

## Lectures

# Parametric optimization of an oil-pan - Implementation of the process-chain Pro/E - ANSYS Workbench - optiSLang

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# "Parametric optimization of an oil-pan" Implementation of the process-chain Pro/E - ANSYS Workbench - optiSLang

## Weimar Optimization- and Stochastic Days 5.0

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### **Abstract**

This lecture deals with the possibility to optimize an oilpan with the new method of a parametric optimization. A bidirectional interface for direct modification of CAD Parameters by the optimization tool optiSLang was used.

The analysis was done in ANSYS Workbench. A modal analysis was performed. This was to determine the first eigenfrequencies. Especially the first eigenfrequency has been critical in some cases and therefore it has to be increased.

By doing a sensitivity analysis as a first step, the important parameters for the optimization and possible design space could be determined.

The pan could be optimized in a significant way by performing a parametric design optimization using the Adaptive Response Surface Method algorithm.

After the optimization, a robustness analysis was done to check the robustness of the optimized design for small variations of the input parameters. As a result, the frequencies have been robust against these small variations, so the design can be regarded as optimized and robust.

Finally this optimized design was tested in practical examinations. The design improvements were also significant in these examinations.

**Keywords:** Optimization, Stochastic, Robust Design

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# 1 Introduction

In the virtual product development, CAE-based optimization methods are increasingly used to improve product properties. In the engine development, topology optimization or bead optimization is used frequently for mass-reduction and stiffness-increasing of single parts. These optimization methods are called “parameter-free” because an internal parametrizations are used for describing the design space. The user does not define the parameters explicitly in these methods. Due to the special parametrization, the results of these optimizations have to be transferred afterwards into a manufacturable CAD-geometry.

With the example of an oil-pan, the potential of a further enhancement of the vibration behaviour will be examined by the application of parametric optimization where CAD parameters are used to describe the design space. By using CAD parameters for the optimization, the complicated step of transferring the best designs back to CAD is not necessary. Furthermore, the robustness evaluations of these designs concerning manufacturing tolerances and material scatter, can easily be done.

The regarded oil-pan has to be improved in its vibration behaviour because of resonance effects of the external excitations. A potential for improving this oil-pan could be determined by performing a pre-analysis with conventional topology optimization methods. Unfortunately these improvements could not be approved by practical applications. Therefore, it was assumed that there is a large sensitivity of the characteristics to small geometry variations. This prevented a successful application of the bead-optimization.

The beginning of the parametric optimization was a CAD-geometry in Pro/ENGINEER. After having a closer look at the existing parametrization, it became clear that there will be a lot of work to do to create a parametrization in the CAD system, which is stable enough to realize the designs of an optimization. With a construction tool for creating beads in Pro/E a parametric design was created. The optimization tool should be able to deal directly with these CAD parameters. The automatic process to generate a new geometry, to create a mesh for the structure and then to perform a modal analysis was done in ANSYS Workbench. The whole process chain was established by the interface optiPlug which is a direct link to the optimization tool optiSLang. Then optiSLang generated all the designs for the sensitivity analysis, the optimization and finally for the robustness evaluation. The workflow was fully integrated between optiSLang – Workbench – Pro/E.

## 2 Initial situation

The aim of this optimization was to improve the acoustic behaviour of the oil-pan by keeping the mass on a relatively constant level.

It was necessary to damp the stimulations of an ancillary unit. These stimulations became effect at the first eigenfrequency by crossing a specific speed range.

The necessary bracings should be realized by generating beads. These beads had to be generated parametrically so that they could be taken for a design optimization with optiSLang. In the end, the robustness of the optimized geometry concerning manufacturing tolerances and material scatter has to be proved.

