



CASE STUDY /

Optimization of an Actuator Magnetic Force with optiSLang

With a coupling of Ansys Maxwell and optiSLang, it is possible to obtain geometric improvements of an actuator by optimizing the shape and level of its characteristic force curve.

/ The System, Objective and Constraints

With the possibility of combining Maxwell and optiSLang, the optimization expertise can be used to improve actuators for Hilite products. In the following, an example will show how the combination of Ansys Maxwell and optiSLang was used to optimize the magnetic force curves and to improve valve performance and behavior.

Issue

Hilite produces valves for the usage in automatic and double clutch transmissions (DCT). They contain different valves with different tasks, which usually are optimized separately. For future products a new actuator had to be designed that could be used in multiple valves. Two of them are gear shift and clutch control valves; they are shown in Figure 1. Both curves, the one for the pressure in top and the other one for the flow valve in the bottom have to be actuated optimally. Therefore, different criteria of the different valves ensure the possibility to optimize the new actuator and guarantee the functionality at the same time.

Ansys Maxwell is able to compute magnetic forces, which are part of the main objective of the optimization task. Figure 2 pictures the simulation model that is used to compute the axial magnetic force on the armature. Due to already existing analyses, the number of parameters that mainly influence the force could be reduced to five. All important parameters are located within the same region of the valve. The parameters influence the characteristic curves, which are shown in the figure as well.

Criteria for the Optimization

During the development process, the changes in the initial design lead to various optimization tasks. Therefore, objectives, depending on characteristic pressure curves of the system, have been generated. The most important criteria are marked in different colors on the field of characteristic curves in Figure 3. Here, the criteria 1 to 7 are used as constraints to get the curves in the optimal direction. The criterion 8 is set as an objective.

Number 1 (green) is calculated between two specific stroke positions for two different electric currents. This delta of the magnetic force is important for the shape of the valve's Q-I curve. Number 2 (dark blue) limits the force at zero stroke and maximum current to a specific minimum. This constraint is used as an objective for the first optimization with an evolutionary algorithm.

Number 3 (yellow) ensures a minimum amount of force at maximum stroke for low current. Furthermore, the slope is restricted as well.

Number 4 (light purple) sets a lower limit for the magnetic force at maximum current that effects all stroke positions. Thus, the magnetic force always keeps a minimum level. Number 5 (light blue) works like number 4 but is valid for an intermediate current.

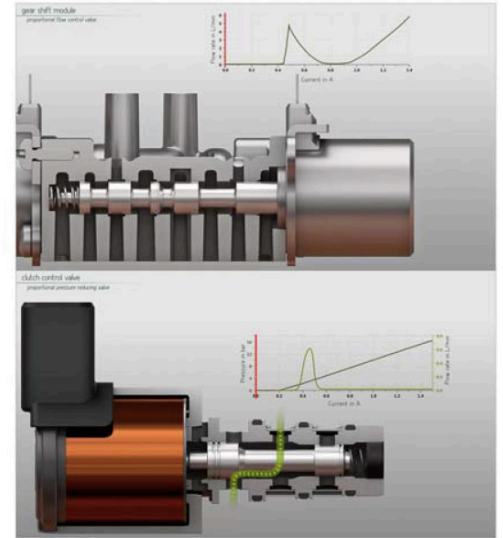


Figure 1: Hilite gearshift valve (top) and clutch control valve (bottom) for DCTs.

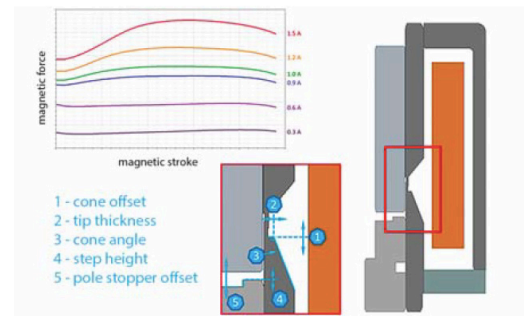


Figure 2: Parameterized Maxwell model with force curve.

