# SMECm Actuator

## Technical Specifications

| Prepared by : | Date : |
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# 1 INTRODUCTION

## 1.1 Purpose

This document purpose is the specification of the linear motor to be used as the actuator of the scan mechanism of HERSCHEL SPIRE Fourier Transform Spectrometer instrument.

## 1.2 SMEC General description

The Spectrometer mirror mechanism subsystem (SMEC) is in charge of the motion of corner cubes mirrors inside the Fourier Transform Spectrometer of SPIRE instrument to be installed in the HESCHELL Space telescope to be launched around 2007.
The SMEC is made of 2 parts:

- the cryogenic mechanism (SMECm) placed inside a cooler at 4K
- the mechanism control unit (MCU) for the servo control of the mechanism.

The mechanism must perform a translation by suspending the corner cubes on a double stage parallelogram, with 16 flexible pivot to produce a spring force proportional to displacement. The motion is kept linear by mean of a synchronisation stage on the top on the mechanism.
The actuator is a linear DC motor (subject of this technical specification document) and the sensors are an optical encoder plus a LVDT sensor.

A prototype of this mechanism has been manufactured and equipped with an off-the-shelf linear motor for control tests (KIMCO motor LA13-30-000A). This motor does not fit the requested performances and cryogenic/space qualification levels. This document specifies the main characteristics to be met for the flight model motor and propose a reference solution compatible with performances and constraints requirements.

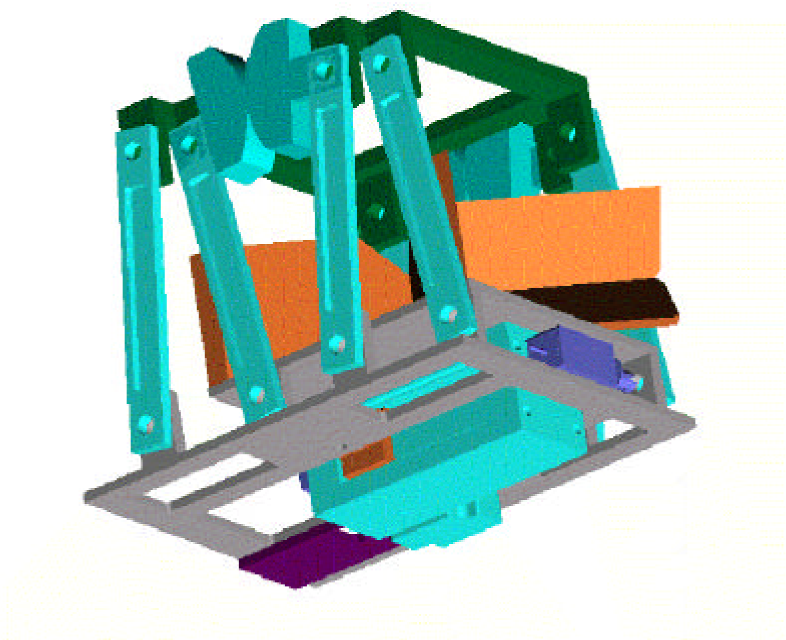


**Figure 1: Prototype of SMEC Mechanism equipped with the linear actuator**

# 2 REQUIREMENTS FOR THE SMEC MOTOR

The main parameters to be taken into account for the SMECm Motor design are expressed in the following table.

| Requirement Item | Value | Remarks and justifications |
|---|---|---|
| Motion range | 40 mm | |
| Maximum available force to be provided by the motor to move the mechanism along the complete range of the motion , i.e. to compensate for the spring mechanism force (plus the gravity effect on ground). | 2 N | |
| Max voltage drop in the motor resistance | 18 V | Limited by the 30V power supply of motor power amp. |
| Maximum motor resistance @ambient temp | 180 Ω | Derived from the maximum voltage drop |
| Maximum intensity | 100 mA | Spacecraft Harness limitation |
| Maximum power dissipation in motor @4K | 10mW | For a maximum force @cryogenic flight operation = 1.5 N |
| Operating temperature | from 300 K to 4K | The motor shall be used for both temperatures with identical functional performances |
| Magnet | Samarium Cobalt | qualified for space application and high performance |
| Coil wire gauge | 0.1mm (TBC) | The wire diameter is limited by the maximum intensity through the motor (100mA). |
| Actuator max dimensions | Length = 100 mm<br>Height = 25 mm | Max available room in mechanism |

