ANTENNA DEPLOYMENTS: A SELF-MOTORISED HINGE

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ABSTRACT:

New satellites require adapted mechanisms with good efficiency for low cost and weight. It is therefore very attractive first to integrate several functions in the same device, and additionally to develop generic technologies that may be reused for several missions.
Following this philosophy, the present poster deals with the successful example of a self-actuating, guiding and locking (accurate positioning) hinge for antenna deployment.

The technology and dedicated tools (both experimental and numerical) that may be used to scale the design to any kind of applications are described in a first part. The basic concept lies upon a particular arrangement of three spring strips. It has been developed together by METRAVIB RDS and the CNES during past years.
Specific means have been set up to help the design versus the three functional key points:

- the stiffness and the positioning in locked open situation
- the unlocking (holding) loads capacity to support satellite attitude control
- the deployment kinematics

A significant effort has been necessary to develop and validate relevant analysis (numerical FE simulations) able to predict with enough accuracy the behavior of the hinge versus its geometry and materials. The developments of a dedicated test bench able to reproduce the «in plane» kinematics of a single hinge system, and a full 3D micro gravity campaign in Zero-G flights have been proceeded.

In a second part, existing applications will be presented, including, up to now, essentially micro satellites equipments.

1. INTRODUCTION

METRAVIB RDS Company and CNES (French Space Agency) have been working for more than 7 years on technological simplification and technical comprehension of Carpentier Joint based hinge principle for space applications. The basic idea consists in fully avoid a dedicated guiding mechanism, involving any kind of sliding or even rolling contact as a potential source of problem related to tribology.
Therefore, a specific design has been imagined to combined, simply by using elastic strips, the functions of driving, guiding and locking satellites deployable appendices.
The concept has been validated and is presented in section two. Then, an industrial development has been conducted during last years. Specific tasks related to the design of such a mechanism have been followed from finite element modeling to micro gravity flight deployment tests.
Presently, the final product has been selected for three applications: Solar arrays deployment on CNES micro-satellite platform; IMSC sensor deployment on DEMETER mission and Antennas deployment on ESSAIM satellites.
The last one is qualified and the two others are under qualification.

2. CONCEPT

Carpentier Joint principle consists in a (usually steel) strip with a curved cross section. It permits to combine guiding (anisotropic stiffness), actuating (spring effect) and locking (high deployed stiffness) functions.
The hinge principle is a clever arrangement of three Carpentier joints that have been selected to provide a quasi center pin guiding behavior and high twist stability.
Thickness and related positioning of the strip are adjusted to tune the final design (motorization torque, stability, stiffness).

