Optimization of Engineering Systems

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Introduction

Engineers are forced to design products that are higher performing and more complex due to increasing market pressure. This results in the need for more complex simulation models that take into account nonlinear phenomena. In these models, gradients are often unavailable analytically, so optimization must be performed using methods that do not require gradients.

In this study, several problems are presented where the system was optimized using a new hybrid optimization strategy that does not need gradients. This strategy was applied to three problems: design of a chemical process, design of an automotive front suspension system, and design of a rubber automotive engine mount.

Optimization strategy

For the three problems studied a new hybrid, adaptive optimization algorithm called SHERPA was used. This is a proprietary algorithm distributed by Red Cedar Technology in their commercial optimization and process automation code, HEEDS.

SHERPA is a hybrid, adaptive method that uses several different optimization algorithms at the same time and adapts itself to the problem at hand [1].

Design of a chemical process

The first problem studied was the design of a chemical process where a mixed stream of water and Dichloromethane (DCM), a common chemical byproduct, is input [2]. DCM has a lower boiling point than water, and so the DCM is separated from the water by heating the mixture with a stream of saturated steam. This makes use of the chemical process shown in Figure 1. It is desired to minimize the amount of steam added to the process while still maintaining the amount of DCM in the output stream (EFFLUENT) to less than 150 ppm. Aspen Plus 2006 was used to analyze the process, and was driven by HEEDS to perform the optimization. The optimization problem statement is given below:

minimize	*Total_Steam*
subject to	*DCM_concentration* ≤ 150 ppm
by varying	1,000 lb/hr ≤ *STEAM1* ≤ 20,000 lb/hr
	1,000 lb/hr ≤ *STEAM2* ≤ 20,000 lb/hr

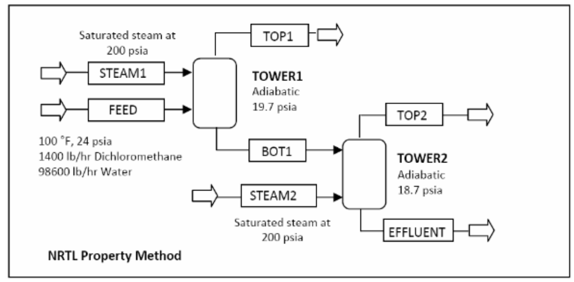

Figure 1. Process flow sheet with stream and process data.

As a result of the optimization, the total steam usage was reduced by 14%, while maintaining the DCM concentration at 150 ppm in the output stream.

Design of an automotive front suspension

A front suspension system was studied with the desire to match the toe and camber versus wheel travel curves to given target curves. This was to be accomplished by moving several control points in the system, illustrated in Figure 2. The control points used were the locations of the upper and lower control arm connections to the frame, and the location of the outer tie rod connection to the hub assembly.

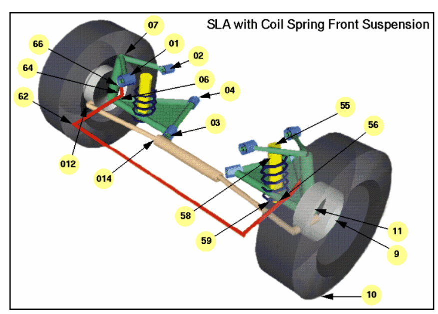

Figure 2. Front coil spring suspension system with control points [3].

The curves were matched by calculating the root mean square (RMS) error between the toe and camber design curves and the target curves. These two RMS values were summed, and the objective was to minimize this sum of RMS error. The analysis was performed using MSC/Adams. The results of the optimization are shown in Figure 3. After optimization, the toe and camber curves were much closer to the target curves.

