Turbine Firtree Root Design Optimization

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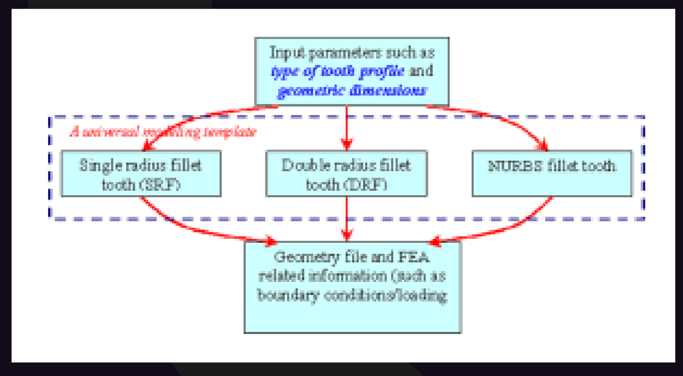
UTP for design

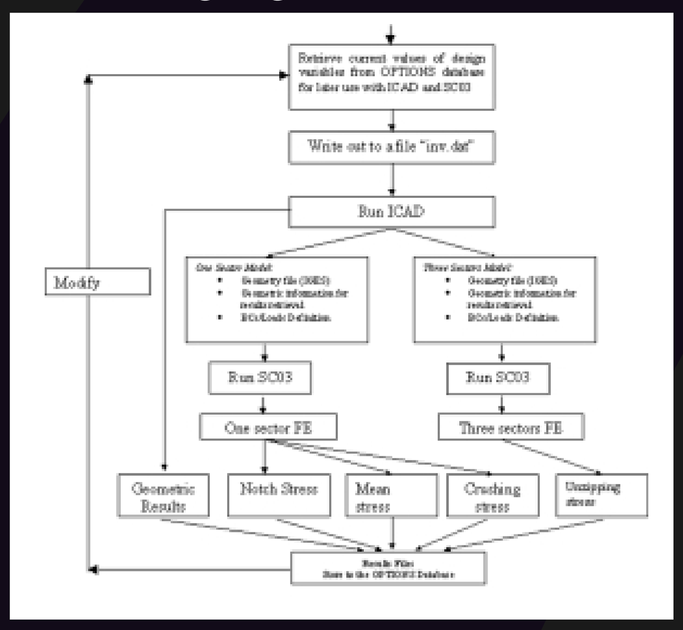
CEDC

Automating the design process through the use of design templates

The use of a rule-based design template enables the complete automation of design process from parameters to stress contour map. This is not only the key step in applying optimization techniques in design, but also provides a platform for the design of a family of similar products. The rules can be modified/upgraded without affecting the interface exposed to the users, thus hiding the details of internal implementation. The rules can also be incrementally enhanced to introduce new features while at the same time providing backward compatibility, so an incremental template (geometry engine) can be developed and used throughout the design process.

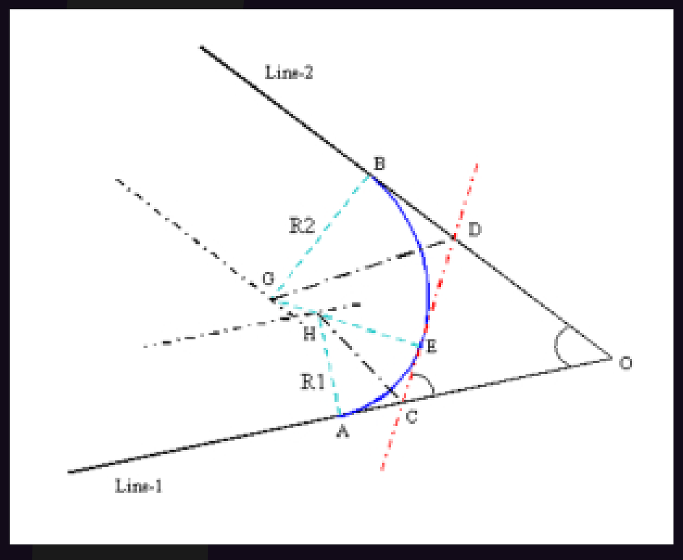


The ICAD system from Knowledge Technology International (KTI) is used in rule-based modeling. The automated design-to-analysis process is further integrated into an Design Exploration System OPTIONS, developed in CEDC, University of Southampton as shown in the following figure.



