THE VACUUM TRIBOLOGY MODEL (VTM) OF TRIBOLAB.

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ABSTRACT

TriboLAB is a tribology instrument that is planned for installation in the EuteF Flight Segment Platform [1], along with several other European scientific instruments. Eutef will be fixed onto an Express Pallet Adapter (ExPA), which provides standard structural, mechanical, electrical and communications interfaces to the Columbus External Payload Facility of the International Space Station (ISS).

As a part of the model philosophy, a vacuum tribological model (VTM) has been developed to generate “on ground” tribological data of selected lubricants. The idea is to compare the results obtained “on ground” with those that will be produced in the space, in order to investigate the different behaviors of same tribological films and to be able to compare the performance of specific lubricants in Low Earth Orbit (LEO) conditions.

The VTM is composed of six double experiment cells that perform respectively ball bearing (BB) experiments (with liquid and solid lubrication) and pin-on-disk (PoD) tests of solid lubricants. Thin films of alloyed MoS_2 are being tested in the VTM under controlled vacuum conditions.

In this work, the two sections of the VTM are described.

INTRODUCTION

The tribology is a well developed field of science which has received significant attention from research groups all over the world. The presence of the friction phenomena is always a challenge for the design of mechanisms and machines: sometimes is used as a part of the functioning of the machine but other times is something to get rid of. The liquid and solid lubricants and, specially, thin film lubricants have been used in space applications for the purpose of diminishing the friction phenomena for many years. It is of outmost importance the correct selection of the lubricant to be used in a specific application: it is a fact well known that some of the failures of deployable antennas and other space mechanisms have been produced in the joints due, sometimes, to a non adequate lubrication. As an example, Borrien [2] and Fusaro et al [3] have published good reviews of tribological problems occurring in spacecrafts.

The TriboLAB instrument, which will be located in the International Space Station along with other European experiments in the EUTEF platform, will perform tests with different lubricants and different devices at basic and component level respectively: pin-on-disk and ball bearing. TriboLAB is a tribometer, a device that measures the friction coefficient between two surfaces under the tribo-conditions investigated. The most usual tribometers measure only one sample at a time and the users change the new samples. TriboLAB is meant to work without any action from the astronauts at the International Space Station. As more than one disk or ball bearing have to be tested, the concept of the instrument is that of a rack of experiments, that will be tested sequentially. Expected duration time of each experiment in space is between two and four weeks for the PoD and several months for the BB. This duration fits quite well with the expected time of the Eutef mission (3 years), and materials will be studied after returning back to Earth.

Figure 1: General view of the VTM.

The data that will be acquired during in orbit functioning will be sent to the ground station, where it can be monitored and studied almost on line, according to the expected ratio of velocity of communications. The data that will be measured are the temperature in the cell where the experiment is being performed, the vertical or normal force that is applied on the disk, the horizontal or tangential force which appears due to the friction and the friction coefficient itself, ratio between tangential and normal forces.

Due to the high effort of setting in orbit an experiment and due to the fact that the number of samples or experiments is very limited by the stringent conditions that rule in the space experiment world, a carefully selection of films and experiments that will be flown is required to have a high probability of success in them. Moreover, it would be out of question to fly a completely new film or lubricant liquid without a consolidated record of good behaviour of that lubricating film in a set of experiments done on Earth.

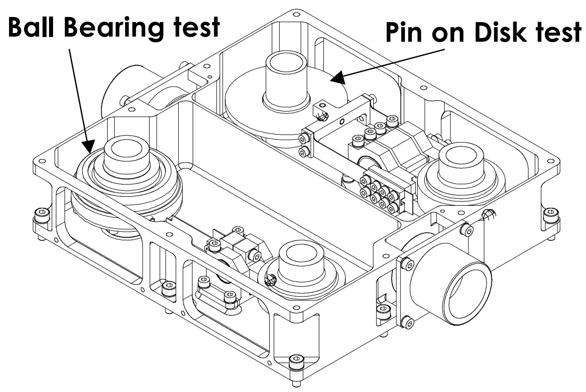
The purpose of the construction of the TriboLAB Vacuum Tribometer Model (VTM) is thus double. On the one hand, it serves as a engineering-development model for the Tribolab Flight Model (FM) and on the other hand, it is used also as a bench for the testing of different film lubricants and comparison with ISS data from FM.

This contribution deals with a summarised description of the TriboLAB VTM, for details of the testing carried out, please refer to the work by J.I. Oñate and co-workers in these proceedings [4].

