ECAL_CMS PROJECT: ANTI VIBRATION CAGE FOR TRANSPORTING ELECTROMAGNETIC CALORIMETER MODULES FROM C.R. CASACCIA (ROME) TO CERN (GENEVA)

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ABSTRACT

A protective anti vibration cage have been developed by ENEA to protect delicate instrumentation and goods of art from vibrations and shocks induced by natural or mechanical events like earthquake or transportation. The anti vibration cage has been used to transport very delicate crystals within the ECAL-CMS experiment. The Compact Muon Solenoid (CMS) is a detector for the Large Hadron Collider (LHC) at the CERN laboratory of Geneva. The Electromagnetic Calorimeter (ECAL) inside the CMS is an ensemble of modules made by special crystals of Led-Tungstate. These modules have been assembled in two regional centres located at the CERN laboratory of Geneva, Switzerland, and at the ENEA laboratories of the R.C. CASACCIA, Rome, Italy, where the crystals have been tested and assembled in special modules. At the end of the assembling process the modules have been delivered at CERN to be packed and installed in the ECAL configuration. Once assembled, the modules must be very carefully handled to avoid any undesired shock or vibration which could cause relative motions between crystals. The target design of the protection system in the transportation tool is to maximize the isolation of the module from any vibration source, both inside the regional Centre and during the transportation from the Casaccia Regional Centre the CERN.

KEYWORDS: seismic tests, shaking table, structural behaviour, dynamic analysis, shock

1. INTRODUCTION

The anti vibration cage must protect the crystals from outside vibrations and shocks during the transportation. The design goal is to obtain the modal isolation rate value η not less then 95% (i.e. 95% of the input energy must be dissipated or filtered). The η index is related to the frequency ratio and the damping by:

$$\eta\left(\lambda,\zeta\right) = (1.\text{-}T_R)\cdot 100\,\% = \left(1.\text{-}\sqrt{\frac{1+\left(2\cdot\zeta\cdot\lambda\right)^2}{\left(1-\lambda^2.\right)^2+\left(2\cdot\zeta\cdot\lambda\right)^2}}\right)\cdot 100\,\% \quad (1)$$

Where T_R is transmission rate, ζ is the non dimensional damping, and $\lambda = f_e/f_n$ is the ratio between the main frequency excitation f_e and the system natural frequency f_n . For any dynamic system the transmission rate T_R between the external excitation and internal response is always $T_R > 1$. At excitation frequencies below the resonance (more precisely, for $f_e < f_n\cdot\sqrt{2}$) , and goes to zero at frequencies above the resonance ($f_e > f_n\cdot\sqrt{2}$). If ζ << 1 the isolation rate become

$$\eta\left(\lambda\right) = \left(1-\left|\frac{1}{1-\lambda^2}\right|\right)\cdot 100\,\%. \quad (2)$$

When $\lambda < \sqrt{2}$ the isolation is negative, and the system amplifies the external input. Hence the isolation

system must be designed to shift the system natural frequencies as far from the main exciting frequencies as possible, so to have a frequency ratio between external excitation and internal resonances $>> \sqrt{2}$.
Among the existing vibration isolators, air springs produce the lowest system natural frequency, and they have chosen to damp the vibrations transmitted to the module during the transportation.

2. DESIGN OF THE TRANSPORTATION TOOL

The transportation tool is compound by a free oscillating part (see the fig. 1) inserted with air springs in a rigid box. This box is provided by wheels to insert the system on the fixed base mounted on the truck (see the fig. 2).

