MECHANICAL DESIGN AND TEST OF ROSETTA PLATFORM LOUVRES

Miguel Domingo, José Julián Ramírez

SENER Ingeniería y Sistemas, S.A.
Avda. Zugazarte 56, 48930 Getxo, Vizcaya, Spain
Tel: +34 94 481 7500 / Fax: +34 94 481 7603 / E-mail: miguel.domingo@sener.es

ABSTRACT

More than one hundred trimetal actuators and three hundred bearings will allow the blades movement in the 14 louvres fitted over the radiators of the ROSETTA S/C. Near the Sun, the blades shall be open to allow the radiators to dissipate heat into space. During the prolonged periods of hibernation and comet rendezvous, the blades shall be close in order to retain as much heat as possible in the spacecraft.

SENER design of the Rosetta Platform Louvres consists of a framed array (397 x 430 mm) of highly specular reflecting blades which are individually pivoted to temperature-sensitive actuators. The novel actuators are trimetallic (traditionally were bimetallic) coil springs enclosed within a housing that is well isolated from the external environment but which maintains good thermal contact with the mounting panel requiring thermal control. The actuators are "calibrated" to cause the associated blades to be fully open and fully closed at prescribed temperatures. As the temperature of the panel begins to increase, the related rise in the actuators temperature creates a thermal moment which forces the louvres blades to open and hence lead to an increase in the radioactive power to space. Similarly, as the panel temperature decreases, the actuators tend to close the blades, which now offer a high resistance to radiation losses.

1. INTRODUCTION

Rosetta´s mission is to complete the most comprehensive examination ever made of a piece of primordial cosmic debris, a comet. After a long travel around the inner Solar System, Rosetta will be the first spacecraft to examine from close proximity how a frozen comet is transformed by the warmth of the Sun. Shortly after its arrival to the comet, the Rosetta Orbiter will dispatch a robotic Lander for the first controlled touchdown on a comet nucleus.

Temperature control was a major critical point for the designers of the Rosetta spacecraft. Near the Sun, overheating has to be prevented by using radiators to dissipate surplus heat into space. In the outer Solar System, the hardware and scientific instruments must be kept warm (specially when in hibernation) to assure their survival. This is achieved by using heaters located at strategic points, placing louvres over the radiators and wrapping the spacecraft in multi-layered insulation blankets to cut down on heat losses.

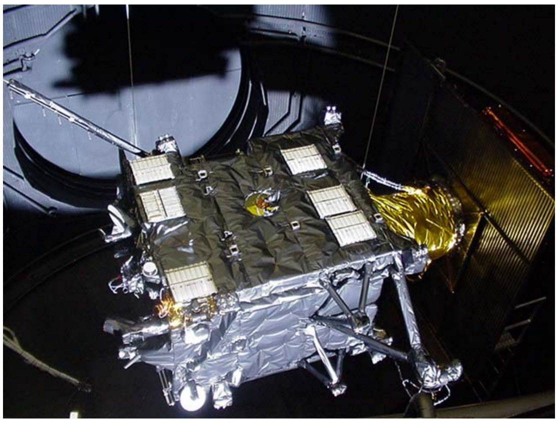

Figure 1, The Orbiter´s side and back panels are in shade for most of the mission. Since these panels receive little sunlight, they are an ideal location for the spacecraft´s radiators and louvres which regulate its internal temperature. In the figure Rosetta S/C in thermal vacuum test showing six louvres .

Figure 2,QM louvre instrumented for testing on the S/C.

Louvres are mechanical devices for active thermal control that have been used in different forms on numerous spacecrafts. The most widely used louvre assembly is the bimetallic spring-actuated rectangular-blade (venetian blind) type. Rosetta mission had from the beginning the possibility of using standard louvres but after a dedicated trade-off SENER louvre was preferred for the application of Rosetta spacecrat due to its superior thermal performances and lighter mass.