TRIBOLAB VTM

Figure 1 shows a general view of the already constructed VTM. Twelve external gears can be seen in the photo. Its purpose is just to transmit the movement that is generated by the motors to the different cells that are inside the tribometer. Figure 1 also shows some of the cables that are used to transmit the signals from the internal gauges to the computer that controls and monitors the experiment. Each cell is composed of two experiments, one pin-on-disk and one ball bearing. This can be seen in the CAD drawing of Figure 2.

Figure 2: Cross section of a VTM experiment cell,



showing the pin on disk test (right) and the ball bearing test (left).

The left part of Fig. 2 represents the ball bearing experiment and the right one the pin-on-disk test. Two motors move independently the shafts that support both experiments. Forces are measured through strain gauges and data sent to the control computer, outside the tribometer.

The motors are located in the basement (see Figure 1, right part) and also the electronics are positioned in this area. Some additional components complete the whole vacuum tribometer.

A) Pin on Disk tests

Figure 3 illustrates the pin on disk test lay-out and its different components. This test set up consists in a *coated disk* that rotates, attached to a main shaft that drives all experiments. The *arm,* containing a ball or spherically ended pin at one extreme, is made of two stainless steel flexures and the ball at the end is positioned in contact with the disk by means of a *pivot flexure* (torsional spring, see Table I) that applies the nominal contact force between ball and disk. The load applied by this method has been calibrated to 5 N +/- 10%.

Table I: Main characteristics of the pivot flexure.

Parameter	Value
Type	6024-400, Lucas Aero. Ref
Material	AISI 410, AISI 420 stainless steels
Torsional stiffness (N/º)	0.36
Angular range (º)	± 6º
Size (mm)	ϕ19 x 30.5
Radial stiffness (N/m)	18.2×10^6
Axial stiffness (N/m)	13.7×10^6

The torsional spring is used for two main purposes: apply the required load between ball and disk and remove and change the experiments by separating ball and disk by the action of a *cam*.

The *cam* controls the angular position of the torsional spring and the applied force. Its function is to select the disk to be tested, since only one pin-on-disk test is carried out at a time from a total of 6 positions available. This cam rotates attached to a shaft that is shared for all experiments; a ball at one end of the arm is in contact with the cam.

Friction and normal forces are measured by means of two sets of semiconductor *strain gauges* (see Table II) bonded on the flexures, which are deformed under the action of these forces. Both flexures are equipped with full wheatstone bridges to produce a voltage output proportional to the friction and normal forces.

Pin on disk tests in the TriboLAB are carried out with solid lubricant films based in MoS_2 alloyed with hard phases [4-6]. The base material is AISI 440C martensitic stainless steel.

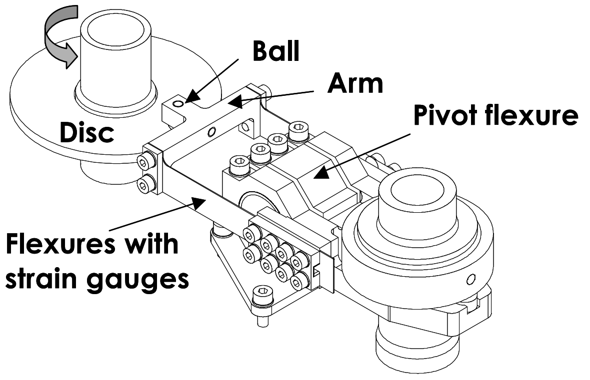


Fig. 3: VTM pin on disk test and components

Table II: Main characteristics of the strain gauges.

Characteristic	Value / Remarks
Type	KSP-2-1K-E4 / from Kiowa
Resistance	1000 Ω / At 24°C
Gauge Factor (GF)	160
Max. allowable strain	± 3000 μm/m
Max. allowable current	20 mA
Thermal output	29.3 μm/m/°C / Apparent strain on steel
Temp. coefficient of GF	-0.27% /°C / 500 μm/m
Size	7.7x 4 mm

B) Ball bearing tests.

The ball bearing test initially shown in the cross section of Fig. 2 is presented in more detail in Figure 4. Each experiment cell is independent, with the following main components: a flexible arm with a ball at one end (the arm contains one flexure), a set of four strain gages (sensors) for friction torque measurements bonded at both sides of the flexures, one pivot flexure (torsional spring), one bearing to be tested and finally one cam.

In the ball bearing experiment, the *bearing* to be tested is mounted in the housing which is joined to a shaft shared for all experiments. This shaft is supported at both ends by bearings with a configuration of a duplex preloaded pair face to face bearing at one extreme and one single deep groove bearing at the other extreme. The bearings shaft is rotated by a DC brushless actuator.

