DYNAMIC BEHAVIOR OF LOCKING MECHANISM OF MICROACCELOMETER

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ABSTRACT

The article describes developing phases of Locking mechanism (LM) of Microaccelerometer (MAC). Because of LM failure during testing appropriate design changes were doing and computational models were developing at the same time to asses LM and its crucial parts. Analyses justified final design solution which succeeded in testing as well.

1 INTRODUCTION

Microaccelerometer (MAC) is an instrument to be used for very precise measurement of acceleration. For linear acceleration, its range shall be $\pm 10^{-4}$m/s^2, resolution shall be better than 3.10^{-9}m/s^2, and accuracy shall be 10^{-8}m/s^2. For angular acceleration, its range shall be ±9.6 10^{-3}m/s^2, resolution shall be better than 10^{-7}m/s^2, and accuracy shall be 10^{-8}m/s^2. It has been finishing for SWARM mission. The most important and complicated mechanical part is Locking Mechanism (LM) which locked Sensor. MAC contains three LM, i.e. one for each axis.

The previous version of MAC had difficulties with unlocking due to cold weld in vacuum, thus a new mechanism using fiber was developed based on a lever hold in locked position by fiber. But LM failed during vibration test campaign that time. Performing random vibration fiber Power Pro broke at edges. Filleting helped a little but did not solve the issue so that rollers were deployed instead of edges. But Power Pro failed again and therefore was replaced by Dyneema fiber.

2 CURRENT DESIGN DESCRIPTION

All important parts of LM are depicted in Fig.1. The Sensor is locked by a Locking Rod. Its position is defined by a Lever arm which has a slot for head of Locking Rod (see also Fig.3). The Lever arm is secured by a fiber that is tightened by a spring. The spring is located between Piston and Cantilever wall. The fiber is fixed on one side by rope at hole of Piston, then goes through the Piston, spring, Cantilever, over rollers to resistors and is ended up by fixing on the other side. After overburning fiber by resistors, the LM is unlocked, because the fiber is pulled out by the spring at piston and other two springs of different diameters (first one inside the second one) lift up the Locking Rod. Once the Locking Rod is lifted up the Sensor is released. A Lever End Stop on which rollers are mounted (except for one mounted on Lever arm) is not shown in Fig. 1.

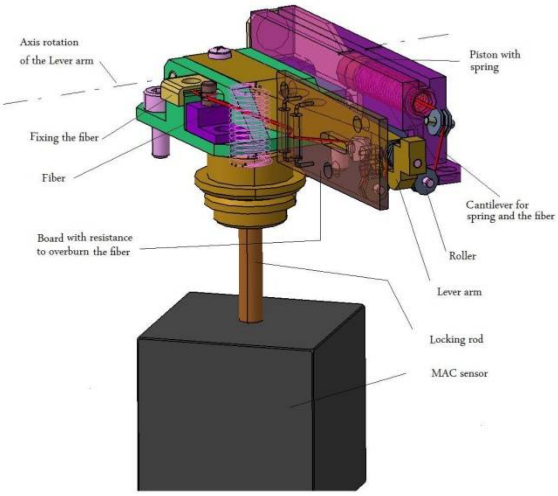

Figure 1 Basic parts of LM

It's evident that the springs, Locking Rod, Lever and fiber are very important parts. They plays crucial role for right function and ensure reliability of the LM.

3 MATHEMATICAL MODELS

There were made three models to simulate dynamic behavior of LM. The first simplest one was made in Matlab software. This model consists of rigid parts only. The fiber was replaced by a spring. The model proved that LM is reliable for various dynamic loads. The second model was made in MSC.Adams. The model is the same as the previous one but flexible lever arm was incorporated, so that deformation of the lever arm could be considered. The last model was made in Abaqus in the most precise manner, simulating flexibility of all crucial parts, contacts between parts (with friction between fiber and rollers) etc.

All three models were loaded according to MAC Specification, particularly by the most dangerous

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random vibration. Random vibration of the MAC shall have been performed with the levels given in the following table, applied to each axis with duration of 120 second in qualification level. The severest load of x axis is depicted in the following table as it was used in analyses (see also blue curve in Fig.2).