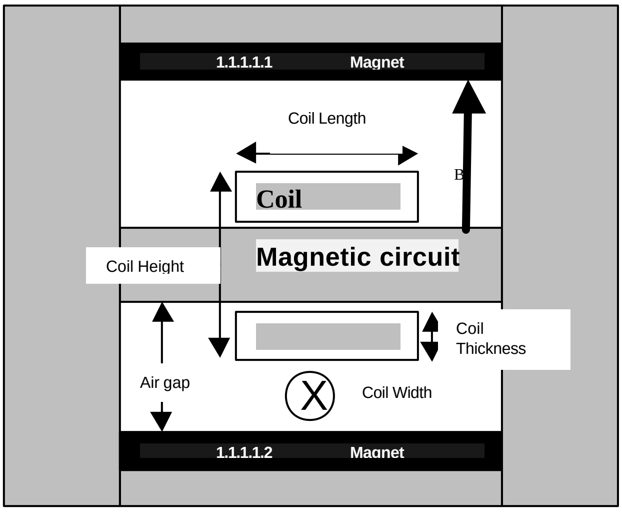
# 3 PROPOSAL FOR A MOTOR DESIGN

## 3.1 Purpose

The GSFC SMECm mechanical prototype is equipped with a commercial KIMCO motor Model LA13-30-000A. The purpose of this section is to propose a design solution based on the extrapolation that fulfils the above requirements. For this, we start with the KIMCO motor specifications to build a CAD model in order to extrapolate desired characteristics.

## 3.2 KIMCO Motor characteristics

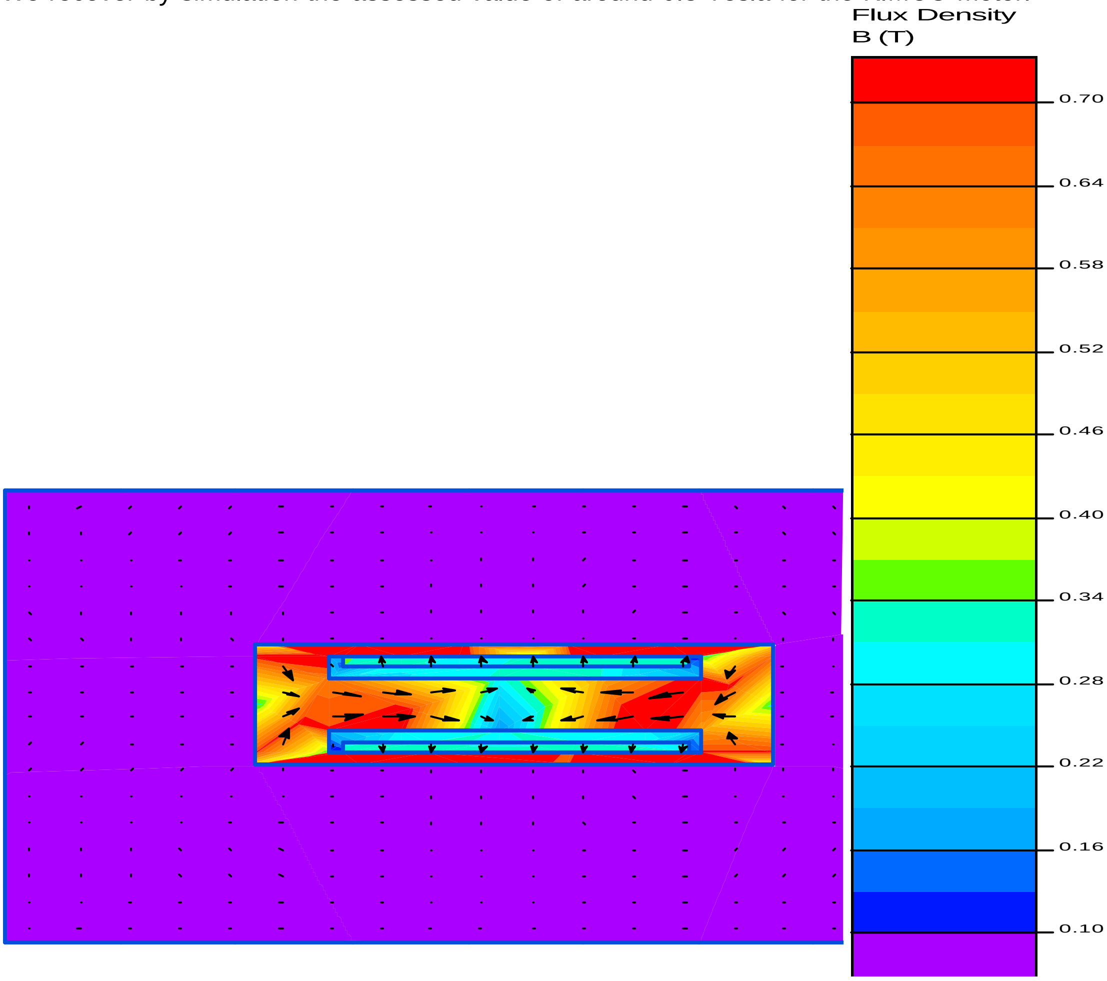
The KIMCO motor main geometrical characteristics have been assessed by measurements.
The coil length, height and width dimensions are defined on the following drawing.
Only wires in the width and length directions participate to the magnetic force generation.




