MINIMIZATION OF STRUCTURE-BORNE NOISE IN LIGHTWEIGHT BUILDINGS

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Summary This paper deals with the problem of minimizing the structure-borne noise induced in a room by machinery vibration. A generalized system consisting of the machine, the base plate, resilient mounts, the floor plate and the room cavity is developed for analysis and optimization. Topological design of the base plate is studied for optimizing machinery installation. Furthermore, periodic mounts are optimized for the noise reduction. Finally, a modular model of a lightweight building is developed for design optimization of dimensions and connections of modules in the building for decreasing machinery vibration transmission.

INTRODUCTION

Machinery vibrations are transmitted as structure-borne sound through the building, from which undesirable noise is radiated. The undesirable vibration and noise emission bring unsatisfactory comfort conditions for the people in dwellings and offices of the building. In the present study, the machinery is to be installed on a relatively flexible floor of the storey in a lightweight building, thus traditional installation design of machinery in concrete buildings may not be appropriate [1]. There is a need to analyze and optimize the structural-acoustic coupled system of the machine, the base plate, resilient mounts, the floor plate and the room cavity, and finally the entire building for minimizing the vibration transmission and noise emission. In this work, firstly, an optimum base plate is presented for the flexible installation of machinery. Then, the design optimization of resilient mounts of machinery installed on a module of the building is studied for noise reduction. Finally, dimensions and connections of a modular parameterized building are optimized for the reduction of machinery vibration transmission while the machinery is installed on some storey of the building.

PROBLEM DEFINITION AND OPTIMIZATION RESULTS

Topology optimization of the base plate of rotating machinery

Relatively large machinery including a motor and a pump is normally mounted on a foundation, which is usually designed as a base plate for the machinery with some resilient mounts fixed to the bottom of the base plate and supported by the floor of the storey, as shown in Fig.1. Due to variable service speed and the existence of unbalanced masses, the rotating machinery may be considered a source that within a given range of excitation frequencies excites forced vibration of the foundation, and thereby the floors and walls, etc.

Firstly, topology optimization of a flexibly supported base plate is studied for minimizing the vibration of machinery installation system. A bi-thickness interpolation model is adopted for the optimization problem. In this model, the same material is used for the whole plate structure, but at each point of the plate one of two different thicknesses is to be chosen by optimization. The base plate to be optimized is resiliently supported by spring-like mounts. The machinery is rigidly connected on the top of the base plate, and is modelled as a rigid body. The coupling of a rigid and a flexible body is considered in the analysis and optimization. Several design examples with various stiffness values of springs and different excitation frequencies are considered in order to identify optimum topologies of the base plate.

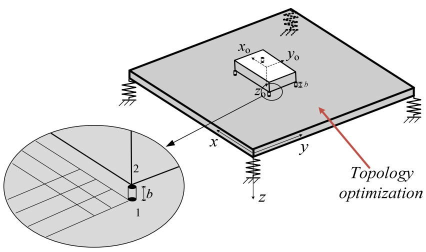
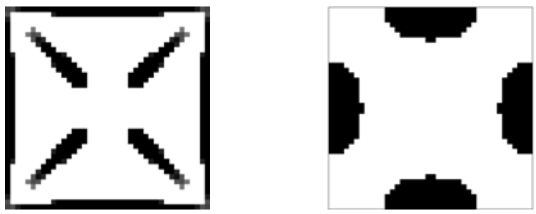


Fig. 1 Topological design of a flexibly supported base plate with an unbalanced rotating machine



(a) f=10 (b) f=50

Fig. 2 Optimized topologies of the resiliently supported quadratic bi-thickness plate-like structure with a machine above and medium-stiffness springs below for minimizing the dynamic compliance at the excitation frequency f = 10 and 50 Hz, respectively. Black and white indicate domains with the larger and smaller plate thickness, respectively.

