Design Optimization for Fatigue Life

Introduction

To ensure reliability of designs, fatigue life performance is often an integral part of today's CAE evaluations. In addition to meeting design targets for allowable deformations, stresses, and strains under the prescribed loading conditions, a reliable structure should also perform as intended for a minimum number of loading cycles. Fatigue life predictions are generally calculated from the results of finite element based simulations.

When a design does not meet all of the performance targets, the design must be modified iteratively until a suitable design is found. This process is very inefficient and expensive if done manually, since many CAE models must be built, executed and evaluated.

HEEDS™ Professional is a multidisciplinary design optimization software package that eliminates frustrating manual iterations while providing better and more efficient solutions to challenging design problems. It is able to effectively search broad and complicated design spaces using intelligent and adaptive techniques, locating those designs that best satisfy all performance specifications. HEEDS works with existing CAD and CAE tools to modify a design's attributes and to predict the performance of a design. It performs these steps automatically and iteratively while searching for the best possible design(s).

This process is illustrated here for the shape design of a torque arm to meet a fatigue life reliability criterion. In this example, the fatigue evaluations were calculated using the software package FEMFAT from Magna Powertrain, Inc. and the finite element evaluations were carried out with Abaqus, from Dassault Systemes, S.A.

Torque Arm Baseline Design

The initial (baseline) design for the torque arm contained a mass reducing cutout of constant width, as shown in Figure 1. Considering a loading history of 100,000 cycles, a fatigue analysis was performed to predict the damage factors in the structure. The predicted lifetime of the structure was approximated by dividing the number of loading cycles (100,000) by the maximum predicted damage factor. As shown in Figure 1, the maximum damage factor in the baseline model was 1.6E3, which corresponds to an estimated lifetime of 62.5 cycles. The stress amplitude contours are shown in Figure 2.

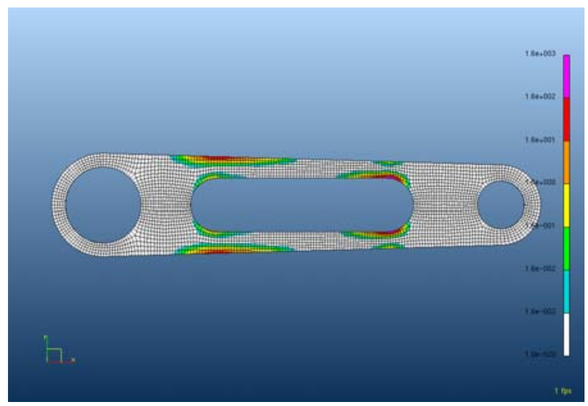

Figure 1. Damage factor contours of the baseline design.

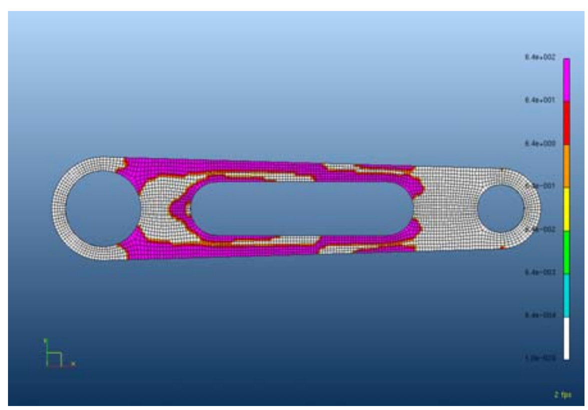

Figure 2. Stress amplitude contours of the baseline design

HEEDS Optimization

The objective of the HEEDS optimization was to find the lowest mass design that also maintained a fatigue life of greater than 1 million cycles, corresponding to a damage factor below 0.1. Four shape design variables were considered, which controlled the geometry and location of the cutout. The overall length, width, taper and relative location of the cutout were allowed to vary.

Using the HEEDS Professional process automation capability, the following steps were performed for each design iteration:

- Abaqus/CAE was used to create a geometric model and to generate the finite element mesh for each proposed design, based on HEEDS-specified values for the shape design variables.
- The Abaqus/Standard solver was used to predict the stress and strain results for each design.
- The FEMFAT fatigue evaluation software was executed to determine the damage factor for each proposed design.

The resulting optimized design found by HEEDS is illustrated in Figure 3, which shows the geometry of the new cutout and the new damage factor contours. The contours of the stress amplitude are shown in Figure 4.

Comparing the baseline design with the best design found by HEEDS, it can be seen that the maximum value of the quantity most meaningful for fatigue life, the damage factor, is reduced from 1.6e3 to approximately 0.09. This corresponds to increasing the fatigue lifetime from 62.5 cycles to over 1 million cycles. This was accomplished strictly by changing the geometry of the torque arm cutout, leaving the external dimensions unchanged.

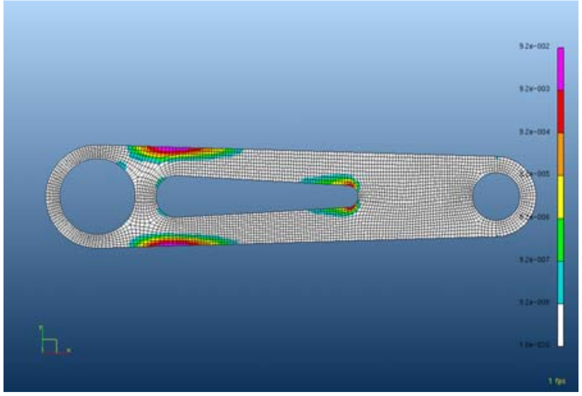

Figure 3. Shape and damage factor contours of the HEEDS optimized solution

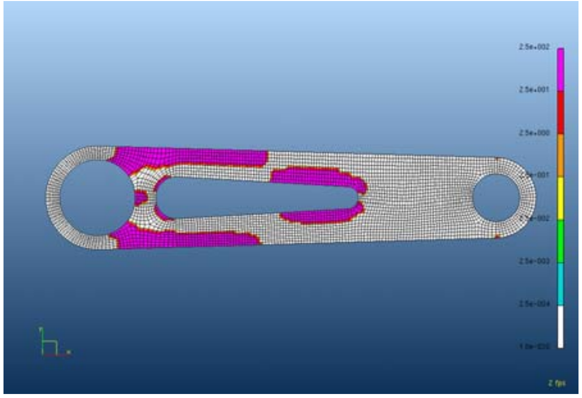

Figure 4. Stress amplitude contours of the HEEDS optimized solution

Conclusions

This example illustrates how HEEDS Professional can be incorporated into the standard CAE-based design process for finding mass efficient designs that also satisfy reliability requirements. The automated HEEDS optimization process frequently yields designs that are better than those found from a manual search process, and in a fraction of the time.

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