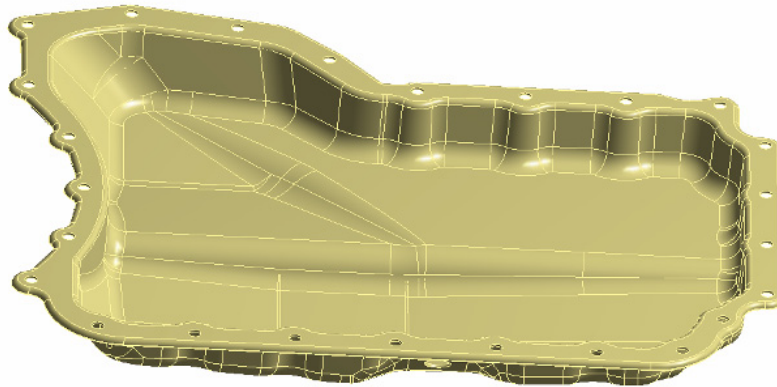
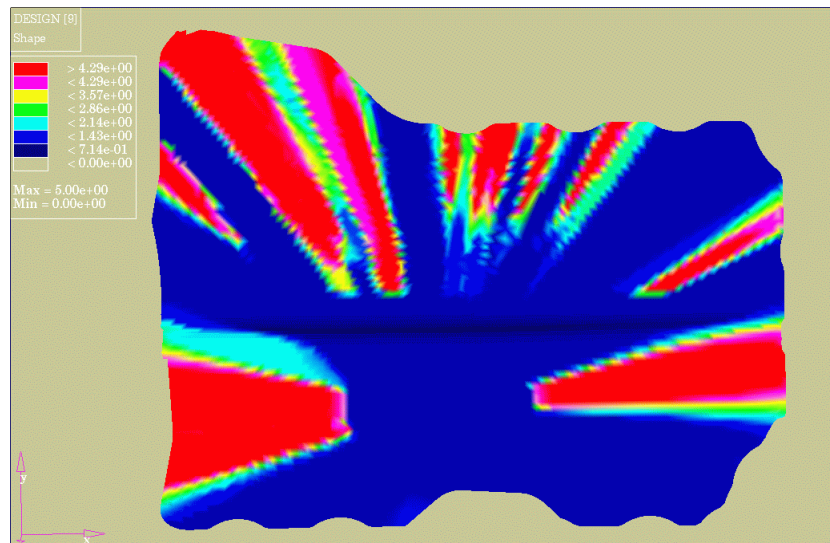


Figure 1: Initial situation: oil-pan without beads

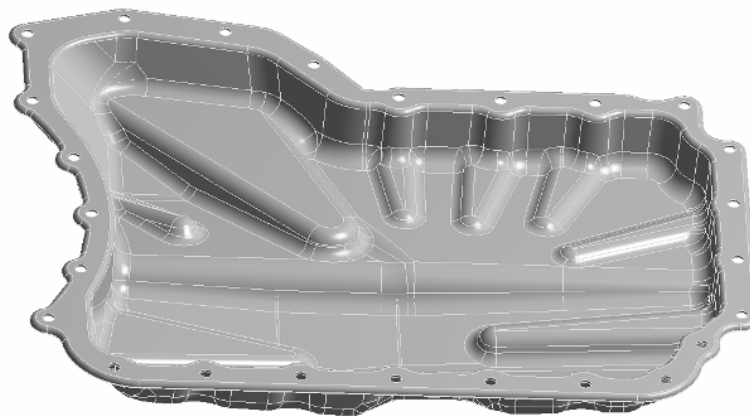
## 3 Stiffening of the oil-pan by parametric beads

### 3.1 Generating flat beads with Pro/E

The first attempt was to generate flat beads with Pro/E's bead-tool. These beads are relatively simple to adapt to the manufacturing process. The geometry and the location of these beads had been taken from the previous topology-optimization process (Fig.2 and 3). Unfortunately no significant increasing of the eigenfrequencies could be realized with this bead generation. Even a "generously" variation of the geometry did not lead to a success. So it became clear that an adequate flux of force into the coating had not been realized yet.



