PERFORMANCES OF LINEAR ELECTRO MECHANIC ACTUATORS (EMA) FOR THE INTERNATIONAL BERTHING AND DOCKING MECHANISM (IBDM)

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ABSTRACT

The IBDM is a mechanism to provide self aligning, attenuation, capture and retraction functions to the docking or berthing halves of two mating Spacecrafts. It is based on an hexapod which include the six Linear EMAs and force sensing function in the moving ring which also have some alignment devices. The Linear EMA of the IBDM are commanded to provide force input to the instrumented load ring to self align the two halves of the mating parts during a docking or berthing operation. The control loop takes force inputs from the instrumented load ring loads cells to detect contact forces and to define the force inputs to the actuators that support it.

This paper presents the verification testing of the Linear Electro-Mechanic Actuators (EMA) for the International Berthing and Docking Mechanism (IBDM) soft docking capture system and the measured performances. In the paper, the main characteristics of the actuators are described and the performances measured in the seven units manufactured.

The main performances of these actuators are the high linear speed (150 mm/s) and low hysteresis, the low back driving force, volume and mass. Other features of the actuator like stroke limitations, actuating stroke or position monitoring are presented. Upgrade of performances w.r.t. Linear actuators on the market is presented to show the advantages of this design.

The paper presents the measured performances at temperature limits and vacuum, the vibration environment and life verification. Description of test setups and lessons learnt during the test execution will be also presented.

The description of the actuator, trade off of the design aspects as well as analysis and simulation predictions were presented in ESMATS 12.

1. INTRODUCTION

The International Berthing and Docking Mechanism (IBDM) is a contact force sensing, magnetically latched for capture, low impact docking system, capable of docking and berthing large and small vehicles. The IBDM consist of two systems, the soft docking system and the hard docking system.

The soft docking system consists of a computer controlled 6 degree of freedom table driven by 6 linear electrical actuators.

The main functions of the linear actuators are:

- To provide strength and stiffness during launch
- To provide linear movement for positioning the six degrees of freedom table, with a computer controlled kinematics
- To provide command interface to the six dof table controller
- To provide monitorization of the position of the actuator (actual length) to the table controller
- To provide controlled stiffness in orbit
- To drive the six dof table with the speed characteristics required to perform capture
- To provide push/pull force enough to attenuate the impact between the two mating parts

The linear actuators are composed of the following main components:

- Two independent brushless DC motors working in cold redundancy
- A lead screw drive, to transform the angular motion of the electrical motors to a linear motion
- Two independent contact-less sensors for position monitorization and redundant end switches to detect both ends of travel
- A gear train to couple the motion of motors sensors and lead screw
- A base structure to attach the main components, motors, sensors and gears and fitting to provide mechanical interface between the base structure and the external I/F
- A guiding telescopic structure to guide the linear motion and provide mechanical output interface
- Redundant electrical connectors with power and signal in separate harness.

In the frame of the IBDM contract SENER was responsible for the provision of the linear actuators for the hexapod (the six Acceptance Models, AMs,

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according to the level of tests performed on them). An additional actuator (the Verification Model, VM) was foreseen for the full verification and characterization of the actuator performances.
The AM actuators were integrated in the IBDM and form part of the IBDM Engineering Model.

2. FUNCTIONAL PERFORMANCES

The functional performances of the IBDM Linear EMA are presented here showing the compliance to all specified requirements.
Next chapters shows the summary of performances as well as detailed data of measured values in both the Validation Model Actuator (VM) and the six Acceptance Model actuators (AMs)

2.1 Functional performances vs. requirements

All functional parameters included in the specification were verified by tests. Table below shows a summary of the obtained result as a comparison to the value indicated in the specification