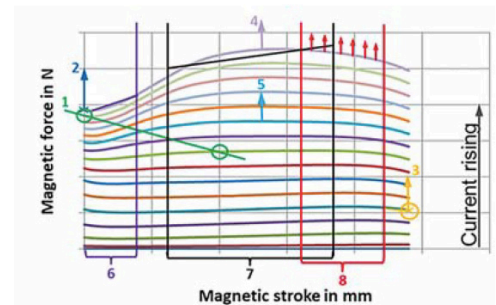


Figure 3: Field of magnetic force over stroke with criteria for optimization.

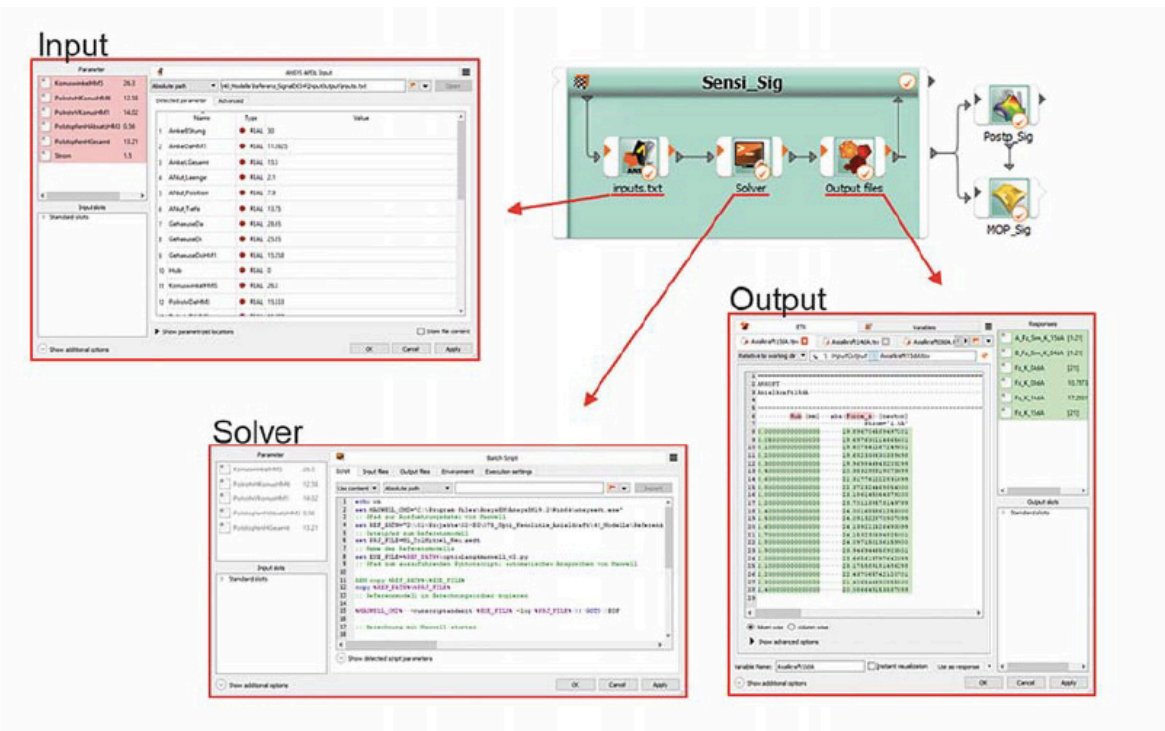


Figure 4: optiSLang System with Maxwell integration.

The Number 6 constraint (dark purple) limits the slope of the curve to a minimum in a specific region of small stroke positions. Number 7 (black) operates similar to constraint 6 but the region contains middle stroke positions.

Number 8 (red) is an objective and aims to maximize the magnetic force at large electric current in an area of large stroke.