Axis	Frequancy	Aceptance.	Qualification
X	20-100 Hz	+3dB/Oct	+3dB/Oct
	100-300 Hz	0.27 g^2/Hz	0.27 g^2/Hz
	300-2000 Hz	-5dB/Oct	-5dB/Oct
		12.02 g (RMS)	15.23 g (RMS)

Table 1 Random environment levels

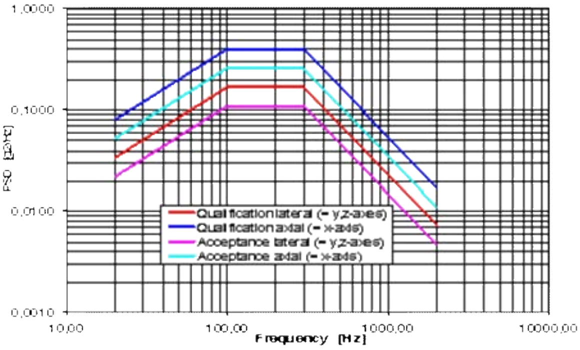

Figure 2 Random environment levels

3.1 Models verifying locking force

The new design of LM in MAC posed issue about stiffness of springs. They were calculated by hand from basic quasistatic analysis considering mass of Sensor and acceleration. Since the most sensitive part – Sensor shall be locked during the whole launch some check analysis had to be done to prove that no loss of locking appeared. For that reason the following models in Matlab and in MSC.Adams were developed. The most important parts influencing locking force were taking into account. The schematic drawing of model is in Fig.3. All parts are joined to center point where dynamic loads were applied. Contacts were made up between Lever and Locking Rod and between Sensor and Locking Rod at the center point. Hertz rule (continuous force) was used for the contacts. The Lever was joined to center point by rotational joint and the Sensor and the Locking Rod were joined to center point by translational joint. The fiber was replaced by spring. Vibration loading was applied in the centre point for both models.

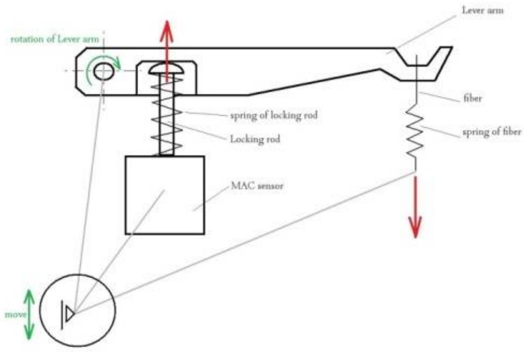

Figure 3 Simplified model of LM

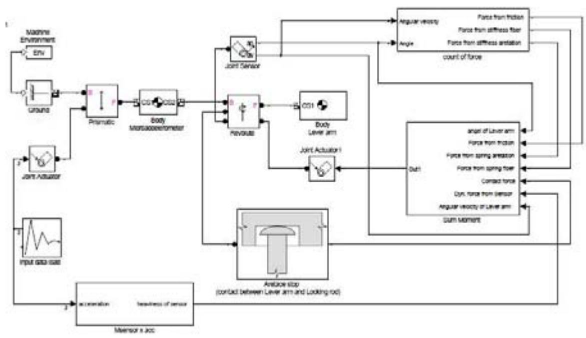

Figure 4 The diagram of model of LM

Model in Matlab took into account rigid parts as baseline. Toolbox SimMechanics were used for implementation of the model which is shown in Fig.4.

Rigid Lever was replaced by flexible part in MSC.Adams model. It makes the analysis more precise Locking forces result lesser than the locking forces for the rigid model. And you can also find Lever deformation.

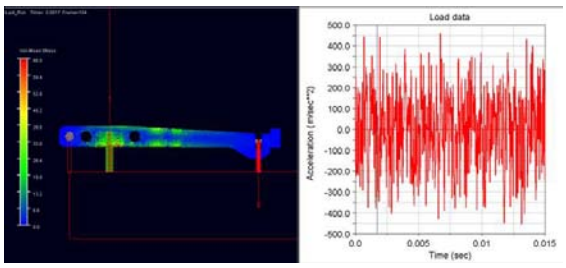

Figure 5 Model of LM and random load in Adams

Results were similar for both models except for magnitude. You can see it in Fig.6. It was proven this way that LM reliably locks the Sensor in the course of vibration spectra excitation.