Actual Value	Requirements
Speed	Up to 125 mm/s
173 mm/s	
Stroke	≥ 293 mm
> 293 mm	
Acceleration	Up to 1,27 mm/s2
OK	
Backlash	≤ 75 microns
Less than 20 microns	
Thrust capability	Nominal force > 400 N
Maximum force 730 N	
At 12 mm/s 710N	Peak force > 700N
At 75 mm/s 630 N	
Stiction	No requirement
Max. 0,1 Nm	
Back drive force	Backdriveable
OK, 80 N max.	
Static torque margin (MoS)	Positive (according to ECSS)
0,04 for peak load	
0,825 for nominal load	
Dynamic margin	> 0 (4,5 kg 1270 mm/s2)
OK	
Absolute position feed-back	Accuracy better than 0,25 mm
OK	
End position detection	
Radial end stop OK	
Signal reed switches OK	
Stiffness	>5e5 N/m
Retracted > 2E6 N/m	
Deployed >4E6 N/m	

Table 1 Summary of performances and requirements

All these performances are necessary for the functional feasibility of the IBDM, providing high speed and acceleration and low friction/hysteresis as well as low backdriving force when motors are not powered.

2.2 Functional performance test configuration

The functional performance test includes different test configurations. The force vs. speed test is performed on a dedicated hydraulic rig, instrumented to measure both force and position (speed) with the capability to tune the resistance force in either actuation directions to have a constant force during the stroke.
Figure 1 shows the type of test results obtained from the test configuration.

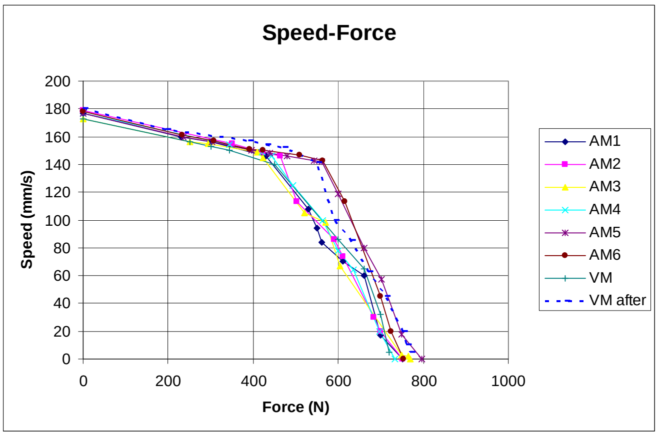

Figure 1: Actuators performance summary

In addition to force and speed the current through the motor windings is also measured providing electrical performances of the actuator as shown in Figure 2

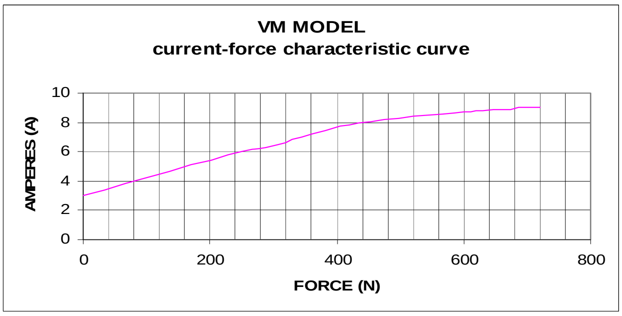

Figure 2 Current- force curve for VM actuator

The test set up for acceleration measurement is shown in Figure 3

The measured values are similar or exceeding the predictions and a good correlation with the predicted behaviour was noted. That was important for the successful operation of the IBDM.

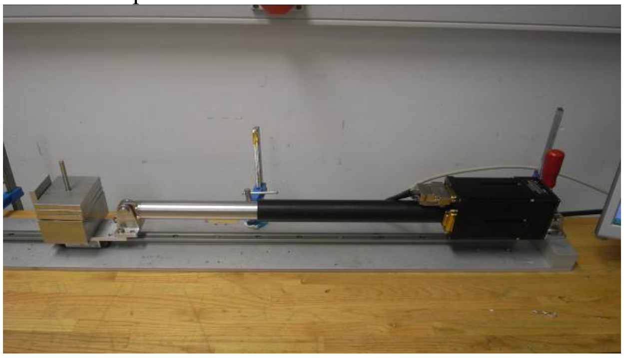

Figure 3 Acceleration test configuration

This test is performed to determine the acceleration profile of the actuator with a 4,5 kg mass on the tip.