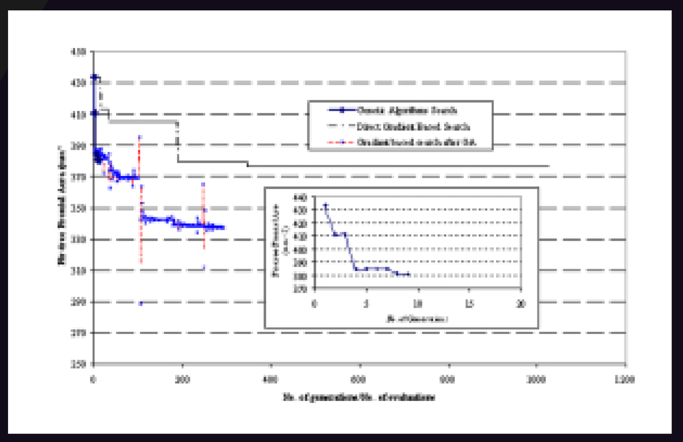
Sequential geometry modeling – handling geometric constraints

Geometric constraints are handled explicitly in a sequential manner so that incompatible geometries will be signaled to the optimizer and possible corrections can be provided according to user's requirements. Sequential handling of geometric constraints eliminates the need for a geometric solver, which otherwise will need an iterative process to obtain solutions. An example of double-radii fillet is illustrated in the following figure in which relations between geometric quantities, and constraints on parameters are defined. The fillet shape can be uniquely defined by the parameters R1, R2, and θ.



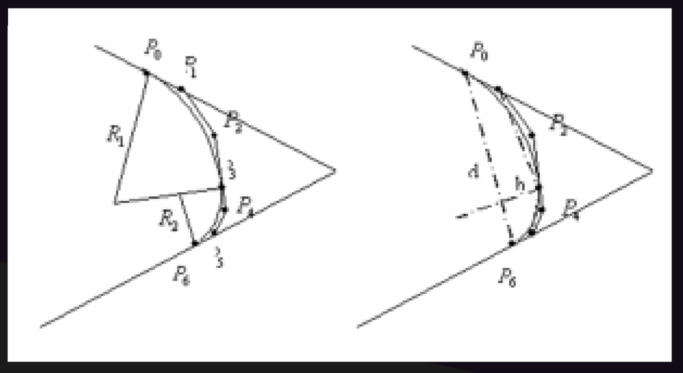
Shape Design Optimization Using Existing Features

Conventional shape of a turbine blade firtree root is defined using straight lines and circular arcs only, which are referred to as existing features. Such a shape is optimized against a number of geometric and mechanical constraints. Finite element analysis is carried out using Rolls-Royce in-house FE package SC03 to produce stress distributions for the model. A simple two-stage strategy (Genetic Algorithms + Local gradient search) was employed in the solution of the problem. A convergence curve is plotted in the following figure.



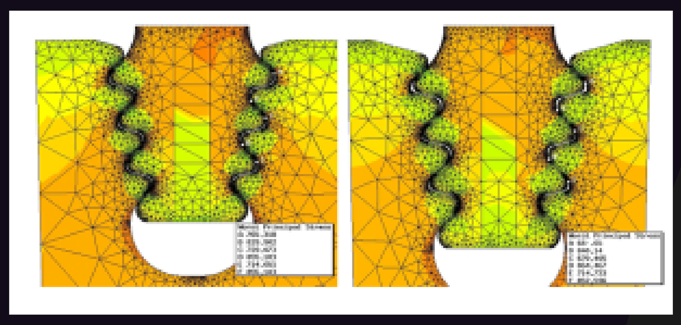
Parameterization using Non-Uniform Rational B-Splines (NURBS)

