



CUSTOMER STORY // AUTOMOTIVE ENGINEERING

COST AND FUNCTION OPTIMIZATION APPLIED TO A PROPORTIONAL SOLENOID

The application of optiSlang supports CAE-processes of cost and function optimization to create, compare and evaluate different competitive design variants of solenoids used for the control of automatic transmissions.

Introduction

Dilemma of the Product Development

Cost as well as function of a product are decisively influenced by its requirements, customer benefits and, especially, by its design. There are different development approaches to reduce the cost and to optimize the function of products, which differ in scope, potential of influence and required time for either new development or an extension of a new variant or a ratio project.

In addition to a reduction of the product costs, these approaches also lead to a launch of new products and technical innovations in shorter time, with the goals of high quality and attractive prices. The greatest potential for influencing costs and functions is in the time of product planning and development at the beginning of a product realization like shown in Fig. 1. The design, development and production planning departments influence cost and function of a product with approximately 90 % by a simultaneous cost share of about 9 % as given in Ehrlenspiel et al. (2014). Due to these facts, a very close networking of technical-scientific and cost accounting aspects in these three departments is necessary.

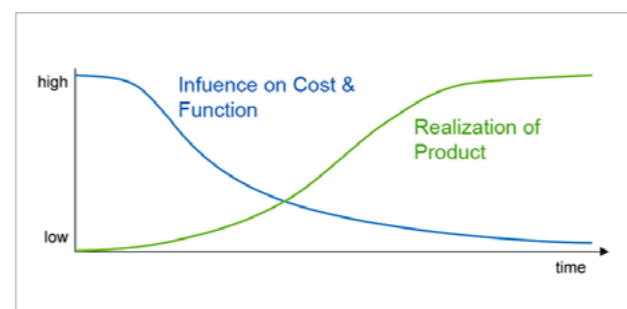


Fig. 1: Dilemma of the product development in reference to Ehrlenspiel et. al. (2014)

The challenge in designing products is to seek an optimal combination of function and cost fulfillment without the knowledge where to search exactly. One reason for this dilemma can be different and contradictory needs of customers and the number of possible solutions. In order to determine the cost and functional optimum, several component topologies with different materials, manufacturing processes, geometric parameters and tolerances would have to be developed, designed and compared to each other.

Even a simple comparison of different screw connections, which can be interpreted as different product topolo-

gies, shows the complexity cost correlation only in terms of different relative costs.

Performing such a detailed study as shown in Fig. 2 for all components of a product will require a large number of samples, development time and costs. No company can afford such an effort due to the cost and time pressure referred by Reischl (2000). In practice, therefore only a few detailed solutions are compared for example on the basis of a morphological box and a subsequent pairwise comparison or similar development methods. The resulting product costs are either estimated using different methods or calculated with the appropriate effort as mentioned e.g. in Pahl et. al. (2007).

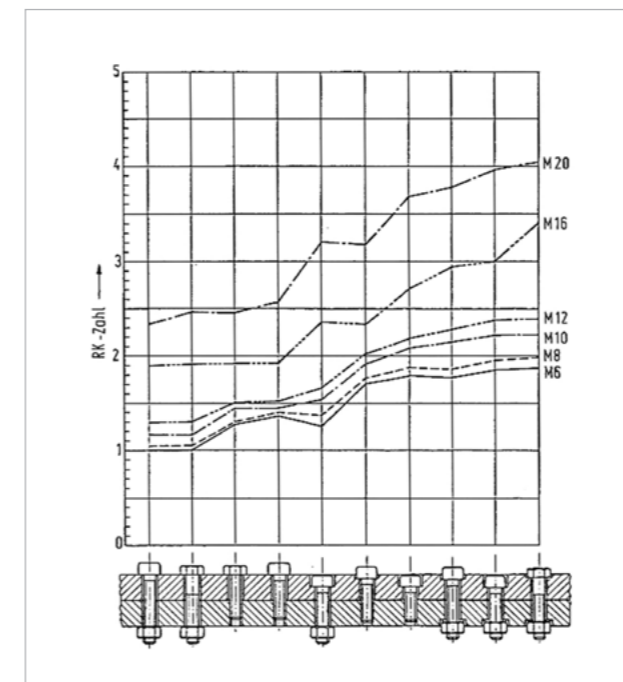


Fig. 2: Influence of the component topology on the costs using the example of relative costs for screw connections as shown in Naefe (2012)

Innovation Hypothesis

This detailed problem description clearly shows the complexity and comprehensiveness of a cost and function optimization. It also becomes obvious that there is a great potential in creating such a methodology. Here, the basic focus is to produce a variety of variants with different component topologies in a short time for the analyses of their functions and costs. Finally, this evaluation enables a faster development of competitive and innovative products.