Figure 4 shows the acceleration of the VM actuator

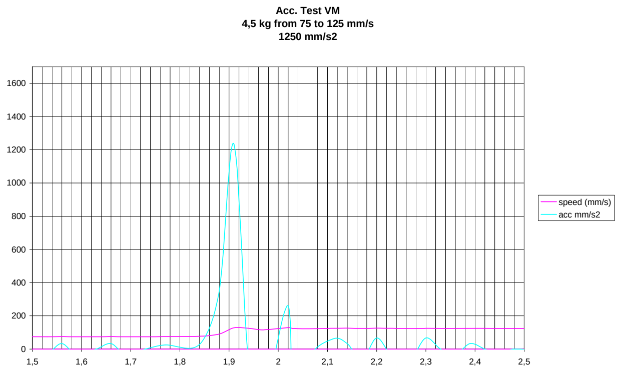

Figure 4 Acceleration profile on the VM actuator

3. MECHANICAL ENVIRONMENT

Sine and random vibration tests were performed on the VM actuator. Figure 5 shows the configuration of the test for the Y axis of the actuator.

The following eigen-frequencies has been measured:

- f1= 56 Hz (Y axis)
- f2= 65 Hz (Z axis)
- f3= 118 Hz (Y axis)
- f4= 174,5 Hz (Y axis)
- f5= 185 Hz (Z axis)
- f6=190 Hz (X axis)
- f7= 472 Hz (X axis)

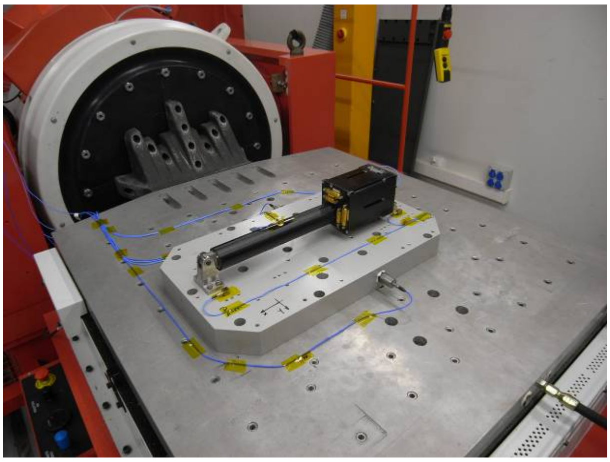

Figure 5 Vibration test configuration

No significant variation in eigen-frequencies before and after running qualification levels were identified.

The applied Sine test level for axes X,Y & Z were:

Frequency range [Hz]	Acceleration [g peak]
5.0 to 15.0	± 11 mm
15.0 to 50	± 10 g
50 to 80	± 6.0 g
80 to 100	± 3.5 g

Table 2 Sine input

Notch : X axis : not notching. Y& Z axis : automatic notching (encoder 30 g´s limitation)

Random levels:

Frequency range [Hz]	Qualification level X & Z axis
20 to 100	+ 3 dB/oct
100 to 300	Z axis 0.5 g^2/Hz X& Y axis 0,3 g2/hz
300 to 2000	– 5 dB/oct
RMS value	Z axis 17 g_{rms} X & Y axis 13 g_{rms}

Table 3Random input

Notch : X axis : not notching
Y axis at 174,5 Hz 0.0042 g2/hz
Z axis at 185 Hz 0,00125 g2/hz

Although the seven actuators built for the IBDM were used for an Engineering model, not subjected to Flight environment, the VM actuator proved the design for this environment and the correctness of the design for flight use.

4. LIFE TEST

Life test has been passed successfully. The following can be assessing:

1.- More than 22.000 strokes and more than 20h has been done. At least 30 minutes at vacuum condition: -40C (10 min.), 20 C (10 min) & 80C (10 min).

