10th Student Symposium on Mechanical and Manufacturing Engineering, 2022

Vibration Analysis of Grundfos Pump Station for Component Optimization Based on Numerical Models

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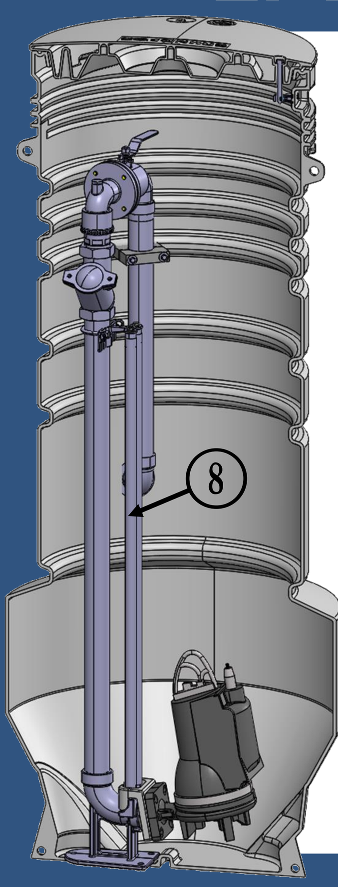
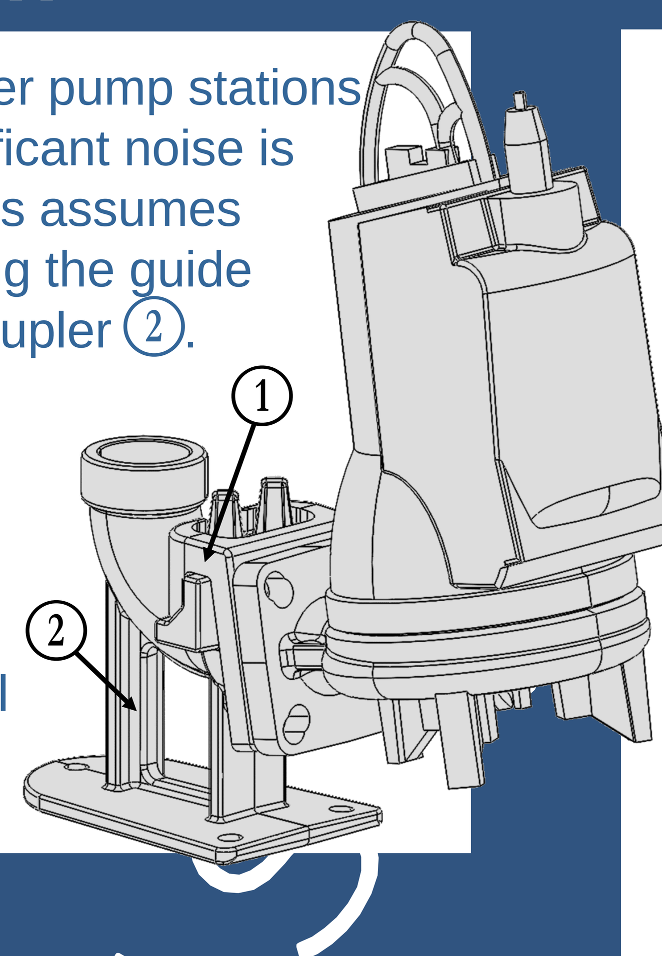
1. Wastewater pump station



Grundfos manufactures and sells wastewater pump stations for collecting and moving wastewater. Significant noise is emitted from the pump station, and Grundfos assumes that the noise can be reduced by redesigning the guide claw 1 connecting the pump to the auto coupler 2. The redesigned guide claw must move the eigenfrequencies of the pump station away from the operating frequency of the pump. A critical frequency band is defined from 31.8 Hz to 71.5 Hz. Analysing the pump station with a detailed FE Benchmark model 3, shows that eigenfrequencies f_2, f_3 and f_4 must be shifted, see Figure 5.



2. Design process

A flowchart summarizing the design process is seen in Figure 1. At 4, a simplified Design model is developed, which is able to replicate the results from the Benchmark model, with lower solution time at the cost of model accuracy. At 5, guide claw design concepts are developed and parameterized CAD models of these are made. A single concept is chosen and ANSYS DesignXplorer is used to produce an approximate response surface, Ω, relating the eigenfrequencies to the parameterized dimensions. The chosen concept and its parameters are seen in Figure 2. An optimization is conducted using this response surface to obtain dimensions for the guide claw concept. At 6, the guide claw concept is adjusted to comply with wishes from Grundfos. At 7, a final verification step is performed, where the Benchmark model is solved to ensure that all eigenfrequencies lie outside of the critical frequency band. Furthermore, it is verified that the guide claw does not fail in static or fatigue loading.