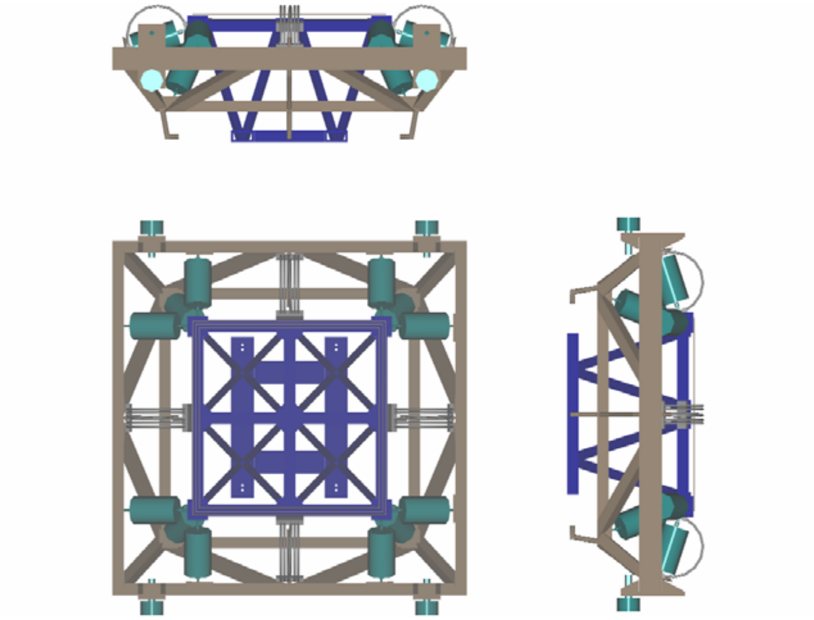

Figure 1 Module suspended at the oscillating tool

Figure 2 transportation from Rome (Italy) to Geneva (CH)

The suspension of the module at 12 o'clock orientation has been chosen to maximize the stability conditions. This is also the final position during the assembling phase at the Casaccia Regional Center, so it is not necessary to rotate the module for the installation in the transportation system, which is approached from above using a crane. Once the plate of the transportation tool is bolted with the module back plate, the system is ready to be moved inside the regional center suspended to the crane, and delivered at CERN.

2.1. Finite Element Analysis

During the transportation the module is suspended through Air Springs at the moving part of the tool, and is free to oscillate as a 6 Degree Of Freedom (6DOF) system. Therefore, to maximize the isolation rate $\eta(\lambda)$ the following conditions should be satisfied:

i.) The first 6 frequency modes of the transportation system must coincide with the 6DOF free oscillations of its moving part.

ii.) The first 6 natural frequencies should be the lowest possible to maximize $\eta(\lambda)$.

iii.) Since the other frequency modes of the system are related to the elastic deformations of the structure, they should have as high as possible natural frequency values (i.e. to maximize the stiffness of the structure).

- *Natural Frequency Calculations*

In the tab.1 there are the first 9 natural frequencies evaluated considering an inflating pressure of 80 psi of the Air springs. In this simulation the gravity center of the module not aligned with the symmetry ax of the structure. This is the extreme worst condition; the real configuration will have the gravity center of the module aligned with the symmetry ax of the transportation system. The modes N° 1,2,..6 are the 6DOF oscillations of an off-centered rigid body, the modes N° 7, 8, 9 are higher order modes representing the elastic deformations of the structure. The FEA geometry is represented in the fig. 3.

tab. 1: First 9 Natural Frequencies and mode shapes

Mode N	**Frequency Hz**	**DOF**
1	1.062	Vertical
2	2.373	Longitudinal
3	2.426	Pitch
4	2.812	Lateral
5	2.954	Yaw
6	3.061	Roll
7	167.1	1st Elastic deform.
8	250.9	2nd Elastic deform.
9	261.5	3rd Elastic deform.

- *FEA dynamic simulation*

The numerical simulation of the dynamic response of the system during the transportation have been performed considering two type of input excitations:

a) Vibration profile from the MIL-STD-810D specifications for basic transportation (Method 514.3) ;
b) White noise Random profile.

The fig. 6 shows the input profile from the MIL-STD specifications. The input spectrum applied at the node 251 and the response spectra at the nodes 999 and 63 are shown in the figs. 7 and 8 considering the two damping values of $\varsigma = 1$ % and $\varsigma = 10$% respectively.

In the fig. 3 are represented the PSD value (g^2/Hz) at the nodes 1, 14, 29, 45. The input white noise has been applied at the node 14. The fig. 10 shows the Frequency Response Functions (FRF) with respect the input at the node N°14. The isolation rate target value $\eta > 95\%$ for the node 45 at the lower corner of the module is reached at 1.8 Hz.

