Combinatorial optimization of welding sequences

This article may be found at
http://www.soton.ac.uk/~cedc/posters.html

Ivan Voutchkov, Andy Keane,
Atul Bhaskar
Computational Engineering and
Design Centre,
School of Engineering Sciences,
University of Southampton,
Highfield, Southampton
SO17 1BJ

UTP for design

CEDC

CEDC

The problem

Combinatorial optimization usually involves many iterations, which makes such approaches computationally expensive, especially when dealing with complex finite element models. This work demonstrates a model that can bring down the computational expense of sequential combinatorial finite element problems. The model is illustrated using a welding example of a tail bearing housing vanes – Figure 1. The major structural details are the outer ring, the inner ring and the vanes. The vanes are welded to the rings using TIG welding.

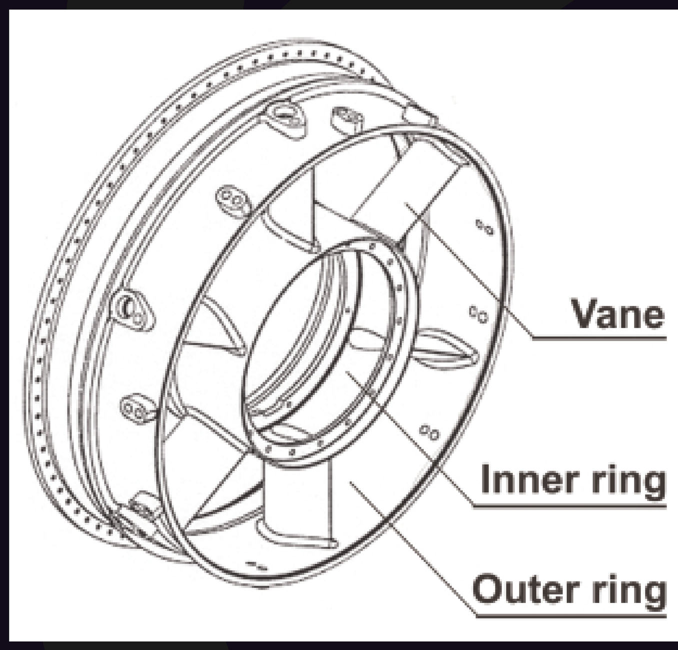

Fig. 1: Tail bearing housing

The inner ring and the vane are both clamped during welding, however, due to the internal stresses generated by heating, the vane deforms and this is measured by the displacement of the two nodes opposite to the welding pool, identified here as Nodes 10 and 96. The welding parameters are defined by the welding process itself and therefore cannot be altered to reduce the deformation. One solution is to divide the welding path into smaller segments and try to find the best sequence of welds to cause minimal or no deformation.

Why is it difficult to solve using an exhaustive search?