The *arm* is composed of the elements (Fig. 4): one flexure, a set of four strain gages (sensors) for friction torque measurements bonded at both sides of the flexure, a main body attached to the torsional spring with a ball at one extreme, a clamping piece to join the flexure to the main body and a support base for the above assembly.

The *arm* made with flexures is rotated to contact with a *pin* fixed in the outer bearing ring to avoid its rotation. The flexible arm position is controlled by a *pivot flexure* (torsional spring) and a *cam* that rotates attached to the shaft shared for all experiments; a ball at one end of the arm is in contact with the cam. The friction torque is measured by means of *strain gauges* bonded on the flexures.

The measurement system is based on a set of strain gauges bonded on the cantilever flexible arm, which is deformed under the action of bending forces. Semiconductor strain gauges, all of the same type (see Table II) are used to measure those forces.

The VTM allows the testing of 6 pairs of angular ball bearings with the dimensions shown in Table III. The bearings are mounted and hard preloaded in a dedicated housing. A pin is joined externally to the outer housing case to react on the flexible arm and fix the rotation of the bearing outer race.

Table III: Bearings selected for testing.

Parameter	Value
Material	AISI 440C
Inner race diameter (mm)	32.5
Outer race diameter (mm)	44.45
Width (mm)	6.35x2
Separators width (mm)	3
Tolerance class	TA4

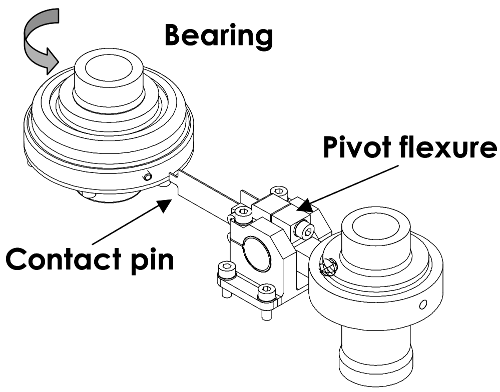


Figure 4: Ball bearing experiment lay-out and components.

VACUUM CHAMBER

The VTM is introduced for testing inside a vacuum chamber that has been designed and constructed to generate tribological data under ground conditions with this instrument (see Figure 5).

The design of the vacuum chamber was optimized for a correct operation of the VTM. As is usual in these cases, a tunning of the different components was required in the initial setup of the vacuum system, as vibrations had to be minimized, and signals and correct vacuum levels guaranteed. These facts remark the idea of the need of a very high quality fabrication of the real components for the Flight Model. The experience gained with the VTM system, has been invaluable for application in the FM TriboLAB.

Not only the components but also the assembly of the vacuum chamber presented some problems. One of them was the vibration induced in the VTM due to the frequency of rotation of the vacuum pump. The exciting frequency was not far enough from the first natural frequency of the tribometer, so a special rubber support were needed to avoid the negative influence of the vibrations in measurements to be done, especially on the values obtained for normal and tangential forces. Finally, after some time of work, the needed adjustment was obtained. Partial results with the pin on disk test set up at the VTM are presented in these proceedings [4].

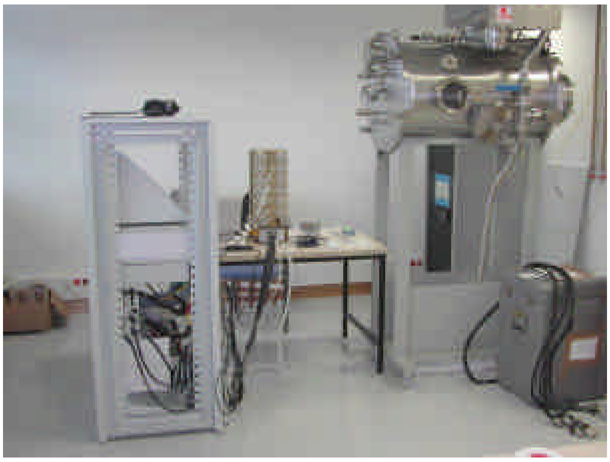


Figure 5: Vacuum chamber (right) and VTM at the center.

CONCLUSIONS

A vacuum tribometer model VTM has been designed, constructed and used as an engineering model for the design and validation of TriboLAB Flight Model. Several difficulties were found in the process but promising results with the developed film coatings have been obtained. Pin on disk and ball bearings tests are in progress and computer programs for the statistical treatment of data have been developed.

Work is in progress out to select the optimum thin lubricating films that will be finally tested at the FM TriboLAB on board of the EuTEF platform at the ISS.

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