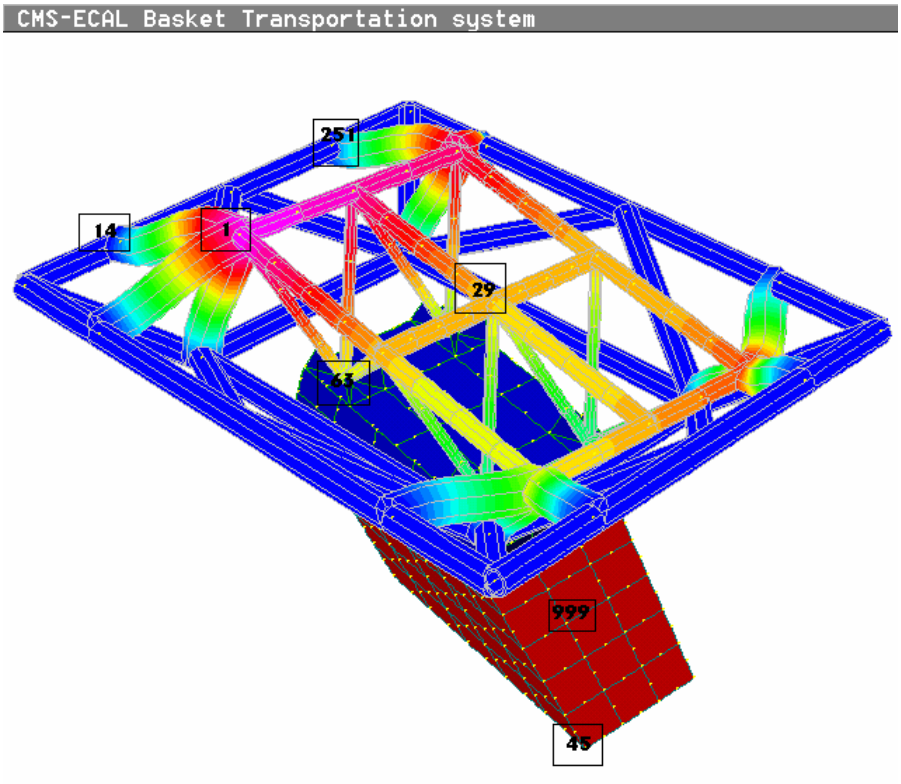

Figure 3 control points for the analysis

The nodes 251 and 14 are the application points of the MIL-STD-810D and the Random White noise external loads spectral profiles. The nodes 1 and 29 are on the oscillating part of the structure. The nodes 45 and 999 are at the lower corner and at the gravity center of the module respectively.

