Industrial Applications Using Structural Optimization with GENESIS

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1. Abstract

This paper describes structural optimization capabilities available in the GENESIS program to solve industrial problems. The first part of the paper describes analysis and optimization features of the GENESIS program. The second provides several problems from the industry.

2. Keywords: Optimization, Structures, Industry, GENESIS

3. Introduction

It is widely recognized that engineering companies face today the problem of designing structures more quickly, more reliably and more economically than ever before. To achieve that, their engineers need tools that automatically generate, check, analyze and optimize their data. They need tools that can allow them to verify the results and compare with other alternatives. In this paper, the GENESIS program that addresses some of these designers' needs is discussed. Industrial applications that show the scope of the GENESIS program are presented.

4. The GENESIS Program

GENESIS is a structural optimization program that allows the user to solve the following analysis problems: Static, normal modes, direct frequency response, modal frequency response, buckling and heat transfer. Inertia relief is also available. GENESIS can solve sizing, shape and topology optimization problems [1]. Topology optimization is typically, but not necessarily, used for creating preliminary designs while shape and sizing optimization is normally used to obtain final designs or detailed designs.

5. Background and Technology behind GENESIS

In 1960, Prof. Schmit presented the first paper showing that it was possible to integrate structural analysis and optimization [2]. GENESIS is a program that does that. In fact, GENESIS is the first commercial program that was developed from the beginning to completely integrate optimization with finite element analysis. For shape and sizing optimization, GENESIS typically can find an optimal solution in ten or fewer full-system finite element analyses for almost any type of structural problem with almost any kind of structural response. This is possible because GENESIS uses the latest approximation concepts available. Approximate concepts were introduced in the seventies by Schmit and co-workers [3,4] and enhancements to response approximations in the eighties [5,6,7]. The high quality approximations used in GENESIS are able to capture the important physics of the structural optimization problem, substantially reducing the cost of performing multiple finite element analyses. Advances in the computer industry have also made possible the solution of very large problems, consisting of hundreds of thousands of degrees of freedoms with thousands of design variables and millions of constraints. Occasionally the problems contain millions of degrees of freedoms with tens of thousands of design variables.

In topology optimization, GENESIS also uses approximation concepts [8]. The cost of solving the topology optimization problem is normally higher due to the increased complexity of the problem. GENESIS, in this case, typically converges in 15 to 25 design cycles. GENESIS topology optimization is based on the density method [9].

To solve the approximate optimization problems, GENESIS uses the DOT [10] or the BIGDOT optimizers. BIGDOT is a large-scale optimization program that is currently being developed by Garret N. Vanderplaats using algorithms discussed in reference [11].

6. Features in GENESIS to Solve Industrial Problems

The GENESIS program has built-in special capabilities that help engineers solve industrial problems. Some of these capabilities are: Automatic generation of basis vectors for shape optimization, mesh smoothing, geometric responses, user-supplied subroutines, mode tracking, fast and efficient solvers and optimizers [12,13]. The ability of GENESIS to optimize for multiple load cases simultaneously is also one of the key capabilities built-in that allows engineers to solve industrial problems.

6. Industrial Applications using GENESIS

The GENESIS program is now being used in several industries; however, most of the GENESIS users are in the automotive or aerospace industries. It is interesting to mention that today almost any part of a car can be optimized using GENESIS. Applications are numerous. They range from small parts such as mirrors, steering knuckles, rocker panels, mounting brackets, pillars, seat frames, trunk reinforcements, suspension rings, tie rods to large parts such as engine blocks, chassis and whole car bodies.

The models to be optimized can be small with a small number of degree of freedoms (e.g., one thousand to ten thousands) with a small number of variables (e.g., one to one hundred), or they can be large, with one to five million degrees of freedom with very large numbers of design variables (e.g., one thousand to one hundred thousand). At a client site, the largest eigenvalue problem solved in terms of number of degrees of freedom contained approximately three million. The largest model solved in VR&D in terms of number of design variables using a real finite element model is 105,000 (the thickness of each shell element). Examples of the use of GENESIS for industrial applications can be found in references [14 through 18]. Next, some industrial examples are provided.