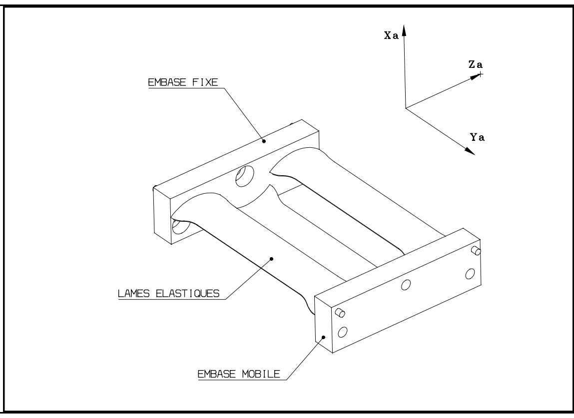

Fig 1. Hinge design

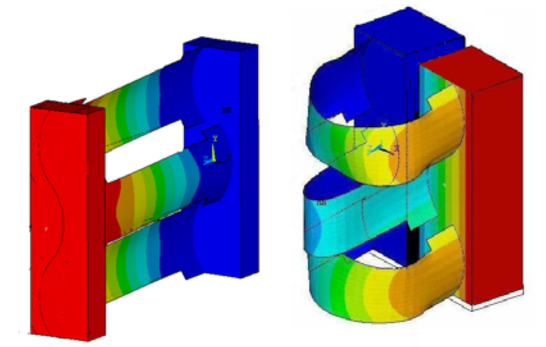

Fig 2. Deployed and 180° position

On a technological point of view, as the material of the strips must be highly resistant versus large deformations and induced stresses (special steel) while the base plates must be light and compatible with spaces interfaces (aluminum alloy), it is mandatory to manufacture the articulation in several parts.
Strips are squeezed between two semi base plates. Pieces are bonded and screwed with such a design that stress concentration is limited under mechanical and thermal loads.
Strips design, especially near bases, is also define to reduce stresses during opening strain.

Fig 3. 180 ° closed hinge

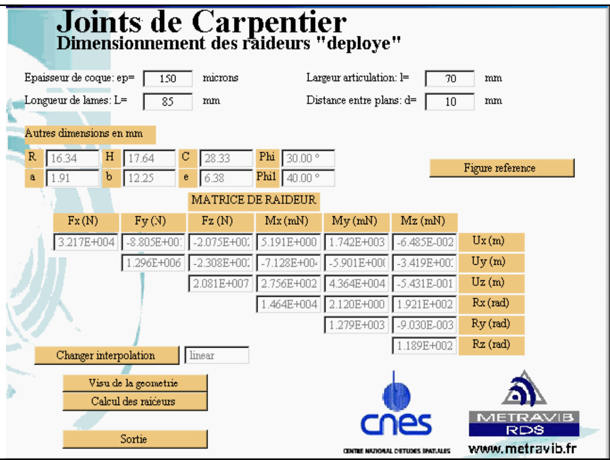

Fig 4. : Example of stiffness estimation issue from the model interpolation (simplified model in MATLAB® environment)

3. DESIGN - MODELS

The development has been conducted along two steps.

1. At first, we built simplified tools for preliminary design versus geometry. The driving torque is calculated with an analytical model based on an elastic energy balance, validated through measurements.
An interpolation from a parametric FEM (Finite Element Method) model database is used to anticipate the hinge's stiffness. This tool has been friendly integrated in MATLAB environment (see Fig. 4).
Obviously, those models are available to predefine a new design, if existing ones are not fully compliant with an envisaged application.

2. To refine and validate the final design, a complete FEM model has been produced wit the ANSYS software. This model is fully parametric and many results have been validated with measurement (see next section).

A first linear approach permits to obtain the open stiffness. This calculation consists in a modal analysis of the hinge with a single mass fixed one the other base (see Fig. 5) which has the advantage, compared to static calculations, of being directly comparable with experimental measurements. Results may then be used to estimate the first modal frequency of the appendix in deployed configuration.

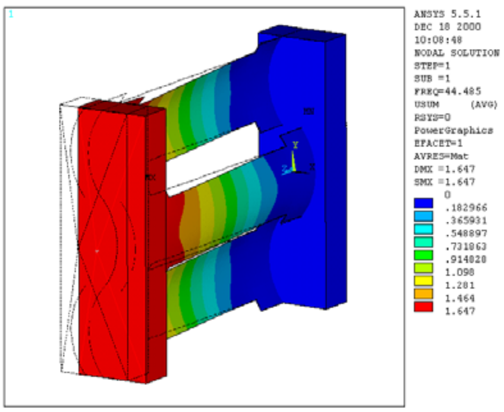

Fig 5. Stiffness calculation (first modal frequency) – The same model is also used to estimate the holding torque by the way of a buckling (critical load) analysis

