THE DEVELOPMENT OF A LOW POWER SOLAR ARRAY DRIVE MECHANISM

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ABSTRACT

Contraves Space AG (CSAG) recently undertook a market survey to identify potential applications for the multi-purpose actuator initially developed by ETEL SA but now adapted for commercialisation by CSAG.

One of the potential applications identified was that there is a need for a "fully European" Low-Power Solar Array Drive (SAD-LP) system.

To date, suppliers within Europe have concentrated on the High-Power SAD market typically above the 2kW level. With the development of smaller satellites flying in small constellations or groups, there is a market for a European supplied SAD-LP system with a typical power demand in the range of 1kW to 2kW.

It is with the intention of being able to offer a suitable alternative to the small platform suppliers, that CSAG together with Mecanex SA have decided to develop a "Low Power Solar Array Drive and Electronics" to fill this hole in the market.

The SADM design is based on the CSA 10 actuator from CSAG, and a slip ring based on the MESAT technology developed by Mecanex SA.

As the Small-Sat market is expanding rapidly, the development of the SADM and Electronics is being undertaken using a "Fast Track" approach with the development being completed within one year from the establishment of the concept.

This paper will presents the "fast track" process at SADM level, and identify the steps taken to produce the high stiffness, light weight, compact but robust mechanism using "state of the art" technologies that are procured totally within Europe.

The paper also focuses on the results from the performance tests on the SADM.

Keywords: SADM, Actuator, Slip Ring, Potentiometer

1. INTRODUCTION

During the SMART-1 programme, Contraves Space AG (CSAG) had the idea for the development of a Swiss Solar Array Drive Mechanism (SADM) but this did not proceed as there was no added value with the development at CSAG.
With the acquisition of the ETEL SA actuator technology, CSAG were able to realise the development using MECANEX SA as the supplier of the Slip Rings.
From market research conducted by CSAG, a market was identified for a SADM capable of delivering between 1 and 2KW of power to the spacecraft.
Such a SADM is ideally suited to Small Satellites, which is a market that is expanding rapidly. In order to develop a SADM in time to benefit from the expanding market, it was important that the development of the SADM followed a "Fast Track" approach.
The "fast track " development approach is possible when technological development programmes are utilised and combined into a finished end product.
In the case of the SADM development, CSAG were able to utilise the MESAT Slip Ring technology developed by MECANEX and of course the Actuator technology at CSAG.
If care is take in choosing suitable developments, the existing design details and test results for the sub assembly developments can be extrapolated up to the end product level. This was the case with the SADM development at Contraves Space.

2. MECHANISM DESIGN

Overall Design of SADM

The overall design of the SADM is shown on Figure 1 and is based on three main components that have all previously been qualified. The modularity of the SADM enables the easy assembly of the SADM.

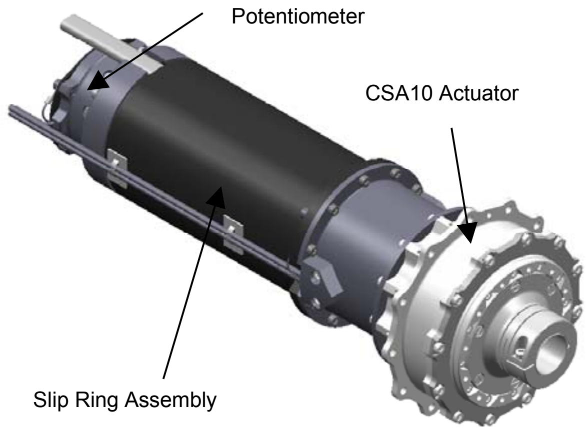

Figure 1

Actuator Design and Development

The actuator utilised in the SADM development is a slightly modified version of the actuator used in the SMART-1 EPMEC, (see ref. [1]). The modifications were made to enable the actuator to be more easily assembled and to reduce the manufacturing costs

In line with the fast track methodology, the actuator used for the SMART-1 EPMEC development was utilised as the baseline for the SADM actuator.
During assembly of the SMART-1 actuator critical design issues were noted and these have now been corrected so that the actuator is both easier to assembly and cheaper to manufacture.
The slightly modified actuator (CSA10) is shown in Figure 2 and consists of a redundant 1° stepper motor, 4 sets of bearings, 4 gears and an integrated eccentric shaft.

