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Determination of acoustic behaviour of locally modified structures by Scanning LDV

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Abstract. Acoustic properties become more and more important in product design. To change the vibration characteristics additional masses or damping systems are common, but not lightweight. Integrated fins and the damping performance of joints have no negative impact on the weight. Another new advanced method is the local change of material properties by bake hardening. A very effective way to quantify the acoustic influence is the measurement with scanning Laser Doppler Vibrometry, also for the quality assurance.

1. Design of low noise products

Besides the main functions and the costs of a product, acoustic behavior becomes more and more important. In general a customer expect a noiseless use, e.g. lift, air condition, premium vehicles, household appliance and so on. Only a few products like motorcycles or sports cars are additionally sound engineered to have a typical acoustic appearance. But the doors, steering system and drive shaft also have to be quiet. Especially products and tools for the use in working environment have to have a minimum vibration and noise emission.

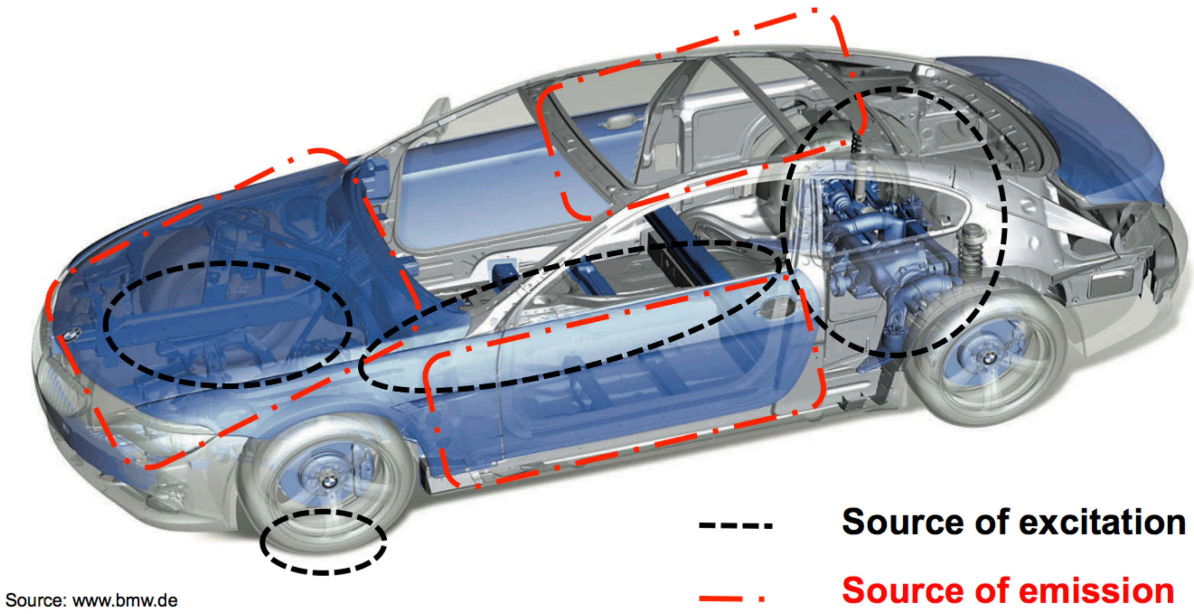

Figure 1: Sources of excitation and emission on a car

To design a low noise product, Dietz and Gummersbach [1] collected a huge number of design rules and defined three basic acoustic elements, see figure 1:

- the origin of vibrations (source of excitation)
- the path between the excitation and emission
- the surface (source of emission), where vibrations are changed into airborne noise

The following chapter 2 deals with some solutions regarding the second and third acoustic element to design a quiet product. Chapter 3 contains some suggestions of the numerical simulation and simple measurements of the acoustic behaviour. Chapter 4 shows some results of the advanced non-contact measurement using a scanning Laser-Doppler-Vibrometer (LDV).

2. Noise reduction by design

Often additional masses to change the natural frequency or damping systems are used to make a product less noisy. The problem of these straight ways to the quiet product is the increasing weight of the product. Regarding the idea of lightweight design, other solutions are necessary, which are focussed on changing the stiffness or using the damping capacity of existing junctions.

2.1. Noise reduction by integrated fins

Figure 2 shows some common versions to influence the stiffness of surface areas, which are causal for airborne noise emission. The integrated fins, which are realised by cold forming, converted the 2D sheet metal into a 3D structure with certain beam stiffness. The geometrical modification works well to the vibration characteristics, without increasing the weight. The disadvantage is the geometry its self, because most of the customers don´t want to have these patterns on the visible surface.