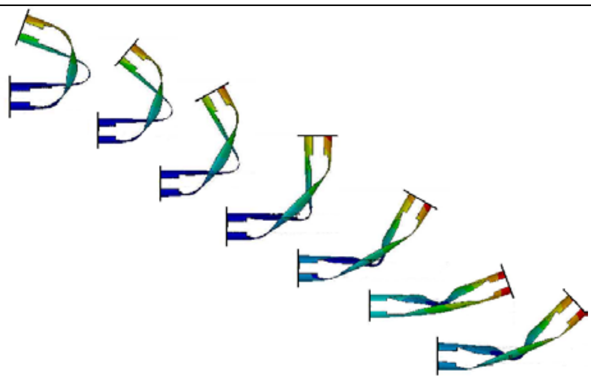

Fig 6. Large strain deformed shapes

A buckling calculation (critical load) leads to define the holding torque, namely the effort the hinge can stand, under satellite attitude control, without unlocking. This latter is performed on the same numerical model as the previous one (see Fig. 5).

Finally, as the main operating function, it is necessary to predict the motorization of the hinge. To that aim, a large strain calculation is mandatory, operated with a nonlinear module of ANSYS. Special cares are required to define efficient and stable numerical schemes, appropriate boundary conditions and shell elements, the driving torque is calculated every 10° positions, passing through many buckling phenomena (see Fig. 6 and 8.).

In the intention of deployment prediction, a kinematics model is in progress at the CNES mechanism department.

4. DESIGN - TESTS

During development, tests were conducted in parallel with the advanced modeling to validate the design.
Elementary measurements (modal analyses, unlocking force) have been performed related to open stiffness and holding torque, which are consistent with calculation results.

For driving torque measurement, it appeared that friction and gravity effects introduce significant perturbations due to low lateral stiffness. This justified the development of a dedicated test bench able to reproduce the "in-plane" kinematics of a single hinge system. This test bench (see Fig. 7) is made of a vertical rotating axis, an air cushion (to simulate zero gravity) mobile with an adjustable inertia (appendix dummy), an angular position sensor and a force sensor to measure the torque.

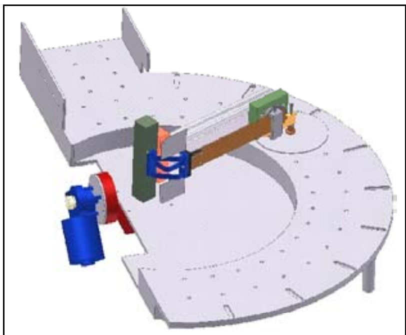

Fig 7. Dedicated test bench

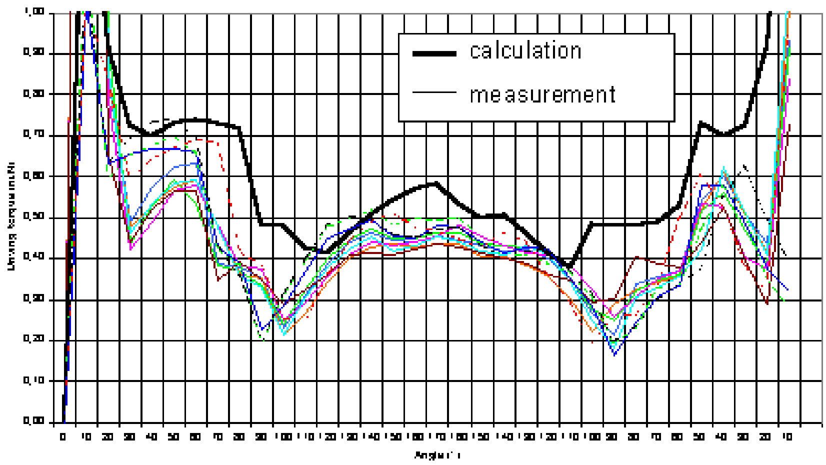

Fig 8. Comparison between measured and calculated torques

Thanks to this bench, an efficient tool to predict driving torque and deployment kinematics is available. Here again, the calculations and the experimental results are quite in good agreement, especially regarding the difficulty of the numerical simulations (see Fig. 8).