The actual state of the art is a purely functional optimization based on a parameterized product model and a defined workflow as shown in Fig. 3. Computer-aided optimization software, e.g. Dynardo's optiSlang, was used as shown in Schwarz (2018). New design variants are generated by using an evolutionary algorithm, which varies geometrical parameters like diameter and length measures within specified limits. Here, the functional characteristics are determined by simulation and are evaluated in accordance with the target values and constraints for each design. Due to the optimization logic, which is contained in the algorithm and the objective functions, a so-called Pareto diagram is created as it can be seen in the middle of Fig. 3 for two technical objectives.

Part of the presented research work is to determine the cost for each generated design and to declare and optimize this value as a target. In this article, such an extension is described for the first time. Consequently, the potential solution space is extended by an economical dimension as shown on the right side of Fig. 3.

Linear Force Solenoid for Automated Transmissions

The method is developed by using the example of a proportional solenoid, as depicted in Fig. 4 (see next page). This solenoid is used to control automatic transmissions. Usually, such a solenoid is operated at a maximum of 1,2 A and generates

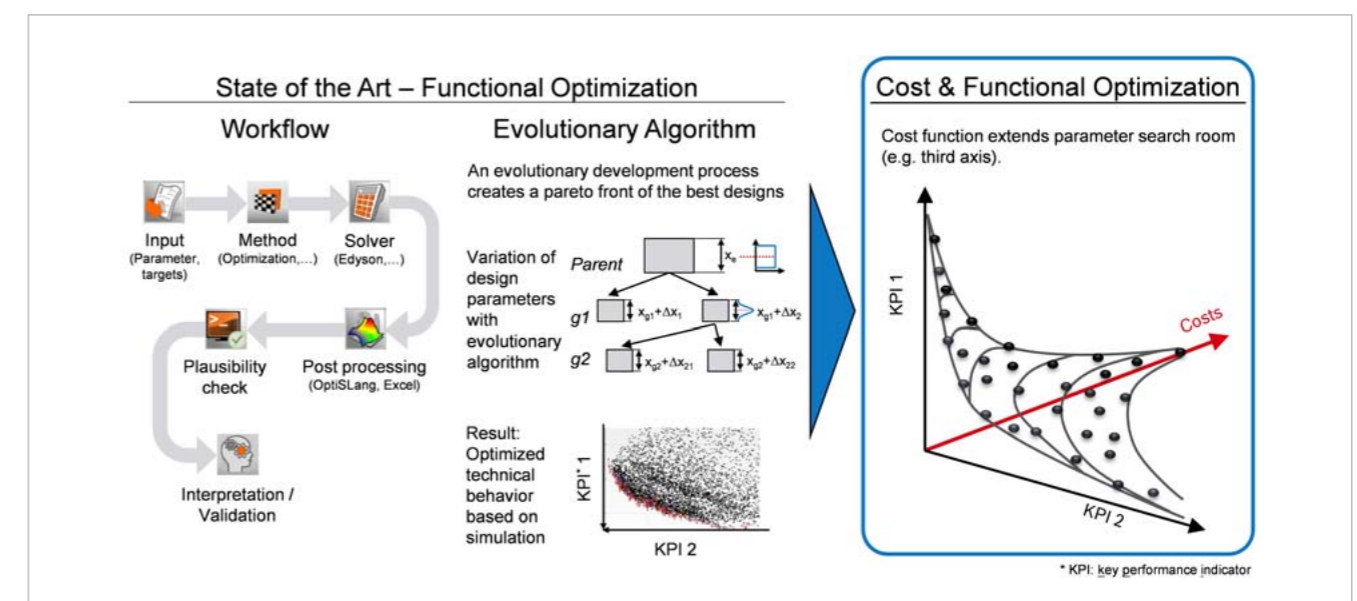


Fig. 3: State of the art and innovation hypothesis

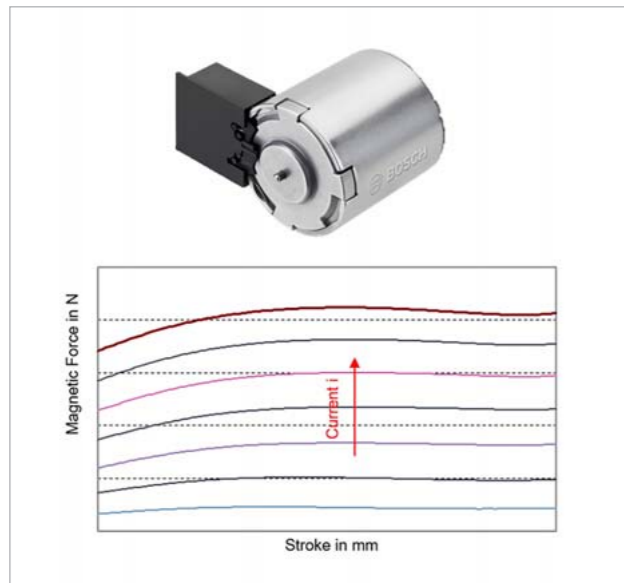


Fig. 4: Linear Force Solenoid with its characteristic curve of magnetic force stroke

a magnetic force of up to 25 N. The customer specifies the characteristic curve of the magnetic force stroke for different current levels as shown in Fig. 4. Typical customer specifications are particular forces and slope gradients at given stroke positions. For the solenoid used in this investigation, a function optimization like illustrated in Fig. 3 (see previous page) has already been available. Due to the large number of pieces, the product is very well suited for an extension of the function optimization to a cost and function optimization.

