Less Effort – More Strength

The accuracy of hub-shaft connections is one of the most important safety criteria for steering components. Statistical Design of Experiments helps to find with a surprisingly small number of trials those factors and their optimal levels that lead to the most pressure-resistant combined keyway and traction connection. ThyssenKrupp Presta uses this efficient instrument successfully for developing steering elements.

In the automotive industry, the quality of hub-shaft connections used in steering components is an important safety issue. The pressure force needed to break off such a combined keyway and traction joint is an evaluable criterion of quality. All the factors having an impact on the connection resistance should be adjusted so that this break-off force becomes maximum.
The most advantageous method to solve this task is Statistical Design of Experiments. It enables to detect the influence of various factors on one or several response variables with a small number of experiments. In a test laboratory, some trials have been run to identify factors that may increase the pressure force. The construction angle A, the depth of the connection Y and the shaft diameter R have been detected as such factors.
Already 3 factors lead to a complex situation in the experimental design. The use of an appropriate software tool is absolutely essential because the complexity of the problem even further increases with a larger number of factors. To find the best configuration of the factors, that is the one leading to a maximum pressure force, this problem has been addressed with STAVEX, a software tool for experimental design from AICOS Technologies Ltd.
This tool guides the user in a very clear way through the experimental design task. First, the response variables with their optimization direction have to be specified. In our case, the pressure force should be maximized. Further, the user specifies the factors of possible influence and their variation ranges. E.g., for the angle A the range A_{min} = 0° to A_{max} = 10° has been defined.

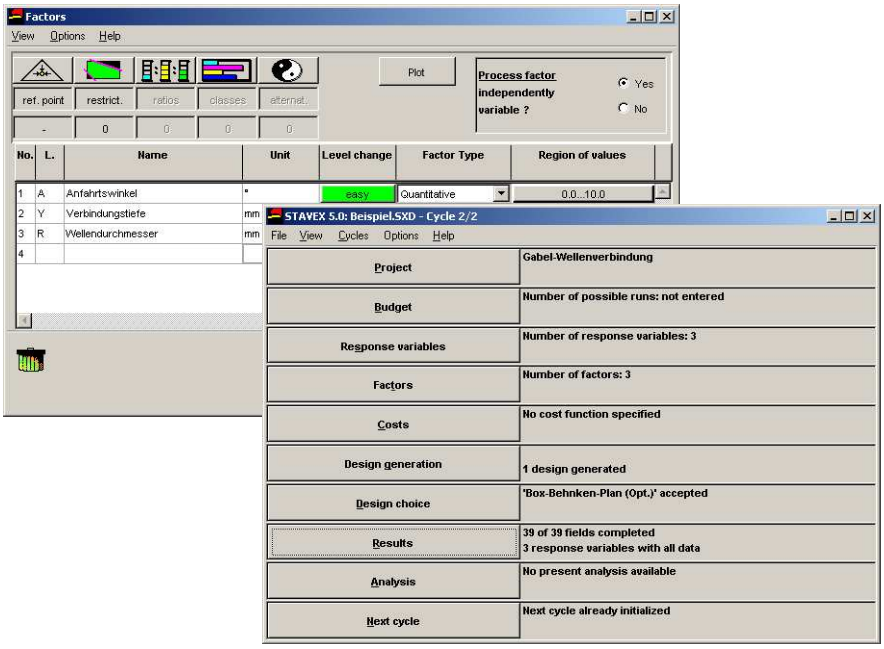

Fig. 1. The main screen in STAVEX guides the user through the experimental design task.
The user has to input the factors and to set their ranges in the factor screen.

Considering these as well as possibly further specifications, like interactions between factors and restrictions of the factor range, the software suggests a variety of appropriate designs. In our example, a Box-Behnken design for 3 factors with 13 trials has been chosen.
The cube in Fig. 2 represents the design built by the ranges of the 3 factors A, R and Y. The colored circles indicate the 13 trials. They have to be run in the lab with the suggested factor settings. Then, the measured values of the break-off force have to be input into to the program.
If it is impossible to hold the suggested factor settings exactly, the actual design can e.g. be stored in Excel and imported into STAVEX. One proceeds similarly to evaluate trials which do not stem from a designed experiment. The software tool then interprets these runs as a so-called external design.

