ROBUST DESIGN BY OPTIMIZATION UNDER RELIABILITY CONSTRAINTS

R. Helfrich, A. Schünemann

INTES GmbH, Stuttgart, Germany, www.intes.de

SUMMARY

A robust design can be characterized by low sensitivities due to parameter changes, where the changes are small and typically within the tolerances of the design parameters. For designs with high safety factors, robustness is often postulated and not studied in detail. But robustness is becoming very important, when optimization is used to widely exploit the material and safety factors are drastically reduced. Then, small parameter changes can have a significant influence on the results and failures become more likely. So, with the wider use of design optimization, robustness of designs has to be considered more systematically than in the past.

From a methodological point of view, optimization and reliability methods have to be available for robust design simulations. Beyond that, the key point is the integration of both methods, i.e. the use of reliability constraints in optimization methods, to directly achieve a robust optimum.

From the parameter point of view, there are design variables for the optimization, and there are basic (uncertain) variables for the reliability analysis. A design variable may be uncertain or not. The selection of design variables depends on possible design variations like material, element properties (e.g. shell thickness, beam cross section), and geometry. The selection of uncertain variables depends on tolerance specifications and manufacturing conditions, which influence the product properties. The right ranges and distributions of uncertain variables need additional model input, which best should be obtained from product and manufacturing quality measurements. In addition, also load factors and load directions can be uncertain.

As an industrial example, the paper shows a charge air cooler, where an optimization is performed to reduce weight and stresses. Then, uncertain parameters are introduced and failure modes are defined. Their influence on the optimized design is studied and sensitivities are evaluated. Finally, an integrated optimization with reliability constraints is applied to directly achieve a robust optimum. Analysis, optimization, and reliability are performed with the industrial FEA code PERMAS.

1: Model of Charge Air Cooler

Fig. 1 shows the model of the charge air cooler and Fig. 2 shows the loading conditions by inner pressure and contact between header and tank foot.

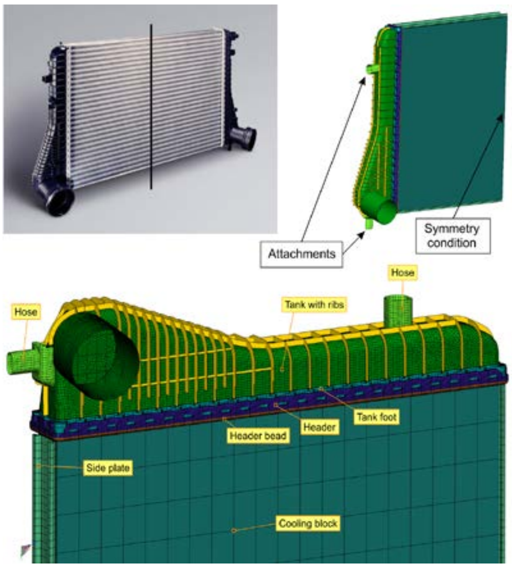


Figure 1: **Model of charge air cooler (photo by courtesy of MAHLE Behr, Stuttgart, Germany)**

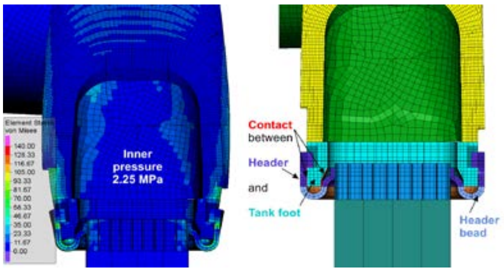
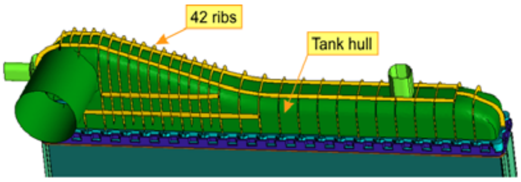


Figure 2: **Pressure loading (deformed structure) and contact condition**

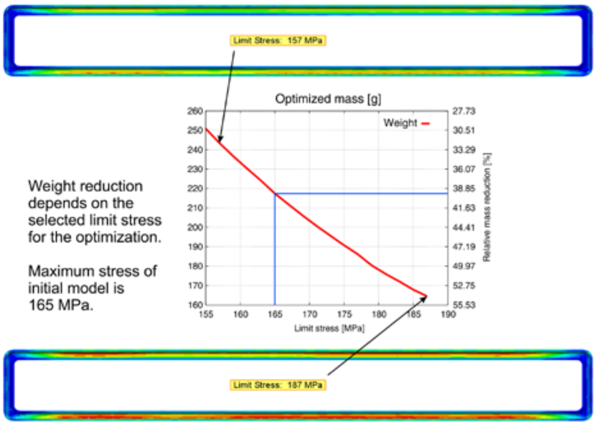


44 Design variables
Rib heights for 42 ribs (± 3 mm; initially 4.4 - 6.3 mm)
Shell thickness of tank hull (0.01 - 5.6 mm)
Shell thickness of ribs (0.01 - 6.0 mm)