**Figure 2: Bead pattern generated by a topology optimization tool**



**Figure 3: Parametric bead-topology of flat beads**

### 3.2 Realisation of deep beads

Studying a design where the beads are designed as a rib-pattern, it was finally possible to generate a bead-pattern with beads in CAD that nearly reached the coating. This pattern shows a high potential of improving the acoustic behaviour.

These “deep” beads made it possible to reach an optimal flux of force into the bearing. The stiffness of the oil-pan could be increased significantly. It was now possible to increase the eigenfrequencies by about 50 %.

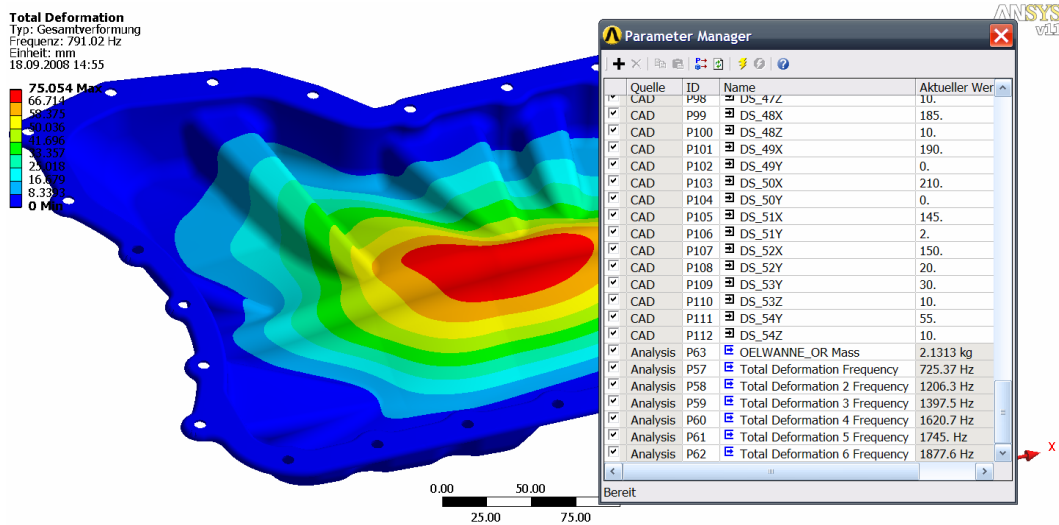


Figure 4: Parameterization in ANSYS Workbench

After generating the beads parametrically in CAD, it was now possible to start the optimization run and robustness evaluation with optiSLang. Performing a sensitivity analysis at first, the potential of an optimization run was determined. The design space was scanned with a Latin Hypercube Sampling. Apart from the variation of the output values (the potential of the optimization), the most important design parameters were determined by a correlation analysis. The importance of these variables were quantified by regarding the Coefficient of Determination (Fig. 5).