2.- Always, a minimum force of 350 N and a minimum speed of 75 mm/s has been applied to EMA. Duration time for each test has been equal or higher than 10 minutes. See table 5-15. So, it has been demonstrated the capability of EMA of working 20 hours without refurbishment giving at least 75 mm/s and moving at least 350 N at the same time.

3.- After 20 hours, thrust capability and performances have no changed.

Figure 6 shows the test configuration for the life test which is similar to the configuration for measurement of force versus speed curves. The life test was performed on the VM actuator.

Life test cycles and forces were performed exceeding the requirement as it is shown in Figure 7

Figure 6 Life cycle test configuration

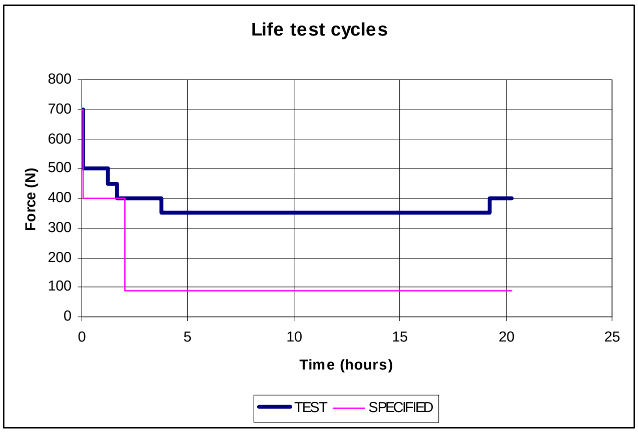

Figure 7 Life cycles tested v.s. requirement

The required number of cycles assumed several in orbit cycles of docking in a demonstration mission. The requirement did not cover life requirements corresponding to reusable mechanisms for several missions. However the additional cycles together with the little damage observed during the strip down showed that life cycles could be largely extended from the test performed.

5. THERMAL VACUUM TEST

Thermal vacuum test were performed to proof the survivability of the actuator to extreme environments as well as to perform life cycles in TV conditions to reproduce as far as possible in orbit conditions.

The test set up for the actuator functional and life test in TV conditions is shown in Figure 8 during the test preparation. Tests were performed with the actuator acting against the gravity in one direction.

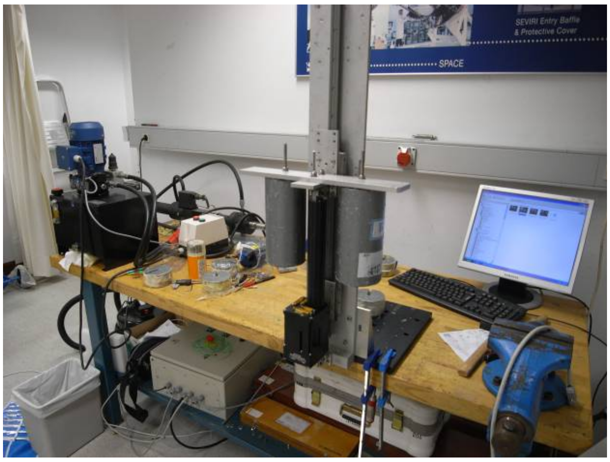

Figure 8 Test set ups for the VM actuator

Initial stage of the TV test was the survivability test in extreme temperatures from -40ºC to +80ºC. The temperatures were defined according to a temperature prediction for a demonstration mission. The force direction (push against gravity) was selected because of the simplicity of the test set up and the representativity case for the in-orbit actuation (during docking actuators are mainly under compression force).