| LA 13-30-00 KIMCO Specifications | Value |
|---|---|
| **Data sheet values** | |
| Force constant | 0.75LB./A = 3.3 N/A |
| Motor resistance @ambient temperature | 4.6 Ω |
| Stroke | +/- 1.75 cm |
| 3.2.1.1.1.1.1 **Assessed/measured Values** | |
| Wire diameter | 0.335 |
| Conductor diameter | AWG 28 = 0.32 mm |
| Coil wire length | 18 m deduced from 1.75$^{e}$-8 copper resistivity |
| Coil external dimensions (rectangular) | Width: 22mm<br>Height: 18mm |
| Coil internal dimensions | Width: 18.2mm<br>Heigth: 14.2mm |
| Mean coil dimensions | Length: 15.7mm<br>Height: 16.1 mm<br>Width: 20.1mm<br>Thickness: 1.8 mm |

## 3.3 QuickField simulation for the KIMCO motor Magnetic induction flux assessment

We recover by simulation the assessed value of around 0.3 Tesla for the KIMCO motor.




## 3.4 Parameters to be optimised

The goal is to optimise the force constant of the motor, using up to 100 mA, but with a constraint on the voltage drop in the motor leading to a maximum resistance @ ambient temperature.

The force constant is given by :

**F (N)= B(T). I(A). Lu(m).**

- B is the magnetic induction around 0.3 Tesla. (assessed by analysis)
- I = current in the coil
- Lu= length of the coil wire in the magnetic field which produces a magnetostatic force (wire perpendicular to the induction field)

The improvement of the existing KIMCO motor may be done through :
amelioration de la force by:

- the magnetic field improvement
- the number of active conductors of the coil in the field
- the intensity

## 3.4.1 Magnetic field improvement

For the KIMCO motor, t he magnetic field induction is assessed around 0.3 Tesla in the 3mm air gap (see QuickField figure).

The improvement of the magnetic field may be done by:

- a better magnet strength
- a better permeability of the magnet circuit
- a smaller air gap and optimised geometry.

### 3.4.1.1 Magnet Strength

The motor design shall include Samarium Cobalt magnets since they provide the best strength (around 1.1 Tesla) and are space qualified.

### 3.4.1.2 Air gap

Due to the coil mount and mechanical clearance the available air gap is limited by the coil thickness + 1.5 mm.
The diminution of the air gap shall increase the induction flux density according to the following figure. Decreasing the air gap from 3 mm to 2mm shall improve the induction of around 45%. But this impacts on the number of allowable wound wires (relates to the coil thickness) and the total improvement is not significant. Consequently, we keep the 3mm air gap as designed on KIMCO motor.

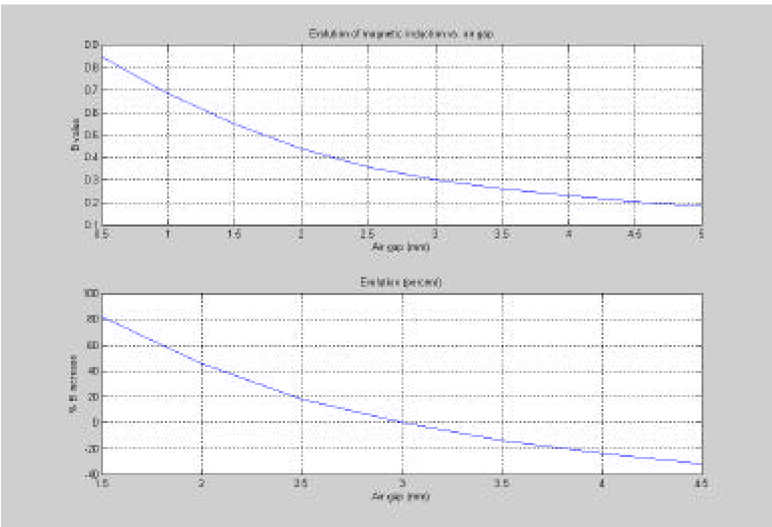



**Figure 2: Evolution of Induction vs. air gap**

#### 3.4.1.3 Magnetic circuit

The 2 magnets coupled in a perfect magnetic circuit shall lead to a 2 Tesla induction flux. This induction shall be reduced by the cross sections of the motor stator and the air gap. The role of the magnetic circuit is to insure a good permeability as well as a saturation level not lower than 2 Tesla. Furthermore, the improvement of the permeability at a low field strength of the magnetic circuit leads to a very poor global performance gain.
Consequently, materials with high permeability but with limited saturation level are not interesting. For this, we chose 2 V Permendur material which yields 2.3 Tesla saturation level.