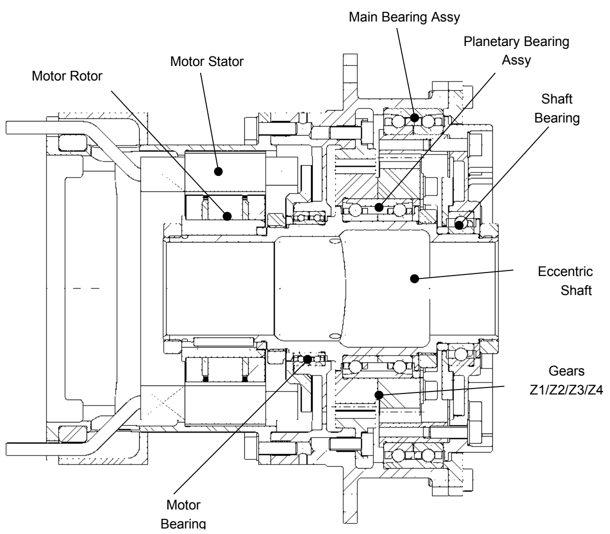

Figure 2

The modifications that have been incorporated include the following:

Gears:
On the previous version, the gear alignment was achieved between the gears themselves, which lead to integration problems onto the shaft, now the gears are aligned using the bearings and shaft making the assembly simpler. Additionally, the gear rims have been bored with equally spaced lightening holes.

Bearings:
The bearing design has been simplified for integration. The bearings in the original actuator have been replaced with super duplex bearings in the case of the three double bearings and with a deep groove bearing on the shaft.
The advantage with super duplex bearings is that the supplier sets the preload and the integration is very simple.

Eccentric Shaft:
The eccentric shaft was previously made from two parts, the shaft, and the eccenter. To simplify the assembly process, these parts were replaced with a single part. This was slightly risky as the part has to be machined in two operations.

Centre Void:
The diameter of the void in the centre of the shaft has been enlarged to allow a greater cable mass to pass through the centre.

As the modifications have been implemented, care has been taken to ensure the qualification status has not been affected.

Slip Ring Assembly Design

The slip ring assembly was manufactured by the company MECANEX SA using technology developed in their MESAT development.
Using the developments from MESAT, it has been possible to fast track the development of the Slip Ring Assembly shown on Figure 3. Small modifications have been made in the overall design to account for the overall design of the SADM. For instance, two bearing sets have been used to support the axis and to provide a stable interface for the potentiometer.
The design of the Slip Ring Assembly utilises compact Gold-Gold contacts to provide longer life
To avoid misalignments between the actuator and the Slip Ring Assy, a single deep groove bearing is utilised at the actuator and a pair of duplex bearings utilised at the potentiometer end of the Slip Ring.
The connection between the actuator and the slip ring is accomplished using a coupling to account for misalignments.

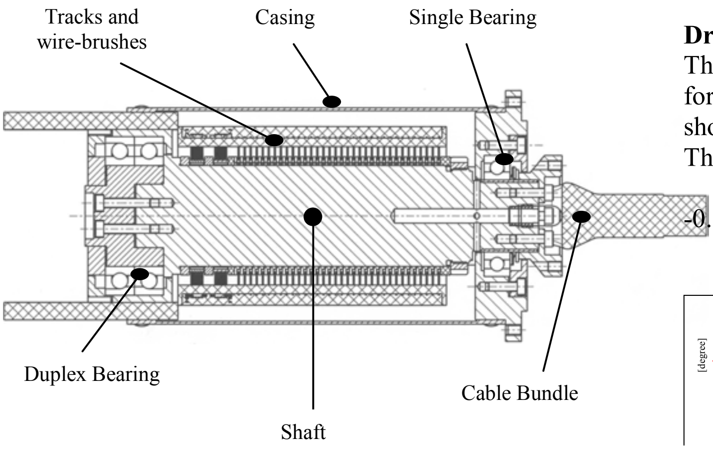

Figure 3

Potentiometer Design

The potentiometer is of the type 02038/A from Eurofarad SA, France, and is of a pancake type. The rotor of the potentiometer is supported by the Slip Ring Assy rotor and the stator attached to the Slip Ring housing.
The design utilises two potentiometers in a redundant configuration but phased by 90°. The potentiometers each have a dead band of 2° and give a linear output between 0° and 358°.

