DEVELOPMENT OF A SUSPENSION SYSTEM FOR THE ROAD TRANS-POSRTATION OF CRYOMODULE SSR1 THORUGH A MULTILEVEL FINITE ELEMENT-MULTIBODY APPROACH

P. Neri, F. Bucchi - *Department of Civil and Industrial Engineering, University of Pisa, Pisa, Italy*
D. Passarelli - *Fermilab, Batavia, IL, USA*

UNIVERSITY OF PISA

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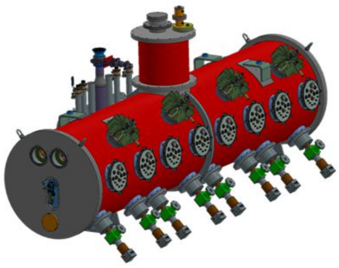
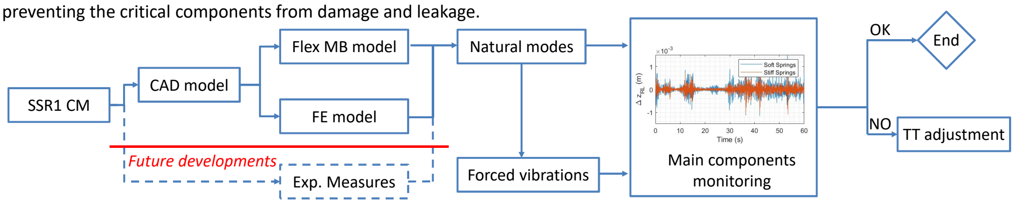
Introduction



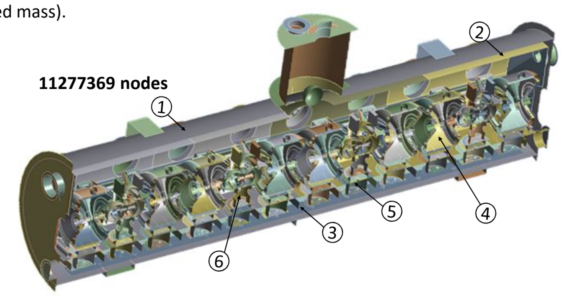
Fermilab

The activity was performed in the framework of PIP-II project at Fermilab jointly by University of Pisa and Fermilab engineering teams. The goal of the activity was to develop a multilevel simulation tool aimed to characterize the vibration behavior of the prototype SSR1 Cryomodule (CM), in the frequency range of interest for road transportation.
These tools can be used to design the Transportation Tooling (TT) needed to filter loads coming from the ground (roads), preventing the critical components from damage and leakage.

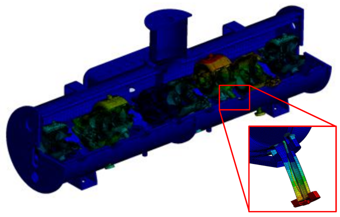


Finite Element Modal model (FEM)

Finite element method was used to develop the modal model. External vessel (1), thermal shield (2), strong back (3), cavities (4), support posts (5) and solenoids (6) were included. The structural components were implemented by meshing the previously cleaned CAD geometries using shell elements. Node merging and fixed joints were used, to completely avoid contact regions. Total mass: 6200 kg (75% of the total estimated mass).

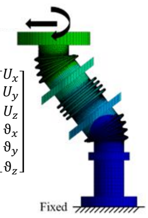


Natural modes



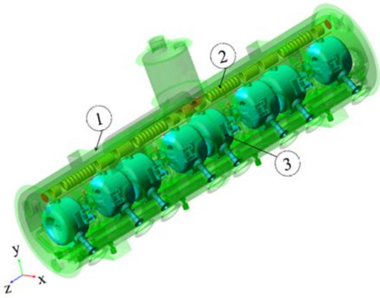
Lumped stiffness matrixes

$$\begin{bmatrix} F_x \\ F_y \\ F_z \\ M_x \\ M_y \\ M_z \end{bmatrix} = \begin{bmatrix} & \cdots & \\ \vdots & K & \vdots \\ & \cdots & \end{bmatrix} \begin{bmatrix} U_x \\ U_y \\ U_z \\ \vartheta_x \\ \vartheta_y \\ \vartheta_z \end{bmatrix}$$



Semi-flexible MultiBody model (SMB)

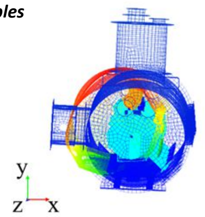
A multilevel approach was used to develop the multibody model. The inertia properties of the most rigid parts were imported from CAD as rigid bodies and the flexible parts were identified and imported as lumped or continuous elements.