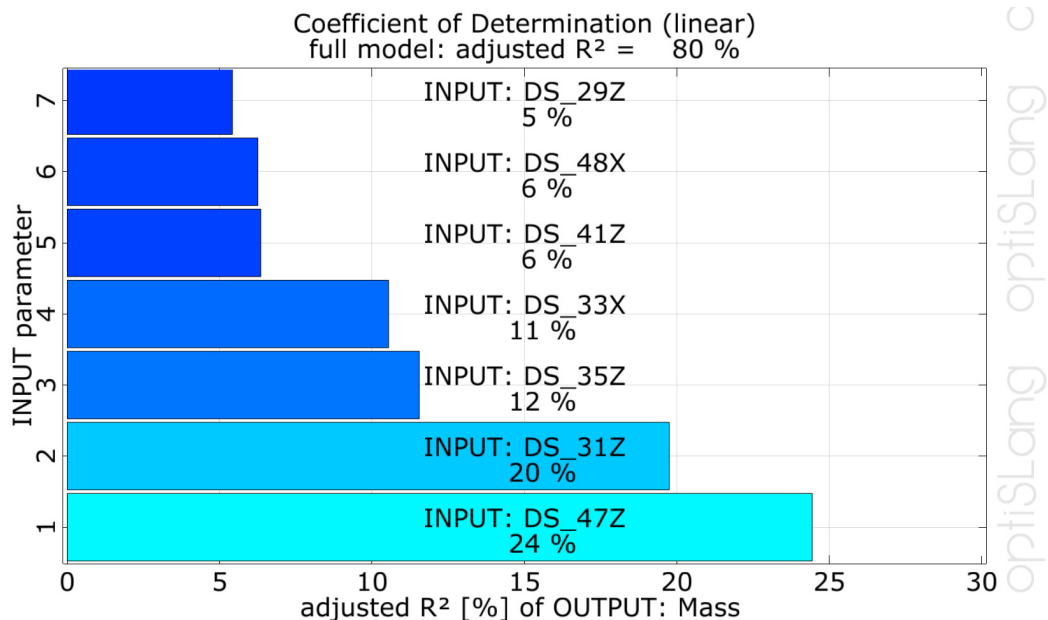


Figure 5: Coefficient of Determination of the first Eigen frequency

So it was possible to determine unimportant parameters before starting the optimization. The design space could be reduced from 35 to 13 parameters. Then it was possible to select one of the most effective optimization method - the “Adaptive Response Surface Method”. This algorithm is able to generate an optimal design with a relatively low number of calculated designs in this reduced design space (Fig. 4 and 5).