6.1 Design of a Truck Chassis for NVH

In this problem, DaimlerChrysler Corporation's engineers designed a truck chassis for NVH using GENESIS. They used shape and sizing capabilities. The challenge was to reduce the weight of the full frame truck with simplified box and cab. The initial natural frequency was to be maintained. Their goals included improving the shape and sizing of the C-pillar, the fuel tank, and the spare tire frame. Also the cross-member size of the complete frame was designed. The shape and gage optimization produced about 17-lbs. (10%) weight saving without violating the frequency constraints. GENESIS hexa domains were used for the shape optimization.

6.2 Design of Heavy Truck Frontal Support

The goal of this task was to reduce the mass of the frontal support of the truck without reducing its stiffness. Shape optimization was used to solve this problem. To do that, candidate designs were constructed using GENESIS hexa domain elements.

Figure 1. Heavy truck frontal support

After the shape optimization was performed, the mass was reduced by 30% without compromising mechanical strength. This result was verified by a photoelastic experimental procedure conducted with planar prototypes of the support. It is interesting to note that no stress concentrations were introduced by the shape optimization procedure.

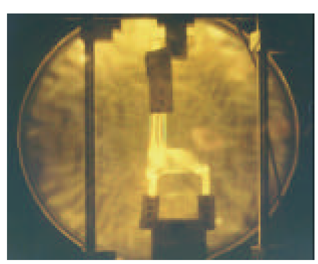


Figure 2. Photoelastic model of the support seen in the polariscope

6.3 Air Cleaner Designs

Air cleaners are commonly used in the automotive industry to clean induction or breathing air of the engine. Air cleaners are composed of a lower housing and an upper cover that seal a filter element between them. Induction air typically oscillates at high noise levels and exerts pressure forces on the air cleaner walls. When the walls vibrate, noise is radiated from the air cleaner's surface. Radiated noise levels can be very high when the air cleaner walls are in resonance. The air cleaner must be stiff to prevent noise radiation from the surface and air leaks at the element seal. Finite element analysis is often performed to assure that the air cleaner design meets requirements.

6.3.1 Design of Air Cleaner using Shape Optimization for Noise Reduction

In this problem, Delphi Automotive System's engineers designed an automobile air cleaner using shape optimization in GENESIS and a user-supplied subroutine to convert the dynamic responses into noise measures. Their goal was to increase the natural frequency of the air cleaner cover and to reduce the radiated noise. First, the rib pattern was optimized with shape optimization. The natural frequency of the cover was increased by 50 Hz and the radiated noise was reduced from 5 to 10 dB. Next, the rib pattern was removed and a large flat air cleaner was also optimized with shape optimization. Radiated noise was slightly reduced and the cover's natural frequency was increased by 100 Hz.

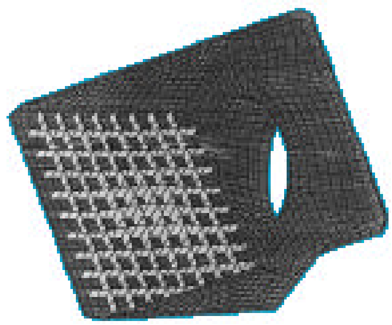


Figure 3. Air cleaner

6.3.2 Design of Air Cleaner using Topology Optimization to Increase Air Cleaner Stiffness

A finite element analysis was performed on the initial air cleaner cover shown in Figure 4. Results revealed possible noise problems as well as possible leaks at the element seal. The cover had low natural frequency modes. Ribs were added to the cover for stiffening and a topology optimization was performed to find the rib pattern. The topology optimization indicated the best location to add ribs to improve cover stiffness. However, the topology also indicated that ribs alone could not sufficiently stiffen the cover. As a result, attention was directed to improving the cover's mounting system. The topology was used to determine the optimum mounting clamp location. The new clamp locations improved cover stiffness without adding ribs. The air cleaner mass was therefore minimized, reducing overall cost.