Optimum design of periodic resilient mounts of machinery installation

Next, design optimization of periodic shear mount [2] is studied for the reduction of transmitted noise in a light-weight building. A generalized modelling of the system consisting of the machine, the base plate, resilient mounts, the floor plate and the room cavity is built using the impedance and mobility representations. The system is sequentially solved

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by separating it into two sub-systems. The first sub-system includes the machine, the base plate, resilient mounts and the floor. The second sub-system consists of the floor and a room cavity. In the second sub-system, weak coupling is assumed between the floor and the cavity since the mechanical impedance of the air inside the room cavity is much smaller than the mechanical impedance of the floor. In order to consider different installation conditions, velocity sources are adopted for the modelling of machinery. The velocities $\mathbf{V}^f$ at the mounting junctions can be determined under free boundary conditions. The transmitted force on the floor plate is solved as

$$\mathbf{F}^R = \left(\mathbf{Y}^S\mathbf{T}^{11} + \mathbf{Y}^S\mathbf{T}^{12}\mathbf{Y}^R + \mathbf{T}^{21} + \mathbf{T}^{22}\mathbf{Y}^R\right)^{-1}\mathbf{V}^f, \tag{1}$$

where $\mathbf{Y}^S$ and $\mathbf{Y}^R$ denote the mobility matrices of the machine and the building floor, and $\mathbf{T}^{11}$, $\mathbf{T}^{12}$, $\mathbf{T}^{21}$, and $\mathbf{T}^{22}$ represent the terms of the transmission matrix of the resilient mounts.

The coupled responses can be described by finite sets of uncoupled acoustic and structural modes [3]. The uncoupled modes are the rigid-walled acoustic modes of the cavity and the *in vacuo* structural modes of the structure. The acoustic pressure p is solved from the structural excitation as

$$p = \mathbf{\Psi}^{\mathrm{T}}\mathbf{Z}^a\mathbf{C}\mathbf{Y}^r\mathbf{f}^r, \tag{2}$$

where $\mathbf{\Psi}^{\mathrm{T}}$ is the transpose of the uncoupled acoustic mode shape function matrix $\mathbf{\Psi}$, $\mathbf{Z}^a$ the uncoupled acoustic modal impedance matrix, $\mathbf{C}$ the structural-acoustic mode shape coupling matrix, $\mathbf{Y}^r$ the uncoupled structural modal mobility matrix, and $\mathbf{f}^r$ is the generalized modal force computed from the transmitted force $\mathbf{F}^R$ in Eq. (1).

The problem of design optimization of the periodic resilient mounts with the objective of minimizing the acoustic pressure in the room cavity excited by the machine can be formulated as

$$\begin{aligned} &\min_{\mu_j} \ p \\ &\text{s.t. given constraints,} \\ &\quad \mu_{\min} \le \mu_j \le \mu_{\max},\ j = 1, \dots, n^{dv}. \end{aligned} \tag{3}$$

The present work aims to realize this objective by optimizing the component sizes μ_j of a periodic unit cell of the periodic resilient mounts in a given range between $\mu_{\min}$ and $\mu_{\max}$.

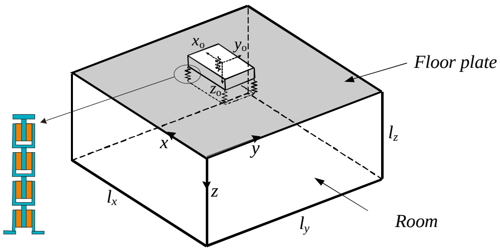

Fig. 3 A simply supported floor plate connected with an acoustic cavity

Design optimization of a modular lightweight building model

Following the studies regarding one module of a building in the previous section, a generalized and parameterized modular model of a lightweight building will be developed. The entire building is constructed through several basic modular elements like room module, corridor module, etc. The parameterization of the important dimensions and partition numbers in the modular building model facilitates the design and optimization of these parameters for reduction of sound and vibration transmission from the mechanical excitation to certain rooms. The influence of different excitation frequencies and locations of excitation on the vibration transmission and noise radiation will be studied and discussed.

CONCLUSIONS

The problem of design optimization of the machinery mounting system in a lightweight building is studied in this paper. Design optimization is extremely useful for the best possible selection of vibration and noise isolator components.

Acknowledgement

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