3. PERFORMANCE CHARACTERISTICS

Test Bench

In order to measure the performance of the Actuator, CSAG have established an automated test bench to enable the measurement of the linearity, backlash and friction torque of the actuator.
The test bench is shown in Figure 4.

Figure 4

Performance Characteristics

Drive Linearity
The gearbox linearity was measured in both the forwards and backward directions. The results are shown on figure 5.
The linearity error is as follows:

$-0.043 < e_{lin} < 0.047$

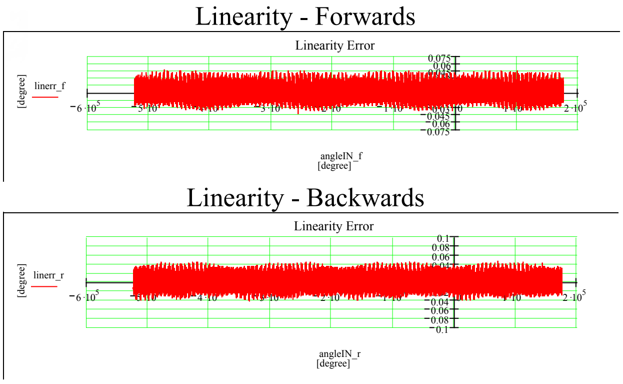

Figure 5

Gearbox Stiffness
The gearbox torsional stiffness shown on figure 6 has been evaluated at an angle of 0°, 90° and 180° at output.

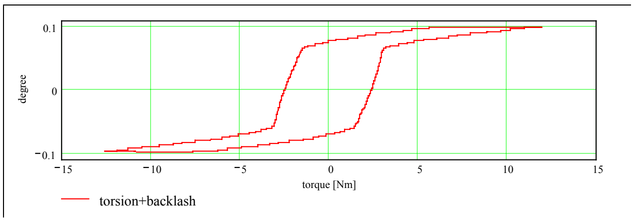

Figure 6
Gearbox Stiffness - Typical

The gearbox stiffness has been evaluated from each of the curves and gives a stiffness for the gearbox of:
10,820 Nm/rad $< K_{gearbox} <$ 17,419 Nm/rad.

Backlash
The backlash is one of the most important characteristics of the actuator as it defines in effect the accuracy of the actuator. The results from the measurements are shown on figure 7.
The average backlash over 4 complete cycles of the actuator output is 0.163°.

Friction Resistance
The friction resistance from the gearbox was measured at the input with a 10Nm load at the output flange. The results from the test are shown on figures 8 and 9.
The maximum and minimum friction torque at the gearbox input is as follows:

-0.089Nm $< T_{FR} <$ 0.079Nm
These friction values are at ambient temperature.

Raw Measurements

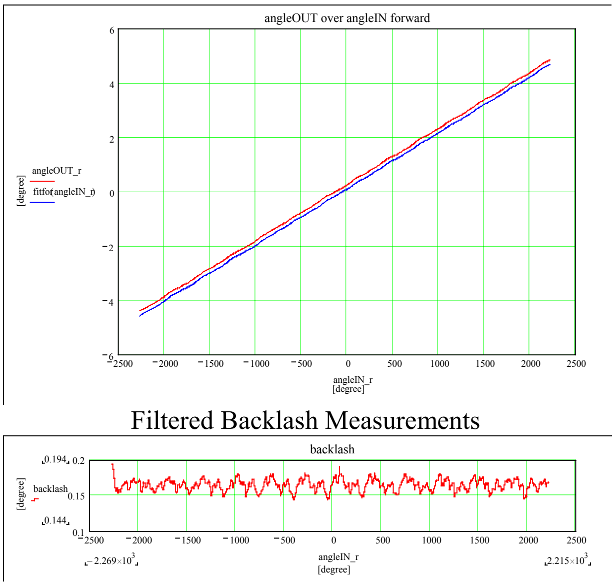

Figure 7

Slip Ring Characteristics

The critical characteristics for the slip ring include the electrical resistance of the cable and brushes, and the friction torque from the bearings and brushes.