Parametric System

The integration of the simulation program Maxwell into the optimization program optiSLang can be done in various ways. One way would be using the AEDT integration that is available in optiSLang since version 7.3. It is easy to create and performs very effectively. As the only problem so far, there is no comfortable way to work with signals.

The only way to optimize the characteristic curves of the magnetic force with Maxwell and optiSLang is to use a script-based integration. With this method, it is possible to let the constraints and objectives refer to the curves and picture them inside the optimization analysis. Moreover, with the amount of different stroke positions and currents that need to be computed for every design in order to create an accurate signal to work with, the script based integration method is almost as efficient as the integrated AEDT version.

In order to successfully build a working optiSLang system for Maxwell computations, one needs a working project (model, parameters, setup and results) at first. With the help of a Maxwell command, it is possible to extract the geometry parameters and the defined responses of the results in separate files (input, output). These files were used to set up the parametric system.

Figure 4 (see next page) shows the integrated Input, Solver and Output of the optiSLang system. The Maxwell files were implemented with a common

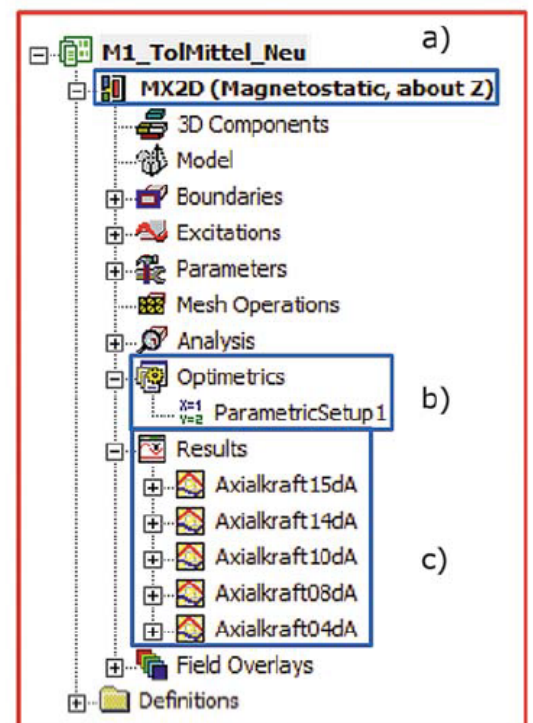


Figure 5: Computation order in Maxwell with optiSLang; a) Input parameter creating geometry, b) Setup of variations, c) Definition of characteristic curves for output extraction.