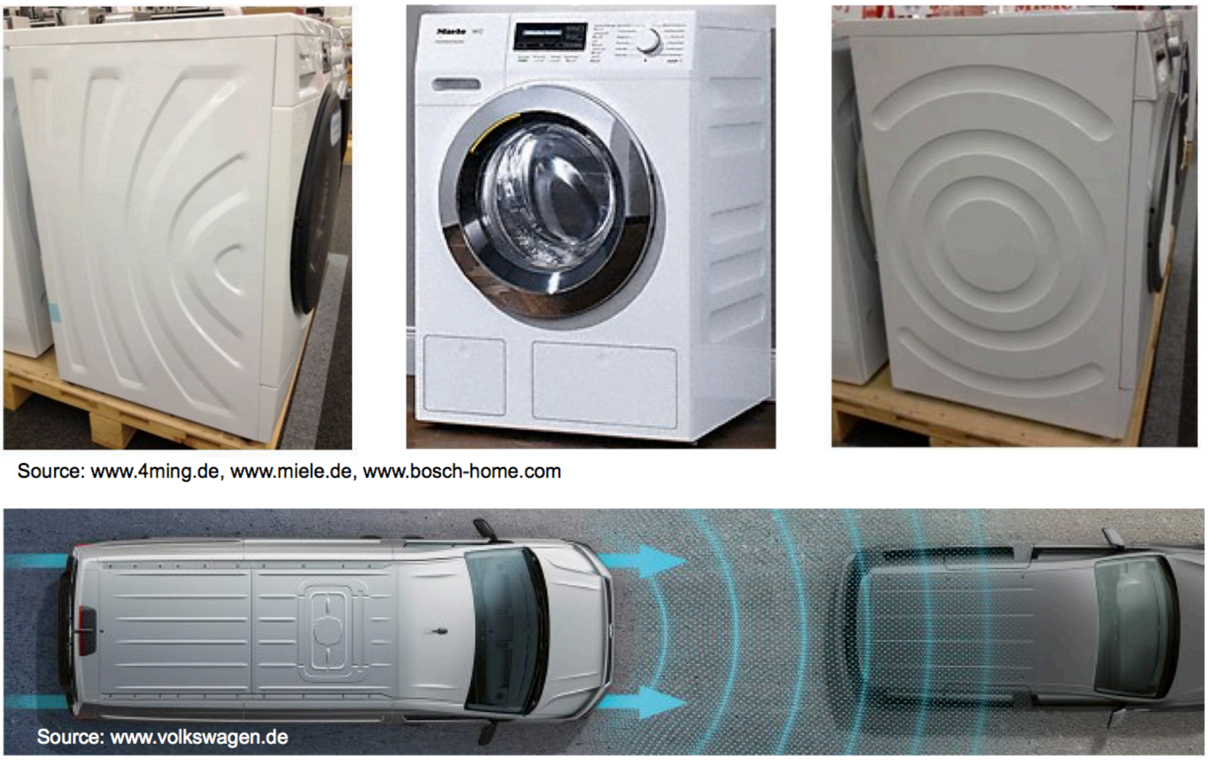

Figure 2: Noise reduction by integrated fins

Reasonable examples for the use of integrated fins are the roof of small lorries, the floor section and bulkheads of cars and the left, right, back and floor section of household appliance, in general all invisible plates.

2.2. *Noise reduction by junctions*

Another kind of noise reduction without additional weight is the use of junctions with high damping characteristics. Junctions mostly necessary in products and so they can be used to influence the acoustic product quality. Figure 3 shows four different local junctions for sheet metal. A complete welding seam is more or less useless for damping. Between two spot welds exists an area with a frictional contact, this leads to the frictional damping of a spot weld junction.

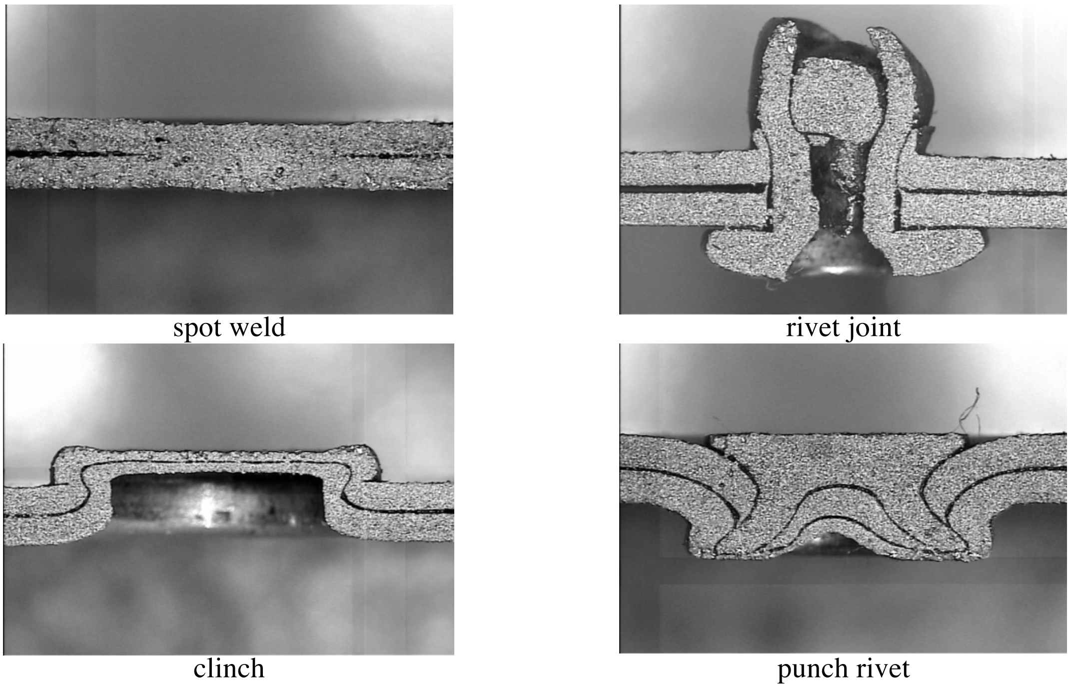

Figure 3: Noise reduction by junctions

Käferstein [2] investigated the damping properties of different sheet metal junctions. The punch rivet showed the highest damping factor, followed by the clinch and rivet joint. The spot weld showed the lowest damping factor of the four junctions in figure 3. In simple words, the damping factor is proportional to the frictional contact area of the junction. In [2] values for damping in junctions up to 800 Hz are determined, also references for FE-modelling of such junctions are given.

2.3. *Noise reduction by additional reinforcing fins or local material modification*

The performance comparison of the integrated fins and junctions on the acoustic behaviour showed a benefit for the integrated fins. To increase this property and overcome the pattern problem, the use of additional reinforcing fins is very common in car industry, see figure 4. By these additional fins the weight of engine hood increases slightly, but the stiffness and acoustic performance is obvious better.

Analysing the way such fins worked, it becomes clear, that the structured local change of material properties, e.g. stiffness and stability, is able to influence the acoustic behaviour.