Requirements to set up a Cost and Function Optimization

The prerequisites for the optimization of costs and functions are, on the one hand, the determination of the component cost and, on the other hand, the expansion of the variables

for effective cost optimization. In each case, a differentiable cost surcharge calculation is performed to determine the component costs. In addition to the material costs based on geometrical parameters, this approach also includes the costs for the added value as shown in Fig. 5. With the information on the production process chains, the respective cycle times and the machine hourly rates must be calculated. The more accurate the underlying data base, the more accurate is the calculation. In this study, the data sources are taken from purchasing, manufacturing and cost experts.

As already mentioned, not only the previous geometric design parameters are varied for the generation of new designs, but also the materials and the associated manufacturing technologies, as well as tolerances and topologies of the individual components. These extensions of the variables have an impact on the cost calculation. As a result, the number of possible variants and combinations increases and correlations become apparent.

Workflow

Derived from the requirements for a cost and function optimization, a workflow is set up, which not only varies geometric design parameters but also materials by its material number. Based on the selected material, the material parameters for the magnetic force simulation are automatically adjusted and the manufacturing processes for the cost calculation are updated, see Fig. 6.

Furthermore, differently designed simulation models for the proportional magnet are created by topology variables. The topology variable controls the selection of a bill of material (BOM) from a large number of already predefined BOMs. They describe possible solenoid structures. Based on the selected BOM, the geometry model is assembled in a Python script and Gmsh does the meshing according to Geuzaine (2009). At the same time, the tolerance classes of