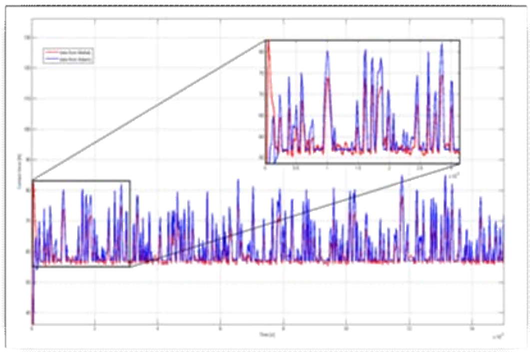

Figure 6 Comparison of models in Matlab and Adams

3.2 Finite element model verifying fiber

Finite element (FE) analyses were done fibers to be checked and considered as reliable. The properties of Dyneema fiber are used in the following analysis.

Model was developed and solved in Abaqus. Since discontinuous effects (contacts and friction) dominate the solution, explicit dynamics approach is often computationally less expensive and more reliable than an implicit quasi-static solution. Next reason for choosing explicit integration schema is possibility to use short time of exciting (e.g. shock spectrum).

Structure of model was adjusted to chosen explicit solution technique. Whole model contains two main families of parts, flexible and rigid body, respectively. Besides, the model contains other structure parts as point mass or spring elements. FE model is shown in Fig. 7.

Time of solution is given by maximal stable time increment. Rigid body does not affect the stable time increment and therefore as many parts as reasonable use rigid elements. Those parts are all rollers, board with resistors, Locking Rod, Cantilever. Flexible bodies are Lever (4-node linear tetrahedron, i.e. continuum solid elements), Piston (4-node doubly curved shell, finite membrane strains, i.e. structural shell elements) and fiber (2-node truss, linear displacement, i.e. no bending stiffness, element can transmit only axial force). The Sensor was approximated as point mass. All springs (it means spring preloading Piston and spring preloading the Locking Rod) are realized using special elements (in ABAQUS called connector elements) which provide nonlinear stiffness behavior and to which is prescribed nonzero force (pre-stress) and zero deformation.

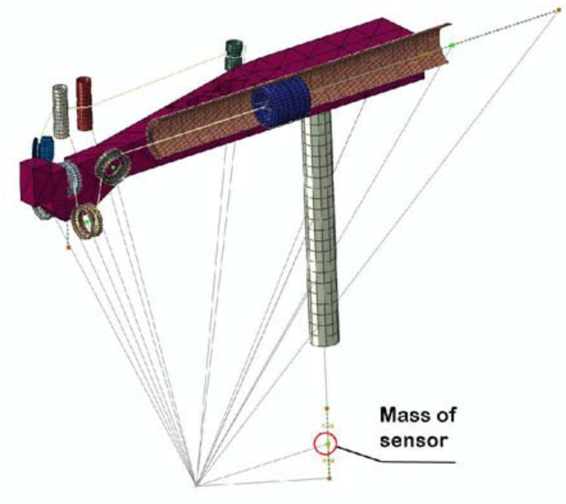

Figure 7 Overview of FEM model

Parts which are in the real MAC fixed to the structure are attached to the single point (connection represent via constrain equation - coupling constrain) in FE model. Interaction between bodies is based on contact including friction.

Dynamic analysis was carried out with random exciting and dynamic behavior of whole model was verified with experimental data, with measurement of natural frequency respectively. Acceleration response on upper side of lever arm (see Fig. 8) was used to compare resonance frequency. Complete run of analysis can be divided into two phases. In the first one LM is loaded from pre-stress spring and in second one is mechanism excited prescribed loading in common point.