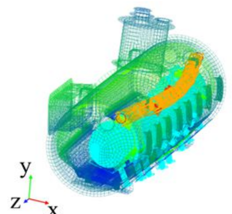
1. Vessel, thermal shield, strong back, support posts, solenoids imported from FE software (Craig-Bampton modal reduction).
2. Two-phase pipe modelled splitting the pipe in several beam elements (Timoshenko beam theory).
3. Cavities imported as rigid bodies, considering their actual mass and inertia properties.
4. Bellows, not represented, modelled as lumped stiffness (equivalent stiffness matrix derived from FE).

Natural modes – *Some examples*

Mode no.	f_{CM}^{MB} (Hz)
1	9.6
2	15.2
3	17.9
4	21.6
5	23.1
…	…

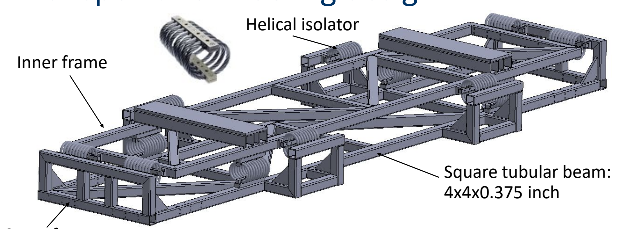


1st mode: thermal shield oscillation



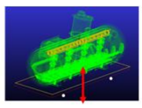
2nd mode: cavities and two-phase pipe bending

Transportation Tooling design

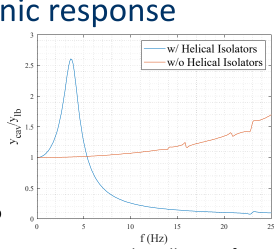


Adjustable to hold different cryomodules

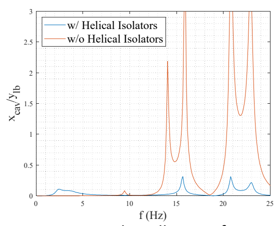
Harmonic response



Vertical unitary oscillating input to the loading bed



Vertical oscillation of the central cavity



Lateral oscillation of the central cavity

Road loading simulation

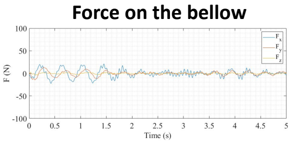
Truck loading bed displacement imported from data recorded during the transportation of a similar CM.
Forces acting on each component were recorded with a particular attention to the **forces acting on the bellows**.

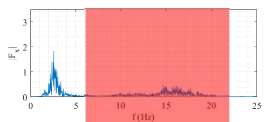
Natural modes of the transportation tool.

no.	*f* (Hz)
1	1.9
2	3.0
3	3.3
4	4.1
5	4.5
6	5.3

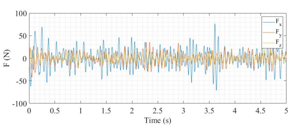
Force on the bellow

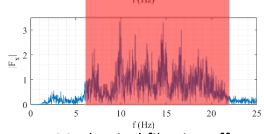
With Helical Isolators





Without Helical Isolators





Mechanical filtering effect

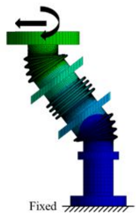
Components verification

From Ansys model, constant in time

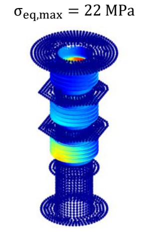
From Adams model, time dependent

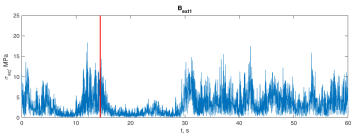
$$\begin{bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \sigma_{zz} \\ \tau_{xy} \\ \tau_{yz} \\ \tau_{xz} \end{bmatrix} = \begin{bmatrix} & \cdots & \\ \vdots & \bar{K} & \vdots \\ & \cdots & \end{bmatrix} \begin{bmatrix} U_x \\ U_y \\ U_z \\ \vartheta_x \\ \vartheta_y \\ \vartheta_z \end{bmatrix}$$

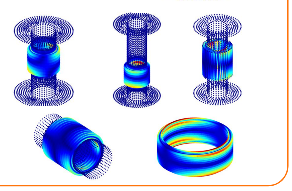
$\sigma_{eq}(t)$ → Analysis along time history



$\sigma_{eq,max} = 22$ MPa







Contact: paolo.neri@dici.unipi.it