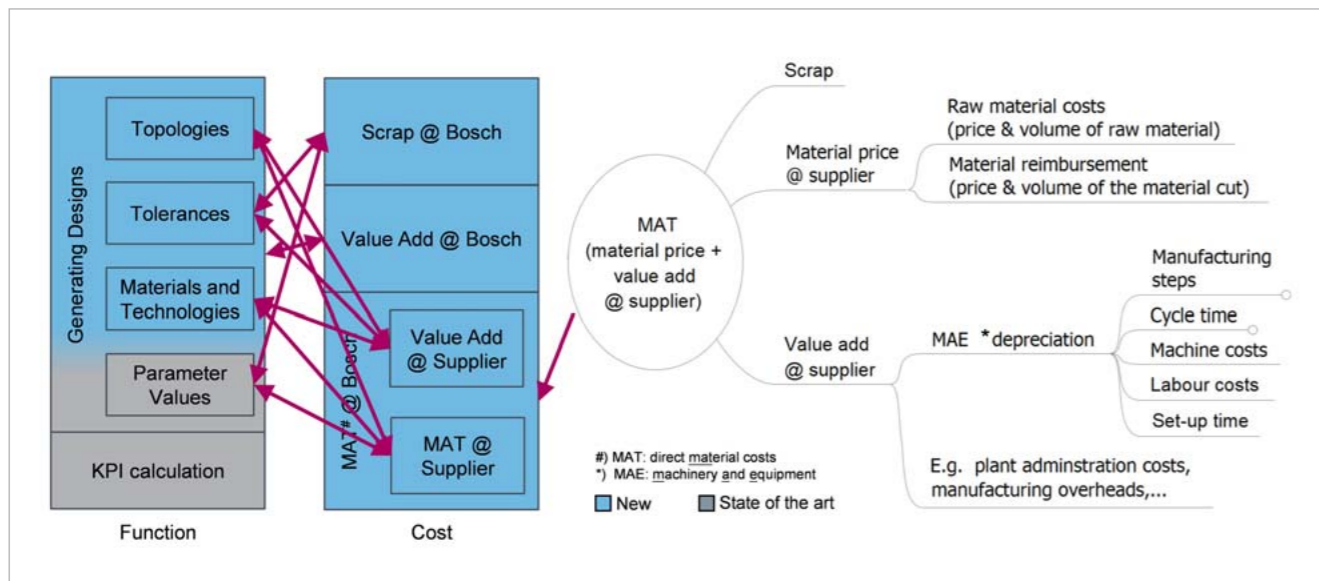


Fig. 5: Requirements to set up a cost and function optimization

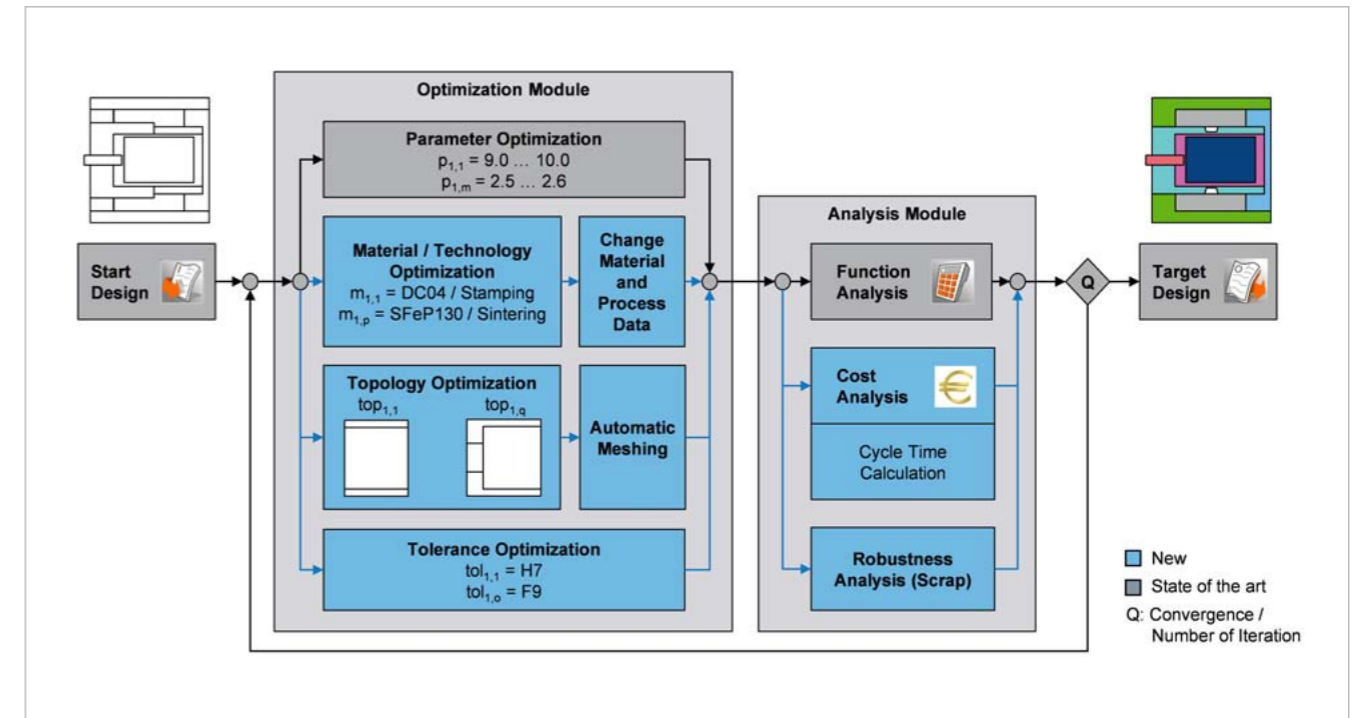


Fig. 6: Schematic representation of the cost and function workflow

the selected geometrical design parameters are varied via discrete variables. The tolerance class has an impact on the manufacturing process chains as well as on the integrated robustness analysis (for more details see chapter Tolerance Optimization).

As a starting point for the optimization either one or more start designs can be defined. Ideally, this start design is determined by a previous sensitivity analysis. Based on the start design, the listed variables, such as geometric design parameters, materials, topologies and tolerances, can be considered, varied or optimized either individually or in any possible combination in the optimization module. After

the optimization module, the so-called analysis module is processed. This analysis module includes the electromagnetic simulation, the Python based cost calculation and the robustness analysis. The process repeats itself until a maximum number of designs has been generated or a convergence with the optimization goals has been achieved.

The realized workflow generates a Metamodel of Optimal Prognosis (MOP), see Most (2008), which is based on a sensitivity study covering 4000 designs using Latin Hyper Cube Sampling, see Fig. 7. The MOP replaces the solver call for the function determination in the optimization as well as in the integrated robustness analysis. While a solver call