The awareness to use a local change of material properties leads to the idea of a structured local heat treatment of sheet metal e.g. by laser. Using the correct laser parameters, there will be no visible pattern and of course no additional weight. This idea in principle is highlighted with yellow laser tracks in figure 4.

After pre-stressing the material by forming the hood, the laser heated up the hood very slightly and structured. This process is well none in general as Bake-Hardening. The local Bake-Hardening should be used instead of the additional fins.

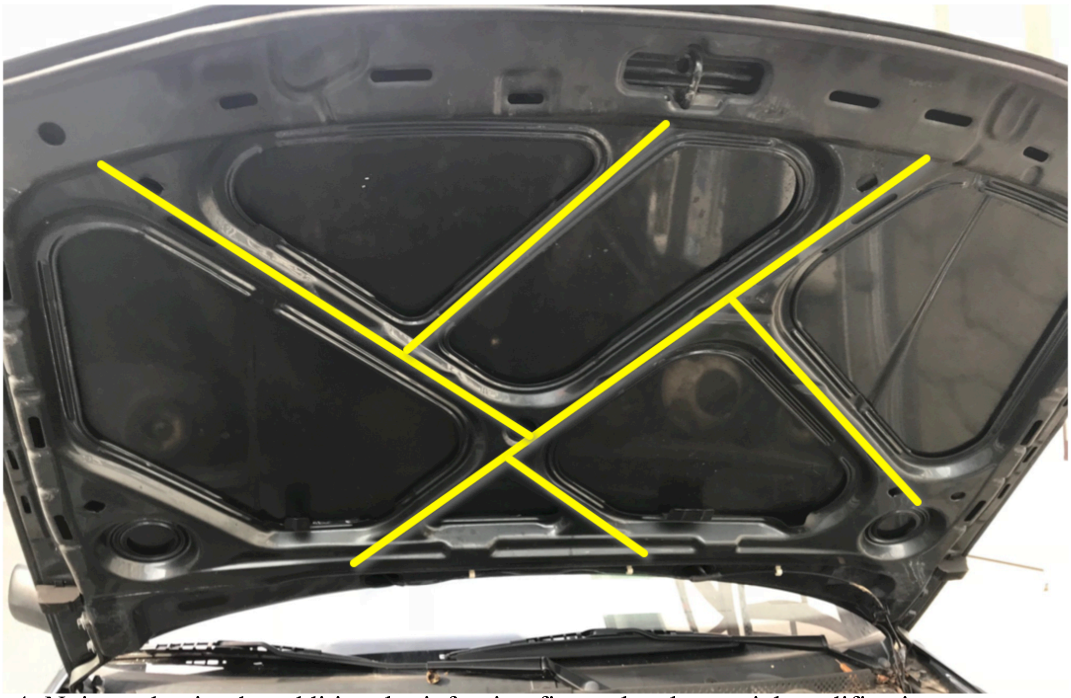

Figure 4: Noise reduction by additional reinforcing fins or local material modification

2.3.1. Material modification "Bake-Hardening". The Bake-Hardening is a combined mechanical and thermal process to increase the stability of steel. The first step is the mechanical pre-stressing to generate dislocations. In the second step the C-atoms are forced by heating to move to the dislocations. The aggregation of C-atoms leads to the hardening effect with an increase of stability, as shown in figure 5.

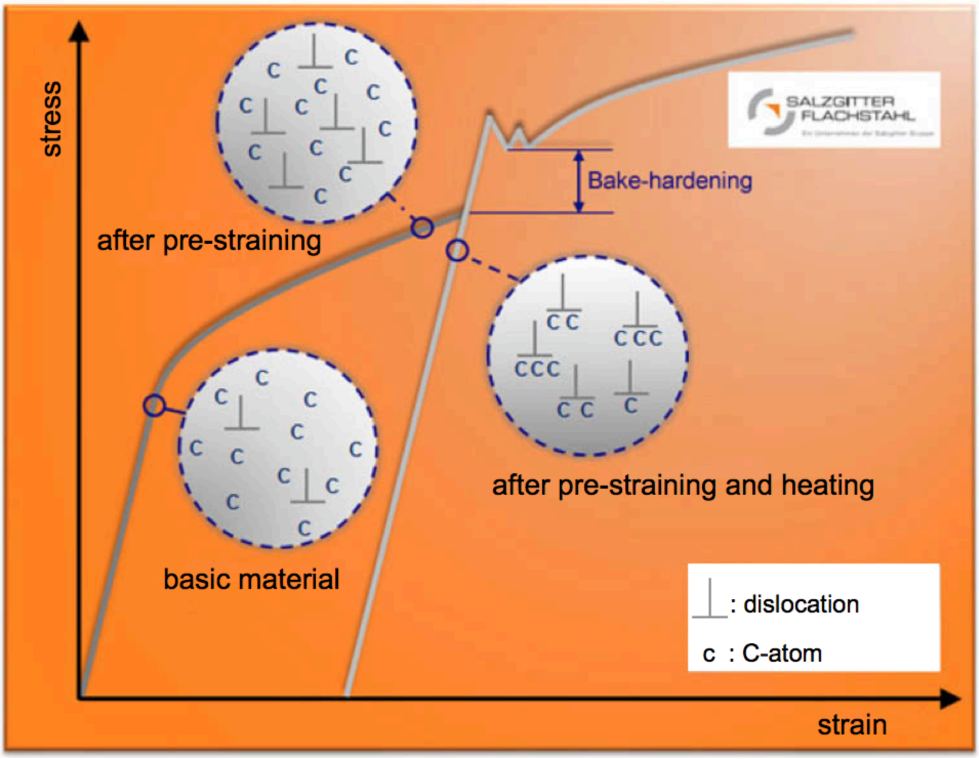

Figure 5: Modification of material properties by Bake-Hardening

3. Numerical simulation and first measurements

The first step for the verification and dimensioning of the structured local bake hardening was the set-up of a simple geometry model according to Hambric [3] with a single line of bake hardening and two measurement points on each side left and right of the line, see figure 6. With this simple model the transfer function with and without bake hardening was measured. Therefore an impact excitation and piezo sensors were used.