These parameters where measured by Mecanex SA and are given on the following:

Starting Bearing Friction Torque	-	30 Nmm
Running Torque from Bearing	-	18 Nmm
Wire Brush Friction Torque	-	100 Nmm

Friction Measurement results - Forwards

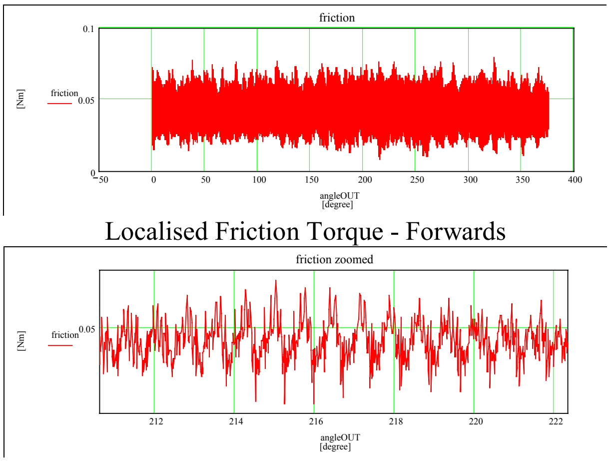

Figure 8

Friction Measurement results - Backwards

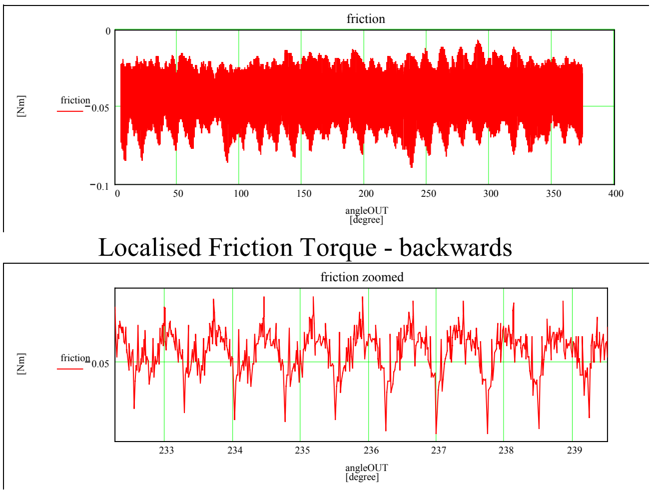

Figure 9

Summarising Performance

Since the design approach was one of modularity, the results from the individual sub-assembly tests can be used to establish the overall performance of the SADM with no risks of unforeseen problems when the sub-assemblies are combined.

The performance characteristics of the SADM are summarised on Table 1.

Characteristic	Requirement	Actual
Position Accuracy (Known)	± 1.0	< 0.8°
Output Step Angle	< 0.05	0.00205
Backlash	± 0.1°	< ± 0.1°
Lifetime	10 Years	10 Years
Mass of SADM	Target 3 Kg	3.345 Kg
Powered Holding Torque	> 10 Nm	> 10m
Unpowered Holding Torque	> 0.3 Nm	> 7 Nm
Maximum Rotation Speed	-	0.7°/Sec
Supply Voltage	-	28V
Supply Current	-	< 0.6A
Torsional Stiffness	> 7500 Nm/rad	> 10,820 Nm/rad
Axial Stiffness	> $140x10^6$ N/m	
Bending Stiffness	-	95,000 Nm/rad
Axial Static Load Capacity	-	3,920 N
Transverse Load Capacity	-	2,000 N
Bending Moment Load Capacity	-	130 Nm
Power Transfer Capability	1 – 2 KW	< 2 KW

Table 1: Performance Characteristics of SADM

4. FAST TRACKING -CONCLUSIONS

Although the Slip Ring Development is not yet completed at CSAG, the Fast Track approach utilises the results from the individual sub-assemblies to be extrapolated to the performance of the overall SADM.
Fast Tracking developments is really only possible when designs details and test results exist already and have been sufficiently documented. The use of the documentation established during the earlier development programmes for the actuator and the slip ring, has allowed for an accurate assessment of the implications of the potential redesigns and modifications that have been introduced, and has not meant that complete analyses have had to be performed to demonstrate suitability.
Without supporting documentation and know how, it is not possible to fast track a mechanism development.
In addition, there are obviously mechanical problems with the design of a SADM, for example, the thermal behaviour. In order to undertake a Fast Track development, the critical issues must be clearly understood.
In order to understand these issues it is important to involve a multi-discipline team at the outset of the programme to identify all potential problem areas and to understand their influence on the design.

This approach was undertaken for the SADM development and enabled an understanding of the critical issues to be quickly established.

Using this approach, it was possible to produce a product that meets the requirements, with few problems during the development.

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