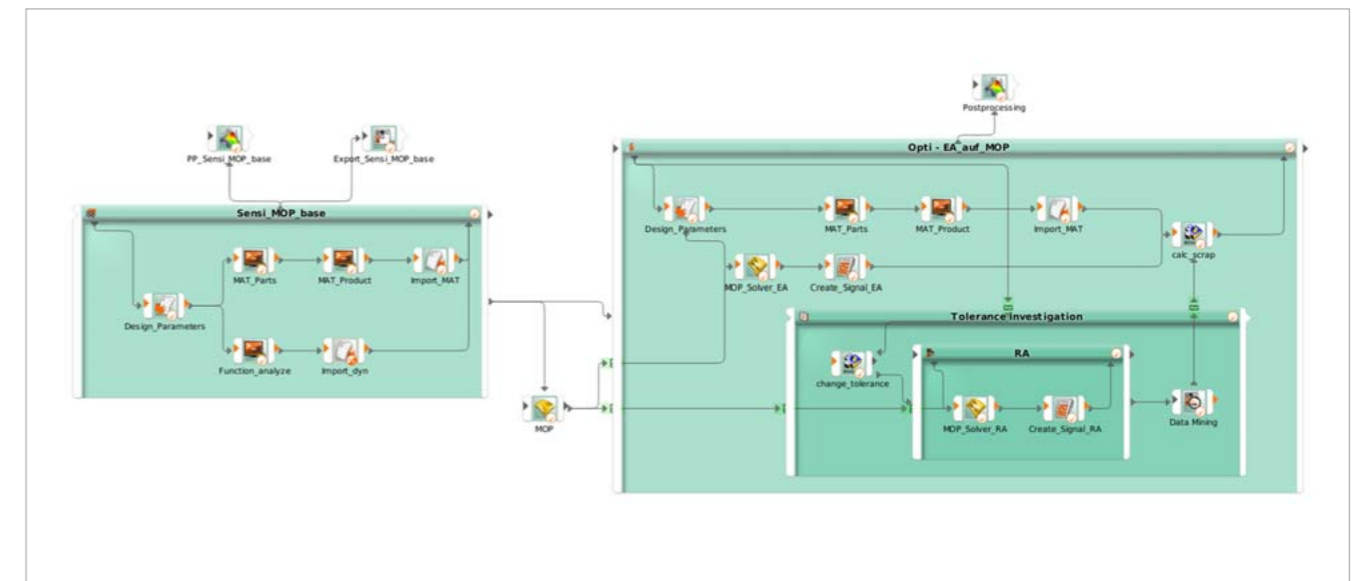


Fig. 7: Realized workflow in optiSlang

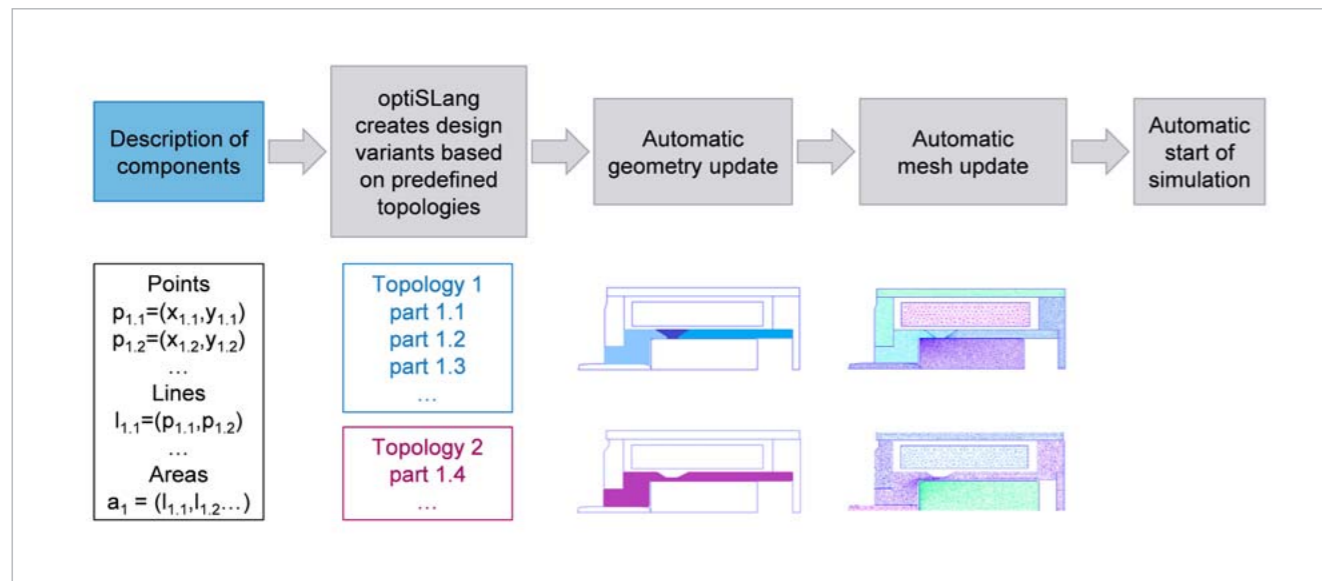


Fig. 8: Workflow of the topology optimization in detail

requires approximately 5 minutes the MOP produces an equivalent result instantaneously. Thus, replacing the solver call with MOP speeds up the optimization drastically. Using a Python script, the robustness analysis distributions are automatically calculated based on the generated designs. A data mining node extracts the distributions to check and pass on the relevant KPI like scrap-rate to the subsequent cost node.

Topology Optimization

All components are described upfront of an investigation by simple specification of the x, y coordinates, line definition and area assignment as shown in Fig. 8 on the left side. As already mentioned, the component descriptions are transferred into a geometry script by means of a Python script based on an already predefined bill of materials. This geometry script describes a design of which the simulation mesh is automatically generated with the use of Gmsh. The electromagnetic simulation starts as soon as this simulation model is available.