### 3.4.2 Optimisation on the intensity

The max intensity is constrained by SPIRE instrument harness design (0.1 mA). We cannot increase this value.

### 3.4.3 Optimisation of the length of active conductors in the field

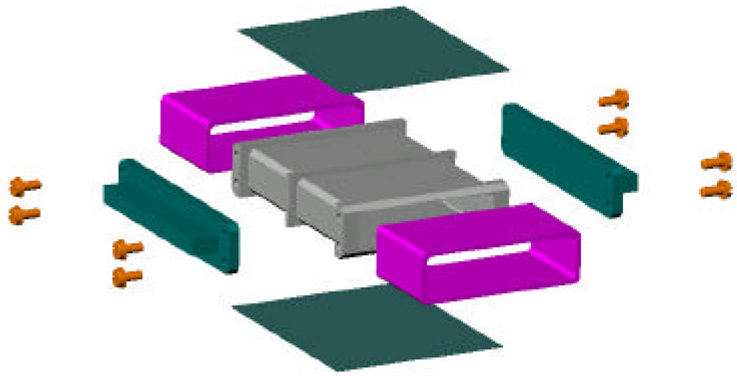
The motor improvement shall mainly consists in the optimisation of the active conductor length Lu and, given the geometry of the coil, the number of windings.
The coil shall have a maximum resistance compatible with the voltage drop admissible when the max current is passing through the motor. To be able to operate a warm temperature, the maximum resistance is given for 300K.
The motor power supply (30V) allows a 20V operating voltage. For a **100 mA current**, the voltage drop in the motor up to 18V (2V in the harness) leads to a maximum resistance of **180 Ohm.**
The length of active wire in the field is optimised by increasing the coil width, decreasing the coil height allowing a better efficiency since conductors in the height dimension are not active. We must not however reduce too much this section to avoid magnetic circuit saturation. For that a wire gauge less than 0.1 mm is not desirable (on SMECm the maximum current shall not be permanent).

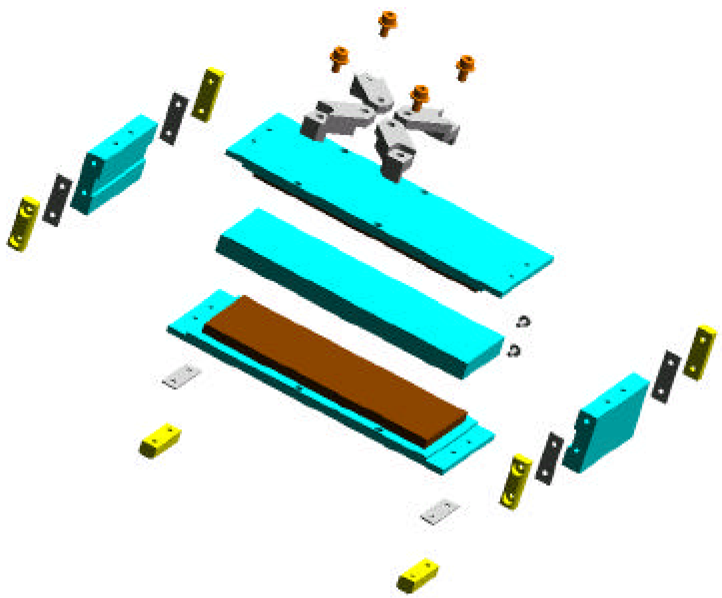
| dia (mm) | dia (inch) | AWG | max safe permanent current in magnet wire (mA) |
|---|---|---|---|
| 0.3 | 0.0118 | 30 | 477 |
| 0.1 | 0.0039 | 39 | 56 |
| 0.07 | 0.0028 | 42 | 28 |

