Design of flexible watch industry mechanical components with ANSYS Workbench and optiSlang.

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Abstract

Watch industry mechanisms involve a large number of high precision flexible pre-constrained mechanical components. Using traditional prototyping, the definition of non-deformed geometries for production is a costly manual iterative process. The optimization of a set time mechanism and the robustness analysis of a glass driving process show how the coupling of non-linear finite elements codes to an automatic stochastic optimization toolbox like optiSlang improves the convergence to a robust optimum.

Keywords: optimization, watch industry, non-linear, large deformations, plastic, ANSYS Workbench, optiSlang, pareto, ARSM, sensitivity, robustness

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1 Introduction

Virtual prototyping is used in watch Industry to anticipate dimensioning problems and therefore reduce the number of prototypes.
Amongst the wide range of components constituting a bracelet watch, two key mechanisms are presented below as examples to demonstrate the use of numerical simulation using ANSYS Workbench combined with the OptiSlang stochastic optimization toolbox.

2 Force tuning of a set time mechanism with ANSYS Workbench and optiSlang

2.1 Problem description

Figure 1 shows the set time mechanism connected to the pull-out button of a watch. The button actuates a winding shaft that can be pulled up to its stop position; its rotation then allows time setting. The winding shaft is connected to the pull-out piece via a pin. The pull-out piece can rotate on a fixed axis but is constrained by the spring that pushes on a pin at its end and therefore sets its actuation moment. The maximum pulling force on the winding-shaft has to be 5N in order to ensure a good sensitivity when pulling with the fingers on the set time button. At the same time, stresses in the spring have to remain below the yield strength.

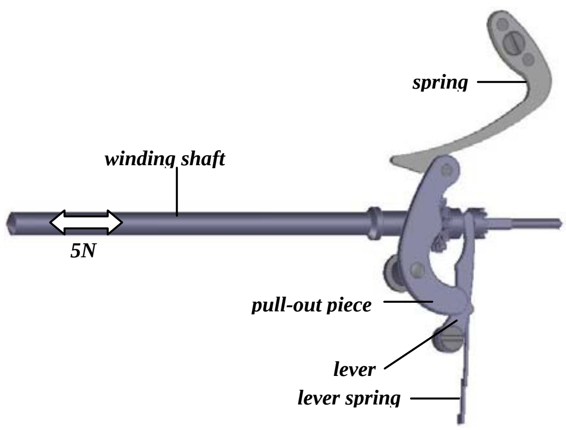


Fig. 1: Set time mechanism

2.2 Adaptive response surface optimization

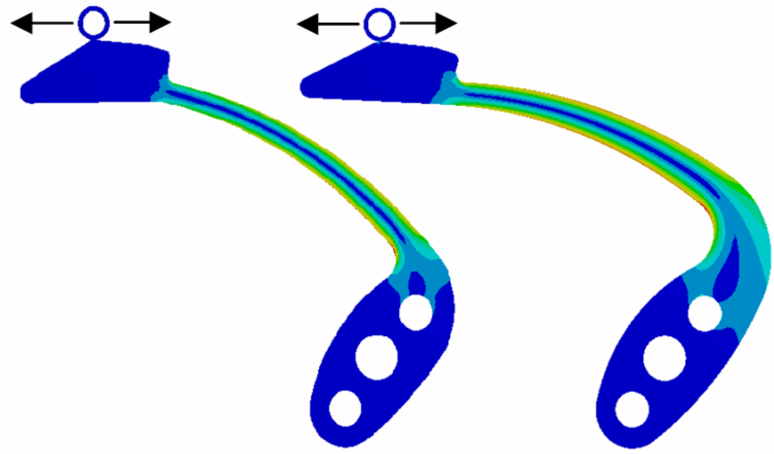


Fig.2: Spring initial shape (left) and tuned shape (right). The pin of the pull-out piece is at the force inversion position where stresses reach their maximum. The positioning and angle of the two flat contact faces of the spring determine the pull and push forces.