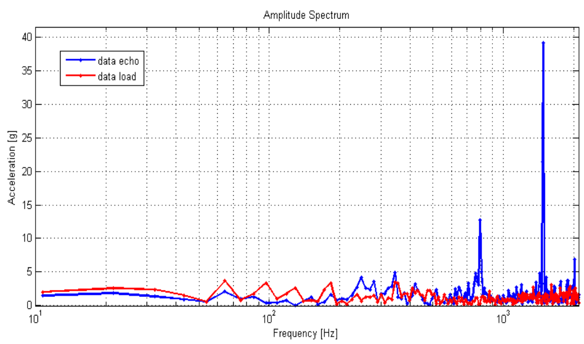

Figure 8 Acceleration response on Lever

As shown in Fig.8 and in Tab.2 first resonance frequency is relatively closed considering the simplification of model.

	Frequency of resonance
Experiment	620Hz
FEM	797Hz

Table 2 Comparison between test and FEM results

After verifying dynamic behavior of FE model by comparing first resonance frequency, crucial element in fiber was determined based on maximal tensile stress in fiber. Location of the latter element is the same as location of point of failure of former fiber, i.e. behind the first roller from piston side (see also Fig. 9 and Fig. 10).

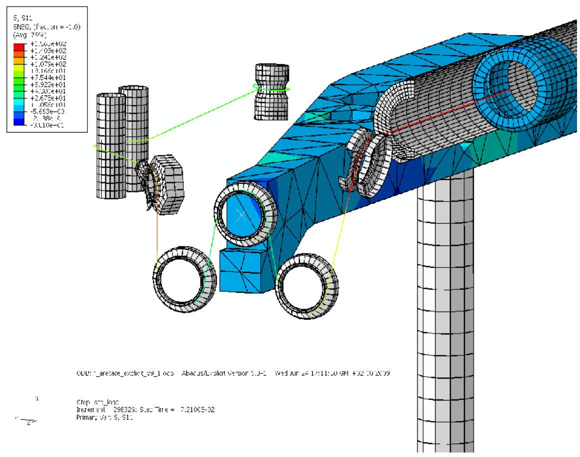

Figure 9   Stress response of LM (random)

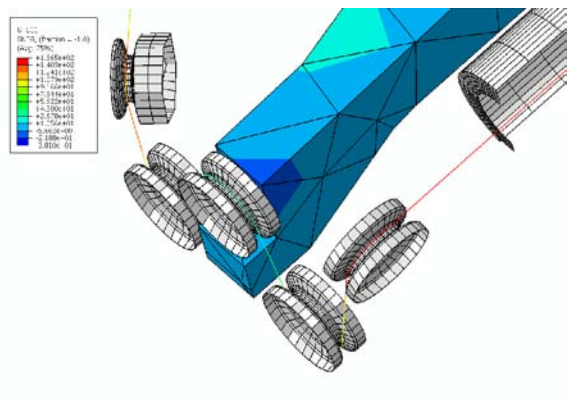

Figure 10 Stress response of fiber going over rollers (random)

In the following picture is point out stress in fiber during random vibration. Results showed no problem in

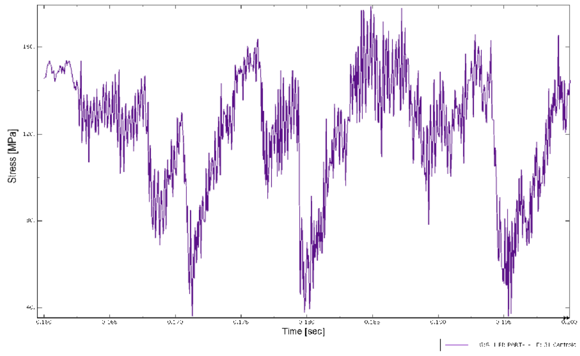

Figure 11   Stress in the fiber in critical point

4   VIBRATION TESTS

Sinus and random vibration tests of the MAC were carried out at Aeronautical Research and Test Institute (VZLÚ, a.s.) in Czech Republic. The tests showed that a critical point of the LM is the fiber. During random vibration test the former Power Pro fiber broke (see Fig. 12) although redesing using rollers was performed. At that point a new fiber (Dyneema) was selected and comprehensive analyses described in previous chapter were done. As their results confirmed ability of new fiber to withstand the vibration new tests were carried out.