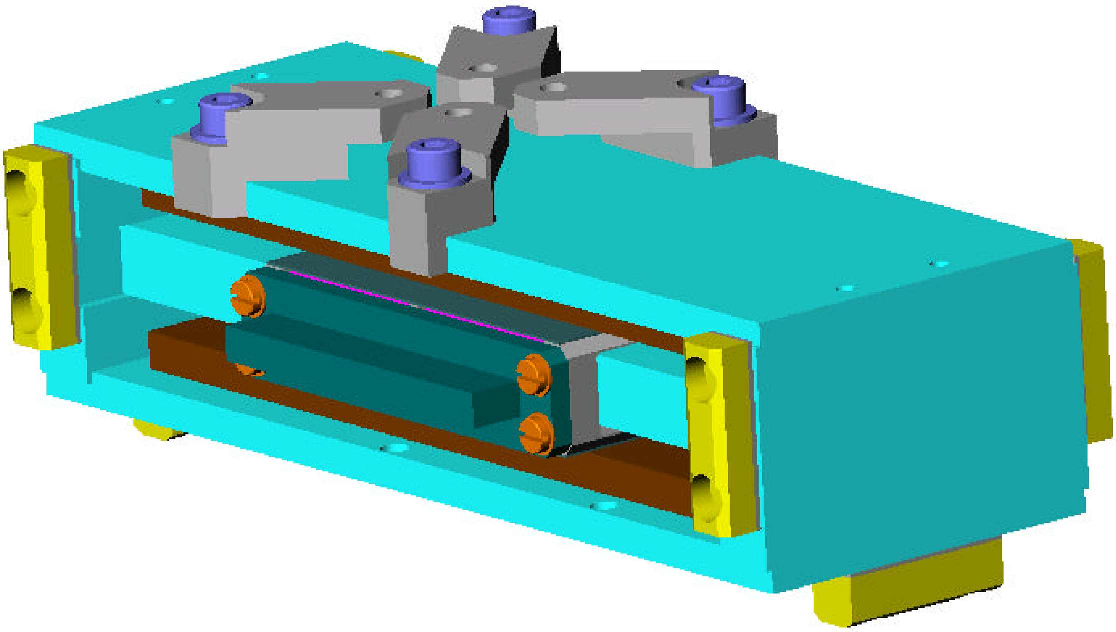
**Table 1 : Max safe permanent current vs wire gauge**

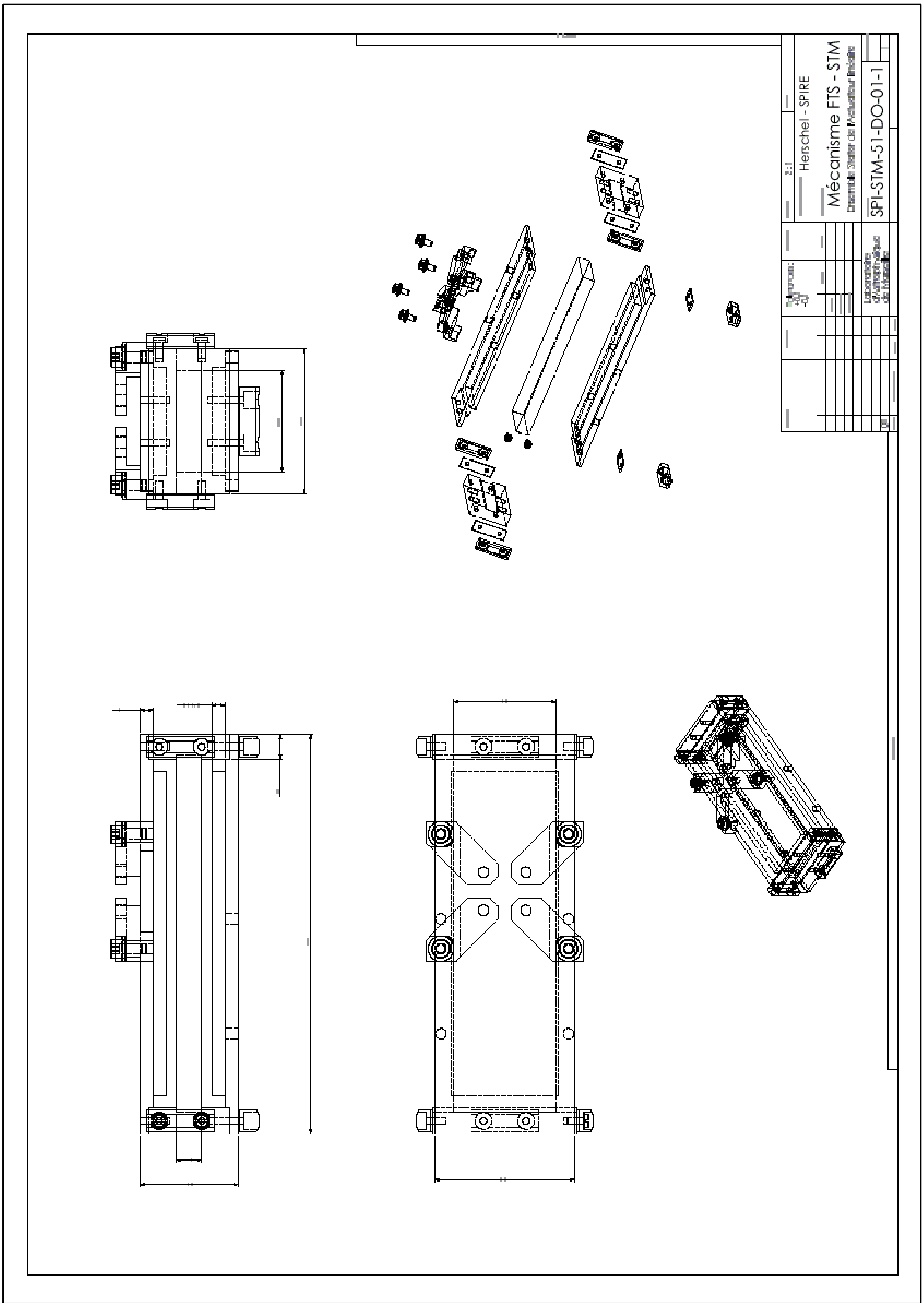
## 3.5 Optimisation of motor geometry within dimensional constraints