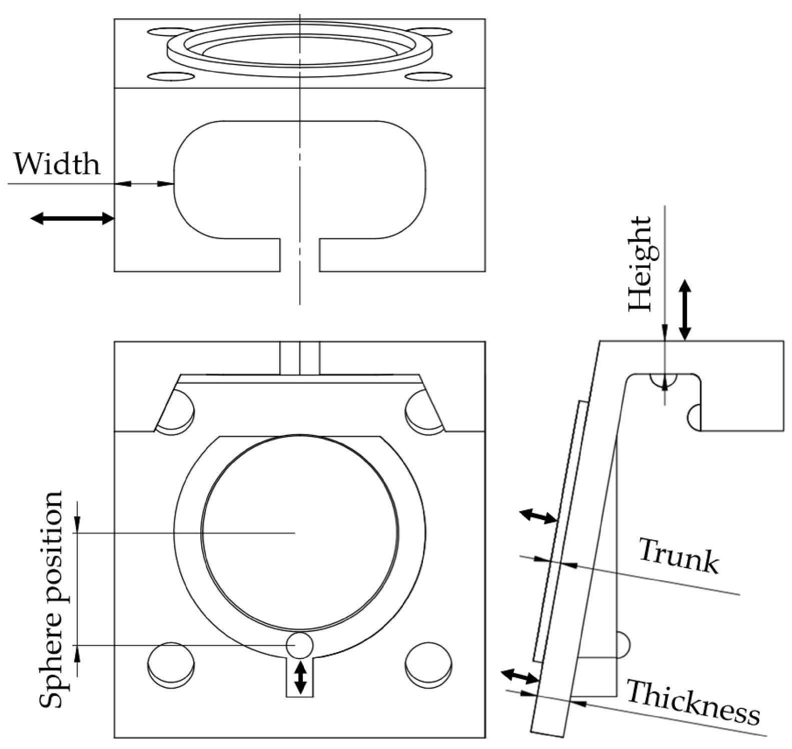


Figure 2. Chosen concept with input parameters.

5 dimensions of the guide claw are parameterized. However, the "sphere position" input parameter is found to have little influence on the eigenfrequencies, and is therefore substituted with the "guide rail length" parameter. As the guide rails are found to have a fundamental eigenfrequency within the critical frequency band. The guide rails are seen in the pump station illustration at 8.

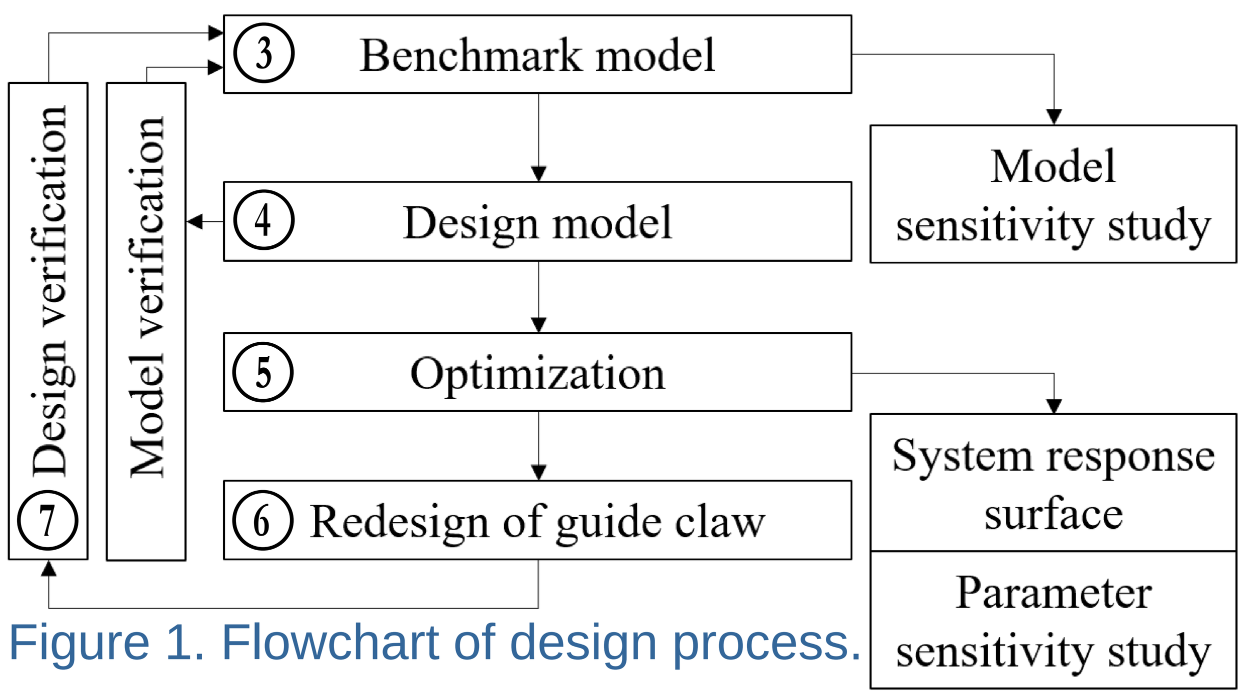


Figure 1. Flowchart of design process.