A two dimensional parametric model of the spring and its non-linear frictional contact with the pin of the pull-out piece was created with ANSYS workbench and coupled to optiSlang via the optiPlug interface. This allowed running an automatic parametric optimization of the spring's shape based on eight geometrical input parameters and three objectives:

1. Set the pulling force
2. Set the pushing force
3. Minimize structural stresses

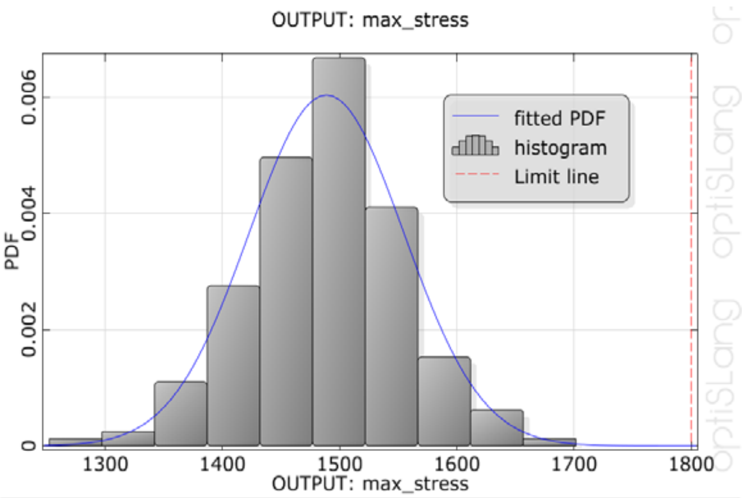
The optimization algorithm chosen was an adaptive response surface method. After 91 automatic design evaluations, the resulting design had pulling and pushing forces set within respectively 1.7 and 0.2% of the required value while the maximum stress was 8% smaller than the value calculated with the initial geometry (figure 2). The mechanism was produced and fulfilled expectations. Obtaining such accuracy on the results given all the constraints on the design could not be achieved by a specialized watch making engineer.

2.3 Objective change

Once the parametric model was created, changing the objective proved very efficient; for instance, keeping the pulling force at 5N but changing the pushing force to 5N instead of 15N only took a few minutes engineer time and two hours CPU time.

2.4 Robustness analysis

A robustness analysis showed that the Young's modulus and its probability density function was the most critical parameter as far as stresses are concerned. However, the probability of having stresses higher than the yield stress was lower than 0.3% (analysis sensitivity). Assuming a Gaussian probability density fit, the yield strength of 1800 MPa is 4.5 sigma higher than the mean stress value (Figure 3). A reliability analysis, that would determine the exact failure probability, was not run.



Statistic data			
Min:	1252	Max:	1702
Mean:	1489	Sigma:	66.05
CV:	0.04437		
Skewness:	-0.1112	Kurtosis:	3.416
Fitted PDF: Normal			
Mean:	1489	Sigma:	66.05
Limit x = 1800			
P_rel =	1	P_fit =	1
Probability P(X<x) = 1			
x_rel =	1702	x_fit =	1803

Fig.3: Probability density function for the maximal stress in the structure

3 Robust design optimization of a glass driving process with ANSYS Workbench and optiSlang

3.1 Problem description

Tightness between glass and watch-case is ensured by a flexible joint (figure 4). The force needed to remove the glass has to be maximized whereas the force required to drive the glass should be minimized. Plastic deformations in the joint (figure 5) as well as stresses in the glass and watch-case should also be minimized.

