TELESCOPIC BOOM DEVELOPMENT FOR SPACE APPLICATIONS

Christian DUPUY (1), **Olivier Carrion**(2), **Victor PIRES**(2)

(1) Centre National d'Etudes Spatiales, Mechanisms & ADCS Equipment Office 18 Av. Edouard Belin 31401 TOULOUSE CEDEX 9, France. email : Christian.dupuy@cnes.fr

(2) COMAT Aerospace Z.A de Vignalis, 6 Chemin de Vignalis, 31130 FLOURENS email : carrion@comat-aerospace.com ; pires@comat-aerospace.com

ABSTRACT

In the frame of his Research and Technology program, CNES has conducted studies in order to develop a boom for space application which requires high positioning capability. This last year, few breadboards are manufactured and tested. An engineering model was built. The first deployment tests are successful and validate the different technological solutions used. A short description of the deployment mechanism is exposed. Some technical problems encountered during the production or the assembly phases are also presented with the solution founded.

1. CONTEXT

Numerous space missions need booms to move away specific payloads at some distance from the satellite. For instance, boom could be useful to avoid the platform magnetic field environment, or to build a bigger space instruments. Investigation to develop deployable boom for scientific mission has been initiated in 2001. At this time it was the beginning of the Myriade microsatellite family development. Few scientific missions purposes were done, some of them need to deploy electromagnetic sensor with high precision.

The French scientific micro-satellite DEMETER, launched in 2004 June, is equipped with 5 deployable masts. Four booms were provided by Kaleva and the fifth was developed specifically because of the high IMSC sensor positioning requirements.

Several deployable booms concepts are available on the shelves, with different technology. The main requirements which drive the choice are: stiffness, positioned accuracy, foldable volume, deployable length, weight, and power budget.

The available on the shelves components are more or less compliant with the requirements. It was identified that it will be difficult to comply to a great deployable length with a low mass and a good stiffness to reach a precise positioning for the equipment.

To achieve this, a rigid boom, articulated with locking mechanisms is generally used. Mass budget, allocated volume and deployment cinematic are factors who limit the maximum deployable length.

Most of the time a specific development is done to comply the mission requirements as done for the Rosetta, Mars Express and SWARM project.

2. INTRODUCTION

First of all, a trade off analysis identified the telescopic boom concept as the best solution for needs with high stiffness and accuracy requirements; especially, for needs with a length in deployed configuration between 2.5 meters and 5 meters.

The proposed solution is build on carbon fiber cylindrical parts, with growing diameter, sliding some with the others, deployed with a worm screw mechanism and junction with inter-lockable ring without gap.

During 2005 and 2006, the concept was improved by COMAT company and the main functions were validated.

The objective was to deliver to CNES, an engineering model mast with the following characteristics:

- Deployable length ≈ 3 meters
- Foldable length = 0.5 meters
- Total mass ≤ 3 kg
- End of the boom positioned in a 15 mm radius sphere
- EI = 7000 Nmm² (First frequency mode prediction upper than 1 Hz)
- Electrical power required : 24 VCC - 6 W max

4. DESIGN DESCRIPTION

The studies are focussed on telescopic design because it's were declare as the most compliant with the positioning and stiffness requirements. The design is based on tubular parts deployed by a mechanism using a worm screw. The circular concentric parts are made off graphite epoxy.

The deployment is motorized with a direct current motor and a two stage reducer, which rotates a

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worm screw system, deploying one after the other all the tubular parts. Each tube is fitted with a driving pin which is able to be moved by the screw. When a tubular part reach the end of the screw, a synchronization mechanism locks it with the following part, latches the following part which could move on the screw and so on. The deployment sequence is illustrated in the figure 1.