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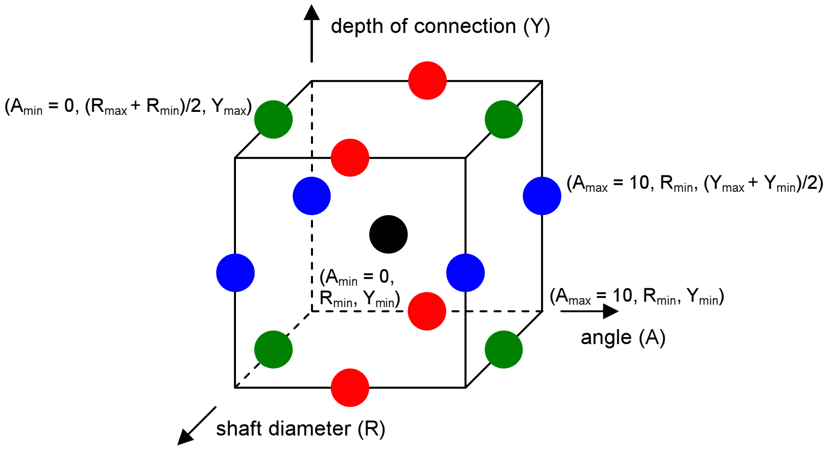

Fig. 2. Box-Behnken design for 3 factors.

The main result of the analysis, which is based on a quadratic regression, was that the break-off force depends on the setting of the angle and on the depth of the connection. The shaft diameter influences the force depending on the angle and of the depth. For optimal factor values (A = 5°, Y = 17.9mm and R = 17.46mm), the break-off force can be expected in the interval 12.3 to 14.8kN. The results of the analysis are automatically commented in detail and interpreted. They are available to the user as an HTML document.

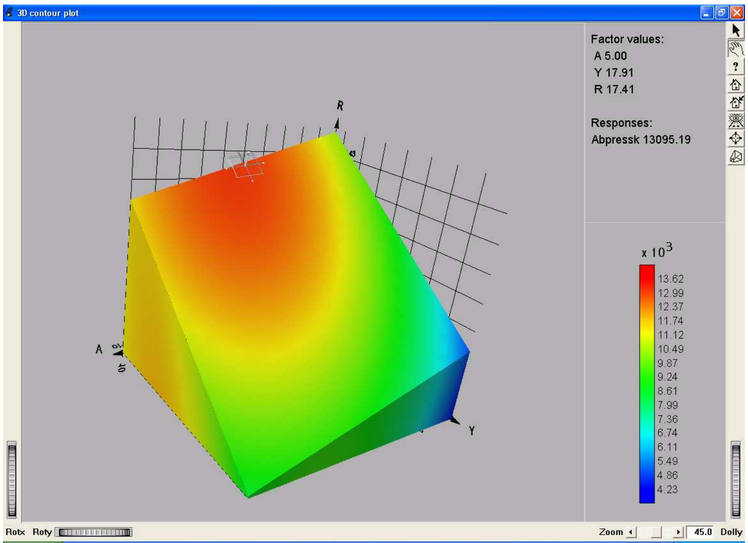

Fig. 3. The numeric results can be supported by various graphics, e.g. by a 4D contour plot.
Each dimension represents a factor and a colour scale corresponds to the values of the response variable.

In addition to these results, STAVEX provides detailed information about the model diagnostics, e.g. the goodness of fit, an analysis of the residuals (inclusive test of normality and quantile plot), transformations of the response variable etc. More than 93% of the variance of the response could be explained by the model. Further, the residual analysis finds no evidence for a violation of the model hypotheses. One can therefore admit that the break-off force is maximal for the calculated factor combination. In the transformation analysis, the software also suggests to consider the squared response variable, since a regression model for this variable would lead to slightly better results. However, since the results obtained were already very good, no transformation has been applied.
After a few test trials in a preliminary phase, 3 factors have been detected as potentially influent on the response variable. With only 13 additional experiments, the unknown relationship between these factors and the response variable could be modelled efficiently. To test the model, a confirmatory experiment with the optimal factor settings has been run. The break-off force was 13.5kN. This value lies inside the expected range and constitutes a further evidence for the good quality of the results.

With the support of Statistical Design of Experiments for the development of a special hub-shaft-connection, it was possible to find with a very small number of trials the factor settings which lead to a maximum connection break-off force. Along with a very small number of trials and an increased know-how about the product, the quality is increased, the costs are decreased and, last but not least, the car safety improves.

The software tool STAVEX for experimental design is currently used in more than 150 companies, e.g. at BMW, ThyssenKrupp Presta or TRW. Version 5.0 with new graphics, an enlarged design library and lots of additional new features will be available soon.