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Vibration analysis of a fully- and partially-filled container – Application to cryogenic tank characterization and dynamic behavior

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Abstract:

1. Introduction

The discussed work focuses on the experimental set-up, acquisition and subsequent structural modal analysis of a suspended representative cryogenic tank, submitted to vibrating stimulations, with the aim of characterizing its dynamic behavior to help ease the certification process of actual tanks used in aerospace applications. The objective of the research is to obtain a modal behavior similar in term of mode shapes and natural frequencies to the behavior of a tank filled with Liquid Hydrogen.

The main postulate -and innovative approach – in this work is to consider Granular Materials as a substitute to cryogenic fluids or compressed gases, namely Liquid Hydrogen (Fig. 1).

Most of the related studies are using water as a surrogate material for fuel or gas tank testing [1-5]. None were found to focus and use Granular Material as a substitute to achieve the same goal, except from Chiambaretto et al. [6] and Nguyen et al. [7,8]. The goal of the present study, directly following these preliminary works, is to explore further possibilities in terms of material substitution and system fixations, as well as filling rate influence and change of excitation modes.

2. Results and Discussion

Experimental set-up: In the current set-up, the cylindrical tank is vertically suspended and isolated, whereas it was vertically standing on its base on the previous work, directly in contact and bounded to the shaking equipment. Investigations are carried out on empty, then fully, and partially filled tanks subjected to vibration, using an impact hammer then a vibrating shaker as testing device. The natural frequency reflecting the dynamic behavior of the system for each vibration mode is measured for the different configurations. Frequency Response Functions are used to represent modal deformations.

Preliminary results: Previous works [6-8] were conducted using only one Granular Material type. Results showed the evolution of each flexural mode as a function of the applied pre-stress. In the current testing, prominent frequencies for the modal deformed shapes are occurring as follow, 55 Hz, 75/80 Hz, 555 Hz, 1035 Hz, 1333 Hz, 1520 Hz, and 2045 Hz on an empty suspended aluminum tank, with the associated shapes of flexion, flexion-torsion, ovalization, trefoil, quadrifoil, then combined and lobed modes, respectively. Observations and analysis from preliminary trials on filled tank tend to display the same deformed shapes as on empty tank, in the same order of occurrence, but at lower frequencies. First results tend to show that materials with lower mass density should be preferred in order to better reach the flexural modes, highlighting the surrogate materials density as paramount.

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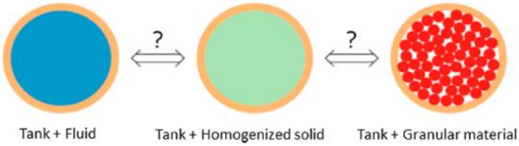

Fig. 1. Theorized equivalence between fluid-filled beam and grains-filled beam using a homogeneous fluid for granular material. (Chiambaretto et al.)[6]

Conclusions: The objective of the current experimental work is to analyze the modal behavior of a tank filled with Granular Materials, and after validating its equivalence with regular fluids, achieve comparisons based on influence of Granular Material types as well as filling rate in vibration analysis. Preliminary results tend to validate the hypothesis of material substitution. The first few modal deformed shapes are correctly observed. The main parameter of influence seems to be the density.

3. Concluding Remarks

The presented work is dealing with the vibration analysis and dynamic characterization behavior of a modelled cryogenic tank system, which is an important thematic in energy propulsion and aerospace engineering. The major objective is to highlight then evaluate the influence of the different parameters, namely Granular Material types, filling rates, excitation mode, and boundary conditions. Results will help validate the new methodology and comfort the hypothesis of material substitution.

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