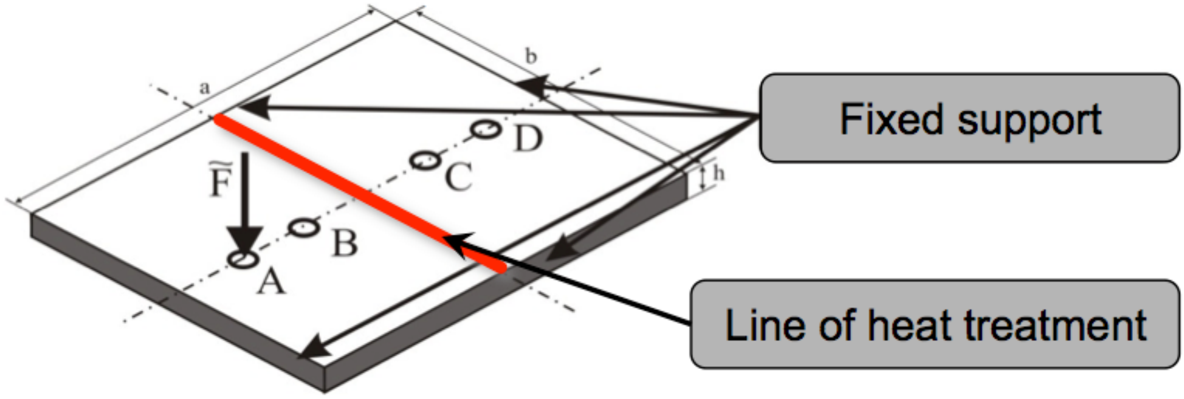

Figure 6: Simple geometry model

For the future numerical dimensioning of structured local bake hardening a valid Finite Element Model was necessary. Equivalent to the simple geometry model in figure 6 an FE-model was generated, see figure 7. On the left side of figure 7 a cross section of the heat affected zone is shown. The first simple seam geometry A was taken from a classic welding seam. The height of the heat treated zone was equal to the sheet metal thickness. The accordance between the measurement and numerical simulation was poor. Having a look to the cross section in figure 7 left, the seam geometry B was generated, which leads to a bit better accordance. Within a third stop of refining the numerical model, the seam geometry C was established. Seam geometry C represents all three areas in figure 7 left, with different modulus of elasticity.

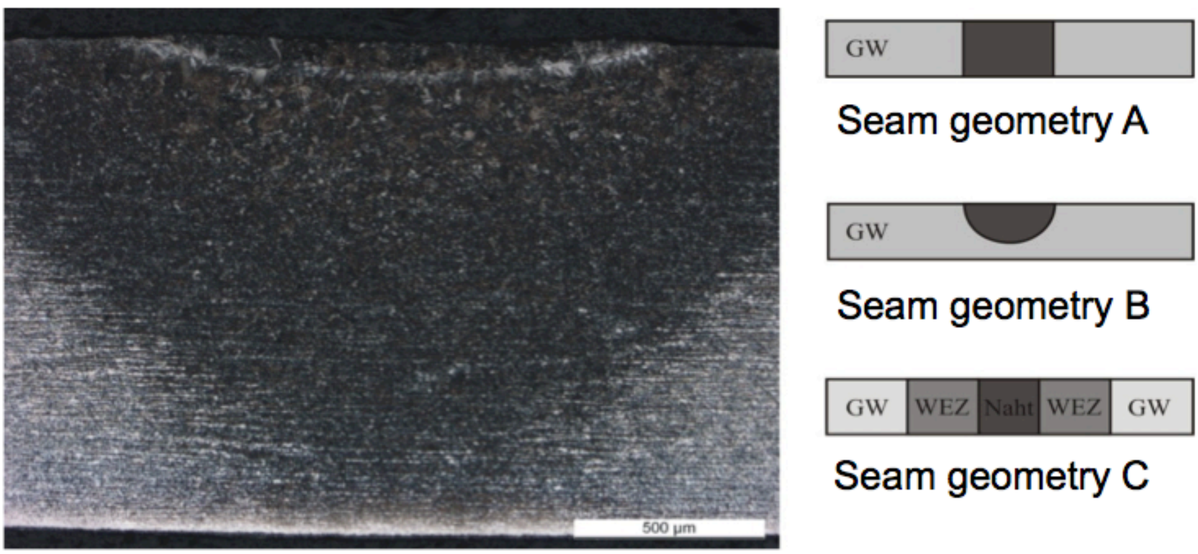

Figure 7: Image of heat treated zone and variations for FE-model, Naht = heat treated zone, WEZ = heat affected zone, GW = basic material

After the first successful matching of numerical and experimental results a second test setup, see figure 9, was produced in sheet metal and modelled for the numerical simulation. First results for the mode simulation without bake hardening are shown in figure 8.

