Symposium of Advances in Contact Mechanics: a tribute to Prof. J.J. Kalker
22 - 24 October 2008, Delft, The Netherlands

Experimental Contributions to the Prediction of the Dynamics of Structures with Contact Interfaces

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THE PROBLEM

In gas turbines - and other critical structures[1] - there are several components whose vibration characteristics must be known very accurately in order to design so as to avoid vibration-related failures. Amongst these characteristics are the stiffness (which must be controlled to avoid the most severe resonance conditions) and the damping (which is sufficient to ensure survivability of those resonances which cannot be avoided). The vibration properties of most components in a gas turbine can be predicted with as much certainty as can be achieved in their manufacture (i.e. errors from modelling deficiencies are of the same order as variability in the manufactured dimensions). However, when components are connected to form the assemblies that comprise all engineering products, this modelling quality is severely compromised and predictions for assembled structures are usually an order of magnitude less reliable than those of the individual components. This is, simply, because at each connection, the interfaces contribute significantly to the dynamic properties of the assembly and these interfaces are – to a very large extent – not modelled. In some cases, interface surfaces are allowed to slide, giving energy dissipation and damping the whole assembly; and an understanding and modelling of interface properties is essential if these are to be properly designed.

CURRENT PRACTICE

How do we cope with this issue? The standard way is to recognise that there *are* stiffness and damping elements in the joints of a connected structure but that we do not understand the behaviour of the interface well enough to be able to make predictions of these properties. Hence, a prototype assembly is constructed and measurements are made from which the unknown stiffness and damping terms are deduced. These can then be added to the otherwise predictive mode for the components to provide a design tool – but only after a prototype test structure has been built. Clearly, this practice is not acceptable in an age world of ever-shortening design cycles, right-first-time philosophies and super computers. More representative predictive models are required and steps towards achieving these have recently been taken.

STATE-OF-THE-ART APPROACH

One approach which has been developed and published in recent years uses an elemental model for the interface based on contact elements with specific friction and stiffness properties. These properties must be provided from measured data, but they are intended to be generic to the given interfacing materials and not case-specific to the actual configuration or joint dimensions on a case-by-case basis.

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[1] ‘ Critical structures’ are those for which structural integrity is a primary design criterion

This paper discusses the experimental contributions to this procedure – which occur at two separate stages – and the future developments that are required to dependence on them so that true predictions can be attempted. The two roles for experimental activities are (i) to determine by direct measurement the specific numerical values for basic elemental properties of friction coefficient and contact stiffness for a given pair of interface materials, and (ii) to conduct tests in order to validate predictions made using the aforementioned model for specific structural assemblies.

MEASUREMENTS OF FRICTION PROPERTIES

The essential elemental model is shown in Figure 1 (a) and the defining parameters for each element comprise two quantities: a coefficient of friction - assumed to be Coulomb-like and constant – and a coefficient of tangential contact stiffness, as depicted by the sketch in Figure 1(b). A test rig was developed in order to measure these parameters under a range of conditions – amplitudes, frequency, normal load, temperature… and this has been used for almost a decade to obtain data for a wide range of materials under a wide range of conditions: see, for example, Figure 1(c). A number of features from the collected results are presented and discussed in the paper. These include calibration of the rig, determining operating procedures to yield reliable and repeatable data; unusual and anomalous results and, recently, a detailed theoretical model of the rig to help understand and control its behaviour. It is notable that the micro-slip parts of the hysteresis loops – where the force changes rapidly with displacement – are not straight but curved, which implies that there is energy dissipation even for small movements and that the curvature should therefore be included in interface modelling.

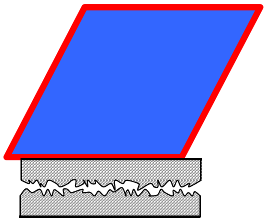

Figure 1(a)

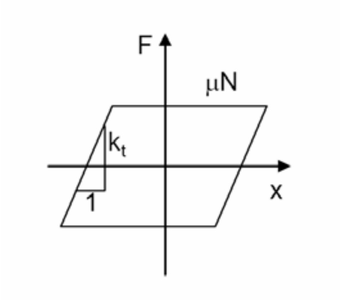

Figure 1(b)

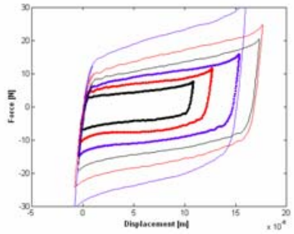

Figure 1(c)

TESTS TO VALIDATE PREDICTION OF VIBRATION CHARACTERISTICS

Certain vibration properties of critical components (specifically, resonance response levels) are of great interest in many engineering structures and predictions of these made using the theoretical model provided by the measured friction data are routinely validated prior to their incorporation into design for production. These tests comprise an important part of the whole design process as products are often optimised using the models supplied with the empirical data referred to above. The paper describes validation tests using both free vibration and forced vibration types of measurement. In each case, great care has to be taken to ensure .that conditions are carefully controlled so that the proper conclusions can be drawn from the comparisons of predictions and measurements. In particular, attention is required to ensure that the background levels of damping and flexibility in the test rig is significantly lower than the corresponding quantities in the interfaces (so that these can be measured reliably) and that full recognition of any non-linear behaviour is preserved and observed.