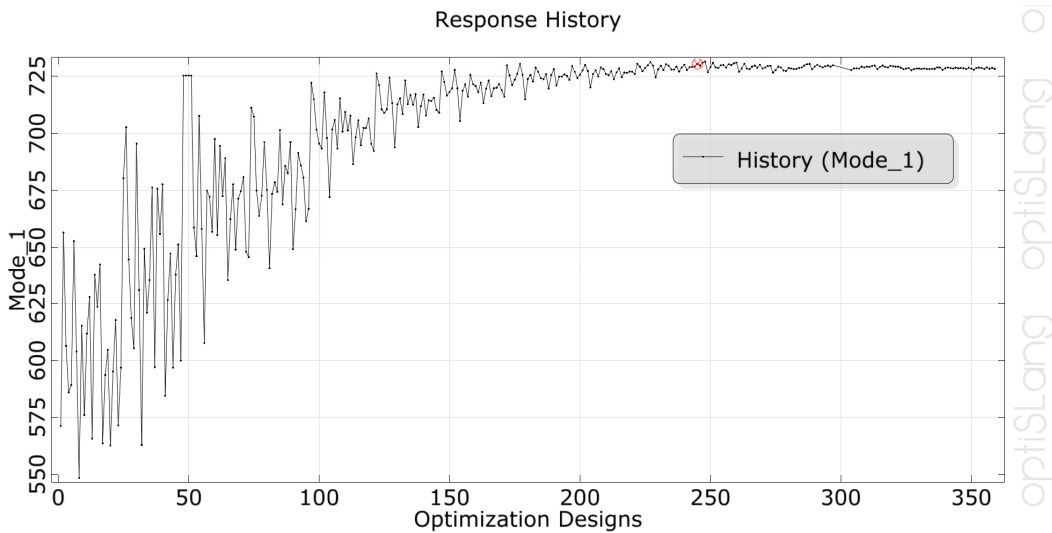


Figure 6: Optimization progress of the first Eigen frequency

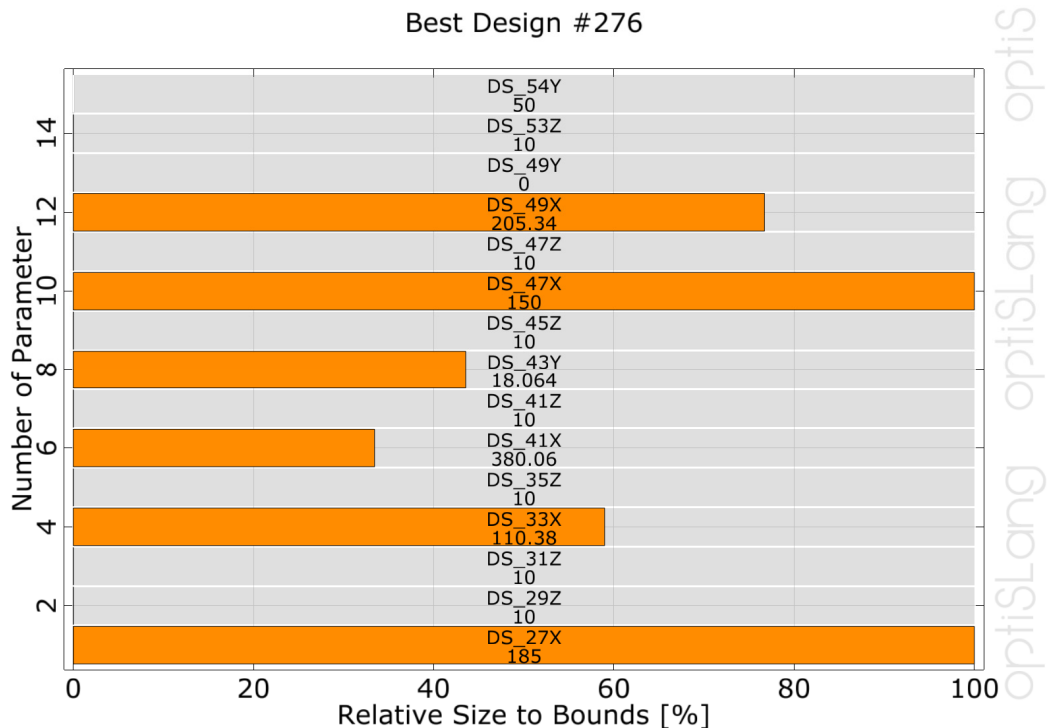


Figure 7: Geometry-parameters of the best design

### 3.3 Intermediate result

The realization of the beads which nearly reached the coating, created a good improvement of the stiffness. The flux of force into the bearing was now realized well. Therefore, the Eigen frequencies could be increased significantly. So, by performing a parametric design optimization with optiSLang, it was able to generate a bead-pattern which obviously improved the vibration behavior of the oil-pan.