| Current | Magnet stroke | VersatzKonus | Spitzendicke | Konuswinkel | Polstopfen Versatz | HoeheAbsatz | Total |
|---------|---------------|--------------|--------------|-------------|--------------------|-------------|--------|
| 0.4 A | 2.4 mm | 100.00% | 0.45% | 0.14% | 0.00% | 0.01% | 100.0% |
| 0.4 A | 2.2 mm | 99.99% | 1.94% | 0.49% | 0.00% | 0.02% | 100.0% |
| 1.0 A | 2.4 mm | 86.26% | 15.31% | 1.29% | 0.00% | 0.04% | 100.0% |
| 1.0 A | 2.2 mm | 70.49% | 26.34% | 3.67% | 0.00% | 0.01% | 100.0% |
| 1.0 A | 2.0 mm | 40.24% | 50.62% | 10.64% | 0.00% | 0.03% | 100.0% |
| 1.0 A | 1.8 mm | 12.22% | 69.97% | 20.55% | 0.06% | 0.00% | 100.0% |
| 1.0 A | 1.6 mm | 11.74% | 60.90% | 30.62% | 0.12% | 0.29% | 100.0% |
| 1.0 A | 1.4 mm | 23.71% | 41.12% | 37.79% | 0.11% | 0.61% | 100.0% |
| 1.0 A | 1.0 mm | 51.73% | 8.06% | 43.94% | 0.76% | 3.12% | 100.0% |
| 1.0 A | 0.6 mm | 67.03% | 21.49% | 6.21% | 2.36% | 9.40% | 100.0% |
| 1.0 A | 0.2 mm | 44.47% | 32.67% | 7.48% | 1.34% | 15.33% | 100.0% |
| 1.0 A | 0.0 mm | 36.49% | 27.47% | 11.46% | 0.89% | 26.87% | 100.0% |
| 1.5 A | 2.4 mm | 73.01% | 22.96% | 4.04% | 0.00% | 0.00% | 100.0% |
| 1.5 A | 2.2 mm | 61.63% | 31.42% | 8.30% | 0.00% | 0.05% | 100.0% |
| 1.5 A | 2.0 mm | 35.29% | 48.19% | 18.63% | 0.00% | 0.11% | 100.0% |
| 1.5 A | 1.8 mm | 10.33% | 58.37% | 31.86% | 0.08% | 0.22% | 100.0% |
| 1.5 A | 1.6 mm | 11.60% | 47.91% | 44.21% | 0.32% | 0.66% | 100.0% |
| 1.5 A | 1.4 mm | 26.56% | 27.84% | 46.23% | 0.94% | 1.59% | 100.0% |
| 1.5 A | 1.2 mm | 49.63% | 10.10% | 40.83% | 1.89% | 3.08% | 100.0% |
| 1.5 A | 1.0 mm | 71.05% | 5.55% | 22.08% | 3.50% | 5.09% | 100.0% |
| 1.5 A | 0.8 mm | 75.19% | 15.18% | 5.93% | 3.72% | 5.59% | 100.0% |
| 1.5 A | 0.6 mm | 65.82% | 27.59% | 1.99% | 3.06% | 6.31% | 100.0% |
| 1.5 A | 0.4 mm | 56.34% | 32.05% | 4.85% | 2.08% | 7.36% | 100.0% |
| 1.5 A | 0.2 mm | 46.74% | 33.67% | 10.13% | 1.34% | 10.16% | 100.0% |
| 1.5 A | 0.1 mm | 42.93% | 32.45% | 12.70% | 1.06% | 13.84% | 100.0% |
| 1.5 A | 0.0 mm | 37.11% | 29.25% | 13.53% | 0.89% | 19.71% | 100.0% |
| 0.8 A | 1.0 mm | 47.14% | 11.99% | 45.18% | 0.51% | 2.11% | 100.0% |
| 1.4 A | 0.0 mm | 37.45% | 28.89% | 13.87% | 1.02% | 20.84% | 100.0% |

Figure 6: Coefficient of Prognosis of the force in different positions for the input parameters, for different positions of the input parameters see also Figure 2.

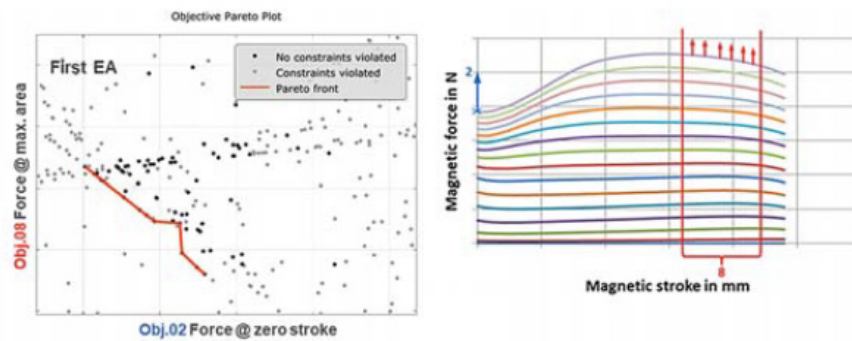


Figure 7: Pareto front of the evolutionary algorithm (left) and its two objectives (right).

