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Topology optimization of an electronics cover plate with respect to eigenfrequencies

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Summary

In the present paper it is illustrated how topology optimization with respect to eigenfrequency can be applied effectively in the product development process. The topology optimization code is implemented in ANSYS by a so called UPF. The maximization of eigenfrequency as objective is invoked into the existing code. As an example is chosen an electronics cover plate. The resulting design devised by the topology optimization yield a significant higher eigenfrequency than obtained by traditional design methods and experience.

Introduction

The aim of this paper is to describe the implementation of a dynamical optimization criterion in an existing topology optimization code developed by Grundfos [3]. The topology optimization in the existing code is based on findings by Bendsøe [1] and Sigmund [2].

In order to perform topology optimization maximizing the eigenfrequencies it is necessary to reformulate the optimization problem and the sensitivities, i.e. the stiffness and the mass matrix need to be described in terms of the density.

When the stiffnessmatrix $\mathbf{K}_{\mathrm{global}}$ and the massmatrix $\mathbf{M}_{\mathrm{global}}$ is known, the equations of motion for the domain can be determined. Omitting dampning and external forces then

$$\mathbf{M}_{\mathrm{global}}(\boldsymbol{\rho})\cdot\ddot{\mathbf{x}}+\mathbf{K}_{\mathrm{global}}(\boldsymbol{\rho})\cdot\mathbf{x}=\mathbf{0} \tag{1}$$

where $\boldsymbol{\rho}$ is the design variables (densities), $\mathbf{x}$ and $\ddot{\mathbf{x}}$ is the nodal deformations and accelerations respectively.

In the developed ANSYS UPF code [3] the stiffness- and mass matrix is unavailable directly from the database [5], i.e. it is necessary to compute the sensitivities from the strain energy, i.e.

$$\frac{\partial\omega_1^2}{\partial\rho_e}=\frac{1}{\rho_e}\cdot\underbrace{\mathbf{u}_e^T\mathbf{K}_e\mathbf{u}_e}_{2\cdot strain\ energy}-\frac{1}{\rho_e}\cdot\underbrace{\omega_1^2\mathbf{u}_e^T\mathbf{M}_e\mathbf{u}_e}_{2\cdot kinetic\ energy} \tag{2}$$

where ρ_e is the element density, ω_1 is the first eigenfrequency, $\mathbf{u}_e$ is the local element deformations, $\mathbf{K}_e$ is the element stiffness matrix, and $\mathbf{M}_e$ is the element mass matrix.

Both the strain energy and the kinetic energy are stored for each element in the ANSYS database [5] and are available to the UPF code.

Furthermore a penalty function applying SINH [4] is adapted which can handle both mass and stiffness. Both penalty functions in the SINH-model is based on hyperbolic sinusoidal functions [4]. The penalization of the stiffness is given as

$$E_e = \frac{\sinh(P_k \cdot \rho_e)}{\sinh(P_k)} \cdot E \tag{3}$$

where P_k is the variable stiffness penalization factor similar to the penalization power in the SIMP algorithm.

The penalization of the mass is given as

$$\rho_{mass,e} = \left(1 - \frac{\sinh(P_m \cdot (1-\rho_e))}{\sinh(P_m)}\right) \cdot \rho_{mass} \tag{4}$$

where P_m is the variable mass penalization factor. By differentiation and substituting the element sensitivies emplying SINH is given as:

$$\begin{aligned}\frac{\partial \omega_1^2}{\partial \rho_e} = {} & \frac{P_k \cdot e^{-P_k \cdot \rho_e}\left(e^{2 \cdot P_k \cdot \rho_e} + 1\right)}{2 \cdot \sinh(P_k)} \cdot \mathbf{u}_e^T \mathbf{K}_{Q4} \mathbf{u}_e \\ & - \frac{P_m \cdot e^{-P_m \cdot \rho_e}\left(e^{2 \cdot P_m \cdot \rho_e} + e^{2 \cdot P_m}\right)}{e^{2 \cdot P_m} - 1} \cdot \omega_1^2 \mathbf{u}_e^T \mathbf{M}_{Q4} \mathbf{u}_e\end{aligned} \tag{5}$$

where $\mathbf{K}_{Q4}$ is the element stiffness matrix for the used Q4 ANSYS element, and $\mathbf{M}_{Q4}$ is the element mass matrix for the used Q4 ANSYS element.

Applying SINH, the optimization problem can be stated as a maximization of the first eigenfrequency, i.e.

$$\begin{aligned} \max_{\boldsymbol{\rho}} \ : \quad & \mathrm{obj}(\boldsymbol{\rho}) = \omega_1^2 \\ \text{s.t.} \ : \quad & V(\boldsymbol{\rho}) - V_0 = 0 \\ & \left(\mathbf{K}_{global} - \omega_1^2 \cdot \mathbf{M}_{global}\right) \cdot \mathbf{U}_1 = \mathbf{0} \\ & 0 < \rho_{min} < \rho_e < 1 \qquad \text{where } \rho_{min} = 0{,}001 \end{aligned} \tag{6}$$

where V_0 is the volume of the admissible design domain.