A first example shows the influence of two different geometries of the so-called pole tube, as they are highlighted in blue and pink in the center of Fig. 8. With the pole tube, the characteristic magnetic force-stroke curve of the proportional solenoid can be formed and also the armature is guided in it. The two considered topologies of the pole tube differ such that topology 1 (blue) consists of a three-part pole tube, whereas in topology 2 (pink), a one-piece pole tube is used. In this example, not only the topology but also the materials and geometrical parameters were varied.

When looking at the results in Fig. 9, two different solution spaces are recognizable, which basically depend on the topology. The solutions of topology 1 tend to be more expensive than the topology 2 due to the larger number of individual parts and the associated higher number of production steps. Nevertheless, its technical behavior is better due to its

complete magnetic separation as described in Kallenbach et. al. (2012). In the end, a smaller deviation of the characteristic curve from the customer specification can be achieved.

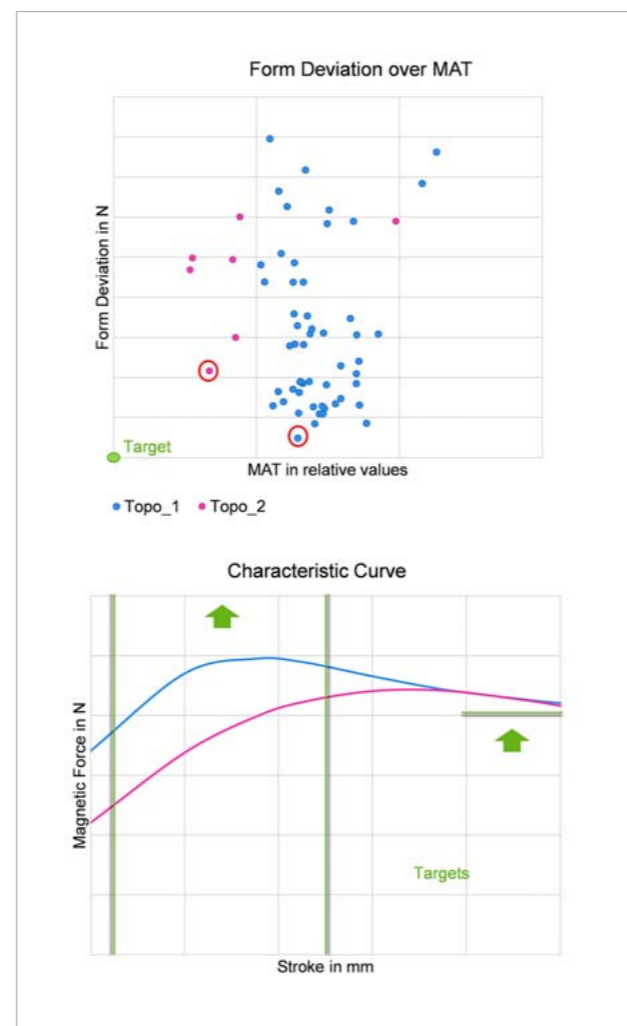


Fig. 9: First results of the topology optimization

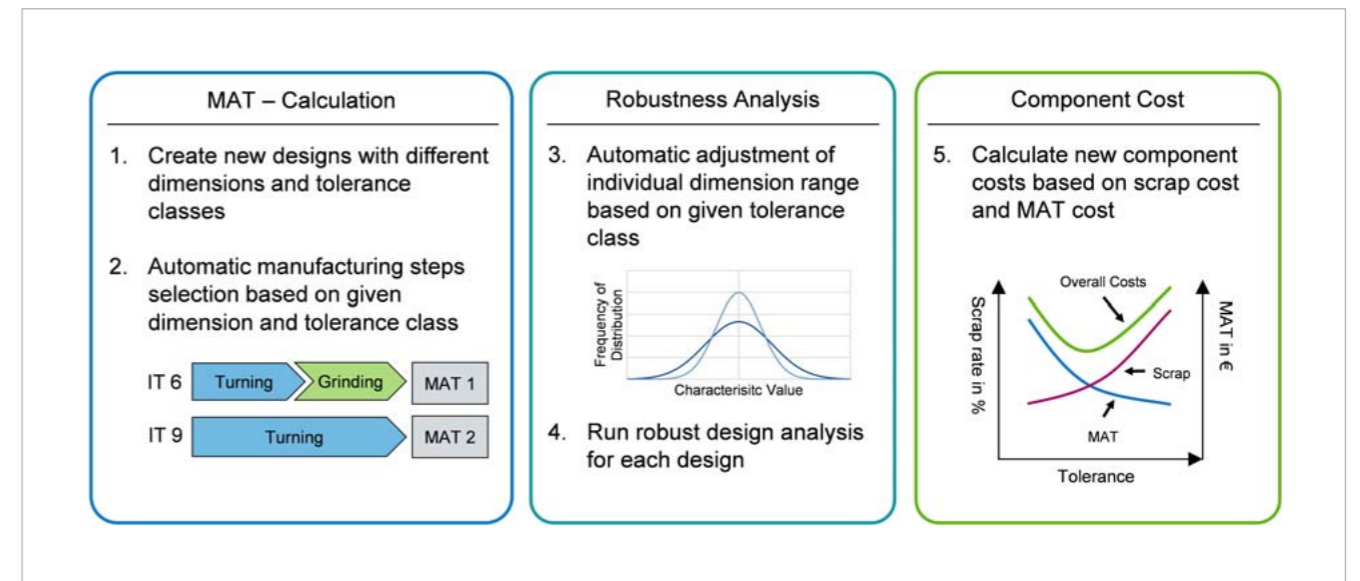


Fig. 10: Details of the tolerance optimization

The functional influence of a complete magnetic separation can be clearly seen by taking a closer look at the magnetic force-stroke curves. At the beginning of the stroke range, the magnetic force of the topology 1 is higher in contrast to topology 2, see the bottom diagram in Fig. 9. Due to the optimization criterion to maximize the force in this stroke range, the optimization algorithm favors the topology 1 as opposed to topology 2. Therefore, several designs are generated with topology 1. The boundary condition of not undercutting a certain force level at the end of the stroke range is achievable with both topologies.

