Cost based Multiobjective Design Optimisation

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UTP for design

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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 is often substituted by weight or volume as detailed manufacturing process based cost models are difficult to build or are unavailable. Recent research carried out in the Design Analysis Tool for Unit Cost Modelling (DATUM) project enables the use of a transparent, well structured and process-based cost model within a multiobjective optimisation framework to observe the trade-off between manufacturing cost and structural performance.

This project aims to demonstrate the use of an integrated system for optimising design/geometry parameters for minimising manufacturing cost, induced stresses and the mass of the selected component. The four different elements essential to the process are: (1) a parameterized 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

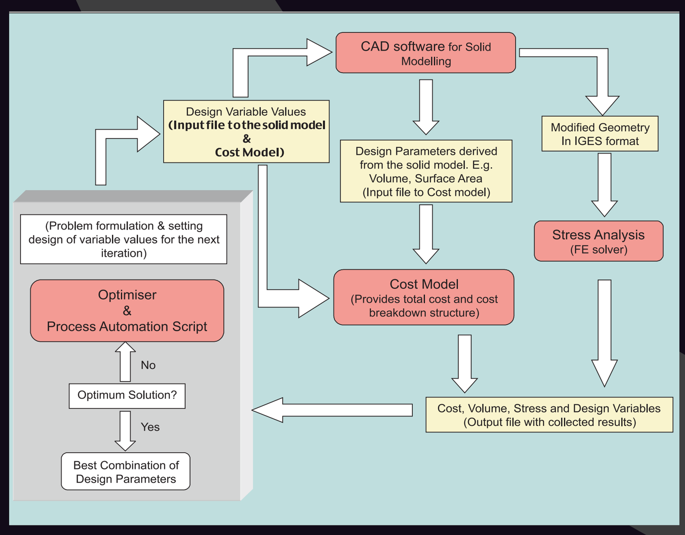

Fig.1 The integrated design system

Multiobjective Optimisation

If a problem has multiple, conflicting, objectives and these cannot be combined by assigning relative importance to each of the goals, then the problem leads to the construction of a Pareto front or surface and the idea of Pareto Optimisation. A Pareto front can be formed from a set of design solutions to a single design problem where each member of the set is an optimal solution, such that improving the design with respect to any one goal worsens it with respect to at least one other. In recent years, several approaches have been proposed to solve multiobjective problems using evolutionary algorithms (MOEA). Since genetic algorithms (the most popularly used method from the EA family) work with a population of solutions in each iteration, it is easy to apply them in finding multiple solutions at each stage, while iteratively moving toward the true Pareto-optimal region. A modified version of the Non-dominated Sorting Genetic Algorithm (NSGA) called optionsNSGA2 available within the OPTIONS design exploration system is employed here to seek the optimal Pareto front.

In this project, two possible design scenarios have been studied. One can minimise both total cost and induced stresses while volume is converted into corresponding material cost of the component. The alternative is to minimise both volume and cost while treating stresses as a constraint in the optimisation process. The first scenario is applied in the design of an engine rear mount link and the second method is applied in optimising the 2D profile for a high pressure turbine disc.

Design of the Rear Mount Link

Figure 2 shows the geometry of the rear mount link with the design variables arc radius (r) and thickness (t). Geometry modelling was carried out in Catia" and static strength analysis in Ansys" to extract the maximum induced Von-Mises stress. The manufacturing cost was modelled in DecisionPro (a generic modelling software) using resource consumption equations for various manufacturing processes.

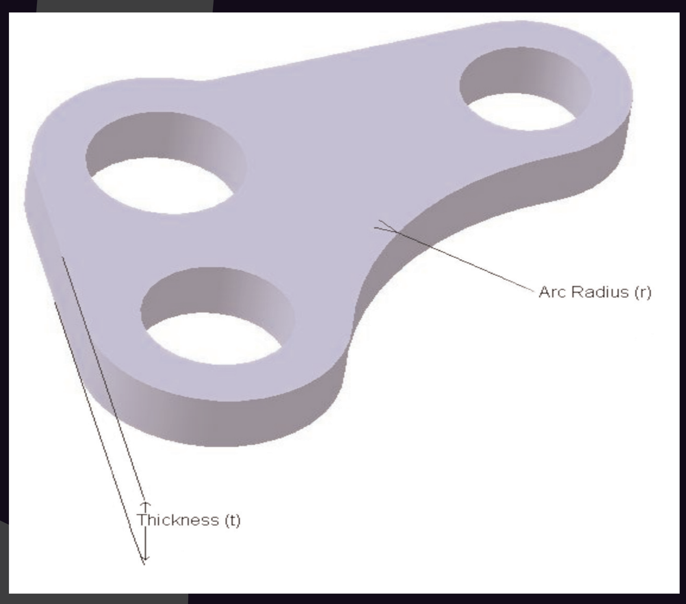

Figure 2. Solid model of the rear mount link in Catia"