Finally, deployments have been processed in a micro-gravity flight to validate simple deployments and estimate a two hinges and two arms deployment kinematics. Several configurations have been tested with various inertias. It appears that the kinematics may exhibit several unlocking before reaching the ending open position.
For correlation with the kinematics model, videos have been translated in graphs with angles versus time.

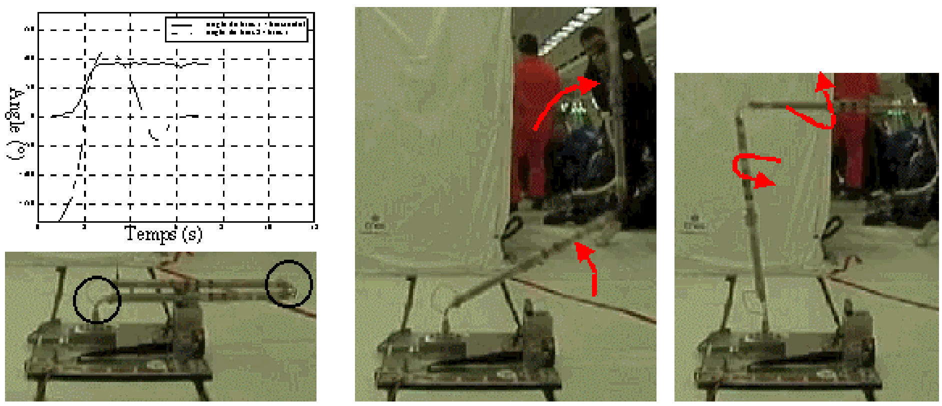

Fig 9. Micro-gravity two hinges / two arms deployment

5. PRODUCT CHARACTERISTICS

Hereafter are given technical data for the present industrial product. This space-qualified product may be efficient for a lot of micro satellites applications but, thank to the previously presented design tools, both the geometry and materials may be adapted to favor a specific characteristic (stiffness, torque…).

· Deployment torque:	> 0.15 N.m
· Deployed stiffness:	1000 N.m/rad
· Position Accuracy:	< 1°
· Holding torque:	4,5 N.m/rad
· Bulk:	70 x 20 x 110 mm3
· Weight:	85 g
· Temperature:	-85°C to +115°C

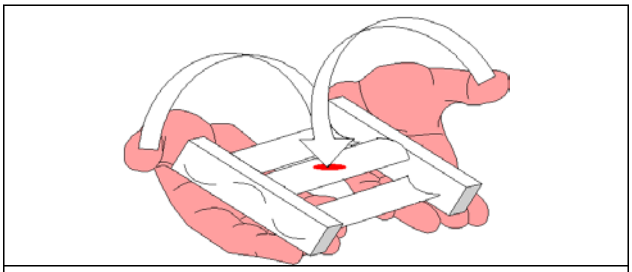

Fig 10. Fastening procedure

6. CURRENT APPLICATIONS

The presented applications are mainly dedicated to deployable equipments onboard micro satellites.
The product is today the generic solution for solar arrays and instruments of CNES (DEMETER and following) and ESSAIM micro satellites.

Antennas on ESSAIM satellites

The ESSAIM program is composed of a 3 micro satellites (constellation). Each of its is equipped of two antennas.
Those antennas are deployed thought 90° and are locked with a single hanging point. Qualification tests have been successfully completed during this year.