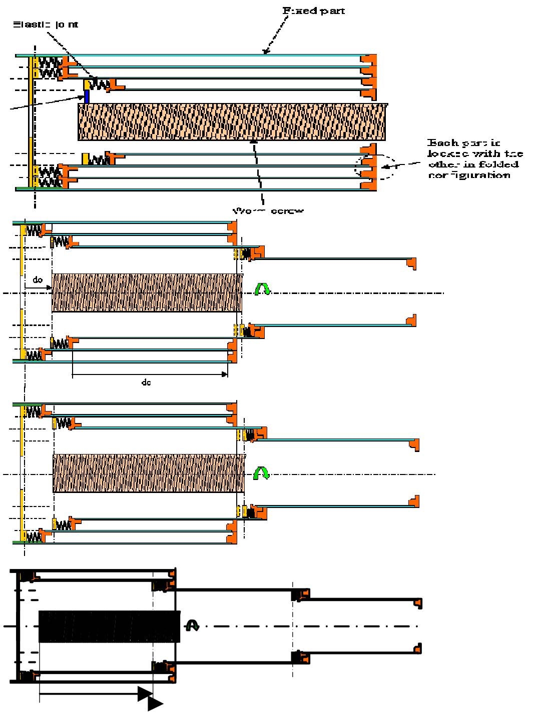

Figure 1: Deployment sequence description

This concept using a worm screw was already used in space for the OTD boom developed by AEC ABLE. The challenge is to increase the ratio deployed length / total mass and to adapt this type of mass for small satellite.

5. INTER-LOCKING RINGS DESIGN

The link between two consecutive parts has to be rigid and ensure a good positioning. At the end of the boom, the geometrical defaults are mathematically added and all the local articulation stiffness are added in this manner:

$$\frac{1}{k_1}+\frac{1}{k_2}+\ldots\frac{1}{k_n}.$$

For this reason, the local stiffness (k_1, $k_{2\ldots}$) should be as high as possible.

At the beginning, of the study, for a better positioning, the chosen solution was similar to the electronic "jack" plugs. The junction between to consecutive part have conical shapes and the locking is producing by an elastic cylindrical open ring mounted in a groove. See figure 2.

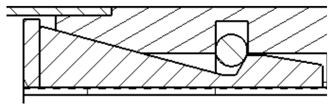

Figure 2: Detail of conical junction assembly with elastic ring

The stiffness capability of this type of assembly depends on the cone geometrical parameters (angle, length) and on the preload supplied by the locking system.

If we consider the junction in locked configuration with the preload Pz, under the effect of a bending moment Mfz as follows.

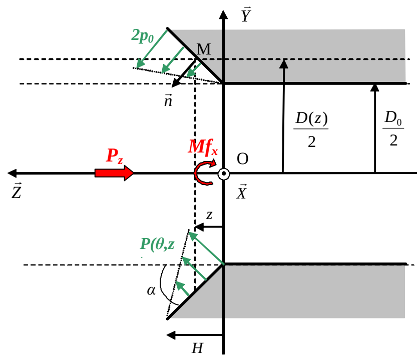

Figure 3 : Schematic representation of conical assembly

With the hypothesis on the pressure linear variation along the conical shape between 0 and 2.p0, we could write the pressure field equation as

$$p(\theta,z)=\frac{p_2(\theta,z)-p_1(\theta,z)}{H}z+p_1(\theta,z)$$

After integration:

$$\boxed{Mf_x=\frac{P_z H}{6\sin\alpha(D_0+H.\tan\alpha)}\left(\frac{D_0}{2}(1+2\tan^2\alpha)+H\frac{\tan\alpha}{\cos^2\alpha}\right)}$$

The bending moment is directly dependant on the preload Pz.

To complete and evaluate this work, we also studied the design using junction with planar contact.

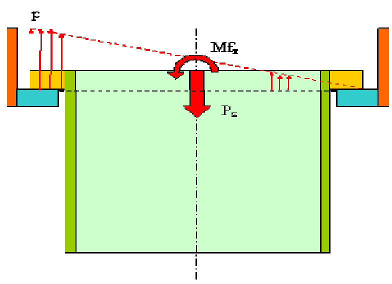

Figure 4: Schematic representation of junction with planar contact

The resulting bending moment is directly dependant of the preload Pz.

$$Mf_x = \frac{P_z(D_{ext}^{\ 3} - D_{\text{int}}^{\ 3})}{6(D_{ext}^{\ 2} - D_{\text{int}}^{\ 2})}$$

On the pure theoretical point of view, conical coupling gives a better stiffness and a better axis alignment (see chart 1), because of his auto-alignment capacity. Tests done on breadboards have shown the difficulties to obtain conical shapes on thin aluminium rings. Considering the dimensions, the obtained cone circularity is not sufficient to provide an accurate alignment. The evaluation testing has shown a better reproducibility of the plane arrangement in term of stiffness. The self alignment capacity of conical link is degraded by manufacturing defaults.

	Standart deviation / Mean value	**Minimum mesured value (Nm)**	**Mean mesured value (Nm)**
Conical assembly	86%	0,35	2,69
Plane assembly	13,8%	1,68	2,1

Chart 1: bending moment capability

Finally as we see in the chart, the test had highlighted the complexity of the conical junctions and its bad behaviour in term of alignment and stiffness. The planar contact configuration was chosen.