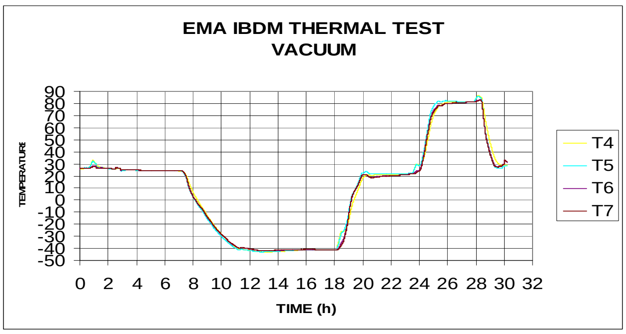

Figure 9 Temperature profile of TV test

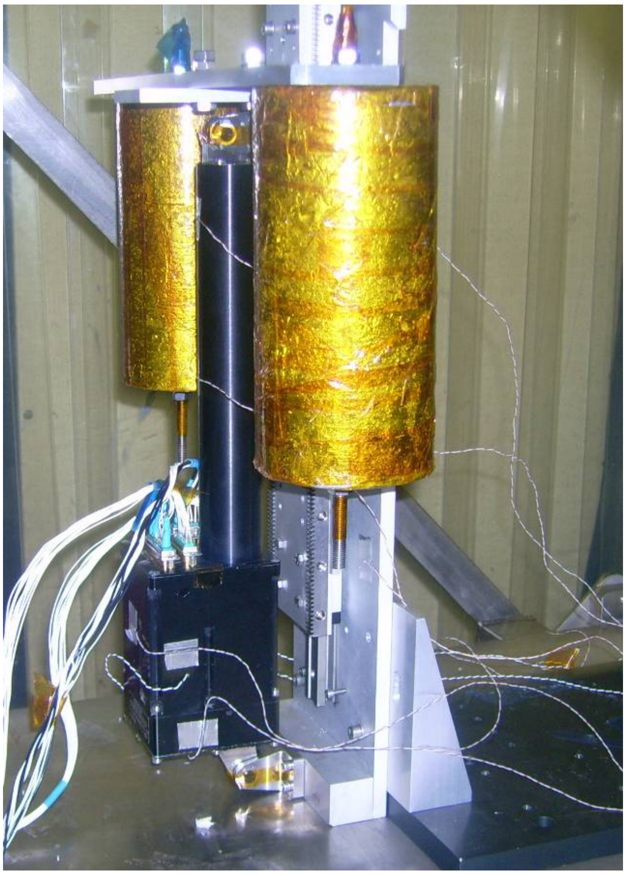

Figure 10 VM actuator in TV test configuration

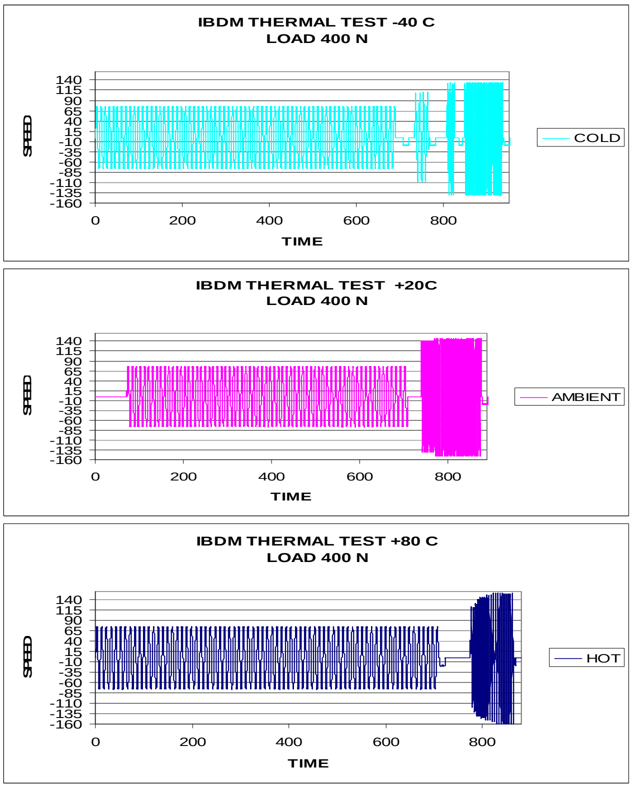

Figure 11 VM actuator life cycles during TV test

The life cycles performed under TV condition showed a good performance of the actuator and little or no detectable performance degradation in comparison to ambient tests. However it was identified as it was foreseen, better performances for hot conditions due to the reduced contribution of frictions and higher torque on the motor. This was significantly apparent in Figure 12..