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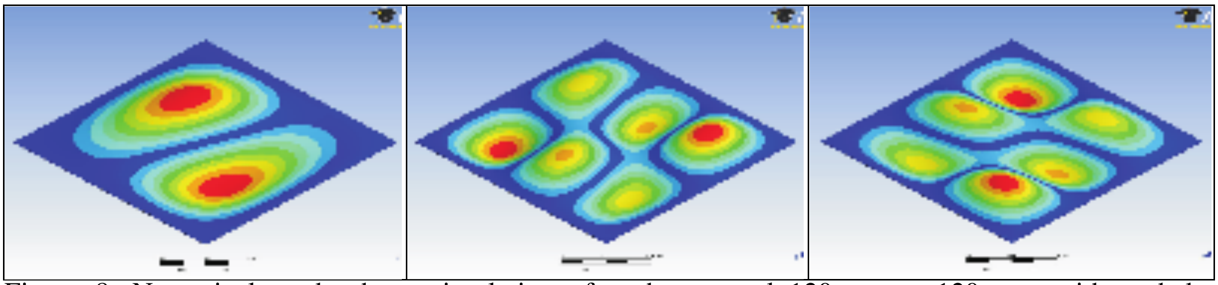

Figure 8: Numerical mode shape simulation of a sheet metal 120 mm x 120 mm without bake hardening

3.1. *Experimental tests with structured local bake hardening*

After the first experimental measurements and numerical simulations with simple geometries, a DP800 sheet metal specimen with a circular structured local bake hardening was tested, see figure 9. The measurement was carried out with two piezo sensors in three repetitions, so that six sensor positions were used to get a good local resolution without having to many masses on the specimen.
On the lower left corner a shaker induced a chirp signal. The measurement was done once with the circular bake hardening and once for comparison without bake hardening.

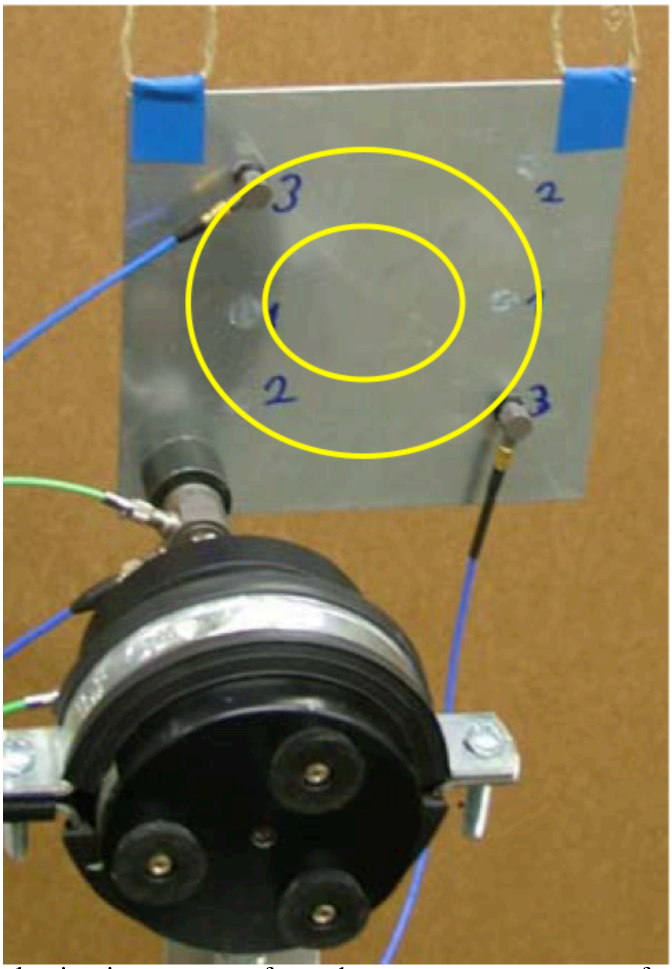

Figure 9: Set-up with classic piezo sensors for a three step measurement of two DP800 sheet metal plates 120 mm x 120 mm

The results for the sensor position 3, like it is shown in figure 9, are compared in figure 10. Around 4 kHz a significant positive influence of the bake hardening is observable. The acceleration peak is decreased to less than 50%.

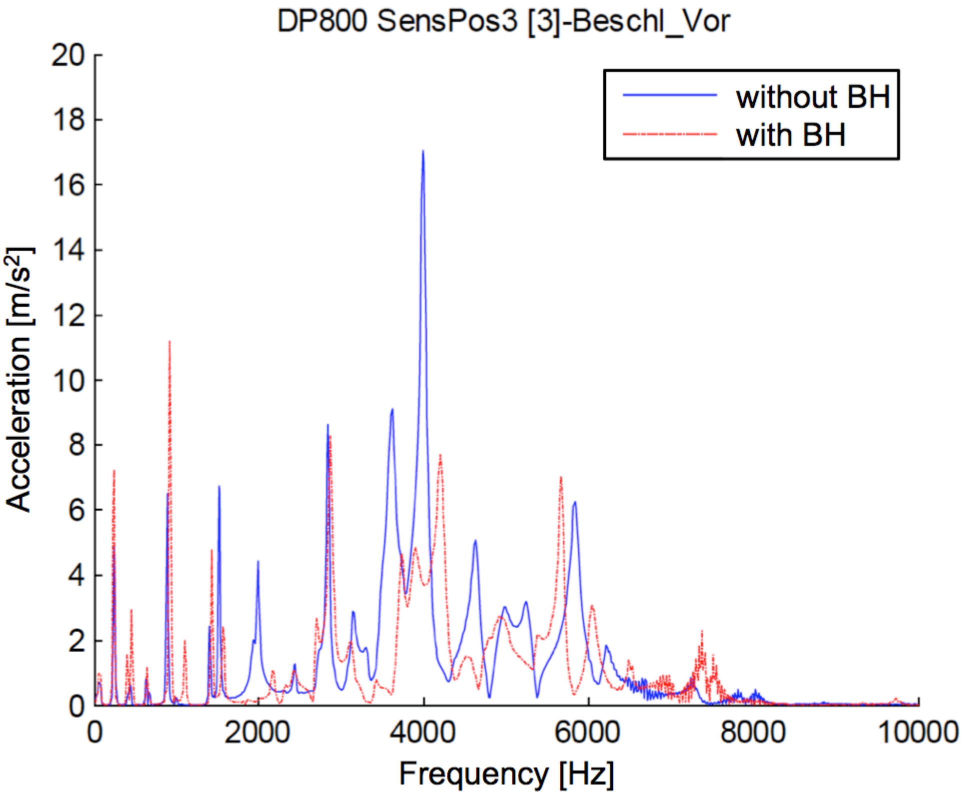

Figure 10: Comparison of two DP800 sheet metal plates, with and without bake-hardening (BH) traces by electron beam