6. LOCKING SYSTEM

Interlocking mechanism system is necessary to provide junction preload. Taking into account the space mechanical environment during the operational phase, the minimal preload value required to maintain the first frequency mode up to 1 Hz is 50 Newton without any margin. At the beginning of the study, elastic opening ring was used to provide both preload and locking. This solution seemed to be simple and cheap to manufacture but the breadboards test showed the impossibility to reach the required preload value.

The worm screw used to deploy the boom, transforms the rotating motor torque into axial load. Due to the reduction ratio, this load value could be higher than the 50 N needed. What we have to do is to imagine a mechanism using this preload capability to pre-strain the junctions consecutively, in order to provide the targeted stiffness. That is done, but the main difficulties were to synchronize the complete deployment sequence as shown in figure 5.

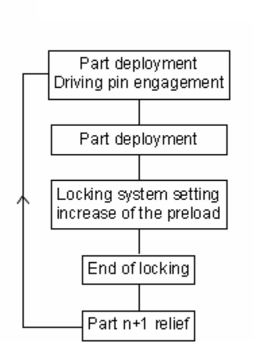

Figure 5: deployment sequence

The design details of this function are not described in this paper, because a patent is in pending status.

7 EM MANUFACTURING

The objectives of the Engineering Model are to validate the complete design and to test the capability in term of accuracy, stiffness and power budget.

The tubes were fabricated with 6 layers Carbon /Epoxy composite interleaved like 0/60/0/-60/0/60°. The layers of 0.14 mm woven epoxy pré-impregnated material were assembled on internal mandrel with a slight taper to increase extraction ability after cure. A specific tool was developed to assemble the tube with the two aluminium ring at both ends.

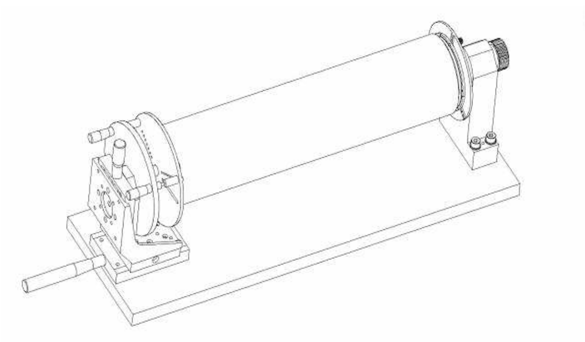

Figure 6: Tube assembly tool

Each ring is mounted on the tool. As we see on the figure 6, one of the rings is mounted on the left part on a 3 dimensions movable piece. The targeted position is adjusted with precision micro-control screws and controlled by a three-dimensional measurement system. When the correct geometry is reached, the movable part is translated, in order to set up the carbon tube. Next the junctions areas are bounded with 3M epoxy EC2216 and the second ring is adjusted by translation. Thanks to this assembly procedure and this tool, the total geometric default due to machining process are minimized.

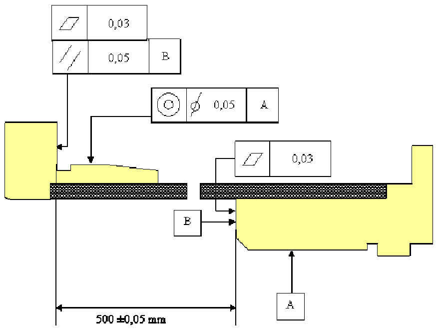

Figure 7: Geometric tolerances between both end rings

8. CONCLUSION

We can't conclude because the work is already in progress. The Engineering Model was delivered to CNES in may and test are planned for the end of this year.

A first deployment test was done by COMAT, to validate the correct behaviour of the synchronism mechanism. This test was successful. During the deployment the input current was recorded to calculate the power needs. The maximum power value measured is a peak of 6.6 Watt, during the interlocking phase. The power needed to deploy is 1 Watt and the entire deployment lasts is 12 minutes for a boom with 8 part and 3.5 m long.

In order to complete the work, this following characterization tests are planed:

- measurement of the accurate capability,
- measurement of the inter-locking stiffness,
- measurement of the first frequency,

A complementary study is necessary, to evaluate the behaviour of the mechanism under thermal hot and cold condition, especially during deployment.

See in the following Figures 8, picture of the Space Telescopic Engineering Model, designed and manufactured by Comat Aerospace.

Figure 8: Engineering model first & second tube deployed