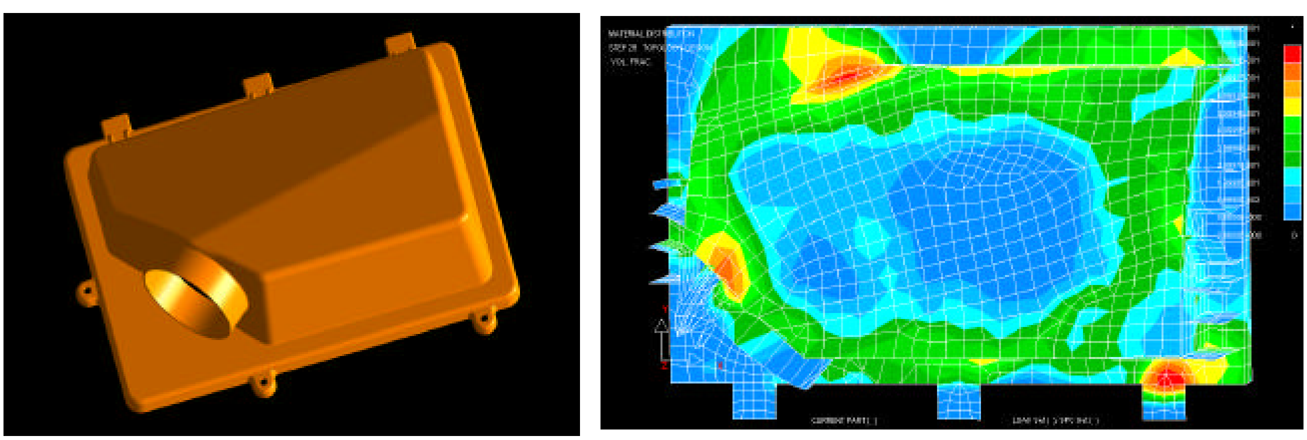


Figure 4. Air cleaner cover and topology density results

6.4 Air Suspension "Z" Spring

This air suspension "Z" spring problem shows the usefulness of structural optimization in attaining feasibility at the lowest possible cost. Figure 5 shows an air suspension system in which the spring's initial design violates a stress constraint by approximately 65%. Two models were developed for this spring. The first one uses shell elements. The second model uses solid elements.

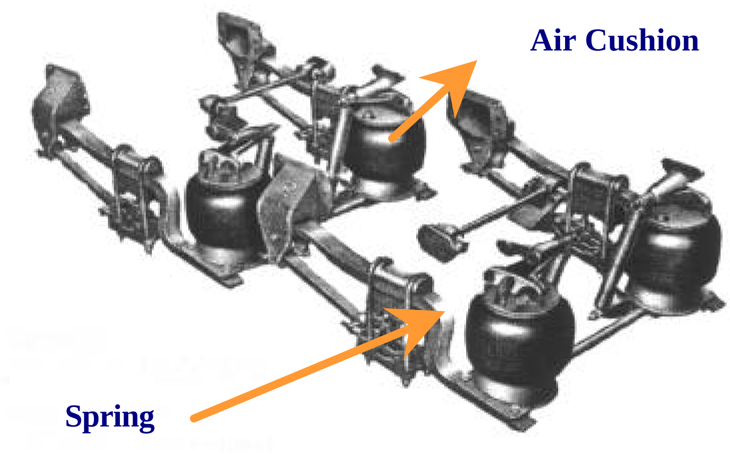


Figure 5. Air suspension "Z" system

6. 4. 1 Sizing Optimization of Air Suspension "Z" Spring

Figure 6 shows the Shell finite element model of the "Z" spring. The model contains 128 different sets of properties. Each set of properties is associated to a design variable aiming at the optimization of local thicknesses. The sequence of optimal thicknesses results in a optimal profile resembling a parabolic curve and leads to the elimination of the constraint violation with only a modest increase in mass (3.5%).