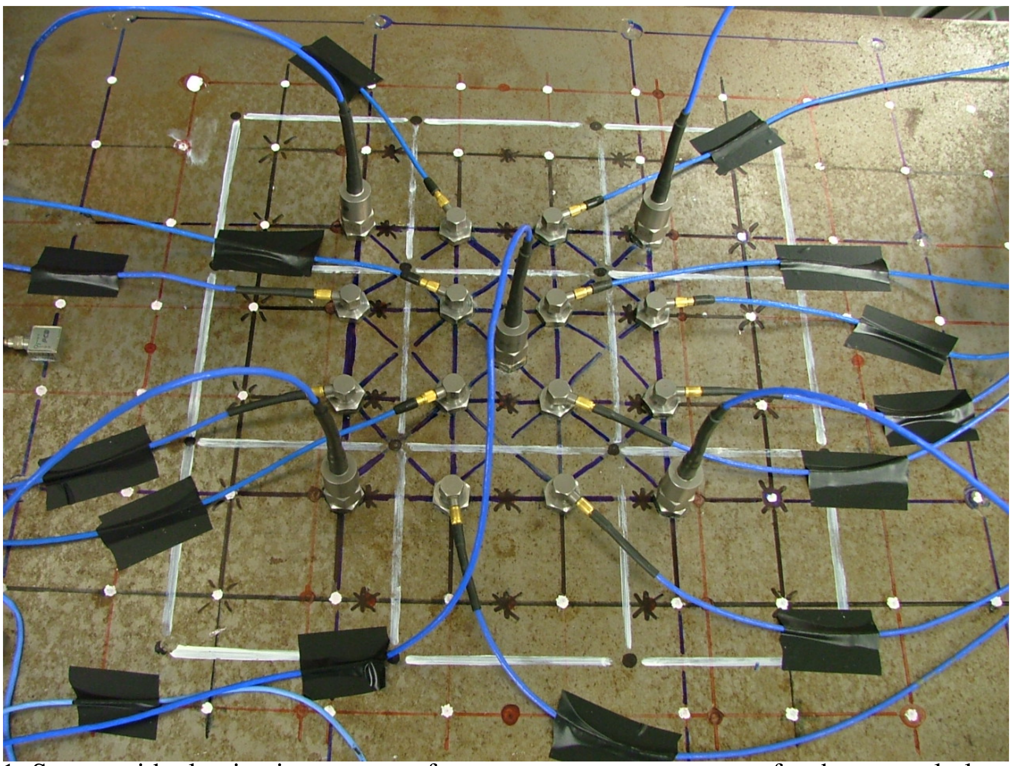

Figure 11: Set-up with classic piezo sensors for a one step measurement of a sheet metal plate 500 mm x 500 mm

The three repetitions for the measurement in six sensor positions and their analyses was very time consuming. The next step was a bigger sheet metal specimen, 500 mm x 500 mm with full sensor equipment, like it is shown in figure 11.

The expenditure of time for the measurement, without the preparation time, was ok, but the comparison of the measurement and the numerical simulation showed a dramatic influence of the sensor masses. The influence of the bake hardening would not be measurable with theses sensors.

4. Non-contact measurement

As result of the full contact sensor measurement, a non-contact measuring device with high local and frequency resolution was necessary. After a market analysis a scanning Laser Doppler Vibrometer (LDV) (Polytec PSV-400 + OFV-5000) was used for the following measurements.

Using the laser beam for the measurement, it is a reactionless method to gather the information's, which are necessary for structural acoustics analyses regarding the local material properties [4].

Figure 12 shows the measuring grid of the scanning LDV, which was used for the 500 mm x 500 mm sheet metal plate. The measuring grid has an increased resolution with 287 measuring dots compared to the 17 piezo sensors in figure 11. The LDV measurement was done with a sampling rate of 2,5 MHz to increase the time resolution.

