500 µm. So, a rotor assembly bench has been manufactured to ensure that both coils are aligned. The stator assembly bench has been used to avoid any risk of damage due to the magnetic attraction between the parts of magnetic circuit.

The RVCM-180 actuator is delivered with a ball bearing guiding (compatible with a cryogenic application) solution between the rotor and the stator (Figure 9).

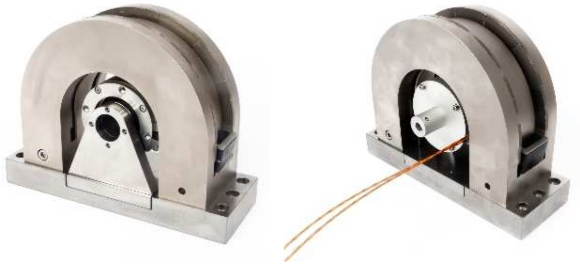

Figure 9 : The test bench of the RCVM-180 motor

5.3 Test bench

The torque is measured using a torque meter sensor installed between the mobile part of the motor ana mechanical clamping. A bellow is used for the misalignment compensation between the rotor axis and the clamping (Figure 10). The test bench included a temperature probe to measure the temperature at the coil level during the test.

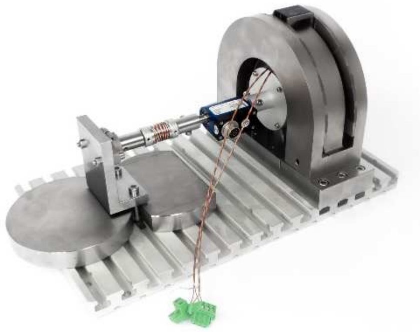

Figure 10 : The test bench of the RCVM-PP motor

6 Cryogenic test campaign.

The motor has been tested in ambient configuration (temperature and pressure) to compare with the simulation. Thereafter, the motor is tested in cryogenic configuration and vacuum.

6.1 Motor performance in ambient temperature

The motor performance is measured in the ambient configuration for a preliminary validation generated torque. The results shows a negligible difference between the simulation (about 5 %) for high torque at the ends of stroke. At the nominal position, the difference is about 20 %.

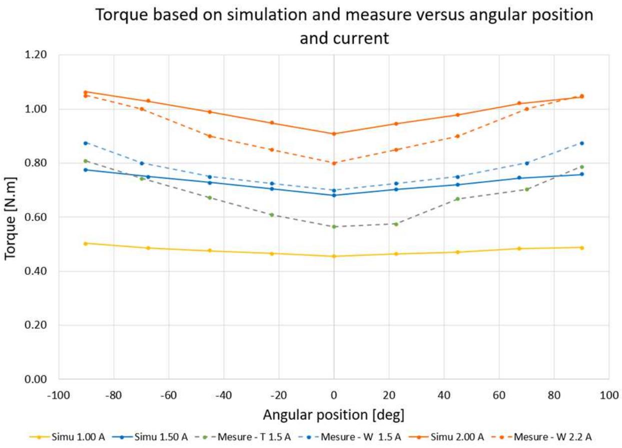

Figure 11 : The torque generated by the RVCM-180.

The performance of the RVCM-180 and the RVCM-MTG motors are given in the table below.

	Units	RVCM 180	RCVM-MTG
Stroke	deg	90	12
T_N	N.m / A	0.51	0.732
K_M	N.m / W½	0.14	0.206
Torque	N.m	1.20	0.42
Temperature	°C	+110 / -140	+60 / -15

Table 3 : The RVCM-180 and RVCM-MTG comparison

The temperature at the coil overmolding level is measured for different courant intensity. The curves of the temperature versus time is given below (Figure 12).

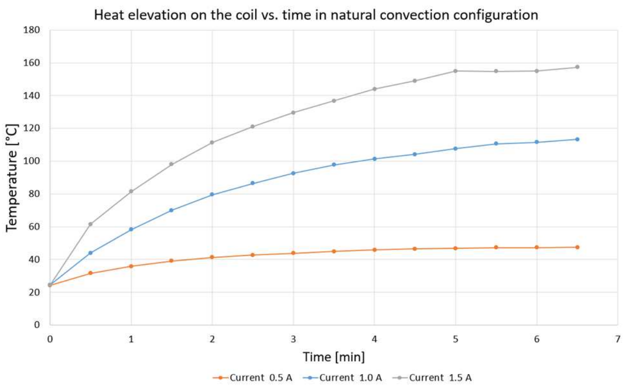

Figure 12 : The temperature at the coil level (overmolding).

6.2 Cryogenic thermal vacuum test

The motor has been tested using a cryogenic and vacuum test bench at Cedrat Technologies facilities. The cooling of obtained using a cold finger coupled with a nitrogen cold plate.

Figure 13 : Cryogenic vacuum test bench

The motor reach the RVCM-180 during the testing. Nevertheless, the temperature requirement for this project was -140°C.

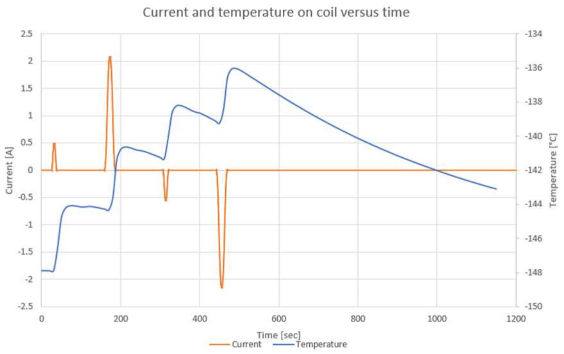

Figure 14 : The temperature at the coil level during activation of the motor

7 Conclusion

A rotary voice coil motor (RVCM) has been designed based on the heritage of the MTG scan mechanism motors. The stoke of the motor has been increased to ± 90 deg. The motor has been designed and tested to be compatible with cryogenic applications. The motor has passed the functional and the storage cycling. The motor has been activated at the highest (+110 °C) and lowest (-140°C) temperature and has been tested to more than 1 Nm torque.

8 Literature

[1] N. Bencheikh, R. Le Letty, F. Claeyssen, G. Magnac CEDRAT Technologies S.A., Meylan, France; G. Migliorero, ESA ESTEC, Noordwijk, '*Limited angel torque actuator for fine angular positioning*' Conference Actuator 2010

[2] N. Bencheikh, A. Guignabert, F. Barillot, C. Benoit, CEDRAT TECHNOLOGIES ; C. Burgui, , C. Compostizo, , I. Bueno SENER; P.Spanoudakis, L.Kiener, P.Schwab; CSEM SA; "*Voice coil actuators for two mtg instruments*"; Proc. '16th European Space Mechanisms and Tribology Symposium 2015', Bilbao, Spain, 23–25 September 2015 (ESA SP-737, September 2015).