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Influences on structural intensity for injection moulded thermoplastic parts

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ABSTRACT

In product development such as electro-mobility engineers have to place special emphasis on Noise Vibration Harshness (NVH). A very large number of automotive interior components consist of injection moulded thermoplastic parts. If required, these lightweight components are reinforced with fibres or fillings. This reinforcement leads to a higher vibration sensitivity and higher natural frequencies. In order to influence the acoustic behaviour in early development stages, the structure-borne sound - including its source and propagation paths - has to be analysed. A suitable tool to visualise these elements is the structural intensity. In addition, the anisotropic material behaviour of reinforced thermoplastics offers the possibility to conduct the structure-borne sound. In this paper a method is presented to examine the influence of fibres, fillings and geometric modifications on the structural intensity. Based on an integrative simulation method (coupling of process and structural simulation) an anisotropic, realistic material model will be generated.
Keywords: Structural intensity, reinforced thermoplastics, Simulation

1. INTRODUCTION

In the development of new products, a huge number of requirements has to be met. NVH has an important role in this topic, because interferences give the impression that a particular product has a substandard built quality. Therefore it is of special interest to predict the acoustic behaviour in early stages of the product development. A goal should be to reduce the causal structure-borne sound instead of the radiated airborne sound. Currently technology is not available to carry out such optimisation.

Automotive interior parts mostly consist of injection moulded thermoplastic parts which are reinforced by fibres or fillings. Through an internal or external excitation the components begin to vibrate and transmit these motions as structural sound. Finally the structural sound is emitted from the surfaces as airborne sound into the vehicle interior.

An important tool for the acoustic part design of automotive interior products is the structural intensity. Its calculation visualises the source as well as the propagation paths of the structure-borne sound. For a frequency-dependent analysis “f” the structural intensity “STI” is calculated as the product of the stress tensor “σ” and the complex conjugated velocity vector “v” using the following formula of Grote and Felhusen [1]:

$$STI(f) = -0.5\sigma(f) \cdot v(f) \tag{1}$$

The structural intensity can be split into an active (real part) and a reactive (imaginary part) part. Only the active part describes the amount of energy which moves through the structure [1]. The reactive part indicates the amount of energy which oscillates in the structure. In the following only the active part will be considered because of its greater interest.

2. INTEGRATIVE SIMULATION METHOD

The calculation of the structural intensity for reinforced thermoplastics takes the anisotropy from the fibre orientation as well as the viscoelastic material behaviour by the use of an integrative simulation method into account [2]. Here a process simulation will be done and the calculated fibre orientation will be assigned to a structural simulation. By taking the material data of the matrix and the filler as well as the fibre orientation into account a new material for each finite element of the structural simulation will be generated. Based on the simulation results the structural intensity will be calculated automatically using Python scripts and will be displayed in the postprocessing. The Python scripts are necessary because stress and velocity are calculated at different positions of the finite element. This leads to different numbers of stress and velocity results and therefore selected datas have to be averaged to get the same number of results for velocity and stress. The following figure illustrates the integrative simulation method.

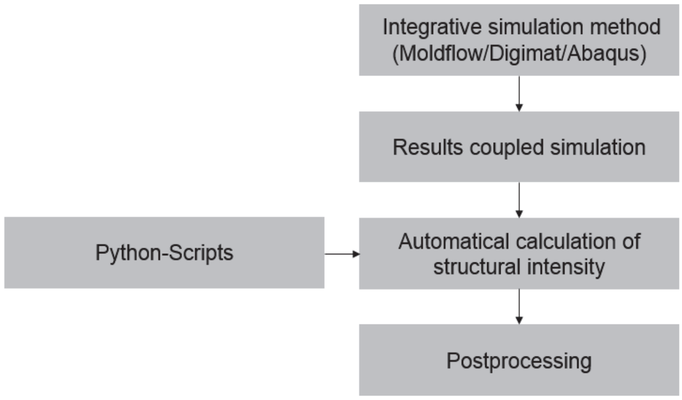

Figure 1 – Procedure integrative simulation method

3. VALIDATION OF THE SIMULATION RESULTS WITH A LINEAR ELASTIC, ISOTROPIC MATERIAL

To verify the simulation results an analytical model of the Kirchhoff plate is used [3]. Additionally a structural simulation was also performed. For this first test no integrative simulation method was used.

For the FE-model the mesh was built of linear hexahedral elements. The centroid was chosen as the position for the calculation. The material data is derived from steel with a density of 7.850 g/cm³, elastic modulus of 204.05 GPa and a Poisson's ratio of 0.28.