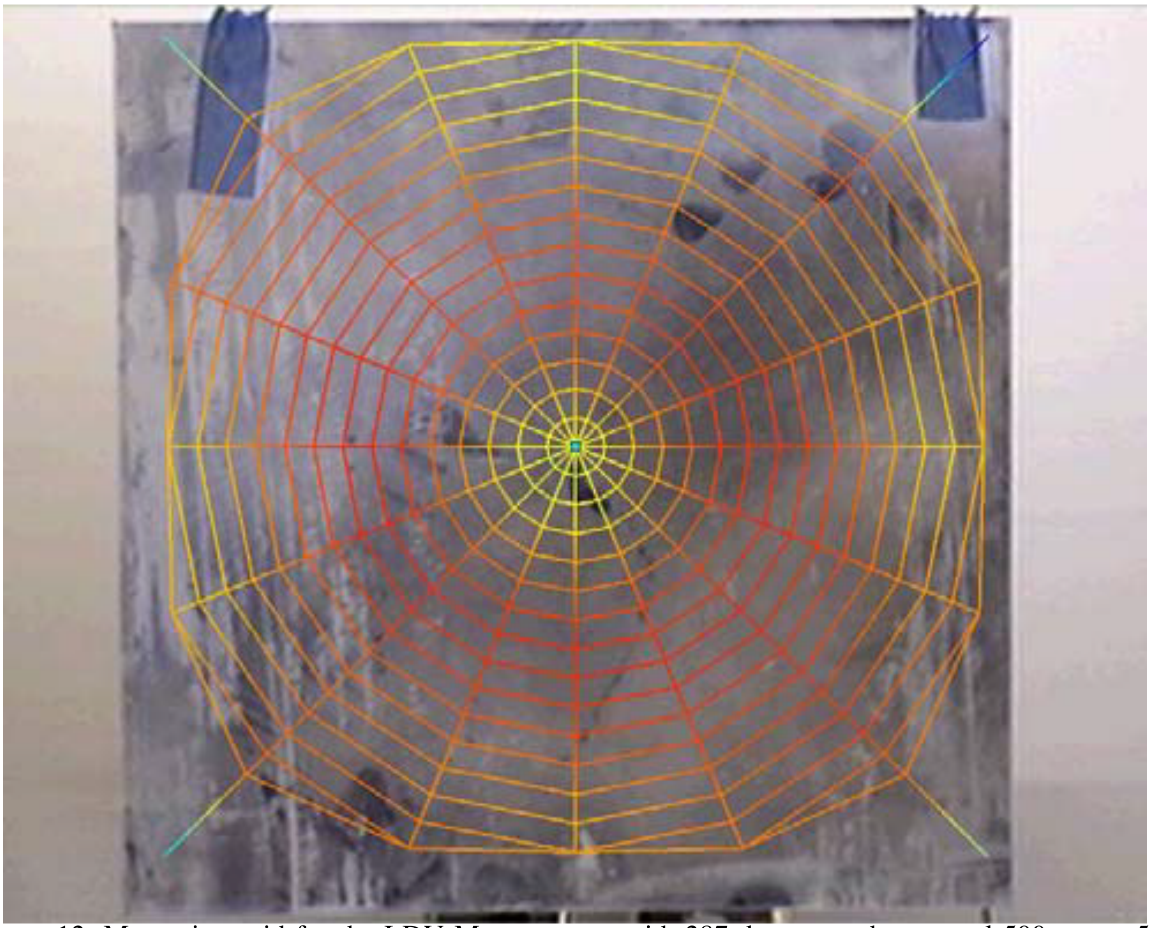

Figure 12: Measuring grid for the LDV-Measurement with 287 dots on a sheet metal 500 mm x 500 mm

One measuring result, the wave shape in time domain of a sheet metal with circular structured bake hardening is shown in Figure 13. The excitation was realised from the backside with an acoustic radiator aligned to the centre of the plate. For other measurements an impact hammer or shaker, connected to the centre of the plate or one of the lower corners, was used.

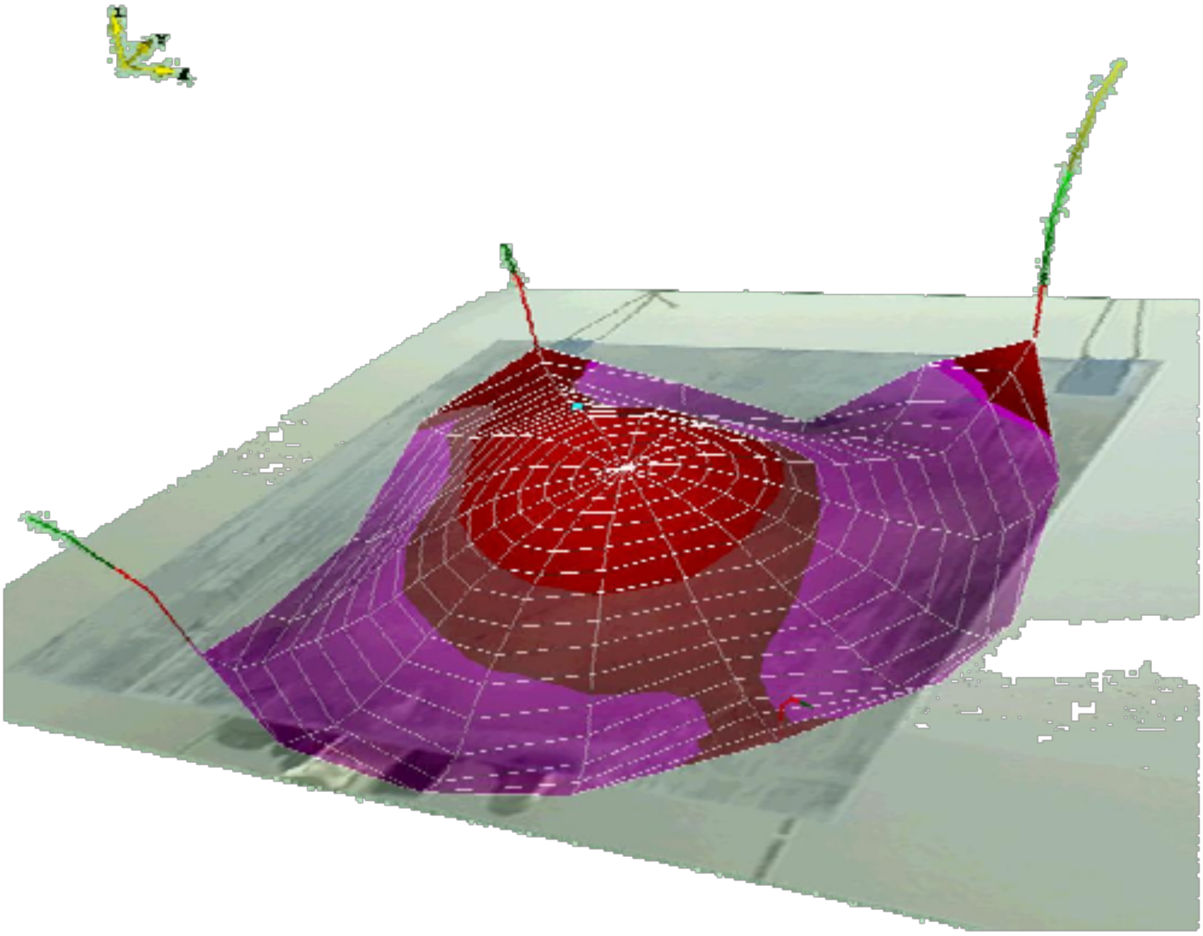

Figure 13: Wave shape in time domain of a circular reinforced bake hardening sheet metal 500 mm x 500 mm