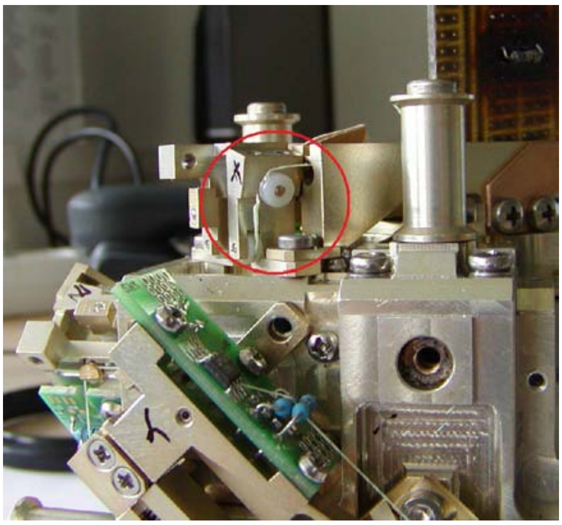

Figure 12   Fiber was broken during some test

To better understand the LM behavior during vibration and to verify LM models an accelerometer was placed on the Lever above the slot with head of Locking Rod during vibration test (see Fig. 13)

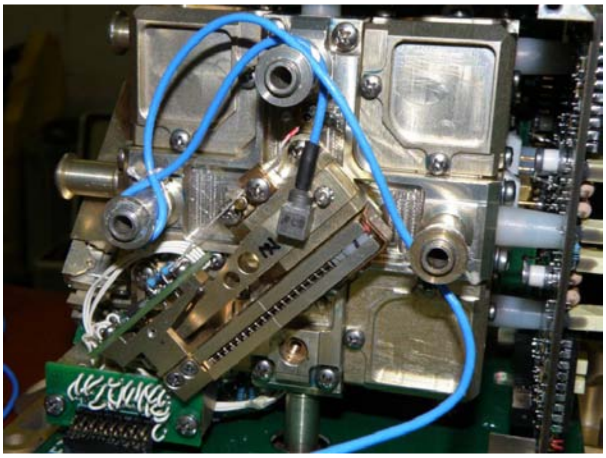

Figure 13 Accelerometer on the Lever of z-axis LM

Qualification levels were applied in successive steps on all axes. No failure of fiber occurred any more. Responses in all three axis from random vibration (blue curve is applied in z-axis) on lever arm of LM locking z-axis are in the following Fig. 14.

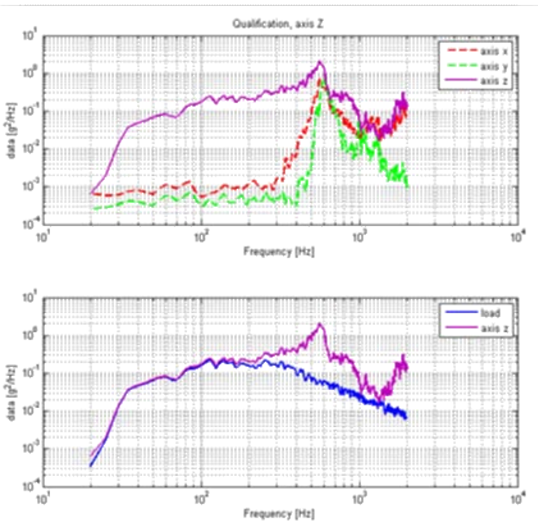

Figure 14 Signal from random analysis

5 CONCLUSION

LM of MAC was successfully redesigned. Set of qualification tests were carried out without any failure of LM.. Models in Matlab and in MSC.Adams predicted no loss of locking force during vibration test which is extremely important in order to cause no damage of Sensor. Above all model in Abaqus was created to analyze the behavior of fiber. It provided with important mechanical parameters for a new fiber with respect to load to be applied.

Nevertheless dynamic analysis performing with simplified virtual models did not involve every physical issue. Breaking fiber over sharp edges could not have been predicted neither from current model. The accuracy of model could also be refined to obtain lower differences in resonance frequencies.