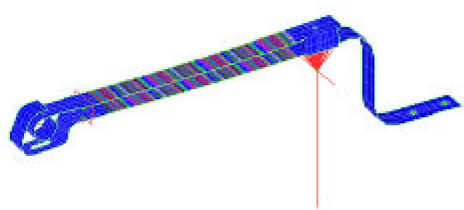


Figure 6. Shell model of "Z" spring for sizing optimization

6.4.2 Shape Optimization of Air Suspension "Z" Spring

Figure 7 shows the solid finite element model of the "Z" spring. The model contains HEXA domain elements to perform shape optimization. Very similar results to the shell model are obtained with this model. The domain element's positions are indicated by the ribbons at the upper and lower spring blades.

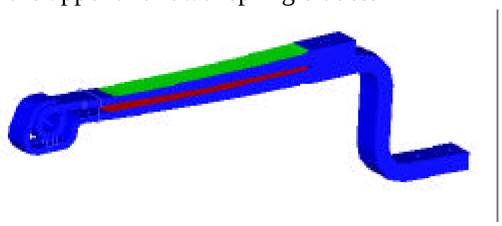
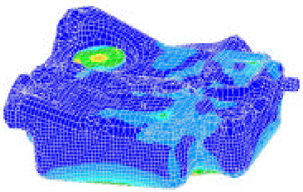


Figure 7. Solid model of the "Z" spring for shape optimization

6.5 Design of a Gas Tank

The design requirements of the gas tank included stiffness and stress. Also, the interior volume of the gas tank could not be less than a prescribed value. Visteon Corporation achieved this goal using shape optimization in GENESIS. For that purpose 99 shape design variables were used to identify an optimal bead pattern design.



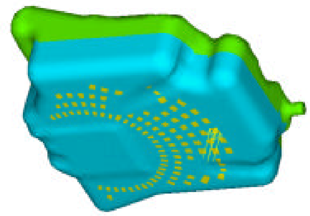


Figure 8. Gas tank

6.6 Sizing Optimization of a External Rear View Mirror

The objective of this problem was to maximize the first natural frequency. The mass of the problem was restricted to be less or equal the initial mass. Thickness design variables were used to design each part of the mirror (eight variables in total). The optimization produces a final frequency of 90.03 Hz. This represents a 34% increase above the initial frequency of 67.2 Hz.

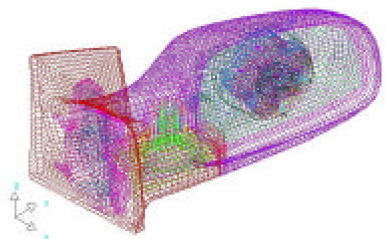


Figure 9. External rear view mirror

6.7 Automobile Seat Frame Design

In this problem, an automobile seat was designed. The goal was to reduce the structural mass. The maximum deflection was constrained to be less than 45 mm and the stresses at any points were constrained to be less than the allowable. The design variables controlled the spring stiffness and the thickness of the recliner. Figure 10 shows static analysis results using GENESIS.

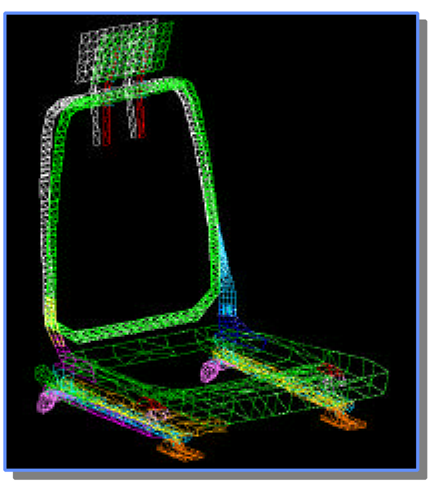


Figure 10. Static analysis results of automobile seat frame

7. Conclusions

The GENESIS program was briefly described. Several examples from the industry have been presented. Examples have shown that a wide variety of problems can be solved. The presented examples have also shown that by using optimization it is possible to considerably improve industrial designs. Improvements of 30% to 50% are often achieved. Improvements can be in terms of satisfying design requirements or in the objective functions themselves or in both.

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