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Optimisation potentials of laminated composites using semi-analytical vibro-acoustic models

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Abstract: Light and stiff composites such as fibre-reinforced plastics are sensitive to propagate structure borne sound but simultaneously offer a wide range of adjusting the material behaviour. Thereby, stiffness and damping of such composites are contradictory material properties related to the fibre orientation. Commonly, the composite design is based on FEA simulations requiring special modelling efforts. In contrast, the multi-dimensional optimisation of a laminate with numerous layers of different materials and orientations requires very fast numerical solutions for numerous repetitions.

Using a complex but efficient vibro-acoustic simulation model is essential in optimising composites. Here, the FEA is extended by a strain energy based modal damping approach for the layerwise accumulation of the anisotropic damping. In addition, the radiated sound power is determined by a velocity-based approach directly on steady state structural simulations avoiding a complex multi-physical modelling. Moreover, the frequency dependent radiation is consolidated to a single scalar optimisation objective using a fast and efficient semi-analytic approach. Therefore, analytical formulations of amplification factors of the modal power contributions are introduced.

This efficient simulation methodology is applied to design a vibro-acoustically optimised composite oil pan. The achieved results emerge the vibro-acoustic optimisation potential of thermoplastic composites with various fibre and matrix materials compared to a steel reference case. Furthermore, the layup is a complex multi-dimensional optimisation problem with an additional potential of improving the NVH performance. In summary, the potential for optimisation of the different steps is compared.

Keywords: sound radiation, finite element analysis, optimisation, fibre-reinforced composites

1. Amplification factors of modal sound power contributions

The radiated sound power of vibrating surfaces is an important objective for acoustic optimisation procedures. Apart from multi-physical models, simplified FEA-based approaches of the sound pressure such as the equivalent radiated sound power, the lumped parameter model or the volume velocity in combination [1] with a scalar measure representing the entire frequency domain [2] are helpful but still cause significant computational costs.

Thus, the amplification factors of the radiated sound power approaches are presented as an analytical formulation of a single mode (Fig. 1). Evaluating only a single resonant frequency step per mode, the modal contributions within the entire frequency range then are analytically determined. Superpositioning all modal contributions then results in the total sound power.

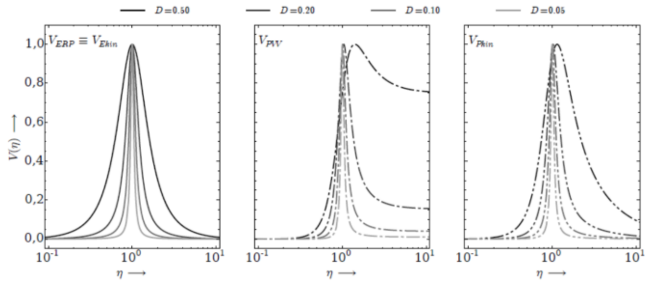

Fig. 1. Modal amplification factors of different velocity based sound power approaches with different viscous damping

2. Optimisation problem and results

The new semi-analytical approach has been applied to the sound power determination of a composite oil pan. Thus, it is now possible to solve this multi-physical problem in huge parametric studies and complex optimisation algorithms.

Therewith, a layup with two independent fibre orientations is acoustically optimised. Due to anisotropic stiffness and damping, each mode is varying in frequency, half-power band width and maximal sound power (Fig. 2). Moreover, the number of modes within a fixed frequency range is changing. The parametric study shows the jumping objective and several local mimima. Furthermore, particle swarm optimisation is used for the efficient solution up to four independent parameters.

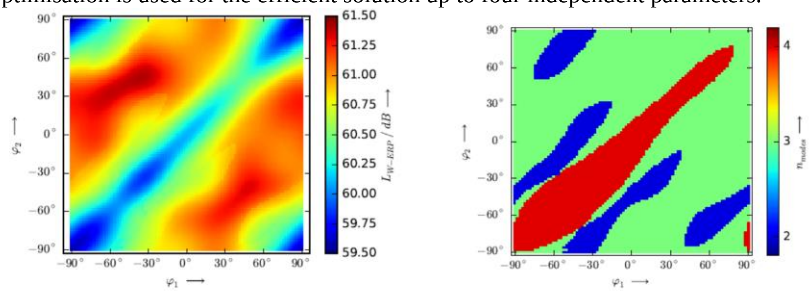

Fig. 2. Optimisation of a composite with two independent fibre orientations: radiated sound power level (left) and number of contributing modes within the frequency range (right)

3. Concluding Remarks

With the semi-analytical modelling, a very fast solution of a single simulation run and thus a complex acoustical optimisation is possible. As a result, the oil pan shows significant optimisation potential. First, a material substitution can reduce the radiated sound power level up to 7 dB. In more detail, the optimisation of the layup reduces the radiation even 2 dB more. The used of particle swarm optimisation therein is more efficient and precise than a full parameter study.

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