2. LOUVRE DESIGN TO SAVE MASS

The mass of one Rosetta louvre is 785 grams.
A good comparison between options is the ratio mass/footprint area (total area covered by the louvre). Standard louvre ratio is 5,3 Kg/m^2. SENER louvre ratio is 4,6. The total saved mass for 14 louvres is 1,26 Kg.
In the traditional louvre, the blades and actuators are fixed during launch through the bearings and support points. The structural elements (actuator housing, frames…) as well as blades and actuators are designed to withstand vibration loads.
In SENER louvre, only the lower part of the actuators housing has a structural mission supporting the actuator and the two shafts through the inner bearing that is screwed onto it. During vibration, the blades are free to move in the shaft direction. Working in this way, blades structure can be reduced to the minimum to support the VDA Kapton tape. The outside frame is only used for handling, outer bearings positioning and MLI attachment. Final mass saving is 12% w.r.t traditional concept which is more rigid causing stress problems to the actuators during launch.

Figure 3, Blades and actuators are free to move during launch in the shaft direction. In the figure this subassembly is being calibrated before mounting.

The outside frame is composed by two side frames and two end frames. It is plenty of holes in all the area that it is not necessary for end-stops and bearings support. The holes are covered with VDA Kapton tape.

The final blade configuration was selected taking into account mechanical and thermal behaviour. Four different kind of blades were vibrated at qualification levels submitted to a solar simulation test in a thermal vacuum chamber at ESTEC. The composition of the four different types of blades is here described :

1. Two Aluminium alloy sheets bonded with adhesive and with Vacuum Deposited Aluminium directly on the sheet. (10.7 grams per blade)
2. Two Aluminium alloy sheets bonded with adhesive and V.D.A Kapton tape in the outer & inner side (12.7 grams per blade).
3. 1 Aluminium sheet and V.D.A Kapton Tape in the inner and outer sides. (7.4 grams per blade)
4. 2 sheets of Kapton 3mil and two small frames at the edges of the blade to provide stiffness for handling and for the end stops contact : (7 grams per blade).

Behaviour during vibration and geometrical stability were important criteria for the final selection of type 3. The final blade design and an explanation about the assembly process is presented in the next figure and paragraphs.

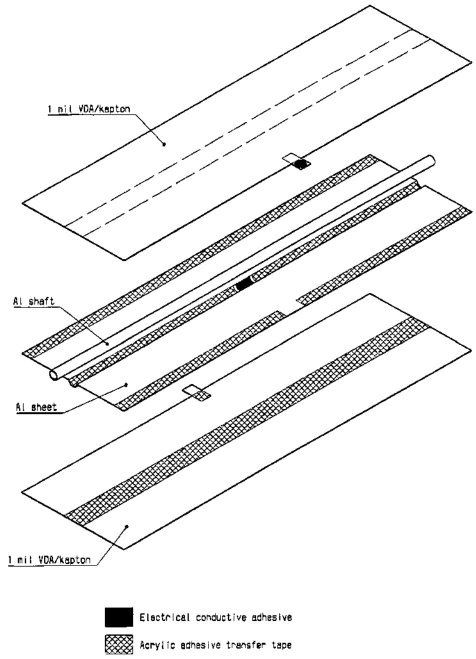

Figure 4, Blade assembly.

The gluing of the shaft is done with simultaneous shaping of the Al sheet in an appropriate deep-drawing tool. The deep-drawing device design ensures that the final position of the glued shaft is slightly off-set out the blade plane in order to insure a good static balance of the blade assembly. For applying the VDA Kapton foil without wrinkles over the whole sheet area the foil has to be slightly stretched. The gluing should be performed from the shaft centre to the blade's edge. The adhesive tapes shall be applied in small stripes on the sheet border, because then blisters in the adhesive area can be removed easier. Existing air bubbles can escape through the non glued areas depicted in the figure.
All the surfaces have to be electrically grounded. This is done by folding up a flap in the middle of the VDA foil's inner side and fix it with an adhesive tape. The flap outside (=VDA side) is covered with a conductive adhesive to obtain an electrical contact to the Al sheet. The conductivity from the shaft to the sheet will also be ensured by a conductive adhesive in the middle of the shaft.

3. ACTUATOR DESIGN

The selection of trimetallic actuator coils for the actuation of the Rosetta Platform Louvres is based on the lack of available power and on the simplicity of the design.

Spiral trimetals convert temperature changes into a rotational movement, or to a torque when the displacement is restrained or impeded. A spiral shape enables a large length of trimetal to be incorporated in a small volume, limited only by strength considerations beyond a certain length.