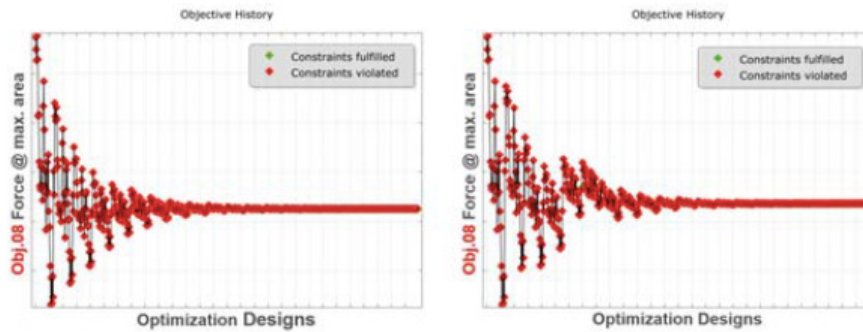


Figure 8: History of the optimizations with adaptive response surface method.

text based solver, for example Ansys Classic (Text Input – Batch Solver – ETK). The input node detects the input parameters. In the ETK node, one can define the force curves as signals and the batch solver activates the solver script to run Maxwell with different designs.

For every design five currents with up to 14 stroke positions per current are calculated, which sums up to 28 calculations for each design. The handling of these different computations are done with “Optimetrics” in Maxwell, which can be used with the script connection.

Figure 5 (see next page) shows the three most important parts of Maxwell, highlighted in blue frames. The model area “MX2D (a)” contains the variable geometry parameters that optiSLang changes and imports into the Maxwell file for calculation. In “Optimetrics (b)”, the different variations of stroke and current are listed and set up for computation. The pre-defined characteristic curves for the output extraction to optiSLang are saved in “Results (c)”.

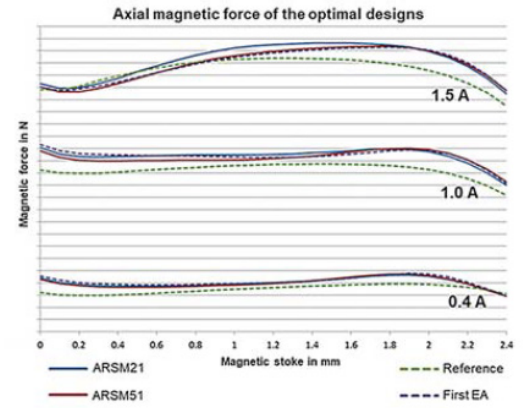


Figure 9: Magnetic force with different currents and optimization designs.

/ Computations

The integration of Maxwell into a parametric system in optiSLang helps to find optimal designs for actuator valves. The search for the best design includes a sensitivity analysis that identifies the important parameters and their mutual interplay. The information collected in the sensitivity analysis makes it possible to use the MOP- and Maxwell-Solver effectively in the optimization. The result of the optimization is implemented in system simulation models to obtain information about the performance of the valves.

Optimization

In the following Figure 6, one can see the CoP-Matrix as a result of the sensitivity analysis using the “Metamodel of Optimal Prognosis” (MOP). Here, the five geometry parameters are listed in the first row. The columns below express the influence on the change of the magnetic force at certain positions. The first and second column show these positions, which are combinations of current and magnetic stroke that define 28 output parameters. All strokes of every electric current combined results in a magnetic force curve that is different for each design. The different parameters have different influences for different currents and strokes. The higher the percentage the higher the influence for the calculated variation. The parameter “Total” at the end of the matrix tells the overall quality of the meta-model (100% means no error). The first three parameters “cone offset”, “tip thickness” and “cone angle” have a large influence on the variation of the axial magnetic force at certain stroke positions. “Step height” only has an influence on the force at small strokes and “pole stopper offset” has small influence overall.

With all the information from the sensitivity analysis about force, stroke and current stored in the MOP, a usage in the optimization can lead to good and fast results. So, for the optimization of the magnetic force curves, Maxwell as well as the MOP was used as a solver. The first optimization was done with the evolutionary algorithm (EA). It resulted in a pareto front which is shown in Figure 7 as a red line. As already mentioned in Chapter “criteria for optimization”, the objectives of the EA were maximization of the force at zero stroke (2) and maximizing the force at high stroke (8). The results show the possible variation of the curve, which were used as start designs for the stricter single objective optimization with the adaptive response surface method (ARSM).