The Non-Uniform Rational B-Splines (NURBS) is introduced in the modeling of notch fillet as a further step in the effort to reduce the maximum notch stress, which is critical to the life of the blade/disc. A double-arc fillet can be alternative described using 7 control points if the component arc is defined by a cubic NURBS, as illustrated in the following figure. This NURBS double arc will be used as a starting point for local shape optimization. In the figure, the point P_0 will be defined by other dimensions (i.e. the end of the straight line segment). The point P_6 is the end-point of the curve, the point P_3 is defined by two non-dimensional quantities *h,d* as shown in the following figure (right) using points P_1 and P_5 as reference points. The point P_2 and P_4 are defined in a similar manner using P_1,P_3 and P_3,P_5 as reference points, respectively. The use of non-dimensional quantities such as *h,d* provides better control in the optimizer as well as sufficient flexibility in the geometry definition.

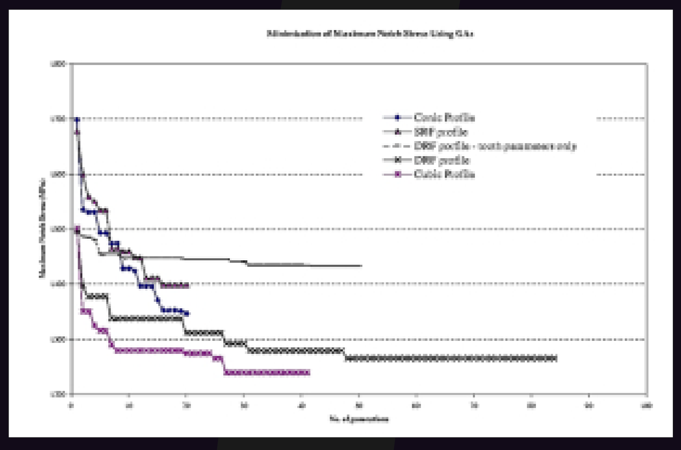


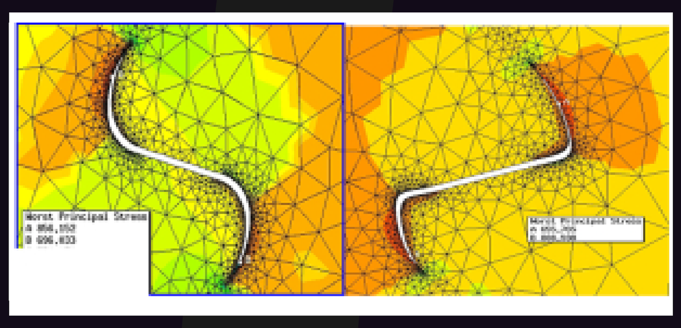
Local Shape Optimization Using NURBS – Exploring New Features

Due to the importance of the maximum notch stress in affecting the life of turbine blade/disc, an optimization problem to minimize the peak notch stress has been formulated for the case of double-radii fillet. However, casting all the geometric dimensions into the category of design variables will lead to the increase of firtree frontal area or the size of the firtree root, which is also a target to be minimized (proportional to the weight when axial length fixed). This can be seen in the following figure that when the notch stress is minimized, the firtree root tends to become bigger.



However, this disadvantage can be overcome using NURBS-based notch fillet. The NURBS definition of notch fillet will bring new features into the shape, which will further drop the stress concentration in notch region. A comparison for using different notch profile is shown in the following figure, in which, convergence curve were plotted for four different profile types including conventional single-radius fillet, double-radii fillet, conic fillet and cubic fillet. It can be seen that better results can be obtained using NURBS fillet. The tooth profile and stress contour map for the original double-radii fillet and optimized cubic-radii fillet were also given.





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