The plate is flexibly supported all around and an excitation of a harmonic force of 1N acting on a single point is applied in direction of the plate thickness [4]. Figure 2 includes the dimensions of the plate, the position of the harmonic force as well as the main orientation directions of the fibres from the process simulation.

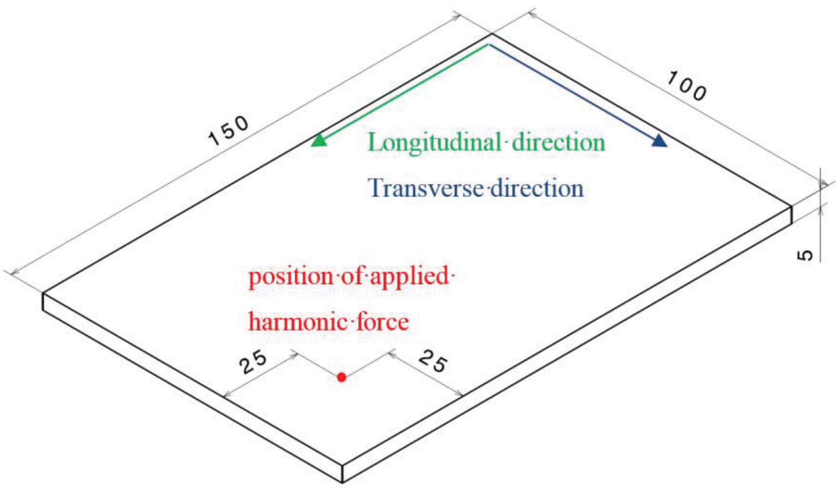

Figure 2 – Dimensions of the plate, position of the force and main fibre orientations

At the fifth natural frequency a comparison between the analytical model and the FE analysis was carried out. The desired natural frequency was 6,427 Hz in the FE analysis and 6,957 Hz in the analytical model. Thus the discernible difference is less than 10 percent. Regarding the structural intensity, quantitative differences could be recognized but the propagation paths of the structure-borne sound from the FE analysis and the analytical model match (see figure 3).

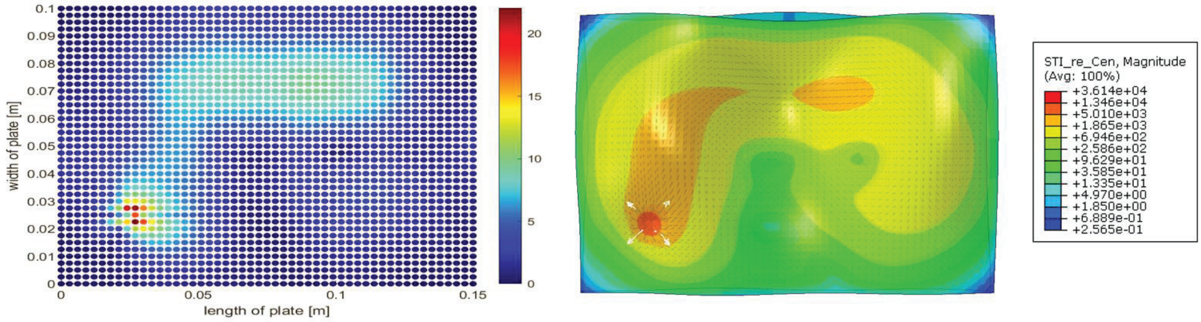

Figure 3 – Propagation paths of steel plate

In the next step the FE analysis was performed with plates made of thermoplastics. For this model the boundary conditions described in the previous section were used. The analysis is meant to show if the generated materials for the FE elements are suitable for an anisotropic structural intensity analysis. The selected materials are an unfilled polypropylene copolymer (PP-C) and a polypropylene copolymer filled with 40 percent glass fibres by weight (PP-C GF40). The orientation of the fibres was calculated through a process simulation.

As in the previous analysis for the steel plate the fifth natural frequency was analysed. The PP-C has a natural frequency of 1,547 Hz. Regarding the plate made of PP-C GF40 one has to distinguish in which direction the fibres are orientated. With a longitudinal direction the natural frequency is 2,211 Hz. A transverse direction leads to a natural frequency of 2,388 Hz.

The propagation paths of the structural intensity proceed diagonally for the unfilled polypropylene copolymer plate. The plates consisting of PP-C GF40 show different propagation paths according to the fiber orientations. This leads to a clearer difference between the filled and the unfilled PP-C for the transverse direction (see figure 4).