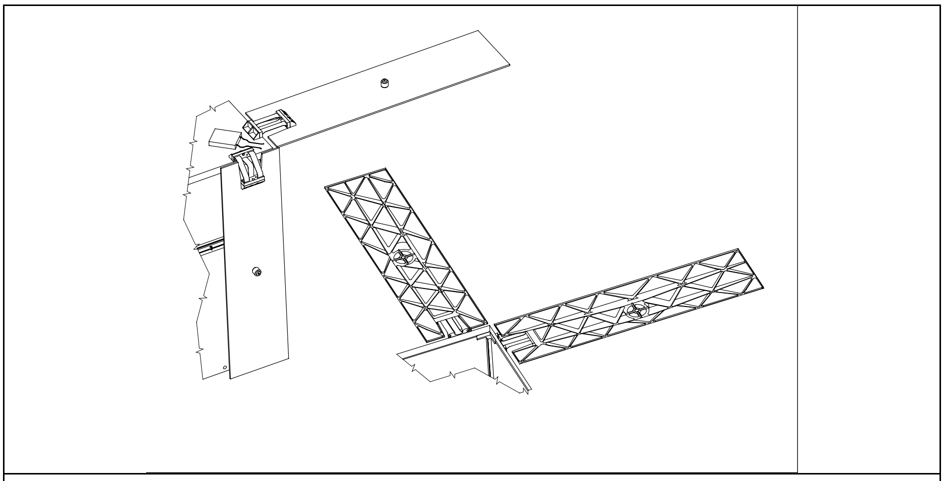

Fig 11. Antenna integration on ESSAIM satellite

IMSC mast on DEMETER mission

The DEMETER mission's aim is to measure earth magnetic fields to watch on volcanic activity of the planet.
The payload is equipped of several sensors. The IMSC is a magnetic one, which have to be positioned away from the satellite to avoid perturbations.
The deployment arm is composed of two composite pipes and two hinges and has a deployed length of 1800 mm.
During launch, a single holding point is in charge of the fixation.

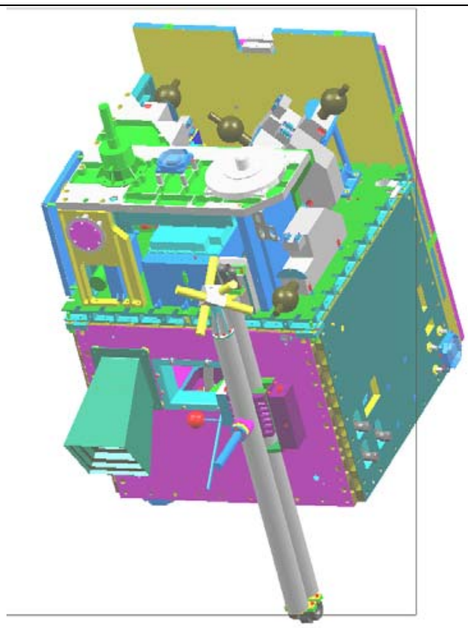

Fig 12. IMSC mast integration on DEMETER satellite

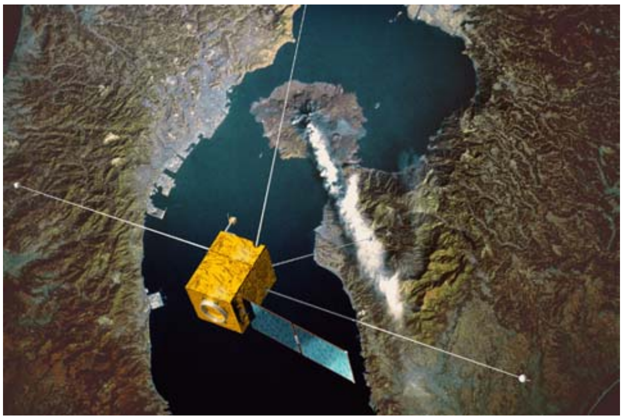

Fig 13. Artist picture of DEMETER

7. CONCLUSION

This publication illustrates the development of a basic but daring concept.
This hinge is presently an industrial solution that could be easily implemented on satellite platforms to deploy solar arrays, antennas, and any other kind of instruments or equipments.

The standard product allows numerous applications and the concept may be adapted to new specifications.

ACKNOWLEDGEMENT

The presented product results from a long-term fruitful collaboration between the CNES and METRAVIB RDS. We thank THALES company for having chose the concept for one of their industrial applications, and therefore given the possibility to improve the technology and extend our knowledge of its behavior through qualification tests in particular.

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