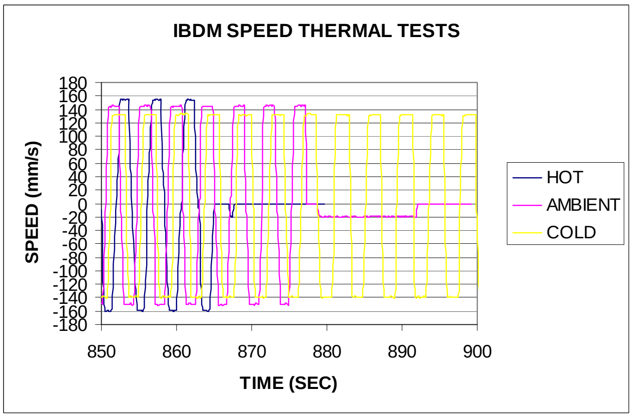

Figure 12 Comparison of speed at different temperatures during TV test

After the environmental test, the VM actuator was re-tested giving the same performances that before the environmental tests or even a small increase in force-speed characteristics, probably due to reduction of friction after the lifecycles.

The VM actuator was dismounted and inspected and no damages or wear on the components was detected. The actuator internal part showed that Braicote Grease turned some dark on the gear train.

All parts were cleaned, inspected and re- assembled and the actuator was verified not identifying any significant modification of performances.

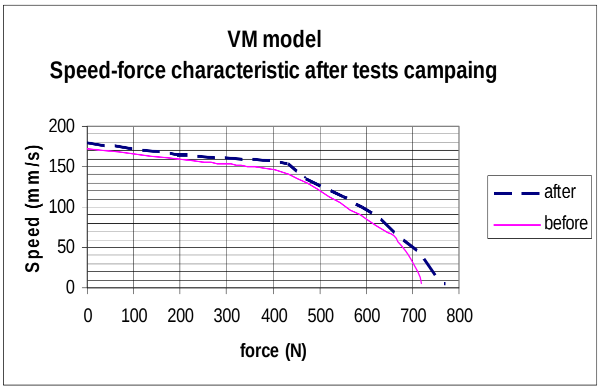

Figure 13 VM actuator performances before and after the environmental tests

6. INTEGRATION OF AMs IN THE IBDM

The six AM actuators are integrated in the IBDM and will be subjected to an extensive test campaign for verification of the IBDM Engineering model.

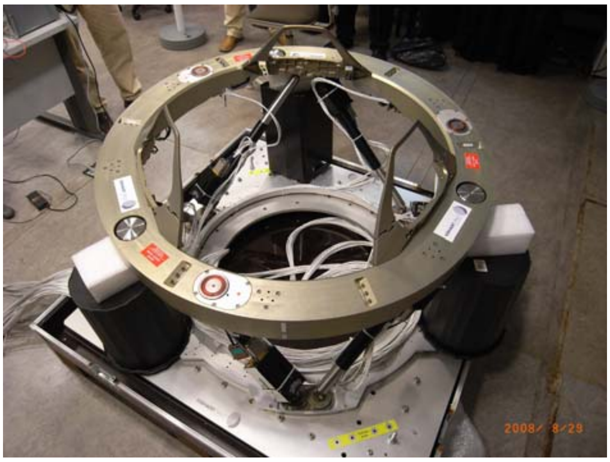

Figure 14 IBDM actuators in the IBDM Hexapod

The tests performed on the IBDM hexapod showed a good performance of the actuator. However hysteresis and friction forces, introduces additional difficulties in the control loop although they are very low in comparison to other linear actuators. Having lower friction forces would reduce control requirements but will imply the modification of r the actuator concept.

7. CONCLUSIONS

A linear actuator was developed in the frame of the IBDM contract which provides unprecedented performances in terms of speed-force, low back driving force and reduced friction. Load capability is not the main driver of this actuator, but acceleration and speed in order to facilitate its control.

The actuator has been verified in typical Space rated environments and becomes one option for the European Space industry when a redundant linear actuator in the range of 600 N is required