The motor which can be implemented within the SMECm cannot exceed 10 cm length and 25 mm height. The mechanical dimensions of the motor are indicated on the following drawings.

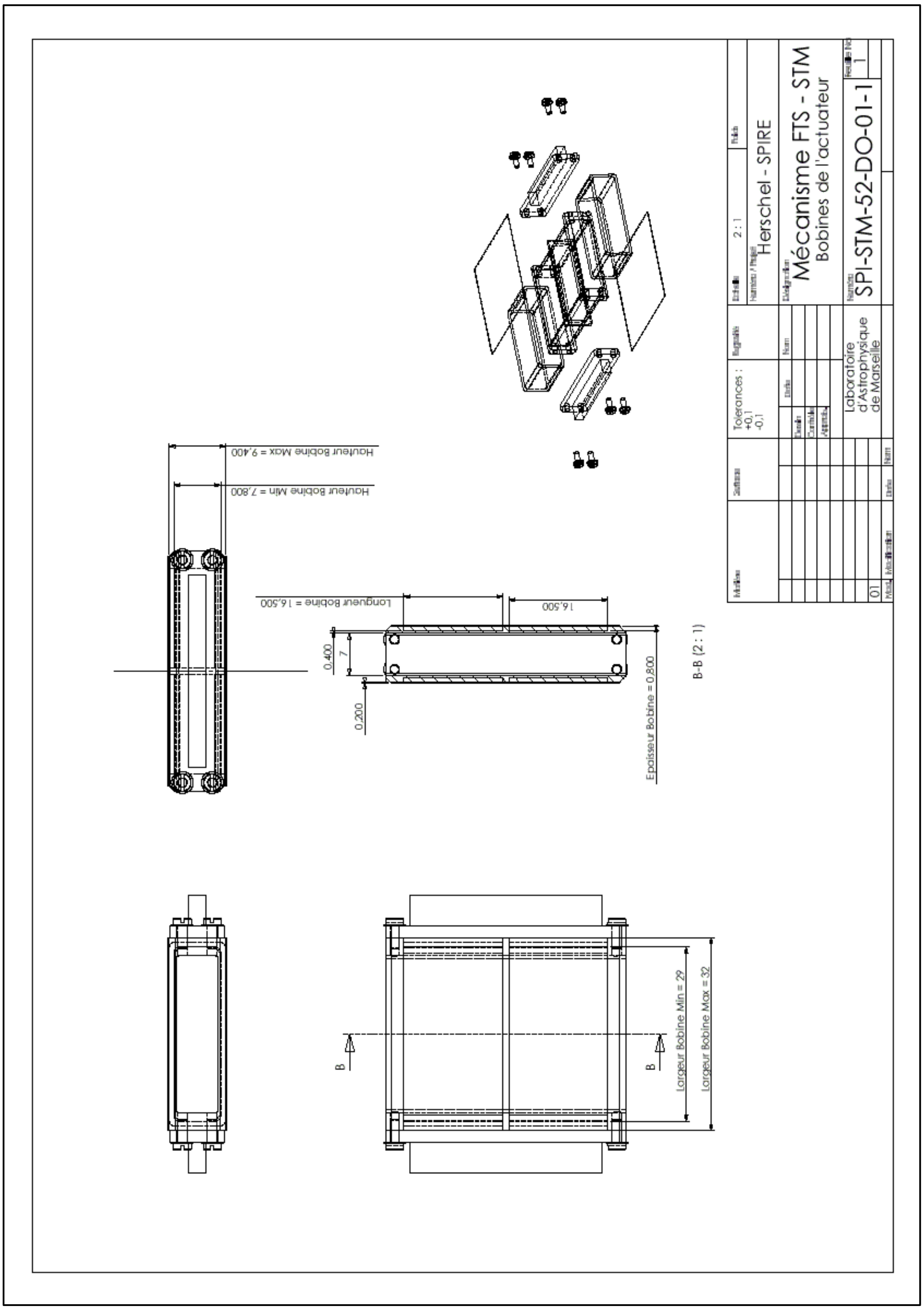








2:1
Herschel - SPIRE
Mécanisme FTS - STM
SPI-STM-51-DO-01-1



Hauteur Bobine Max = 9,400
Hauteur Bobine Min = 7,800
Longueur Bobine = 16,500
16,500
0,400
7
0,200
Epaisseur Bobine = 0,800
B-B (2 : 1)
B
B
Largeur Bobine Min = 29
Largeur Bobine Max = 32
Tolerances :
+0,1
-0,1
2 : 1
Herschel - SPIRE
Mécanisme FTS - STM
Bobines de l'actuateur
Laboratoire
d'Astrophysique
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SPI-STM-52-DO-01-1
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## 3.6 Expected induction flux in the SMECm motor

Within the mechanical dimension constraints, the expected induction flux density in the air gap is about 2.2 Tesla. The interesting induction is to be obtained at the end of the motor stroke since the maximum force to be produced is @ maximum stroke position.

