10th World Congress on Structural and Multidisciplinary Optimization (WCSMO-10)
Orlando, Florida, USA; May 19-24, 2013

Thermo-Mechanical Design and Optimization Using Transient Modal Analysis

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The design of today's precision devices and machine tools has to address the effect of thermal errors, i.e. the undesired displacements and/or displacement differences due to temperature fluctuations. Consequently, design optimization is often applied to meet demands on position accuracy and speed. However, optimizing a thermo-mechanical system can be computationally expensive due to the transient nature of the problem. To decrease the computational time, model reduction techniques can be used. This paper presents a tool for design and optimization of linear transient problems using relevance-based modal basis.

Starting point is a thermal modal analysis to extract the eigenvectors and corresponding eigenvalues of the thermal system, i.e. thermal modes and corresponding time constants. The objective function requires the transient analysis, however, a high-quality approximation to the full analysis may be sufficient for design and optimization purposes. Therefore, we only take into account the relevant part of the response, which is determined considering three design measures:

1) modal excitation by the thermal loads,
2) modal observability, and
3) modal participation within the time frame of interest.

Hence, the response is expressed in terms of a relevance-based modal basis. In summary, the proposed design tool uses relevance-based modal reduction to reduce the system, indentify the relevant modal variables, and apply first-order design sensitivities for design and optimization. The relevance of these design sensitivities also strongly benefits from the relevance-based modal basis.

This design optimization method is examined on several one- and two-dimensional test cases. Several algorithm parameters are investigated, like the move limits and the number of relevant modes. We observed that the method is faster than conventional optimization algorithms due to reduction of the system by the relevance-based modal basis. However, the efficiency depends on the local nature of the problem, that is, local problems may require more modal variables to be taken into account, thus rendering the method less effective.

Next, application of the rendering relevance-based modal reduction provides designers a versatile tool for interpretation of the performance of their designs, and the effect of design changes. This is caused by a powerful separation into space- and time-dependent parts of the transient behavior.

Finally, we conclude that this design optimization method is a good option to thermal error reduction in transient thermo-mechanical problems. In addition, the method provides designers profound inside in improving their designs.