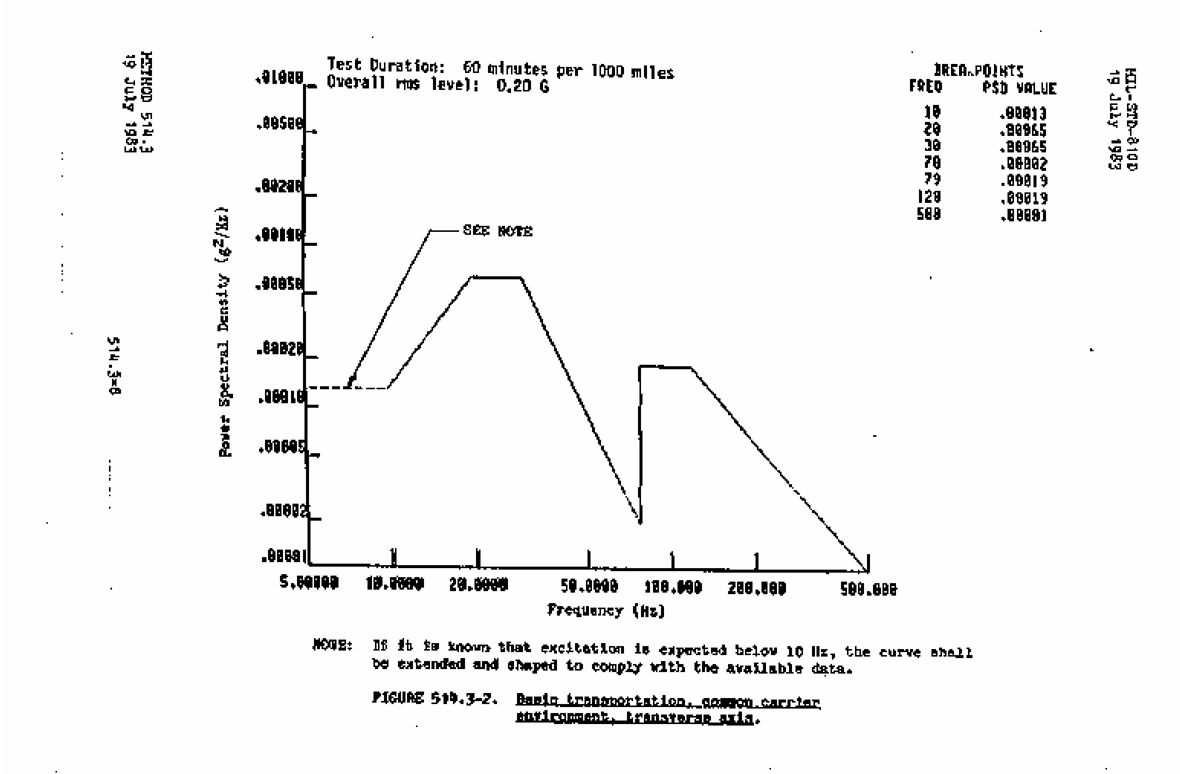

Figure 4 Vibration profile of the **basic transportation common carrier environment** for the shaking table laboratory Qualification test

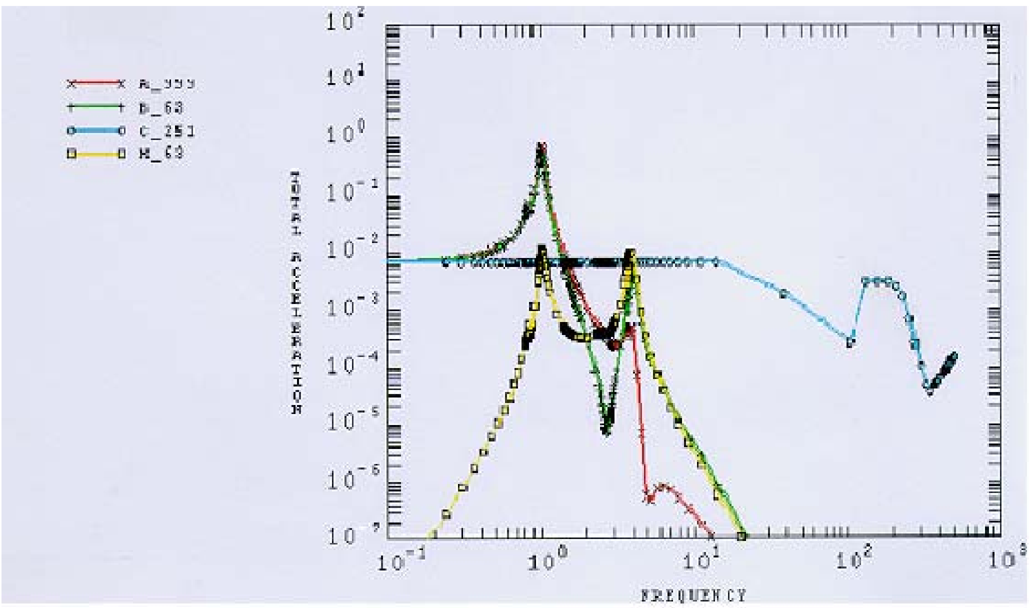

Figure 5 PSD value at the points 63, 251 and 999.