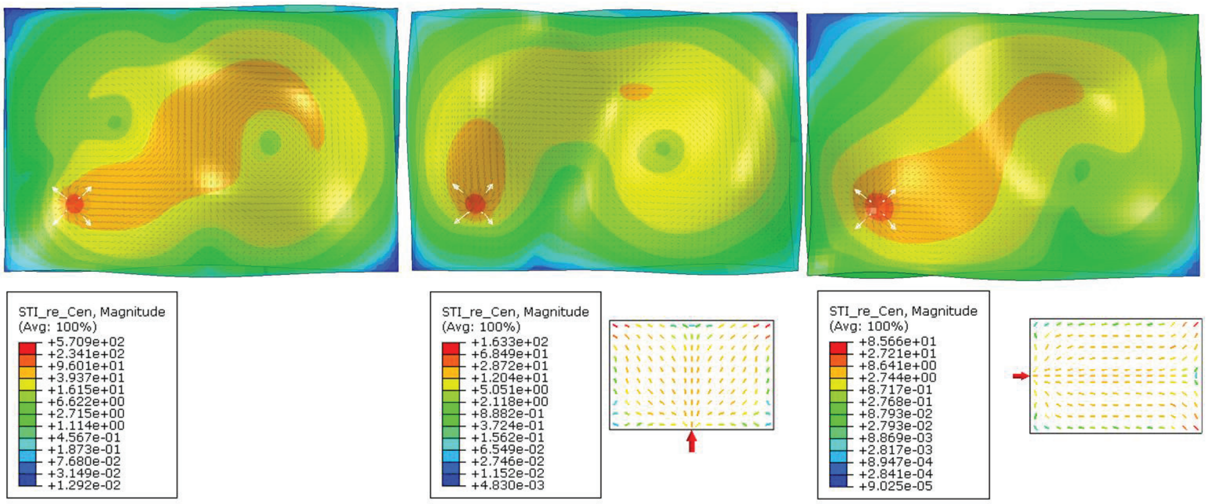

Figure 4 – Propagation paths of thermoplastic plates (PP-C, PP-C GF40 longitudinal orientation, PP-C GF40 transverse orientation)

4. SUMMARY AND NEXT STEPS

The results described in the previous sections clarify that the integrative simulation method is an appropriate technique to determine the structural intensity of reinforced, injection moulded thermoplastic parts. For accurate estimations of the propagation paths information about the fibre orientation are necessary. Methods of obtaining this information are calculations (process simulation) or measurements (CT-Analysis). Investigations at other institutes on the structural intensity were done primarily for linear elastic, isotropic materials. First contemplations on unidirectional fibre composite materials revealed promising opportunities to influence the structure-borne sound of anisotropic materials with the help of the structural intensity [5]. In the near future these opportunities should be examined in detail (see figure 5).

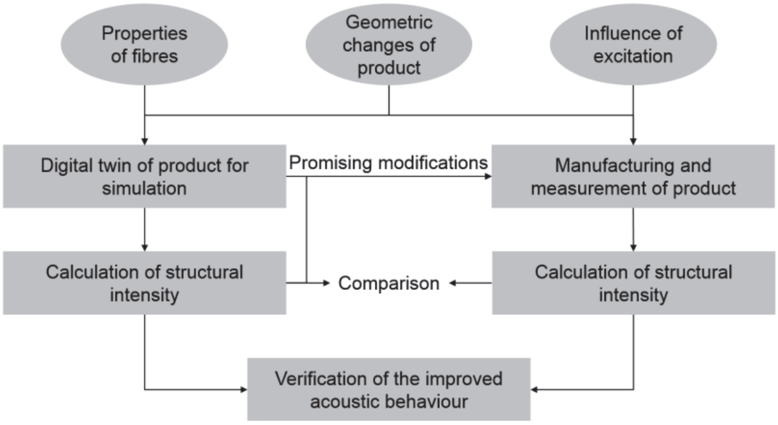

Figure 5 – Overview research project

The acoustic behaviour of reinforced thermoplastics should be improved by directing the structure-borne energy into uncritical or high damping areas using the fibre orientation. Therefore analyses on the importance of different fibres, lengths and filling fractions on the propagations paths of the structural intensity will be executed. In addition the influence of geometric changes of the parts will be examined as well. Based on the results, product developers will have the possibility to adjust the desired mechanical properties and acoustic behaviour. This leads to a better lightweight potential, a more efficient material usage and a sustainable use of resources.
The calculations will be carried out for simple plate geometries as well as a complex geometry used in the interior of a car. In order to prove the propagation paths and the efficiency on the acoustic behaviour measurements will be undertaken.

An objective of the research project is to develop a database which contains a guide to improve the acoustic behaviour with constructive changes and a database with the data of the examined materials and with the ability to input criteria by which to select a material which is suitable for the requirements of a certain product.

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