3. Optimization

The optimization is performed using a Multi-Objective Genetic Algorithm (MOGA) to obtain Pareto optimal points for minimizing the second eigenfrequency f_2 while maximizing the third eigenfrequency f_3. As the MOGA algorithm requires several thousand function evaluations to converge, the response surface, Ω, is used instead of the Design model. Ω is formulated as a piecewise multilinear interpolation between the discrete points $p_i = [P2_i, P3_i, P4_i, P5_i, P6_i]$, mapping $\mathbb{R}^{5+} \rightarrow \mathbb{R}^{2+}$. Such that f_2 and f_3 of the pump station are evaluated approximately as:

$$f_2 \approx \Omega_2(P2, P3, P4, P5, P6) \qquad f_3 \approx \Omega_3(P2, P3, P4, P5, P6)$$

The resulting Pareto front, ψ, in criterion space is seen in Figure 3.

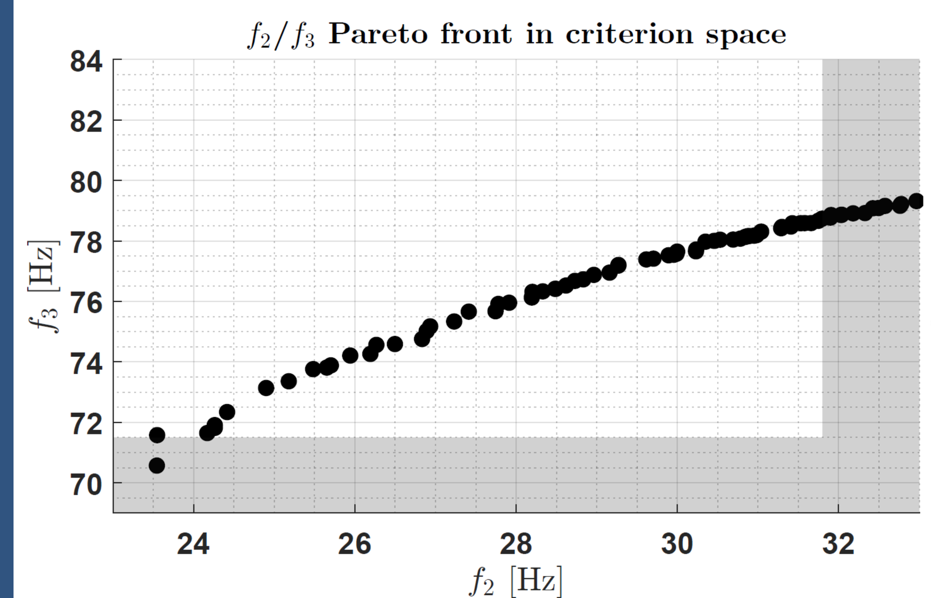


Figure 3. Pareto front.

$$F = Max(G_i)$$

$$G_i(f_i) = \begin{cases} \dfrac{f_i - 31.8}{31.8}, & if\ f_i \leq 44 \\ \dfrac{71.5 - f_i}{71.5}, & otherwise \end{cases}$$

$$f_i \in \psi\ ;\ i = 2{,}3$$

Equation 1. Cost function.

The final optimized design, Figure 4, is chosen from ψ. The chosen Pareto optimal solution has the largest relative distance, F, between f_2 and f_3 and the critical frequency band, as described by the cost function defined in Equation 1.