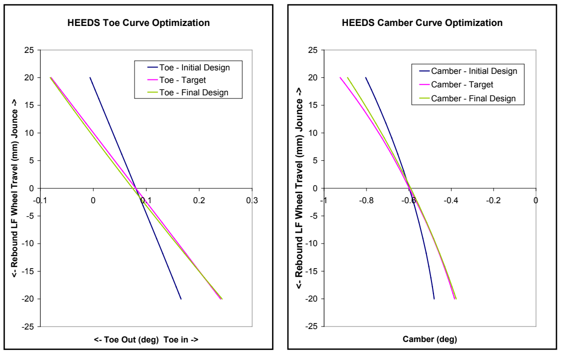

Figure 3. Toe and camber curves for target, initial design, and optimized design.

Design of a rubber engine mount

The third and final problem studied was an engine mount (bushing) made of rubber. The baseline design is shown in Figure 4. This bushing is encased in a steel sleeve, fixed to the frame of the car. The center cylinder is attached to the engine. A nonlinear stiffness curve is desired when the center moves to the left, and a different nonlinear stiffness curve is desired when the center moves to the right. These curves are shown in Figure 5.

The spline points shown in Figure 4 were the design variables. The RMS error between the designed and target stiffness curves was used as the objective to be minimized. The analysis was performed using Abaqus, a general-purpose structural FEA code [4].

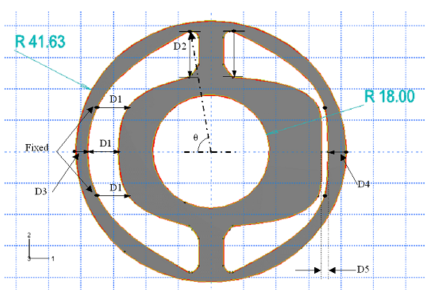

Figure 4. Baseline design of rubber mount with design variables indicated.

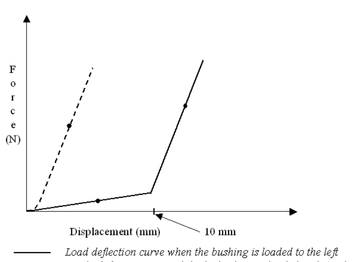

Figure 5. Desired piecewise linear stiffness curves for rubber bushing.

The optimized design is shown in Figure 6, and the corresponding stiffness curve is shown in Figure 7.

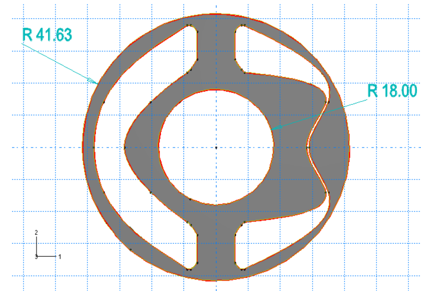

Figure 6. Optimized bushing design.

The optimization produced a large change in geometry that was also innovative. This was a difficult problem to solve manually, due to the nonlinearity from the rubber and the contact, not to mention the complex stiffness requirements.

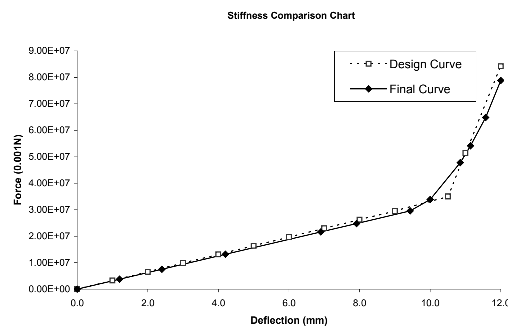

Figure 7. Stiffness curves for target and optimized design.

Conclusion

Three different problems were solved where no analytical gradients are available. In each case SHERPA, a new hybrid optimization algorithm was able to find designs that far out performed the original design.

References

[1] "The SHERPA Method", HEEDS v5.3 User Manual, Red Cedar Technology, Inc., 2009, Chapter 13.

[2] Abdel-Jabbar, Nabil, ChE 590A Course Website (http://www.just.edu.jo/~chemeng/nabil/cad/che590-cad.htm).

[3] "Welcome to Adams/Chassis", MSC/Adams Manual, MSC Software Corporation, 2008.

[4] *Abaqus v6.8 Analysis User's Manual*, SIMULIA, Inc., 2008.