Cost based Multiobjective Design Optimisation

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Manufacturing Cost In
Design Optimisation

Design optimisation typically involves optimising important structural performance metrics such as stress, deformation or natural frequencies. Manufacturing cost, though a decisive factor in a product’s lifetime, is often introduced in a weight or volume as detailed manufacturing process cost-based model is difficult to build and valuable. A research carried out in the Design Analysis Tool for Unit Cost Modelling (DATUM) project enables the use of a transparent multi-objective cost model with a comprehensive optimisation framework to address the tradeoff between manufacturing cost and structural performance. This project aims to demonstrate the use of an integrated system for optimising design activity as a means for minimising manufacturing cost, induced stresses and the mass of the selected component. The four different elements essential to the process are (1) a parameterised solid model of the component in a CAD system (2) a finite element analysis (FEA) tool (3) a cost model reflecting changes in cost as geometry is modified and (4) an optimiser. The system is outlined in the diagram shown in Fig.1.

Multiobjective
Optimisation

If a problem has multiple conflicting objectives and these cannot be combined into a single objective function to ease the task, then the problem boils down to the construction of a Pareto front or surface and the idea of Pareto Optimality. A Pareto front can be formed from a set of design solutions to a single problem where each member of the set is an optimal solution, such that improving the design with respect to any one goal would mean a tradeoff to at least one other. In recent years, several approaches have been proposed to solve multiobjective problems using evolutionary algorithms (MOCA). Since genetic algorithms (GA) are very robust and used method from the GA family work with a population of solutions in each iteration, it is easy to apply them in finding multiple solutions in each design, iteratively moving toward the true Pareto-optimal region. A modified version of the Non-dominated Sorting Genetic Algorithm (NSGA) called Optimised Genetic Algorithm (OGA) is used for using OGA’s design exploration system to effectively solve the optimisation problem for different design scenarios. In this project, two such design scenarios have been studied. One can minimise both total cost and induced stresses while the other was constrained by corresponding material cost of the component. The alternative is to minimise both volume and induced bending stresses as a constraint in the optimisation problem. Finite element analysis (FEA) was performed for determining the design of an engine rear mount link and the second method was applied in optimising the 2D profile for a high pressure turbine disc.

Design of the Rear Mount Link

Design Figure 2 shows the geometry of the rear mount link with the design variables and the constraint imposed. Geometry modelling was carried out in Catia and a model in ANSYS to extract the maximum induced Von Mises stress. The manufacturing cost was modelled in DassaultSystèmes (a general, multi-purpose software) using resource consumption equations for various manufacturing processes.

Figure 3 shows results for a range of designs. On the right-hand side, the optimisation results for the design variables r and t for different values of induced Von Mises stress and cost. A designer can now easily move along this surface to choose the best tradeoff that fits his specific requirements of the product and cost. With a population size of 50 design points in each generation, 30 generations are taken by the GA to find a reasonably converged solution. The solution is said to have converged and the global optimal result is obtained when the number of points on the front taken from the last generation evaluated is greater than the number of points on the front from the last generation. The points derived from the classical weighted sum (WS) method are superimposed on the dense Pareto front, resulting from the NSGA. It can clearly be seen that in this case, the WS approach has a similar accuracy but is comparatively very expensive as it requires 1000 generations to reach 5000 iterations of a GA whereas the NSGA provided a similar result with 1500 iterations on the same problem code.

2D profile optimisation of the High pressure turbine disc

After testing these techniques on a simple problem such as the rear mount link, the profile design of a high pressure turbine (HPT) disc using the optimised criteria was chosen as it was more representative of design problems in the aerospace industry. The objective function in this optimisation module is to minimise both volume and cost. The results tested between these two factors separately due to the condition of the work for the disc being fixed. Therefore, minimising volume is accomplished through excessive machining which correspondingly increases manufacturing cost. A surface finish factor influencing both cost and stress is added to the list of inputs. The results show a classical tradeoff between utilising a highly finished expensive component design being countered by higher stresses as against a relatively weaker component which is cheaper to procure.

The 2D profile is parameterised in Unigraphics NC1 with 8 variables influencing the shape in Fig. 4 and a surface finish factor. The machining stresses are obtained by using the disc data with 11.2% of the end face speed and given loads. This analysis is carried out in the Multi-Response TIA axes (MRI). Cost data is derived from the parts SAP router information and encapsulated in DecisionPlus. The cost model is broken down into the manufacturing process sequence used for the disc. Processes specific volumetric metal removal rates are assumed from the SAP processing time data.