During the single objective optimization, two designs with different constraint values showed very good results. The history of these designs “ARSM21” and “ARSM51” is shown in Figure 8.

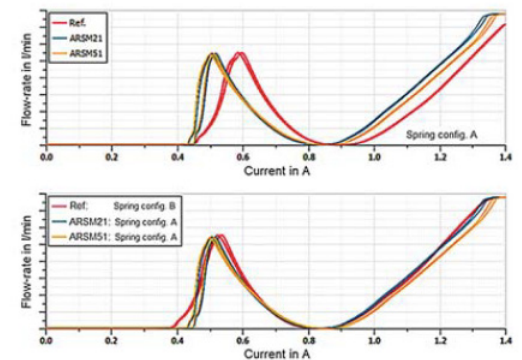


Figure 10: Flow rate over current for optimized designs ARSM21 & 51 with system simulation of gearshift valve.

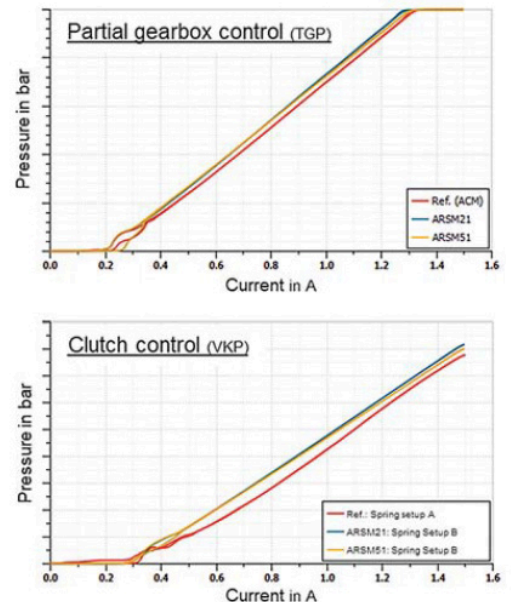


Figure 11: Pressure over current of TGP and VKP with system simulation.

Figure 9 (see next page) shows the characteristic curve of the magnetic force over the magnetic stroke for 0.4 A, 1.0 A and 1.5 A. The curve of the reference design and the first EA are plotted with dashed lines. The optimization result “ARSM21” is depicted in blue and “ARSM51” in red. Due to the successful optimizations and the proper settings and definitions of the relevant criteria, all optimized designs got improved curves when compared to the base model (Reference). The design “ARSM21” can score with the largest force which occurs at 1.5 mm stroke. The design “ARSM51” however has a long smooth slope until the maximum, which is at 1.7 mm stroke.

System Simulation

Both optimized designs “ARSM21” and “ARSM51” exhibit individual qualities and thusly are used in a system simulation that evaluates the valve's behavior.

The difference between “ARSM21” and “ARSM51” mainly occurs between 0.9 A and 1.3 A. The appropriate characteristic curve of the gearshift valve shows Figure 10 (see next page) with different spring configurations in the two pictures. Both valves with optimized magnets reach the first peak in the Q-I curve earlier than the reference design and continue decreasing slower towards the minimum. In the second peak with currents larger than 0.9 A, “ARSM21” equals the base model and “ARSM51” remains below the other curves.

Both new actuator designs allow the usage in different valve types. The optimized designs achieve slightly better results than the reference in the system simulation of the TGP that is pictured on the top side in Figure 11. In the VKP on the bottom, the optimized designs have straight curves and fewer oscillations, something that is not visible in the reference design.

/ Conclusion

With the possibility of optiSLang and Maxwell working together even complex issues can be solved. The example shows that the valve can be optimally adjusted to its designated function and with further developments, even faster and better results are possible.

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