

Mode Shape Optimisation of a Plate in the Ultrasonic Frequency Range

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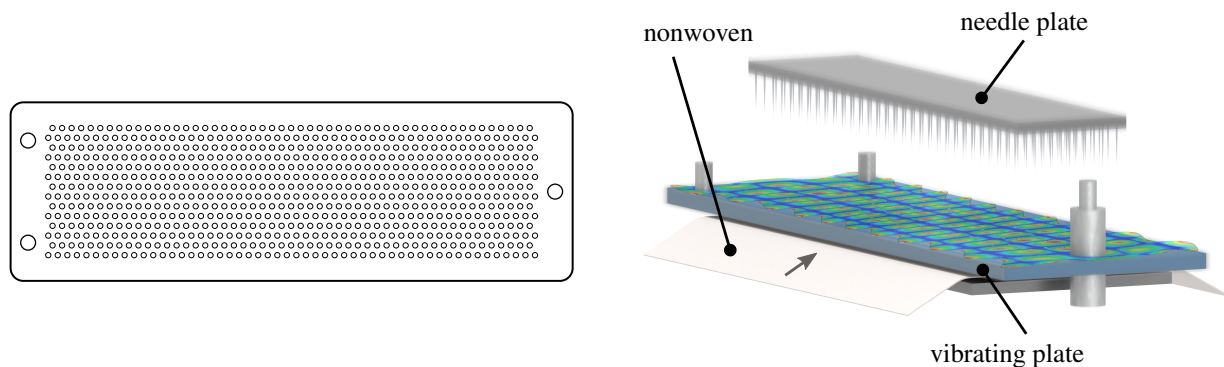
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Abstract

Nonwoven textiles are composed of randomly oriented fibres. The production costs of these materials are relatively low and they can be used in a wide range of applications, including sound or thermal insulation, clothing and geotextiles [1]. The individual fibres are held together by a combination of friction and/or cohesion and/or adhesion. Although these forces provide the material with its mechanical strength and beneficial properties, they also subject the fibres and machine elements to high levels of stress during the manufacturing process. This is particularly relevant during textile needling, where the nonwoven material is passed between two perforated plates and the insertion and removal of needles entangles the individual fibres. An undesirable side effect of this process step is wear and damage to the fibre itself, the needles and other machine parts.

To significantly reduce wear to machine parts such as the needles and the nonwoven, one approach is to excite the nonwoven material with ultrasonic sound waves emanating from one of the guide plates to temporarily reduce friction between the fibres during the needling process, see Fig. 1.



(a) Perforated plate guiding the fibre through the machine.

(b) Abstract representation of the needling process with a vibrating plate, excited by one sonotrode.

Figure 1: Needling process of nonwovens with ultrasonic excitation of the fibre through a perforated plate.

This publication presents the design process of the guide plate, which will be excited by a piezoelectric ultrasonic transducer, to act as a plate sonotrode. The requirements for the plate can be described in two design objectives:

- Efficient and homogeneous transmission of vibration at the natural frequency of the fibres into the nonwoven material.
- Decoupling of the plate from the environment to prevent unwanted transmission of high frequency vibrations.

In order to achieve both design goals, a mode shape optimization is conducted to determine the optimum design parameters of the plate such as, width, thickness and corner radius, Fig. 1a. As stated in [5], changes in corner radius of a vibrating plate can lead to changes in the resulting mode shapes at specific frequencies.

The vibration frequency of the plate is determined by the natural frequency of the nonwoven material to achieve maximum resonance and therefore friction reduction. Preliminary tests have shown that this frequency is in the ultrasonic range of $f = 20\text{kHz}$. A detailed investigation of the natural frequency of the fibre is part of the project's ongoing research. To achieve efficient vibration, the plate is designed so that the natural frequency of the plate is aligned with this target frequency determined by the fibre material. To ensure a homogeneous vibration distribution in the fibre, the plate design should provide a homogeneous mode shape at the target frequency within the area of the holes where the needles enter

the fibre. In addition, outside the perforated area, the mode shape must provide suitable points of contact for bearings in the form of vibration nodes and the sonotrode in the form of vibration maxima. For reference, a perforated plate used in an actual manufacturing machine is measured, see Tab. 1.

Table 1: Plate parameters

	length	width	thickness	corner radius
reference dimensions	790 mm	280 mm	8 mm	0 mm
optimized dimensions	781 mm	235 mm	10 mm	8 mm

The optimization process was carried out by implementing a simulation framework that links the optimization environment, programmed in Matlab with the Abaqus finite element analysis (FEA) software. This allows the automatic generation and calculation of Abaqus simulations based on the specific optimization parameters, as well as the export of the FEA results to Matlab. The optimization problem is formulated as a multi-objective or Pareto optimization with two design objectives, the similarity to a target mode shape is measured by modal assurance criterion (MAC) and the deviation of the corresponding natural frequency from a specified target frequency. The optimization is performed using a generic optimization approach, where the plate parameters thickness, length, width and corner radius are varied. Exact analytical solutions for the free vibration of rectangular plates, which are not supported at the edges are unknown [3, 4]. Thus, for the calculation of the reference mode shape, an approximation based on the fundamental mode shapes of uniform beams with freely vibrating ends is used along the longitudinal and transverse axis. The selection of this approach for the present optimization is motivated, by the popularity of these mode shapes as trial functions for approximating plate vibrations using the Rayleigh and Rayleigh-Ritz method [3].

Fig. 2a shows the free vibration mode shape closest to $f = 20\text{kHz}$ for the parameters listed in Tab. 1. In contrast, Fig. 2b displays the free vibration of an optimized plate at the target frequency $f = 20\text{kHz}$. The plate shows a homogeneous vibration pattern with suitable points to support and excite the plate see Fig. 2b.

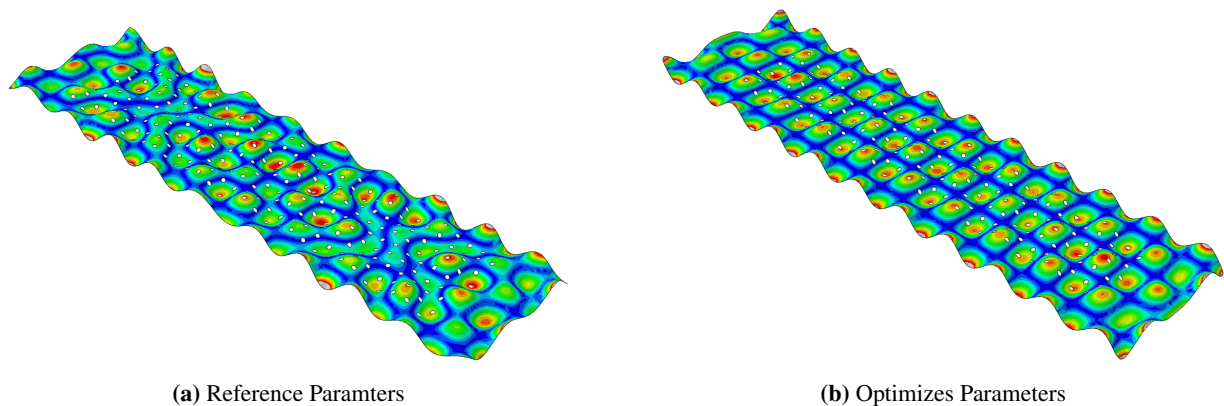


Figure 2: Comparison of two mode shapes with natural frequencies close to $f = 20\text{kHz}$, for a plate design before and after optimization.

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