4.1. Modal analysis

The scanning LDV data were used for an experimental modal analysis with the software ME´Scope VES. Besides the experimental analysis a numerical modal analysis was done with ANSYS.
Within the frame of investigations not only the sheet metal with one layer with and without bake hardening were measured, there are also sandwich plates with two sheet metal and between one polypropylene-polyethylene copolymer (PP-PE) layer measured. The two sheet metal layers allowed a different pattern and orientation of the structured bake hardening which provides a perfect adaptability to the acoustic requirements. The PP-PE layer allows also additional structured reinforcement, so that there is a very wide area of future research work.

For the first test a bake hardening pattern of radial lines with 45° pitch on both sheet metal layers was used compared to a pure sandwich plate without stiffeners. Figure 14 shows the results of the experimental and numerical modal analysis [5]. From left to right the influence of the material modification is perfect observable in both analyses. The experimental analysis of the natural frequency showed also a significant shifting to a higher frequency for the modified plate. The numerical model showed a lack of refinement especially in the PP-PE layer, which is represented only by one element layer.

5. Summary

Acoustic properties become more and more important in product design, therefore are different design rules available. There are different methods for the realisation in production. A new advanced one is the local change of material properties by bake hardening. A very effective way to quantify the acoustic influence is the measurement with scanning Laser Doppler Vibrometry, also for the quality assurance.

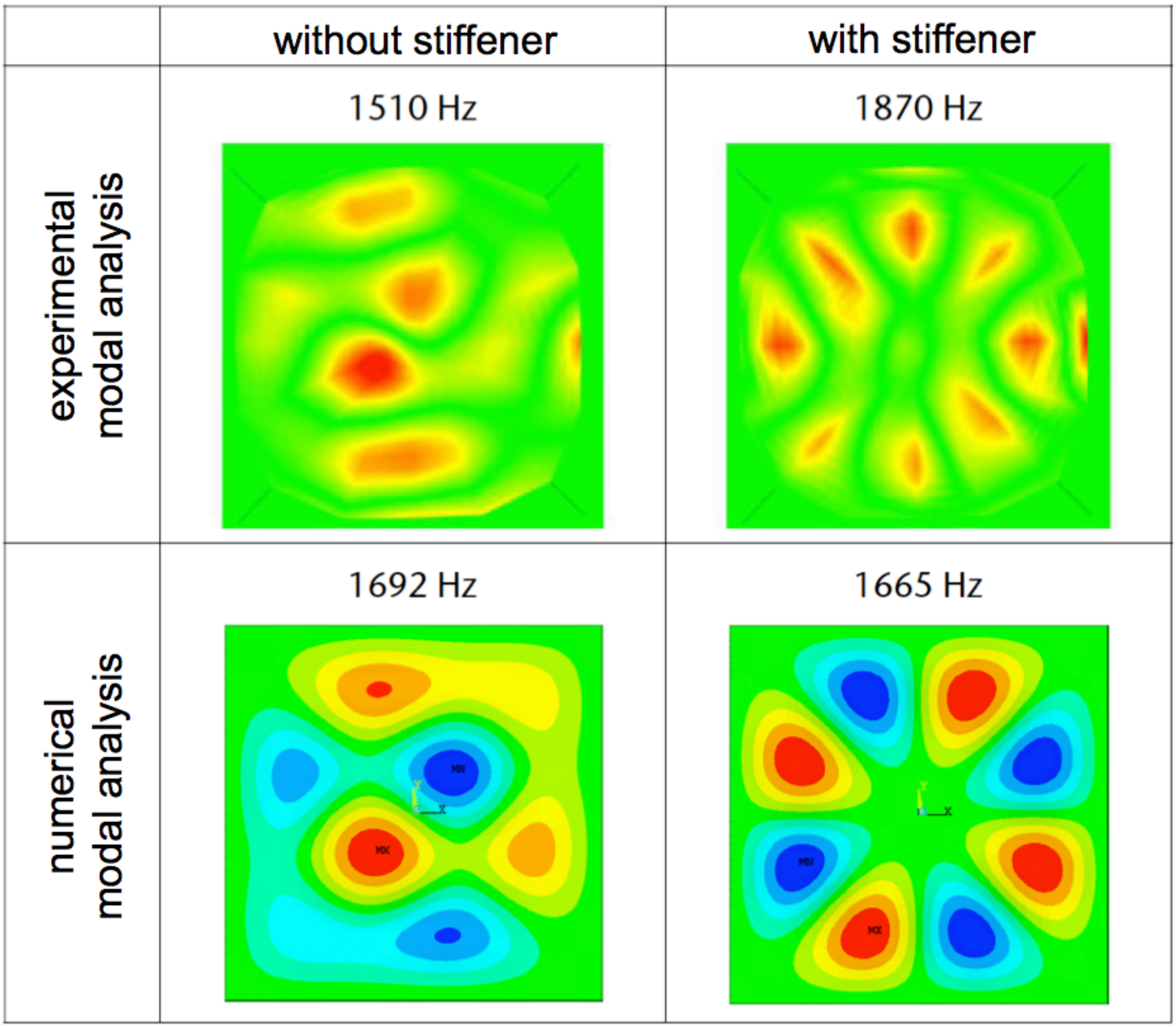

Figure 14: Comparison of two sandwich metal plates 500 mm x 500 mm, with and without circular reinforcement by bake hardening

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