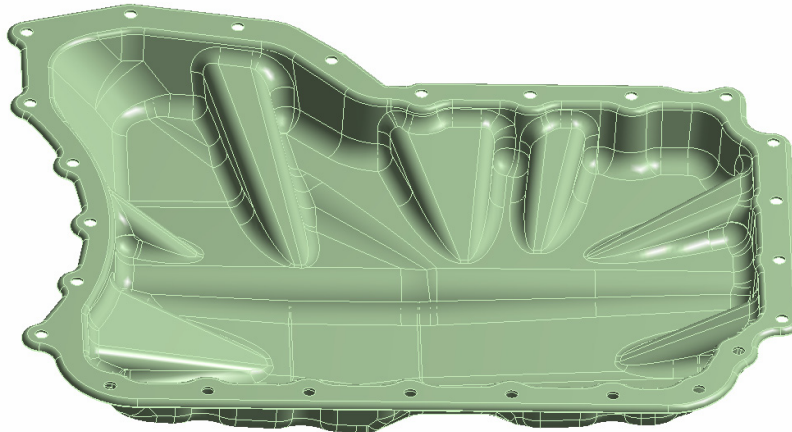


Figure 8: By ARSM optimized bead pattern

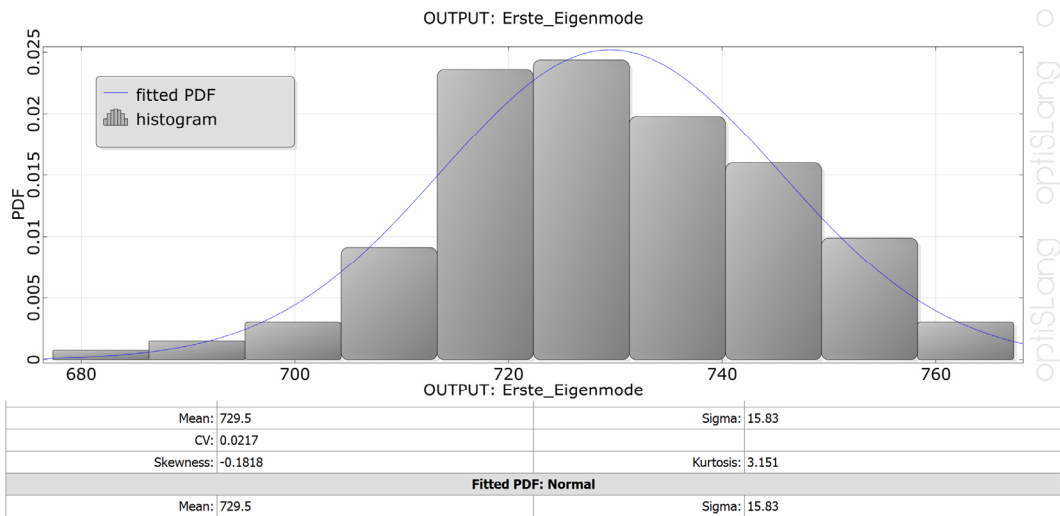
## 4 Robustness analysis

The following step was to examine the robustness of the optimized bead-pattern concerning the manufacturing tolerances and the material scatter. It has to be proved that the design improvements are stable in the manufacturing process where several parameter variations stochastically occur. These stochastic scatters were also simulated by the Latin Hypercube Sampling. Doing this, the necessary calculation time could be reduced to an acceptable period.

The material and geometry parameters were scattered simultaneously.

The variation space of the geometry was  $\pm 1$  mm. The material properties like Young's modulus, Poisson's ratio and density were varied according to examinations of inventory additions. A Gaussian distribution was taken as variation function..





**Figure 9: Probability density function of the first Eigen frequency after the robustness analysis**

The first eigenfrequency varied with a value of about 2.2% along the mean value in-between the 5% quantiles. The 5% quantiles represent here nearly the 2-Sigma-range. Therewith, the variation was below the OEM restrictions which demanded a variation lower than 3%.

So, the optimized bead design could be regarded as robust.

## 5 Summary

A considerably improvement of the vibration behaviour of the oil-pan could be achieved by performing a parametric design optimization.

The optimized design was analysed regarding the robustness against small input variations. This study showed that the robustness is within the demanded constraints. **The achieved improvements were so significant that this oil-pan was implemented in the manufacturing process.**