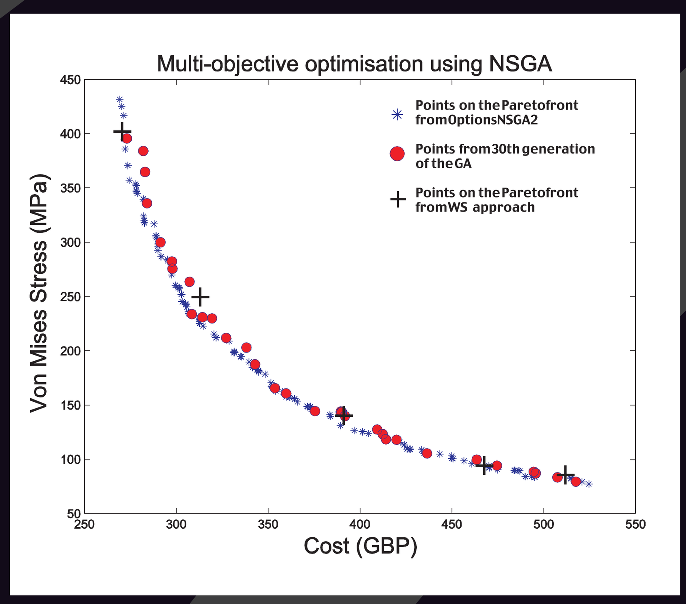

Figure 3. Pareto front of cost against stresses

Figure 3 shows results for a range of designs, all of them optimal combinations of 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 trade-off that fits into the specific requirements of the product and company. 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 Pareto front is obtained when the number of points on the front taken from all the generations evaluated so far is more 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 routine. It can be seen that in this case, the WS approach has a similar accuracy but is comparatively very expensive as 5 points on the front required 5000 iterations of a GA whereas the NSGA provided a similar output 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 overspeed criteria was chosen as it was more representative of design problems in the aerospace industry. The objective function in this optimisation routine is to minimise both volume and cost. The rationale behind treating these two factors seperately is due to the condition of supply for the disc forging being fixed. Therefore, minimising volume is accomplished through excess machining which correspondingly increases manufacturing cost. A surface finish factor influencing both stresses and cost is added to the list of inputs. This reflects the classical trade-off between utilising a highly finished expensive component designed to withstand higher stresses as against a relatively weaker component which is cheaper to produce.

The 2D profile is parameterised in Unigraphics NX3 with 8 variables influencing the shape (see figure 4) and a surface finish factor. The limiting stresses are obtained by sizing the disc to cope with 120% of the red line speed at given loads. This analysis is carried out in the Rolls-Royce FEA code SC03. Cost data is derived from the parts SAP router information and encapsulated in DecisionPro. The cost model is broken down into the manufacturing process sequence used for the disc. Process specific volumetric metal removal rates are assumed from the SAP processing time data.

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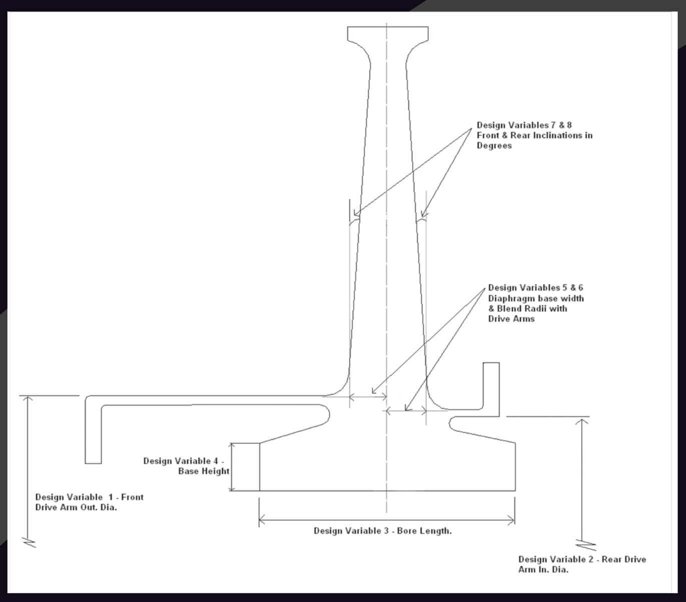