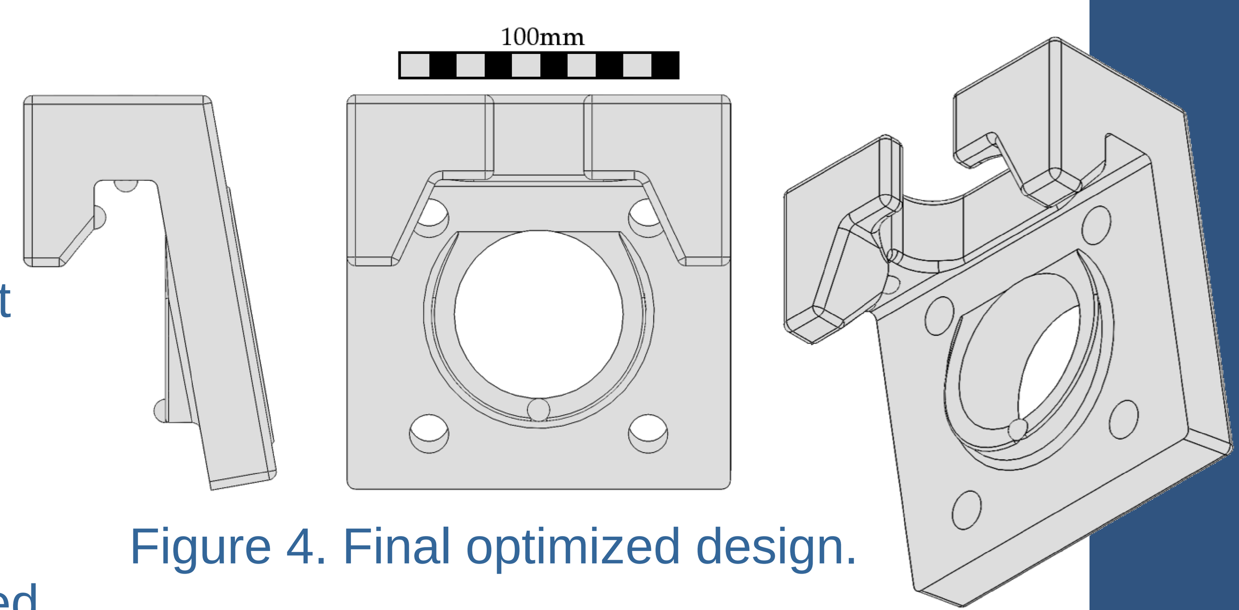


Figure 4. Final optimized design.

4. Conclusion

The eigenfrequencies of the original guide claw and the redesigned guide claw are seen in Figure 5, where the grey area indicates the critical frequency band. It is concluded, that when evaluated in the Benchmark model, all eigenfrequencies of the pump station lie outside of the critical frequency band, thus the solution is accepted.

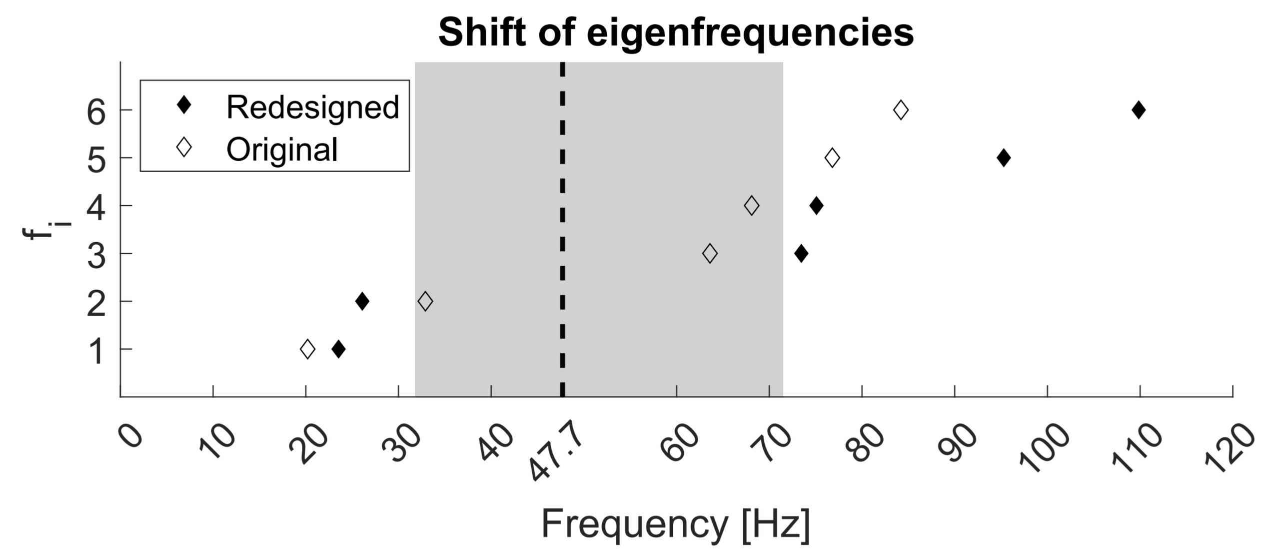


Figure 5. Position of eigenfrequencies.

Acknowledgement

The authors of this work gratefully acknowledge Grundfos for sponsoring the 10th MechMan Symposium