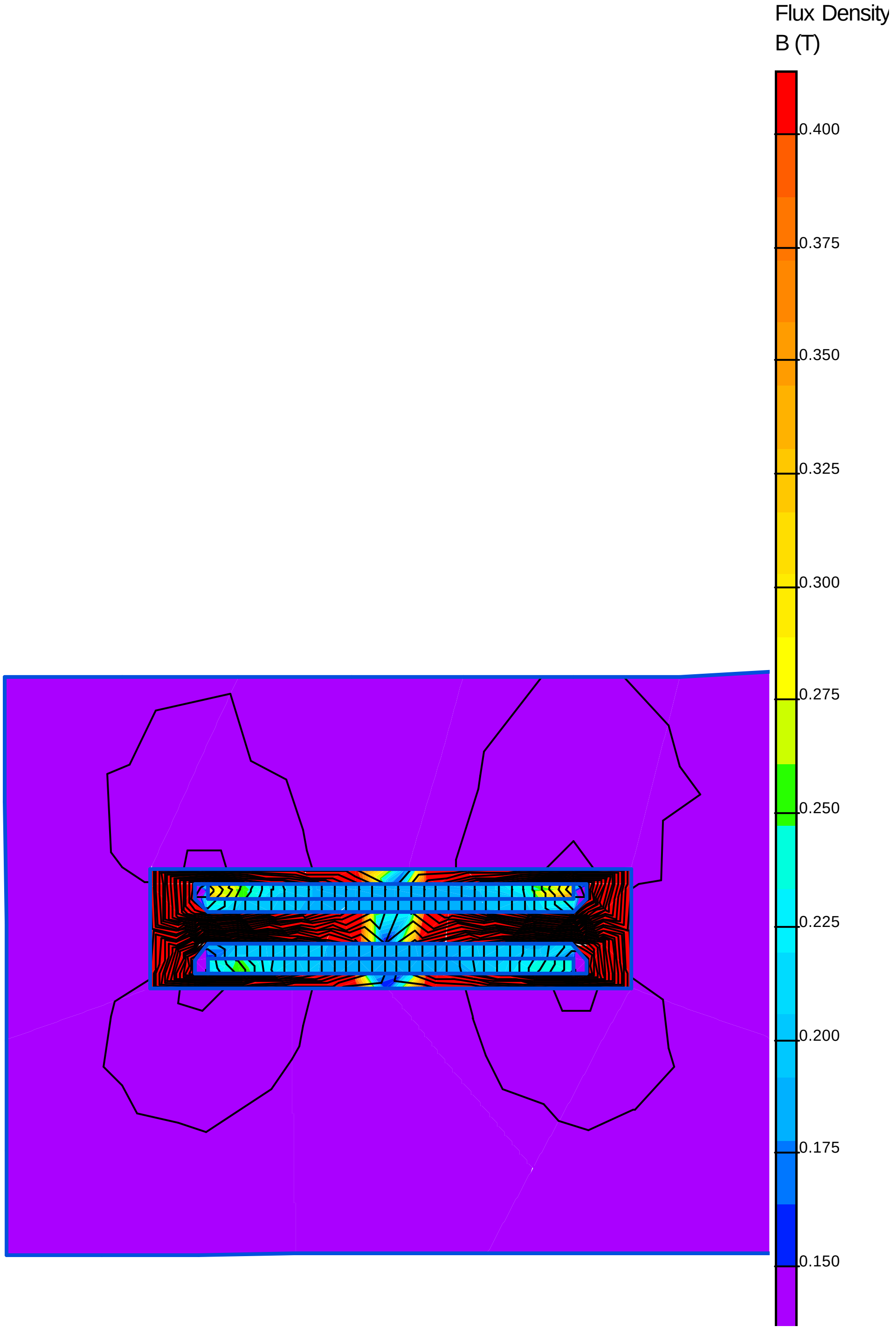


**Figure 3: Magnetic induction B (Testa) for 3mm air gap SMECm motor**

## 3.7 Motor coil wire optimisation results

The motor coil winding optimisation parameters are indicated in the following table.

| Optimised motor specifications | Values |
|---|---|
| Coil mean dimensions | Length: 16.5 mm<br>Width: 30.5 mm<br>Height: 8 mm<br>Thickness: 1.5 mm |
| Wire gauge | 36 AWG |
| Coil windings # | 1534 |
| Wire length | 118 m |
| Useful wire length | 93 m |
| Coil resistance | 199 Ω |
| Max intensity | 91 mA |
| Motor Force constant | 20.5 N/A |
| Max available force | 1.88 N |
| Max dissipation | 16.5mW |
| Dissipation @ 1.5 N | 10.5 mW |

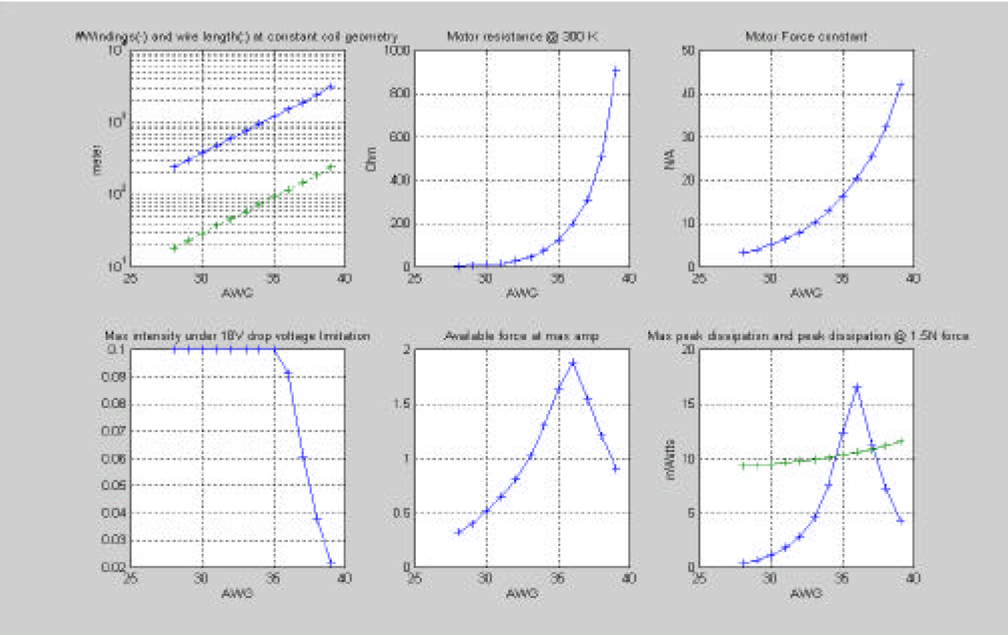


**Figure 4 : Evolution of motor characteristics vs AWG gauge**

# 4 CONCLUSIONS

The motor has been optimised under the constraint of the voltage drop and mechanical dimensions. The expected performances meets very marginally the initial requirements and the margin are very small.

In case of insufficient performances on the real mechanism, the possible margins can be obtained by:

- using both prime and redundant coil @ the cost of additional switching relays and harness wires in SMEC electronics. This solution increases by a factor of 2 force performance, reduces as well thermal dissipation and allows degraded mode using half the motor capabilities in case of a winding failure.

- improving the magnetic circuit design/material to obtain about 10 % more flux

- allowing a greater voltage drop so a greater resistance and coil windings @ the cost of a limited stroke control at ambient temperature and of an increase of thermal dissipation.