In order to apply the same OCM algorithm for both static and dynamic cases, the sign of the sensitivities is changed for the dynamic case, i.e.

$$\frac{\partial \omega_1^2}{\partial \rho_e} = -\mathbf{u}_e^T \frac{\partial \mathbf{K}_e}{\partial \rho_e} \mathbf{u}_e + \omega_1^2 \cdot \mathbf{u}_e^T \frac{\partial \mathbf{M}_e}{\partial \rho_e} \mathbf{u}_e \tag{7}$$

Since both a positive and a negative term is present in Eq. 1.5 the sensitivities can be positive and negative the OCM algorithm has been modifed.

As an example it is chosen to consider a cover plate for electronics as shown in Figure 1. The first eigenfrequency of the cover plate has been determined to be 1162 Hz, which should be increased to 1600 Hz or more as a design criterion.

Figure 1: Cover plate from the outside (left) and from the inside (right).

A number of analyses are performed with varying boundary conditions see Figure 2 and geometrical restrictions on the design domain, and the same amount of material available as in a manually optimized design.

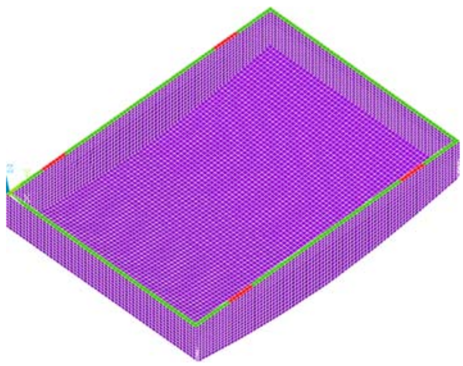

Figure 2: Boundary conditions for the design domain, fixed in bolts (marked by red), and the edge simple supported in the x- and y-direction (marked by green).

For a design domain with no geometrical restrictions the first eigenfrequency of the topology optimized design is equal to 2540 Hz. However, the obtained design is inadmissible due to manufacturing limitations. These manufacturing limitations are introduced in the optimization algorithm be a scheme allowing only designs which can be applied in relation to injection moulding or casting.

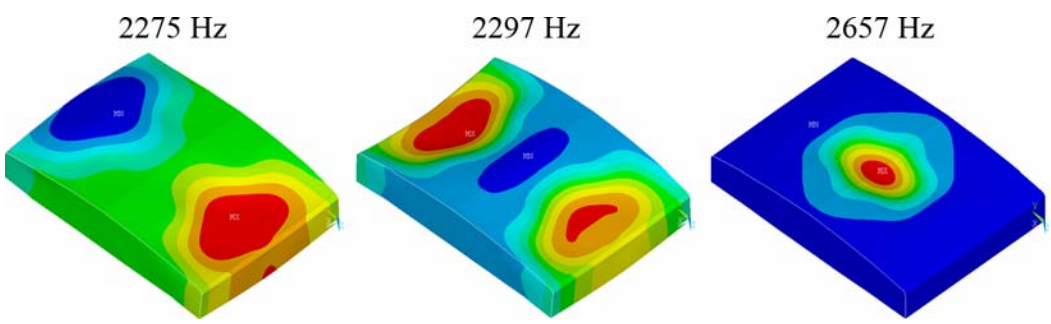

Figure 3: The first 3 modes for the resulting geometry for the free design domain with manufacturing restrictions.

Applying this scheme the eigenfrequency of the optimized design, as shown in Figure 3, becomes 2275 Hz and the resulting geometry is admissible for manufacturing.

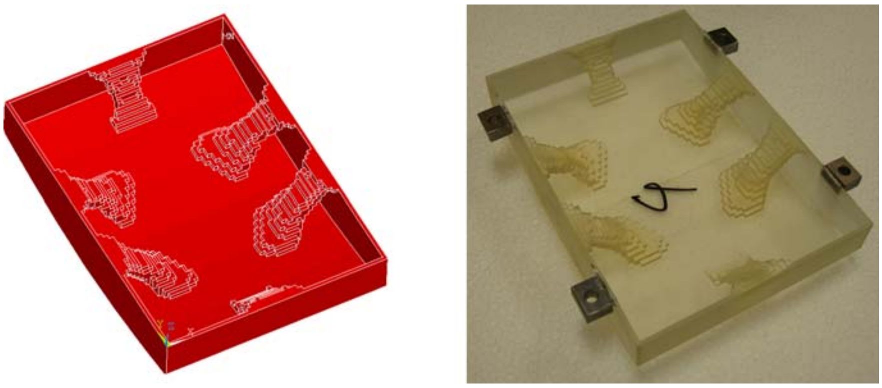

Figure 4: Illustration of the test design and the associated SLA model.

A SLA prototype model, as shown in figure 4, of the resulting optimized design has been created. This SLA model has been used to perform verification tests. The difference found between test results and numerical results is 2%.

Concluding remarks

The topology optimization code developed by Grundfos has been modified to include maximization of eigenfrequencies and the effect of this has been demonstrated with a case study of a cover plate for electronics. The eigenfrequency has been increased by 32.5% to 2275 Hz compared to the manually optimized design, i.e. the eigenfrequency obtained by manual optimization is 1717 Hz. This improvement has been validated with tests on downscaled SLA models of the optimized design.

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