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Thermoelasticity in Multi–Body Dynamics

Since thermal expansion is usually small compared to purely mechanical deflections, the analysis of flexible multi–body systems traditionally uses the isothermal point of view. But such scenarios exist in which the consideration of both displacement and temperature field is important. If, for instance, a system is configured in a way that thermal expansion is blocked, large membrane or normal stresses may arise and lead to decreasing stiffnesses and natural frequencies. Systems with a very strong and non–linear coupling between displacements and temperatures, e.g. brake disc and pad, also require both thermal and elastic analyses.

Using a modal approach in representing the distributed displacements of a flexible body, it is reasonable to adapt the concept for the desired multi-field description. A modal multi-field approach does not only approximate the displacements by the product of time-independent displacement modes and time-dependent coefficients, but also the temperatures are represented by a variety of distinct spatial temperature distributions. These are thermal modes, which are multiplied by the relevant time-dependent coefficients.

In order to verify this approach, the model Thermodisc has been set up in SIMPACK. On one sector of the circular disc (Fig.1) with initially uniform temperature, a constant heat flux is defined, the opposite sector is cooled by a fluid. The simulation reproduces the transient temperature field towards steady state and the resulting displacements, which are visualised by the light red areas in Fig.1 at t_e=18000s. The blue bars give an impression of the related temperature distribution.

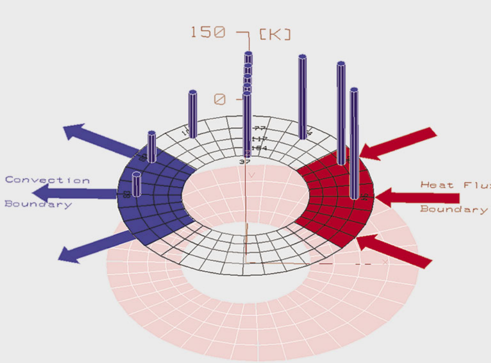
Fig. 2 compares the transient displacement solutions at node 101, obtained by three different set-ups. A transient finite element simulation with 540 degrees of freedom is taken as a reference. The first SIMPACK model uses 7 thermal modes, which gives 7 solutions of the thermal eigenvalue problem, and 18 displacement modes obtained as solutions of the mechanical eigenvalue problem. The second SIMPACK model is based on the same 7 thermal modes, but the displacements are approximated by the corresponding 7 thermal response modes.

A thermal response mode is defined here as the static displacement solution with the corresponding thermal mode as load case. Fig. 3 demonstrates 6 of 7 used spatial temperature distributions by colour. The corresponding thermal response modes are illustrated by the deformed mesh compared to the undeformed outer circle contour.

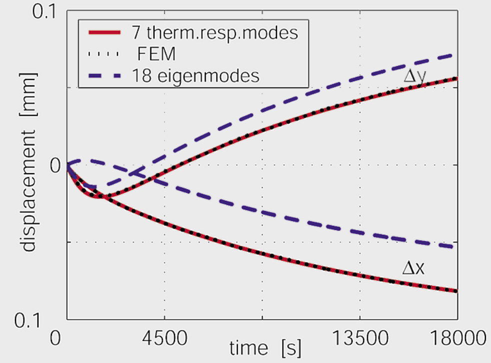
This advanced mode selection approach is justified by Fig.2. The finite element simulation and the SIMPACK model using thermal response modes yield identical results, but the displacements caused by inhomogeneous temperature fields could not be represented by 18 purely mechanical eigenmodes. Looking at the different time scale properties of the thermal and the mechanical differential equations this result is as to be expected.

Finally, it can be concluded that the modal multi-field approach is feasible to reproduce coupled thermal and mechanical problems. This way the capabilities of multi-body dynamics, in particular its numerical efficiency, can be used to evaluate systems with thermoelastic properties.

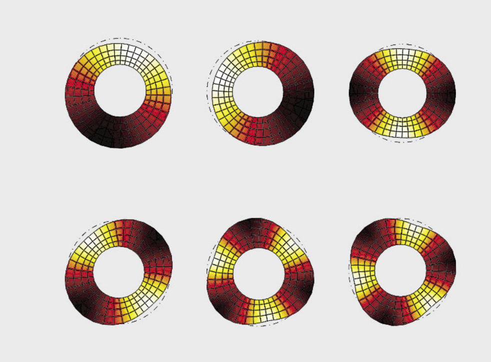
Reference: A. Heckmann, M. Arnold and O. Vaculín. Distributed Multiphysical Phenomena in Multi-body Dynamics. In J.A.C. Ambrósio, editor, Proc. of the International Conference on Advances in Computational Multibody Dynamics (Multi-body Dynamics 2003), Lisbon, 2003.



Definition and results of the SIMPACK thermodisc model (Fig. 1)



Transient displacements at node 101 (Fig. 2)



Thermal modes and corresponding thermal response modes (Fig. 3)