Figure 3: **Optimization model**

2: Weight Optimization under Stress Constraint

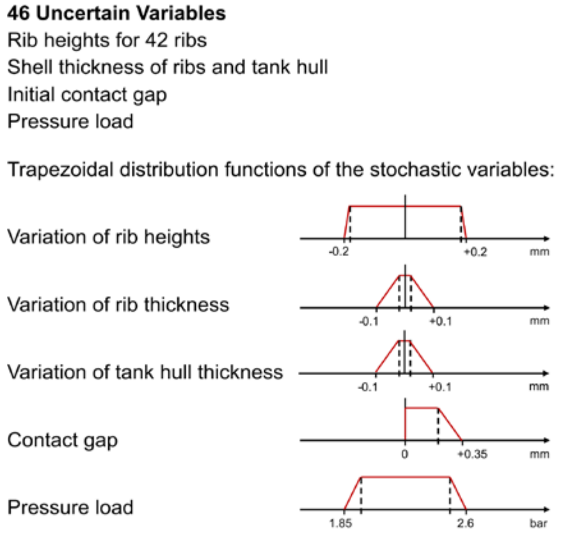
Fig. 3 shows the details of the optimization model. Fig. 4 shows the relationship between the allowed stress limit for optimization and the achieved weight reduction by optimization.



Weight reduction depends on the selected limit stress for the optimization.

Maximum stress of initial model is 165 MPa.

Figure 4: Relation between weight reduction and stress limit



46 Uncertain Variables
Rib heights for 42 ribs
Shell thickness of ribs and tank hull
Initial contact gap
Pressure load

Trapezoidal distribution functions of the stochastic variables:

Variation of rib heights

Variation of rib thickness

Variation of tank hull thickness

Contact gap

Pressure load

Figure 5: Details of the stochastic model

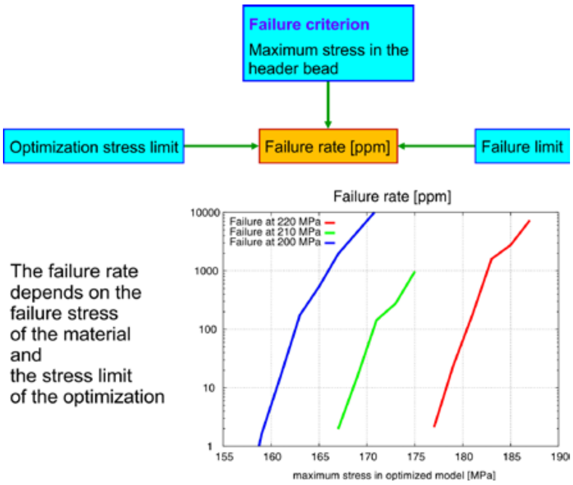
3: Stochastic Model and Reliability Analysis

Fig. 5 shows the details of the stochastic model and Fig. 6 shows the resulting relationship between stress limit for optimization, the failure stress of reliability analysis and resulting failure rate.

4: Conclusions

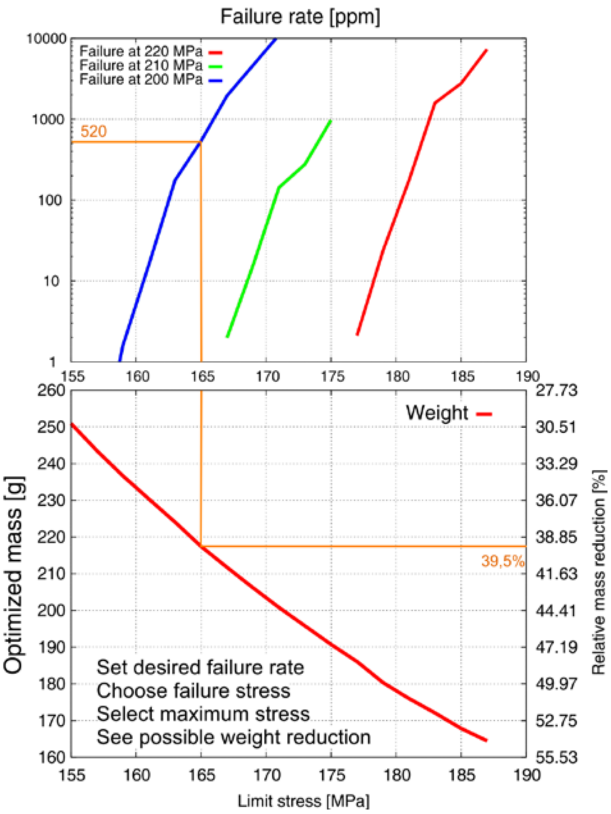
Optimization of sizing and shape as well as reliability analysis with stochastic modelling of uncertainties are integrated in PERMAS including nonlinearities like contact. The combination leads to deeper insight to relations between model data and results and a robust design.

As a result of this combination, Fig. 7 shows the relationship between weight input and failure rate: Less weight reduction increases reliability and vice versa. In general, the presented method can set a transparent link between expense for material quality and quantity on the one hand and the failure rate or safety on the other hand.



The failure rate
depends on the
failure stress
of the material
and
the stress limit
of the optimization

Figure 6: **Relationship between failure rate, failure stress and limit stress (i.e. maximum stress in optimized model)**



Set desired failure rate
Choose failure stress
Select maximum stress
See possible weight reduction

Figure 7: **Weight reduction-failure rate diagram**