The design of a trimetal spiral actuator is determined by the following major drivers:

1. Temperature range of operation
2. Movement required
3. Force or Torque to be developed
4. Space limitations
5. Temperature above and/or below which the element will be restrained from motion.
6. The maximum temperature to which the trimetal will be subjected

The theoretical range of temperature for the Rosetta louvre actuator is 14°C and the required movement in that range of temperature 90°.

The angle α rotated by a non-restraint actuator is defined as follows,

$$\alpha = \frac{360 \times a \times L}{\pi \times s} \times \Delta\theta$$

where "a" is the specific thermal deflection, $\Delta\theta$ the temperature increase, L the length of the helical coil and s its thickness. As it can be noticed, several geometrical parameters and material properties influenced the rotation associated to a certain $\Delta\theta$.

However, the design of the actuator must take into account additional factors that reduce the theoretical rotation calculated based on the geometry of the coil. These factors are basically related to the weight of the assembled elements and to the friction forces that arise between bearings and shafts. These two factors impose a certain restraint to the motion of the actuator in the form of a resistive torque. The actuator will have to develop a torque high enough to overcome the resistive torque to start moving.

The torque that the actuator has to open against (working on ground) is obtained from adding the weight torque and the friction torque. The torque developed by the actuator when the motion is restrained and the temperature increases is,

$$T = \frac{a \times \Delta\theta \times E \times b \times s^2}{6}$$

where E the Modulus of Elasticity and b the width of the helical coil .

In order to meet the Louvres requirements, the actuator is designed taking into account all these factors.

Figure 5, Eight actuators are inside the actuator housing in the centre of the louvre.

Hereafter, the major steps followed in the design of the actuator are detailed. Several concepts and terms need to be defined before proceeding any further:

θ_A: Nominal temperature at which the blades must be fully open.

θ_B: Nominal temperature at which the blades must be fully closed.

$\Delta\theta_{spec}$: Theoretical temperature range according to specification = θ_A-θ_B

θ_{tol} : Temperature tolerance at both ends of $\Delta\theta_{spec}$.

$\theta_{A\ max} = \theta_A + \theta_{tol}$; $\theta_{A\ min} = \theta_A - \theta_{tol}$

$\theta_{B\ max} = \theta_B + \theta_{tol}$; $\theta_{B\ min} = \theta_B - \theta_{tol}$

θ_{set} : Actuator setting temperature.

$\Delta\theta_{friction}$: Estimated temperature raise needed for the actuator to overcome friction.

$\Delta\theta_{friction+margin}$: Estimated temperature raise needed for the actuator to overcome friction including motorization factor and friction factor (worst case resistive torque).

$\Delta\theta_{real} = \Delta\theta_{nom} + 2\ \Delta\theta_{friction}$

T_{deg} : Torque given by the actuator for a 1° C increase in temperature

The design of the required actuator was done following these steps:

1. Estimation of Torque, $T_{friction}$, against which the actuator will have to open the louvres: This torque was derived from a rig test on ground. The value obtained is conservative and represents a maximum value for the friction under flight conditions . The real torque should be somewhere between zero (no friction) and the obtained value.

2. Define nominal range of temperature for the real actuator, $\Delta\theta_{nom}$ .This nominal range will be smaller than the theoretical range defined in the specification. The real actuator should have a T_{deg} sufficient to overcome $T_{friction}$ in a certain, pre-established $\Delta\theta_{friction}$, so that the resulting range of operation of the actuator, $\Delta\theta_{real}$ = $\Delta\theta_{nom}$+2 $\Delta\theta_{friction}$, is within temperature tolerance band defined by the specification : [$\theta_{A\ max}$ - $\theta_{B\ min}$].

$\Delta\theta_{nom}$ has been selected to be $\Delta\theta_{spec}$ – 2/3θ_{tol} , which means that, assuming that the setting point of the actuator is set to be θ_A, there would have to be a θ_{tol}+2/3 θ_{tol} margin for the actuator to overcome friction and cover the required rotation of the louvres within the required temperature range (before $\theta_{B\ min}$).

3. Establish minimum Torque required from the actuator, T_{min} :

$$T_{min} = \varphi \times \kappa \times T_{friction}$$

Where φ= 2 is the motorization factor, and κ=1,5 is the friction factor.