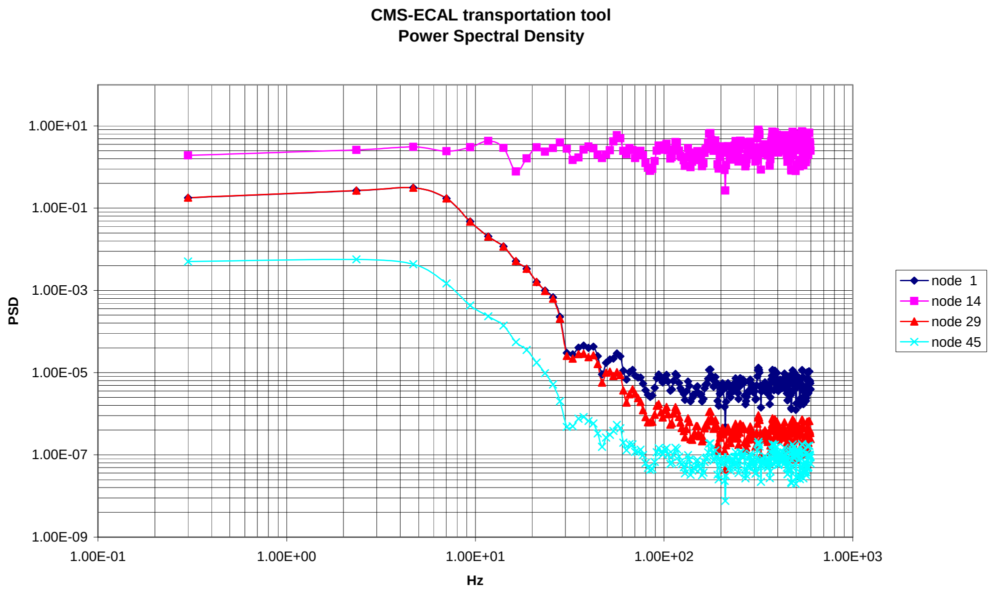

Figure 6 Power Spectral density at node N° 1, 14, 29, 45

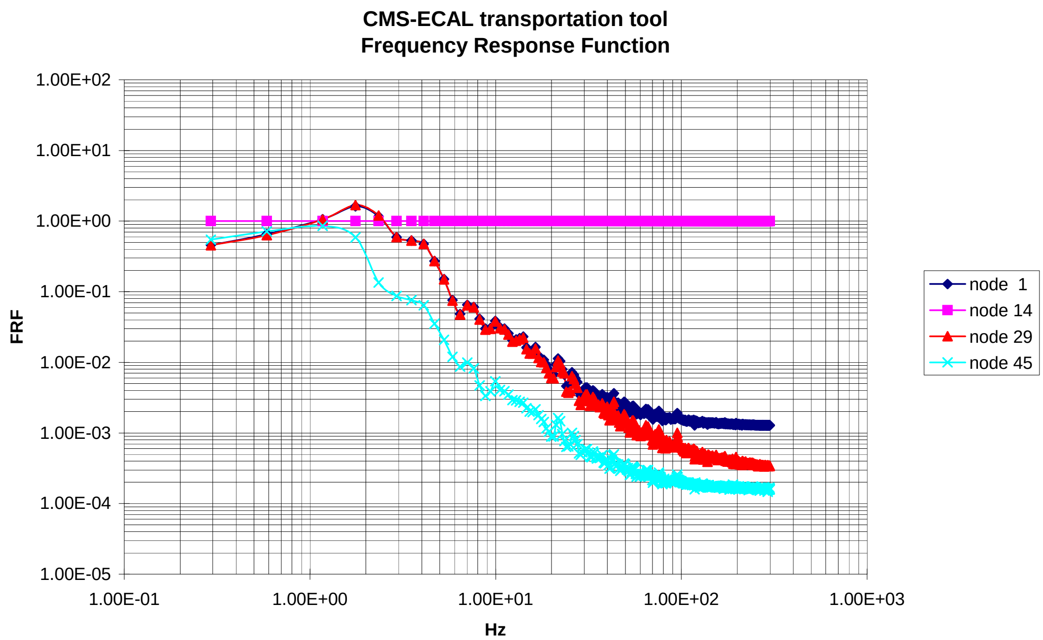

Figure 7 Frequency response Functions of node 1, 29, 45
Reference node N°14

The max vertical and lateral displacements of the air-springs when an acceleration of –0.2g is applied, corresponding to a velocity decrement Δ V=72 Km/h in a range of 100m for 10 sec. are shown in the table N 2.

