Multibody system approach for vibration optimization of vibrating floor in emptying silos process

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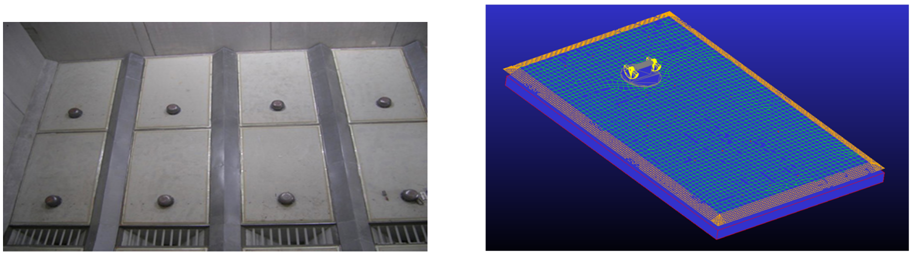
Abstract

Emptying of granular storage systems is a long and delicate operation involving most of the time human intervention. An innovative automated drain system have been developed, which is based on the agitation of the container using vibrating floors [1]. The vibrating system consists of rectangular modules used with unbalanced mass motors. These modules are assembled and set up on the bottom of silos and tanks and allow the flow and complete evacuation of granular material without human intervention (Figure 1a). The destabilization and the collapse of the granular media are caused by the creation of a transverse wave. The vibrations are generated by the unbalance of a motor and then transferred to the floor. In order to optimize system performance it is necessary to adapt the rotational speed of the motor to the dynamic behavior of the system.
The standard module have been improved by learning from experience until now. But the development of usage types and the need to adapt to any kind of storage systems requires the development of a numerical model to finely characterize the dynamic behavior of the system. In order to achieve this purpose, the system can be considered as a multibody system with both rigid and flexible parts which interact with each other [2].



(a) Tank fitted with vibrating floor (b) 3D model

Figure 1: Presentation of the studied system.

The simulation is performed using a model based on rigid-flexible coupling dynamics simulation using Adams (multibody dynamics software)and Ansys (finite element analysis software) (Figure 1b). The use of rigid-flexible simulation allows focusing on the flexible part behaviors and reduce the complexity of the problem to solve. Modal analysis of flexible multibody systems is widely used by now to prevent undesired motions [3]. In the presented study the problem is reversed. To ensure granular collapse, vibration amplitude of the vibrating floor have to be maximized. Therefore, the first step deals with the system modes shape characterization and their associated natural frequency.
Working with flexible bodies needs to perform a preliminary step of modal reduction using the Craig-Brampton method. This step is performed using the FEA software Ansys.

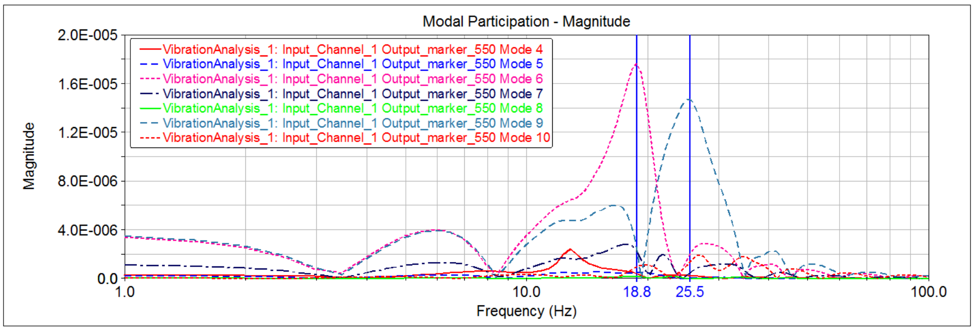
$$\mathbf{u} = \sum_{k=1}^{N} \Phi_k q_k \tag{1}$$

Where $\mathbf{u}$ is the displacement, $\Phi = [\Phi_1 \Phi_2 \ldots \Phi_N]$ is the matrix of modal vector, q_k are modal coordinates.

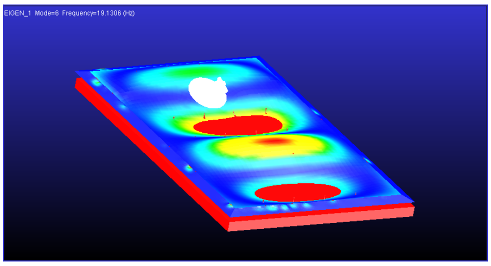
According to the Lagrange equations with multipliers and the floating frame of reference method [2], the governing differential equation of flexible body, in terms of the generalized coordinates is :

$$\mathbf{M}\ddot{\xi}+\dot{\mathbf{M}}\dot{\xi}-\frac{1}{2}\left[\frac{\partial \mathbf{M}}{\partial \xi}\dot{\xi}\right]\dot{\xi}+\mathbf{K}\xi+\mathbf{f}_g+\mathbf{D}\dot{\xi}+\left[\frac{\partial \Psi}{\partial \xi}\right]^T\lambda=\mathbf{Q} \tag{2}$$

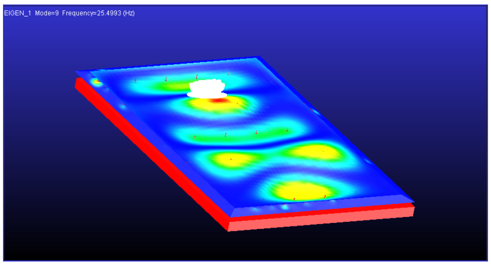
Where $\xi, \dot{\xi}, \ddot{\xi}$ are the generalized coordinates of the flexible body and their time derivatives, with $\xi = \begin{pmatrix} \mathbf{x} & \Theta & \mathbf{q} \end{pmatrix}^T$ with $\mathbf{x}$ the displacement coordinates and Θ the rotational coordinantes. $\mathbf{M}, \mathbf{K}, \mathbf{D}$ are respectively the mass matrix, the generalized stiffness matrix and the damping matrix, Ψ is the algebraic constraint matrix and λ is the Lagrange multipliers for the constraints. $\mathbf{f}_g$ is the generalized gravitational force and $\mathbf{Q}$ is the applied forces which depend on the force induced by the interaction with the unbalanced motor.
In order to characterize the dynamic behavior of the system depending on the rotational speed of the unbalanced engine in the frequency domain, the rotational speed ω is set as variable parameter. According to the curves of the modal participation (Figure 2a) to a specific chosen point, it is possible to define optimized frequencies and the associated modal shapes (Figure 2b & 2c).



(a) Modal Participation



(b) Modal shape n°6



(c) Modal shape n°9

Figure 2: Modal study of the system

To conclude, the approach presented here allows to optimize the performance of a flexible drain system by frequency domain study. By setting the rotational motor speed, it is then possible to study the dynamic behavior of the system in time domain to estimate the displacement field of the flexible parts over a drain cycle.

References

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