Figure 4. 2D axisymmetric section of the disc showing design variables used in optimisation

Figure 5 depicts the pareto front generated for designs possesing an optimum combination of volume and cost for a certain combination of design variables and surface finish. Figure 6 shows screenshots from NX3 of a few disc profiles that are on the pareto front shown in figure 5.

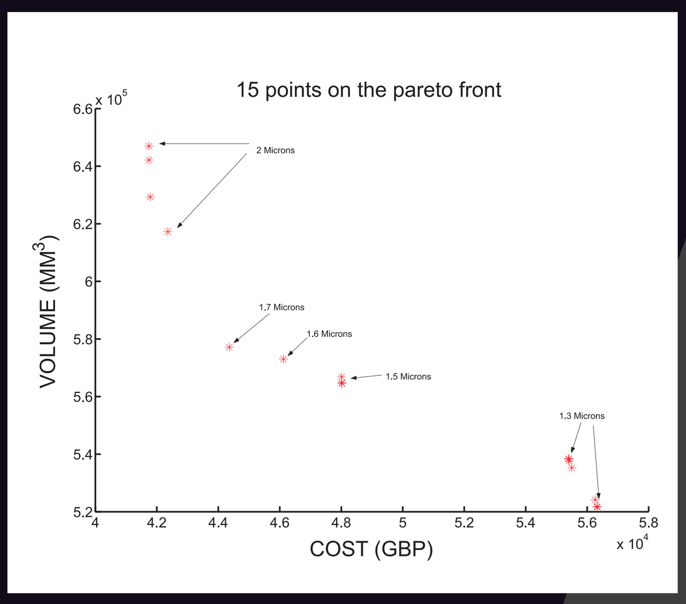

Figure 5. Pareto front achieved for the HP turbine disc after 2500 iterations of the GA.

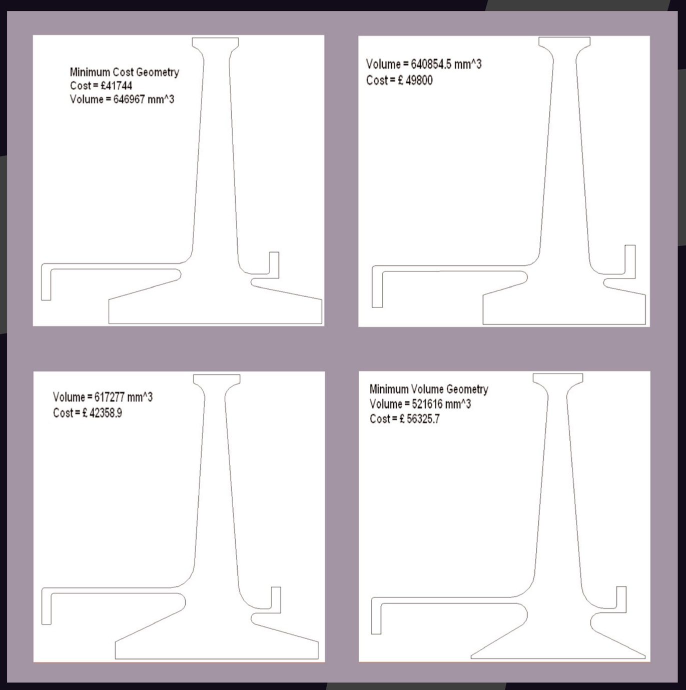

Figure 6. Disc Profiles on the pareto curve

Future work

The models used for examining the effects of changing surface finish on stress constraints can be improved by incorporating fatigue life analysis. Increasing the finish increases the net stresses the disc can withstand for a fixed life. This can be translated into possible weight saving by reducing volume. Conversely it might be cheaper to make the disc heavier with relaxed surface finish constraints for a fixed life. We plan to use the strain-life approach also known as the total life approach in modelling the relationship between surface finish, allowable stresses and fatigue life in the design of the HP turbine disc.

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