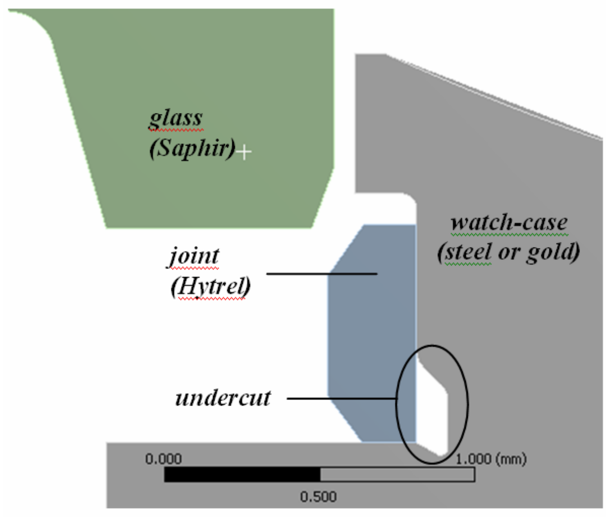


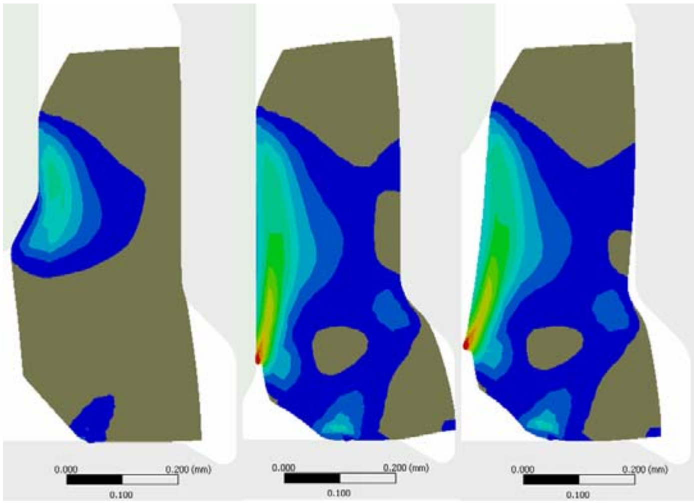
Fig. 4: Bodies taken into account in the model of a glass driving.

A quasistatic two dimensional axisymmetric parametric model was created with ANSYS Workbench and coupled to optiSlang in order to run three different analyses on the model:

1. A sensitivity analysis
2. A Pareto optimization
3. A robustness analysis

3.2 Sensitivity analysis

Amongst a list of 16 geometrical input parameters (dimensions of glass, joint and watch body), the sensitivity analysis delivered a list of 8 most important geometrical dimensions. According to the statistical linear coefficient of importance calculated by optiSlang, these parameters determine 86% of the maximal withdrawal force, 77% of the maximum glace stress and 65% of the joint maximum plastic strain. In addition to the selection of a subset of most relevant parameters, the sensitivity analysis allowed to gain understanding of the physical system. For instance, the correlations between outputs can be seen at a glimpse in the optiSlang post processing. In this case, output values that have to be minimized (stresses and strain) and the output value that has to be maximized (removal force) are positively correlated between each other, which means that attempting to maximize the force will also maximize the stresses and strains. In addition to this intuitive qualitative statement, optiSlang delivered quantitative correlation values that helped defining objective functions for the optimization.



a b c

Fig. 5: Typical results for the equivalent plastic strain in the Hytrel joint a) during the driving process b) with the glass mounted c) after having removed the glass. All plots use the same scale.

3.3 Pareto optimization

Due to these output parameters correlations, a Pareto optimization with two objective functions was chosen; the first objective is a weighted function of the removal force and of the difference between driving and removal force. The second objective function is simply the sum of stresses in the watch-case and in the glass. After 209 design evaluations, the result of this optimization, based on an evolutionary algorithm, is a Pareto front with designs that minimize both objectives (figure 6). In this case, the choice of a best design along this front is motivated by the need to increase the force (move towards the left) while maintaining the stress low enough (move down on the graph).

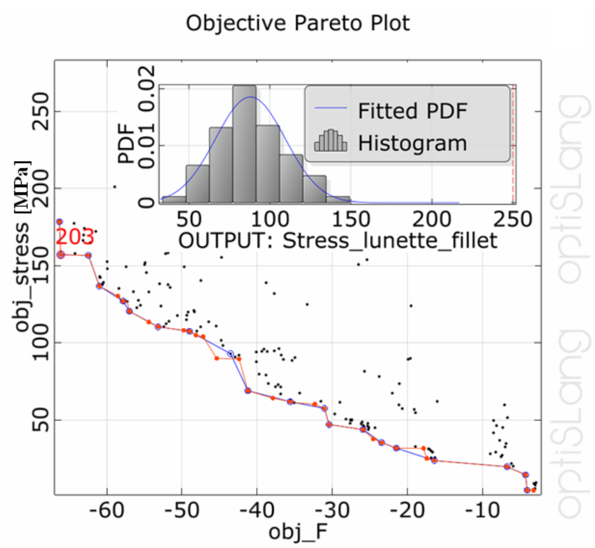


Fig. 6: Result of the Pareto optimization in optiSlang. The probability density function for the maximum stress in the watch-case obtained with a robustness analysis for design 203 has been inserted.

3.4 Robustness analysis

After having selected a candidate design on the Pareto front, a robustness analysis was run for this design. Probability density functions were defined for each input parameter, including material properties. The resulting output parameter probability density functions could then be integrated in optiSlang in order to get the probability of being higher than a given stress threshold. This failure probability gives quantitative information on whether the design is sufficiently robust or not. In this case, the failure probability of design number 203 was 20% for gold (inacceptable) and would be negligible for a material with same Young's modulus but 250MPa tensile yield strength (see red limit on the probability density function of figure 6). Plastic strain in the joint was reduced by a factor 5.9, and the drive force by a factor 3.4. The removal force decreased by a factor 1.75 due to its strong correlation (0.84) with the driving force.

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