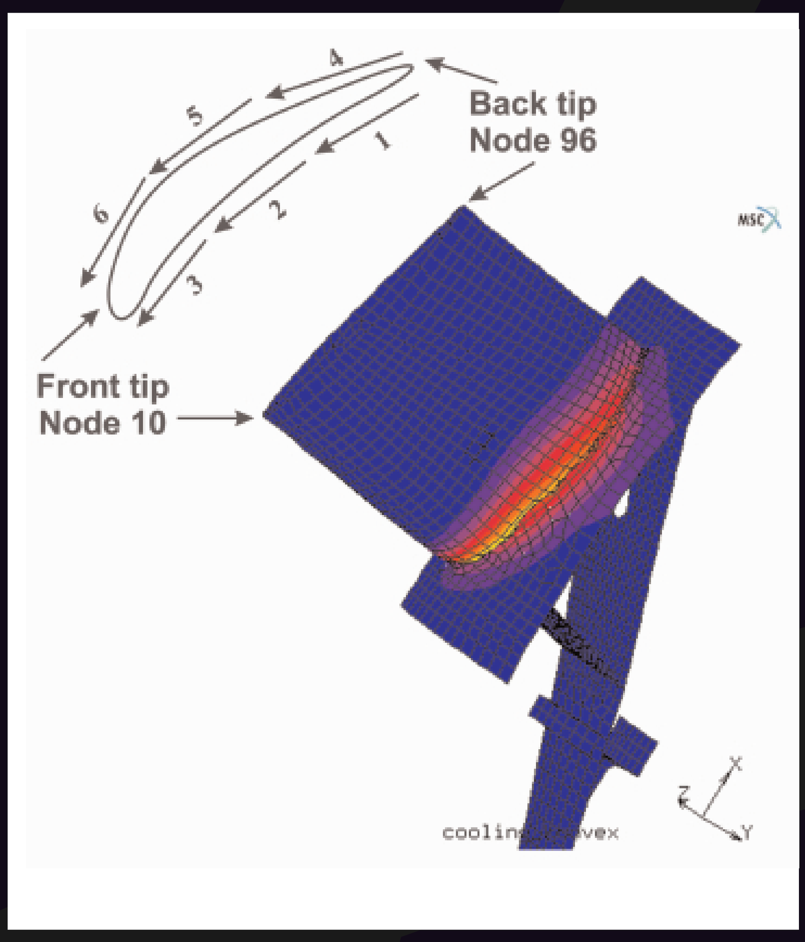

Fig. 2: Welding paths and FE welding simulation.

Figure 2 shows a cross-section of the base of the vane that is to be welded to the inner ring. The welding takes place on the contours of this diagram. Due to manufacturing considerations, the contour has been divided into six welding paths, as shown on the diagram.
The notation adopted to describe two possible welding sequences is presented in Figure 3.

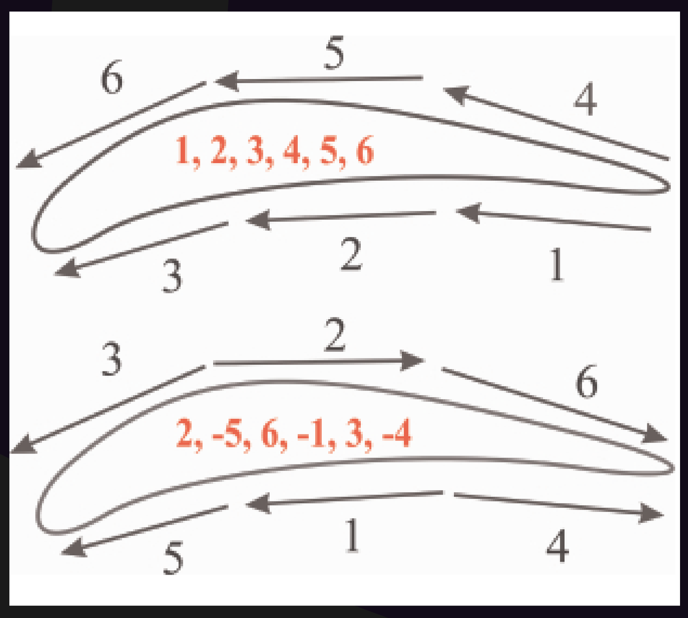

Fig. 3: Variable designation

A finite element (FE) model is used to calculate the displacement at the Nodes. The analysis shows that only the X component of the displacement need be considered for optimization, as it is the most significant component and changes in both directions (plus and minus). The model thus takes as input the welding sequence and produces a displacement diagram over the welding process.
In summary, the aim is to reduce the final displacement by changing the welding sequence. We have six variables (one for each welding position), each of which can take 12 non-numerical values (6 for one direction and 6 for the opposite). An obvious solution is to run all possible 46080 (26 x 6!) combinations and select the best amongst them. An exhaustive calculation will take over 160 years since each FE run takes over 30 hours. Therefore it is necessary to build a surrogate model that is fast to compute and at the same time accurate enough to replace the FE calculations.

