Overview of the requirements of the gas turbine community for improved models of contact interface mechanics

In gas turbines, the ability to model and predict the dynamics of contacts interfaces is crucial. There are two major applications for which this is needed – (i) structural dynamics and (ii) contact (fretting) fatigue.

In structural dynamics, it is necessary to know the stiffness and damping characteristics which are contributed by the joints and interfaces of the critical structures in their operation configuration. These are required (a) at joints such as the flanges where casing components are connected – ideally, rigidly, and (b) at the various interfaces on the blading where relative motion with the disc or adjacent blades or friction damping devices is allowed and even intended. In both of these application areas, the joint properties can have significant effect on resonant vibration levels: the contact stiffnesses influence the precise frequencies of resonance, and the damping directly controls the resonant vibration amplitudes.

These effects must be taken into account in the various structural dynamic analyses, but they are currently represented by primitive models that are deduced a posteriori from measurements on the structures themselves, or testpieces designed to provide the necessary basic properties in the form of hysteresis loops at various normal loads, frequencies, temperatures, vibration amplitudes. It is the replacement of these empirical data by a more predictive model that will permit a priori analysis and thus optimisation of our structures which is sought form the next generation of research on contact mechanics.

We turn now to the second area of major concern in gas turbine applications – contact fatigue. At the length scale of a propagating crack there is general consensus that contact fatigue is not intrinsically different from plain fatigue, although there are frequently complicating factors such as multi-axiality, non-proportional loading, variable R-ratio and high stress gradients. At initiation and short-crack length scales, however, the situation is less clear and an open question is whether surface damage effects need to be captured in a ‘special’ way or whether a more sophisticated analysis would enable prediction of contact fatigue performance using standard material parameters.

Advances have been made in recent years, most notably in the use of contact asymptotics to describe the stress field in the neighbourhood of the edge of contact and this approach seems to offer a promising means of correlating between experimental and component contact geometries. However, dedicated contact fatigue experiments are still required. Finite element analysis of frictional contact still presents difficulties for practical three dimensional geometries at the mesh densities necessary to resolve the stress fields. Further, the required element sizes are frequently so small as to call into question the validity of assuming (elastic) continuum material behaviour, smooth contact geometry, and Coulomb friction. The use of embedded classical ‘half-plane’ or ‘half-space’ contact solutions can be helpful, but in many geometries the effect of other component boundaries means that these can be very difficult to apply. In addition to these microstructural and surface roughness issues it must be recognised that most surfaces contain residual stresses, either deliberately induced or as a result of normal manufacturing processes. We are still some way from being able to incorporate these into robust life prediction methods.

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Overview of the requirements of the structural dynamics community for improved joint models

The drive for extending the predictive capability of structural dynamics is a part of the overall imperative of substituting simulation for the historic dependency on test in design and certification efforts. These issues are most prominent when the relevant experiments are very expensive (such as vibration testing of satellites) or just impossible to do on earth (such as very large aperture space telescopes).

The three most significant impediments to predictive engineering simulation have been discretization error, uncertainty in boundary conditions and load histories, and missing physics. The discretization issue has been mitigated significantly over the last decade through the development of massively parallel (MP) computers and software to run on them. Uncertainty in boundary conditions and load histories remains, but it is being addressed through advances in experimental and computational tools which continue as their own research efforts. In most areas of engineering simulation, it is now appropriate to acknowledge and incorporate the missing physics; in the world of structural dynamics, that missing physics is dominated by the nonlinearities associated with joints and interfaces.

Historically the analysis community has acknowledged the role of joints in structural dynamics ambivalently. Though ascribing the nonlinearities of our structures to the presence of joints, we persist in using linear models. While using linear models, we acknowledge the nonlinearity by calibrating those models against experiments performed at load amplitudes in the ranges for which we intend to make predictions. (A tremendous amount of work has been done to deduce equivalent linear joint properties from measured vibratory response.) On the one hand we argue that a lack of proper tools to model joint nonlinearities or to solve the resulting nonlinear systems of equations forces us to use calibrated linear models; and on the other hand, we relish exploiting the many advantages of linear structural dynamics.

The most common current approach to accommodating joints in structural dynamics is to mesh up the system, placing tuneable springs at each the location of each joint. A full-up prototype is built and subject to various testing (primarily modal testing). The spring stiffnesses are tuned to reproduce the apparent system modes and frequencies at the load amplitudes of interest. Additionally, modal damping values are selected to reproduce the damping observed at those frequencies.

Recently empirical models for the joints themselves have been developed. The parameters for these models are selected to reproduce behaviours elicited on joint specimens. When those joint models are employed in finite element models at the locations of the actual joints, nonlinear structural dynamic response is predicted consistent with that observed experimentally.

Though the simple joint models described above begin to connect structural dynamic predictions with the nonlinearity intrinsic to joints, they do not provide either a rigorous connection to first-principles mechanics or the predictive capability that modern applications require.

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