Inflating pressure psi	max Air Springs displacements:
60 psi	-62 +69 mm
82 psi	-48 +48 mm

The max Air spring displacement available is –75 +78 mm.

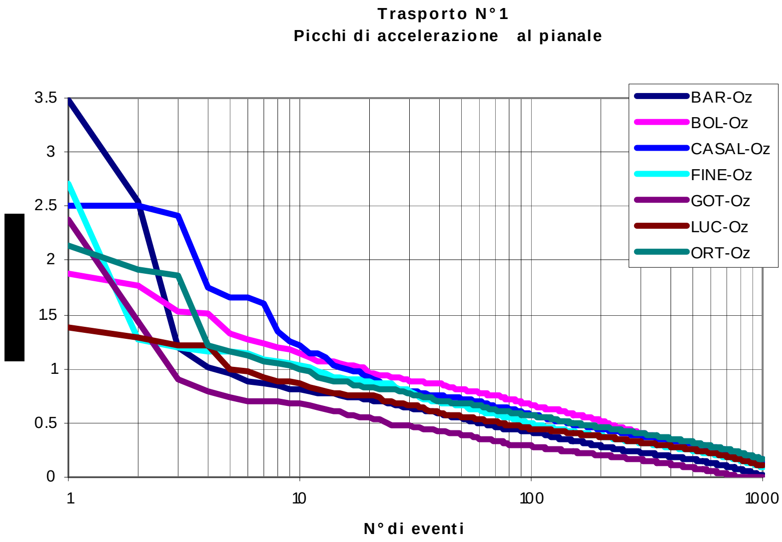

Figure 8 Acceleration Peaks measured at the base of the truck during the transportation from Rome to Geneva

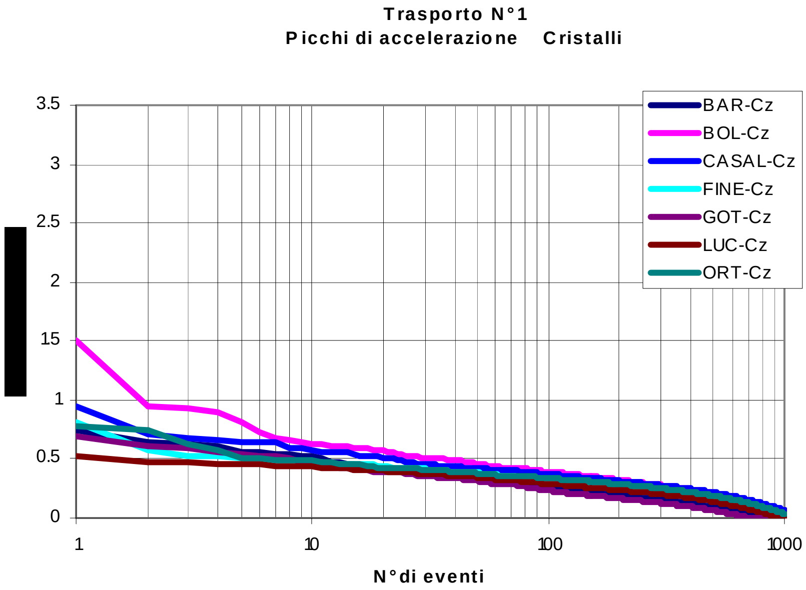

Figure 9 Acceleration Peaks transmitted to the crystals during the transportation from Rome to Geneva

CONCLUSIONS

Once assembled at the Regional Center located at the ENEA CR Casaccia of Rome (Italy), the modules containing the sub modules and crystals must be delivered to the CERN at Geneva (CH).
The proposed tool should be used both during the moving of the module inside the Regional Center and for the truck transportation to the CERN. The FEA calculations results are synthesized with the Isolation Rate index. The transmission rate between several points of the system and the input excitation shows a value of the isolation rate at the lower corner of the module > 0.95 for frequencies above 1.7 Hz. This means that the tool satisfies the conditions of isolation and protection of the module and crystals from vibrations.

References

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