4. Torque Margin, T_{margin} : Assuming that the actuator has to work against the worst resistive torque ($\varphi \times \kappa \times T_{friction}$) it is necessary to guarantee that the actuator torque is high enough to overcome this worst case of load in a delta of temperature such as

$$\Delta\theta_{friction+margin} < (\theta_{tol}. +2/3\ \theta_{tol})$$

Hence, the minimum torque required from the actuator is:

$$T_{min\ deg} = (\varphi \times \kappa \times T_{friction}) / (\theta_{tol} + 2/3\ \theta_{tol})$$

Condition that is used to fix the remaining design parameters of the minimum actuator required. The real actuator has been selected in such a way that the $T_{deg\ real} > T_{min\ deg}$

And the Torque margin T_{margin} is derived from this condition,

$$T_{margin} = T_{deg} / (\varphi \times \kappa \times T_{friction})$$

5. θ_{set} , Actuator setting temperature

In order to facilitate the set up procedure for the actuator, it has been decided to define the actuator setting point as the temperature at which the louvres are in the fully open position. In this way, we will avoid the need of performing the whole set up procedure with temperatures below zero ($\theta_B < 0$ °C).

Bearing all this in mind and based on the experience during the QM qualification campaign a recommended setting point for the actuator around 1ºC below θ_A was selected.

The calibration of the actuators was performed following a specific procedure first at actuator-blade subassembly level (see figure 3) and after that at louvre assembly level using a test rig with electronic coolers (see figure 6).

Figure 6, louvre assembly procedure . Final check of actuators calibration before functional test. Friction torque is checked in each blade.

The results obtained during the qualification campaign confirmed the estimations realised during the design of the actuator.

As an average, for the first functional test performed a $\Delta\theta_{friction}$ of 1,6 ºC (1,67ºC was the value derived from the rig test) and a $\Delta\theta real$ = 15,2º C were obtained.

The functional tests of the 15 FM models shown similar results.

The cylindrical bearings have been designed to minimise friction and to absorb manufacturing and assembly tolerances of the louvre, as well as any distortions of the frame due to quasistatic, dynamic or thermal loads. Additionally, the inner bearing provides an adequate thermal decoupling between blade shaft and Actuator Housing.

4. VERIFICATION / TEST CAMPAIGN

The QM louvre was submitted to an exhaustive test campaign including, functional tests in ambient, vibration, shock, thermal vacuum cycling, effective emittance vacuum test and life test, according to the test sequence shown in Figure 7.

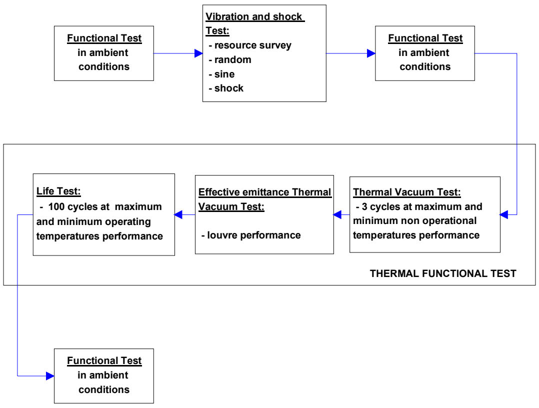

Figure 7, Test sequence at item level.

QM louvre was mounted to the Rosetta S/C for Qualification test campaign (i.e. including acoustic test). The 14 FM louvres mounted in the Rosetta PFM S/C were successfully submitted to the whole test campaign.

5. CONCLUSIONS

Special care during the mechanical design of the louvre for Rosetta mission allows more than 1,25 Kgrs of mass saving. The design of the trimetal actuator takes into account several factors that reduce the theoretical rotation calculated based on the geometry of the coil. These factors are basically related to the weight of the assembled elements and to the friction forces that arise between bearings and shafts. The actuator develops a torque high enough to overcome the resistive torque to start moving. Traditional concept uses bimetal actuator (no intermediate Cu layer which multiply by 15 the coil thermal conductivity). The mechanical design of the blades and structure increases the thermal radiation to space for the fully open position of the louvres by minimising the blade shaded areas on the base panel, and thus increasing the louvre effective emittance in 10% w.r.t traditional concept.

This design can be easily adapted to other shapes and missions : ISS, Beppi-Colombo…

Back to Contents