Tolerance Optimization

In addition to the topology optimization, the newly developed method makes it possible to vary the tolerance classes and, consequently, also the standard deviation of individual geometrical design parameters in order to determine their influence on costs and function. By means of an integrated robustness evaluation in the analysis module, the variance of the design variants is automatically examined based on 50 further design variants, which scatter within the selected tolerance.

With the robustness analysis, it is therefore possible to produce a statement about the expected scrap of a design variant in form of an additional cost point, see Fig. 10. In addition, depending on the selected tolerance, a predefined manufacturing process chain for the production of this design is chosen, which influences the cost calculation. For example, for a very small tolerance class, a grinding process is required in addition to a turning process, see left side in Fig. 10.

In a first application of the tolerance optimization, the tolerance of a parameter, materials and geometric parameters are varied for one predefined topology. As shown in the upper diagram in Fig. 11, there are blue highlighted solutions with nominal tolerance. In addition, the optimiza-

tion algorithm has also selected variants with a tighter tolerance class, which, as expected, have a higher MAT+Scrap value due to the more extensive and possibly more complex

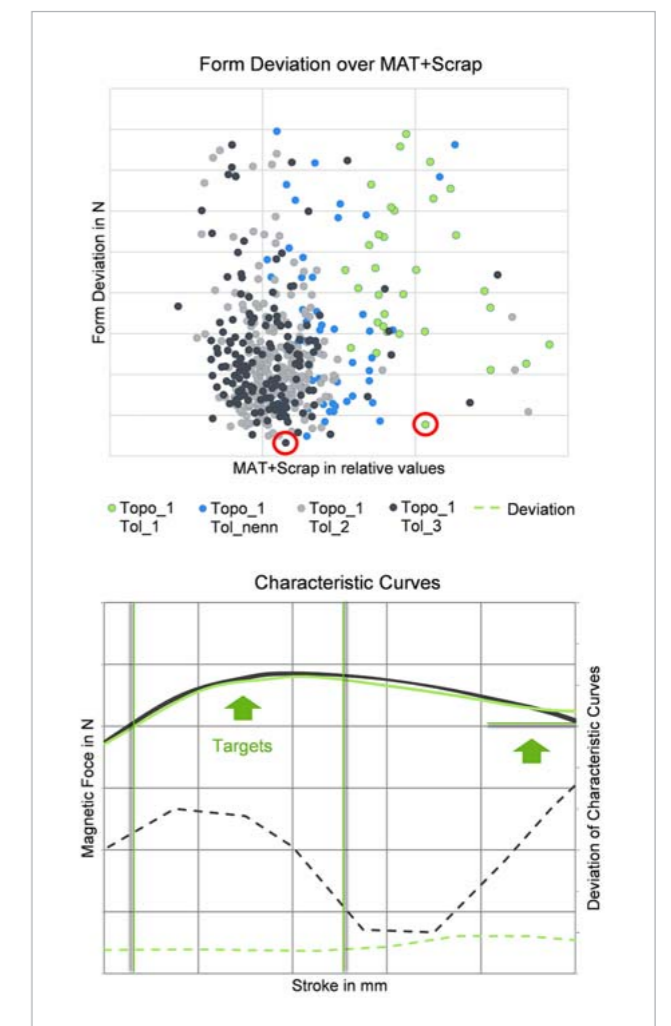


Fig. 11: First results of the tolerance optimization

production. In contrast, the design variants with larger tolerances tend to be more cost effective.