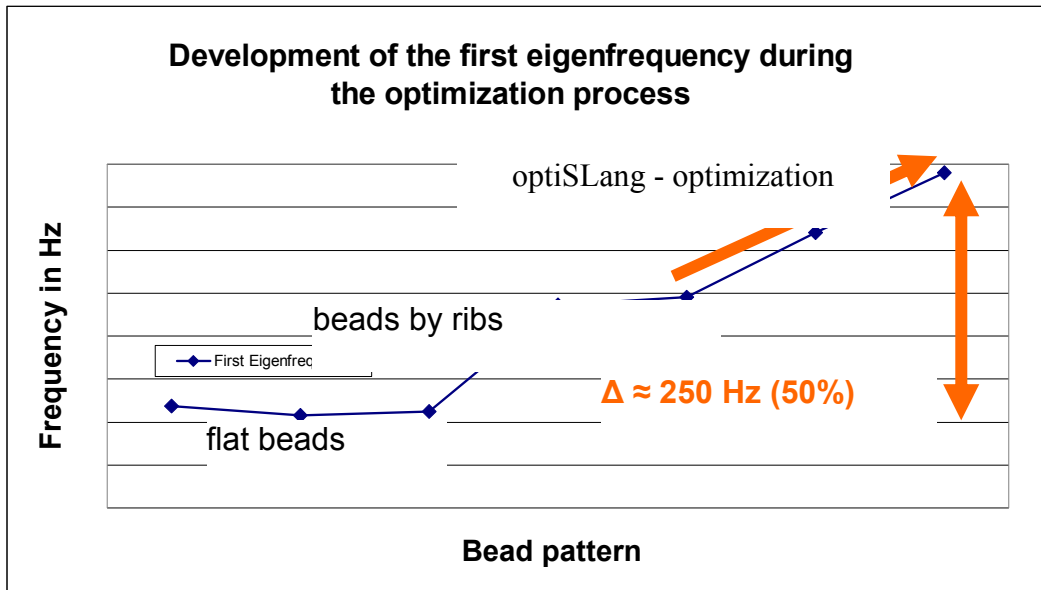


Figure 10: Progress of the optimization run

## 6 Practical implementation and trial

Due to limitations in the manufacturing process, it was not possible to realize the beads in its initial form. The metal gauge during the deep-drawn process would go below a minimum value.

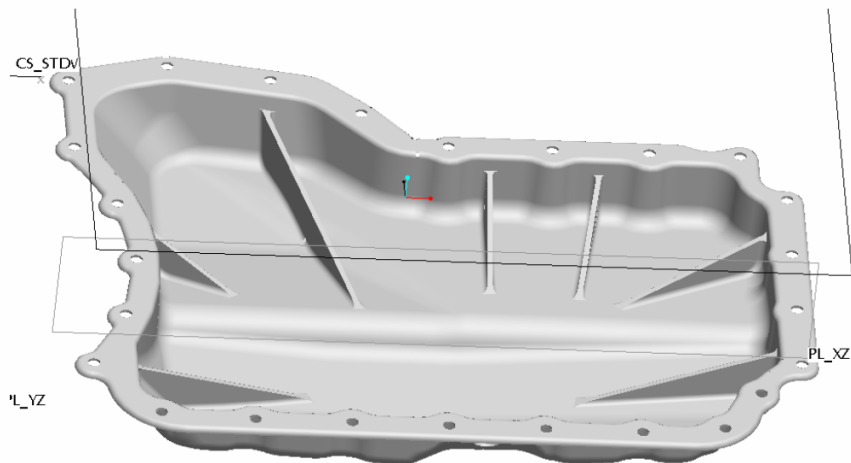
Instead of forming beads, a rib-pattern was realized that have the same type and location.

The positive effect on the acoustic behaviour could be proved in practical tests:

*“During the measurements, a positive effect of a ribbed oil-pan on the motor-acoustic can be determined. ... This positive effect was even more evident in a subjective evaluation.”*

*“The emitted airborne Soundpressure was below the one of a previous serial part.”*

*“The optimized oil-pan tends less to resonate in the redgarded speed range than the serial version of the oil-pan.”*



**Figure 11: Realized oil-pan for tests and manufacturing**

## 7 Conclusion

By performing a parametric design optimization, the vibration behaviour of the oil-pan could be improved significantly.

On this example of use, the potential of dealing with parametric CAD/CAE models for optimization and robustness analysis could be shown.

The CAD-parameters could be optimized directly and the robustness of the optimized design could be proved.

The preliminary inspection regarding topology-optimized beads was helpful to determine the shape and form of an optimal bead-pattern.

This necessary intermediate step showed clearly the large influence of the initial chosen parameterization. The first parameter space was not able to generate the desired improvement. This was quickly determined by a sensitivity study.

Doing principal studies the necessity of deep beads became evident and therefore the variation space was extended.

In the new parameter space the optimization and robustness analysis was performed by application of the automatic process chain without severe problems.

It could be dissipated that for further applications of these methods it is the best way to identify the topology by classic topology optimization at first and then, at a higher level of maturity of the CAD models, to improve the design with the help of parametric design optimization methods and finally to evaluate the robustness.