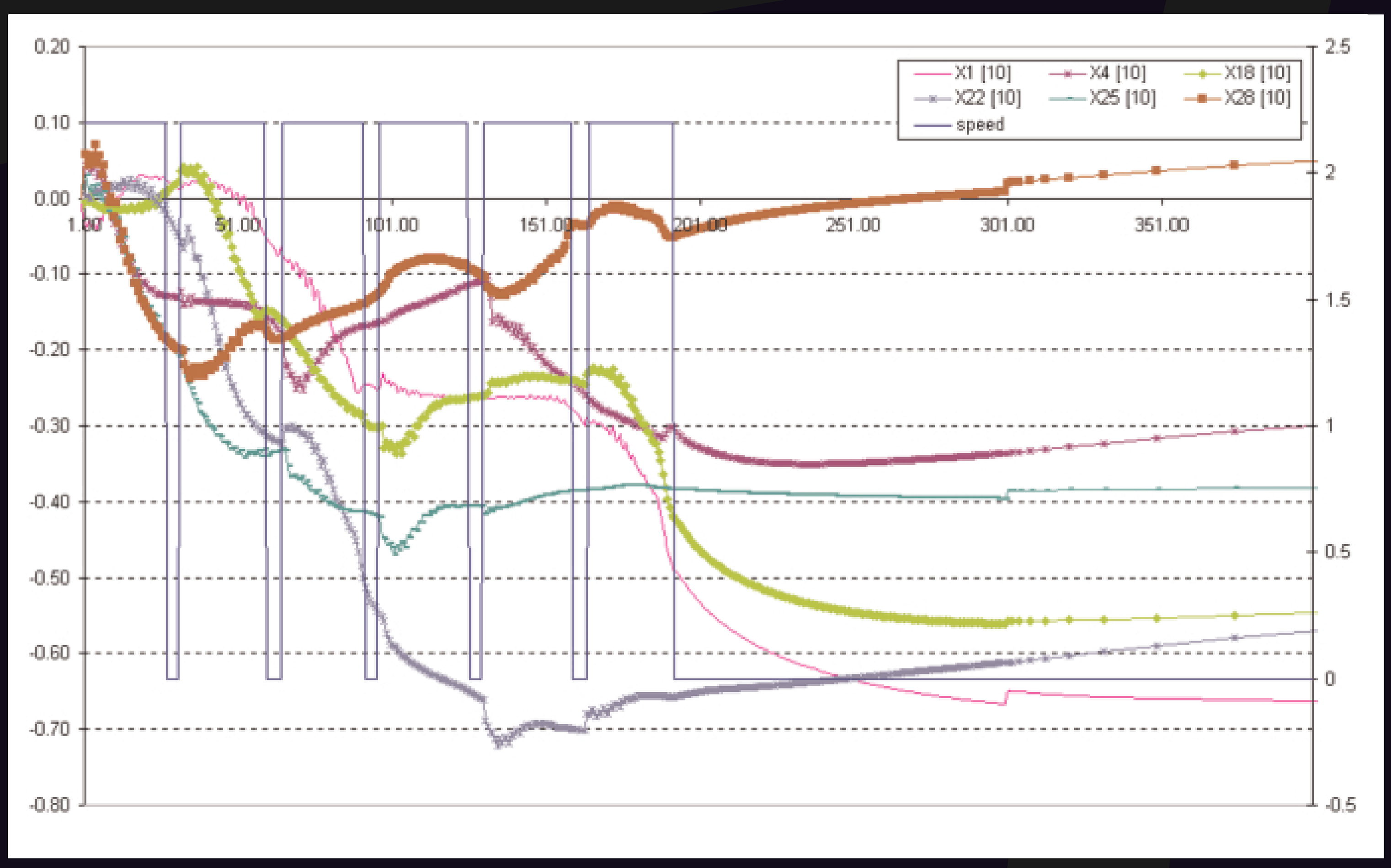

Fig. 4: Run 28 is the optimized displacement with a clamped structure.

Surrogate model

The developed surrogate model is pending a patent and therefore cannot be revealed in this poster, however, it may be noted that the model has the following features:

- It maps the non-continuous space to a continuous one, allowing the conversion of a sequential combinatorial problem to a conventional representation.
- The model is applicable to a variety of sequential combinatorial problems.
- The model is built sequentially – every new combination presented to it makes it more accurate.
- The model is efficient - it extracts all the useful information out of the presented FE runs, and arranges this in a priority list, based on its usefulness.
- The model is fast - All possible 46080 combinations may be calculated in less than 5 minutes on 800 MHz Pentium III machine, using a MATLAB code. A code written in C or FORTRAN would produce results much faster.
- 27 FE calculations were sufficient to obtain a high accuracy, fast prediction, which produced the following value for the optimal displacement – 0.00023mm, which is very close to the FE predicted value of 0.000231mm. The final optimization results are shown in Figure 4, where it is seen that run 28, crosses the horizontal axis for the displacement at the moment of clamps removal, as desired.

Acknowledgments

The authors would like to express their thanks to Mr. Tor-Morten Olsen, from Volvo Aero – Sweden, for providing the 28 FE calculations and Figures 2. We are also grateful to ITP, Spain for Figure 1.

University of Southampton