The comparison of the characteristic curve spread over the stroke range is interesting, as shown in the lower diagram in Fig. 11*. Here, the influence of the tolerance on the function is clearly recognizable and with it the justification of the different costs. Within the additional 50 designs along the entire stroke, the variant with the tighter tolerance (green lines in Fig. 11*) has a significantly lower dispersion (dotted green line in Fig. 11*) compared to the variant with the larger tolerance class (grey lines and dotted grey line in Fig. 11*). According to the simulation, this functional difference is associated with up to 12 % higher MAT. If the higher dispersion is acceptable for the customer, the preferred design should be one with an larger tolerance class. | * see previous page

Conclusion

For the first time, the developed workflow offers the opportunity to carry out an extensive cost and functional optimization. In this computer-aided simulation methodology, different materials, tolerances as well as component topologies are considered in addition to the well-established geometric design parameters. As a result, a variety of very different design variants are generated in a short time and a statement as well as the relationships in a technical and economic point

of view can be derived. Due to a parallelization of the cost and functional analysis, this additional function does not contribute to increase the simulation time.

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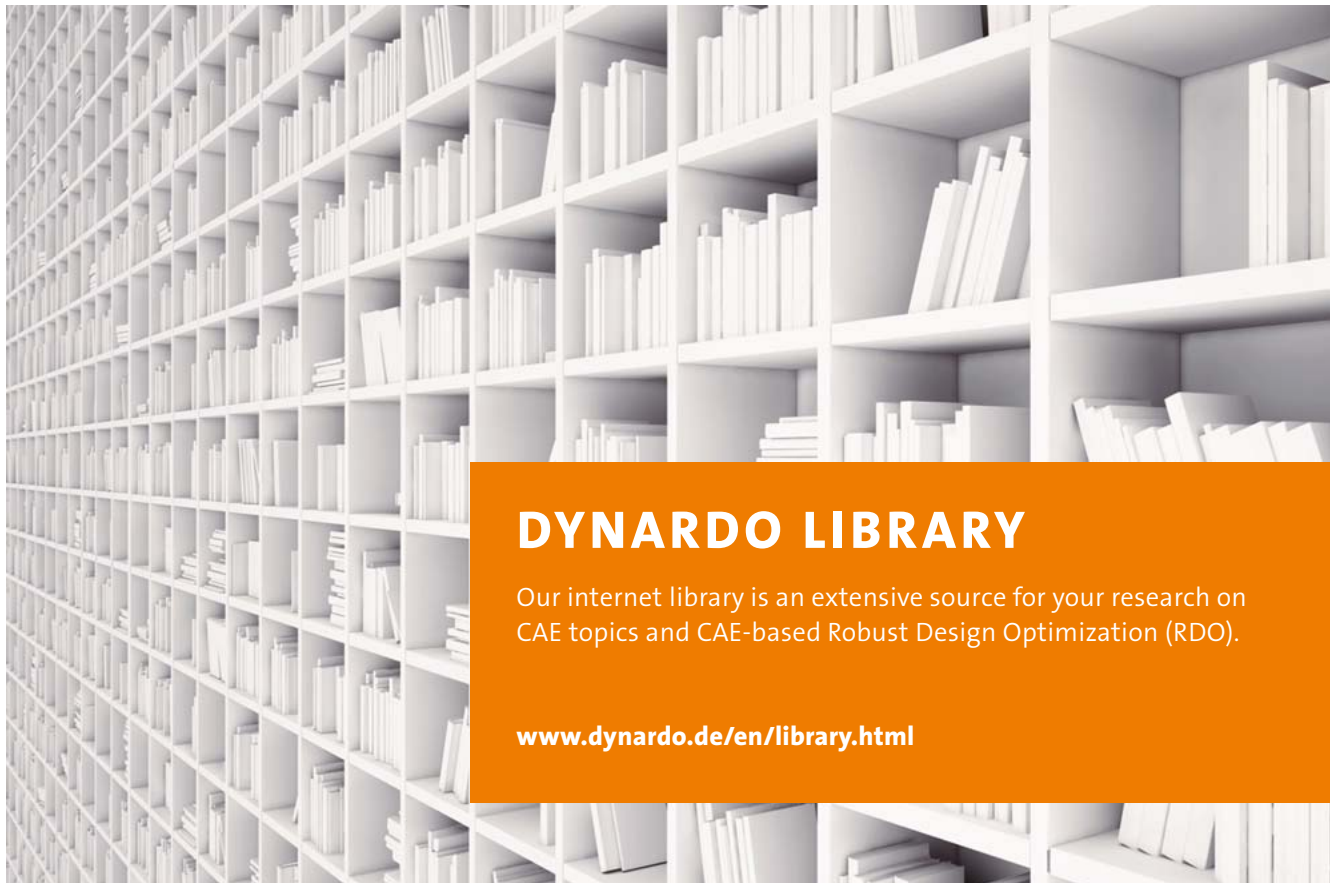
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