FRICTIONAL DAMPING IN STRUCTURES - SOME ASPECTS OF MEASUREMENT AND MODELLING

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Introduction

Wherever parts of a machine or structure are joined in a press fit the possibility exists that energy may be dissipated at the interface as a result of relative displacement between the parts. This source of energy loss, generally known as "slip damping", may prove beneficial as in the case when the amplitude of vibrating systems is to be limited, or undesirable as may be the case if fretting corrosion is likely to cause serious problems. Recent work has indicated that the deleterious effects of fretting corrosion may be reduced by cyanide hardening of mating parts (1) and that the use of electro-discharge machining can increase the damping capacity of joints whilst reducing surface damage due to fretting corrosion by an order of magnitude (2).

For slip damping to be fully utilised in the design of machines or structures it is desirable that the mathematical representation of interface behaviour yields equations which are capable of relatively straightforward solution. The benefits of having a linear model are self-evident, and have given the impetus for past work on the development and refinement of such a model (3) (4). The work summarised here is a continuation of that process based on the concept of complex stiffness. The response of an experimental structure incorporating interfaces was measured and used to quantify the damping present using the techniques of modal analysis. Its dependence on the major parameters of normal load, frequency and slip amplitude were investigated.

Complex Stiffness Model of Slip Damping

The results of earlier research justify three broad conclusions regarding the nature of interface behaviour in relation to its damping properties.

(i) The use of a linearised function for the frictional force is capable of giving a good prediction of system response.

(ii) The dissipative forces at an interface may be taken as being proportional to the relative slip amplitude.

(iii) At a microscopic level the relative slip between two bodies exhibits a component of elastic deformation (5).

The need is, therefore, for a linear damping element whose force magnitude is proportional to relative displacement but in phase with the relative velocity. The notion of such a dissipative element is not new in vibration analysis, the need for a model of internal damping of materials having given rise to the concept of hysteretic damping. It is suggested that the parallel combination of such an element with an elastic one - generally known as "complex stiffness"

- may prove to be representative of the damping aspect of interface slip. The acceptance of such a representation must depend on its ability to predict the response of a particular system rather than on a physical interpretation of the elements forming the model.

The use of such a model for slip damping in a structure enables a response prediction to be made based on modal analysis since although the stiffness matrix for the structure becomes complex, the transformation to normal co-ordinates still results in uncoupled equations of motion. Comparison with the measured response enables damping to be quantified from polar plots in the region of anti-resonant and resonant frequencies. The choice of impedance/mobility as the response parameter facilitates this and enables the presence of any elastic content to interface behaviour to be assessed from changes in the measured natural frequencies of the test structure.

Background to Experimental Work

The optimum design of a structure for the purpose of damping measurement would incorporate a single interface and a means of applying, varying and measuring the normal load across it. Simplicity is best achieved if the device for measurement of the normal load forms one element of the interface, and boundary conditions are best met by freely suspending the structure in the horizontal plane. Excitation in this plane will present the opportunity for uni-directional slip to occur at the interface for particular normal loads. An octagonal ring transducer of the type shown in fig.1 was used as the means of normal load measurement and the benefits of having a symmetrical test structure were obtained by providing two interfaces with associated force transducers, the third element being a central block (fig. 2). A single central bolt provided the means of applying and varying the interface load.

It is evident that in a rig of this type the normal load transducers become a major part of the structure and the dynamic characteristics of a single transducer must be measured and modelled before any analysis of the complete structure can be attempted. This task formed the first part of the experimental work which was carried out on a pair of back-to-back transducers, so arranged to provide a symmetrical structure. The initial design dimensions of the transducer were a compromise between the need to produce a component sensitive to the range of normal loads required in the later tests, whilst having at least one free resonant frequency within the experimental range.

In each case the response of the test structure to excitation of the central block was obtained by means of a swept-sine test using an electro-magnetic shaker. For the second rig the introduction of tracking filters into the measurement circuit produced a response signal which was free from any harmonic content above the fundamental excitation frequency.

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Results

Testing of an initial design of transducer followed by subsequent modification of the thickness of the octagonal flexible portion, has resulted in a transducer having its first anti-resonant and resonant frequencies lying in the range 30 Hz - 1 KHz when freely supported. At satisfactory discrete element, spring-mass model of its dynamic characteristics has been constructed and the parameters evaluated from the experimental response.

Tests have been carried out on the composite structure for a range of normal loads and fig. 3 shows three typical point mobility responses, plotted on a logarithmic basis. Estimates of the level of damping have been made by circle fitting in the complex plane using both mobility and impedance responses. For the former a conventional normal mode transformation yields the damping ratio in the vicinity of the resonant frequency, whilst for the latter, a transformation of the type suggested by Harrison and Bassim (6) yields a set of parallel normal modes for the evaluation of damping in the region of the anti-resonant frequency.

Use has been made of the theoretical model of the complete structure, incorporating a complex stiffness element, to investigate changes in natural frequency which may result from interface elasticity.

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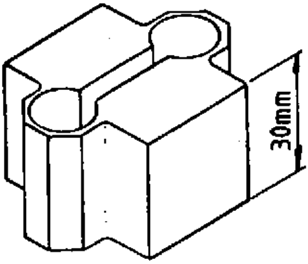

Fig. 1. Transducer for measurement of normal load.

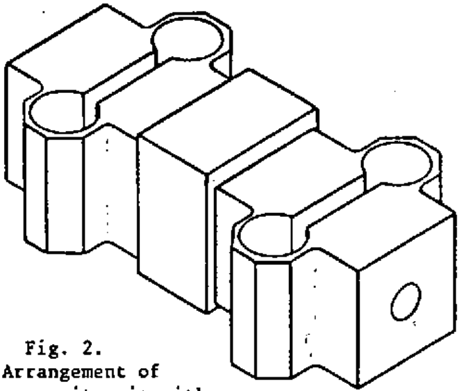

Fig. 2. Arrangement of composite rig with interfaces.

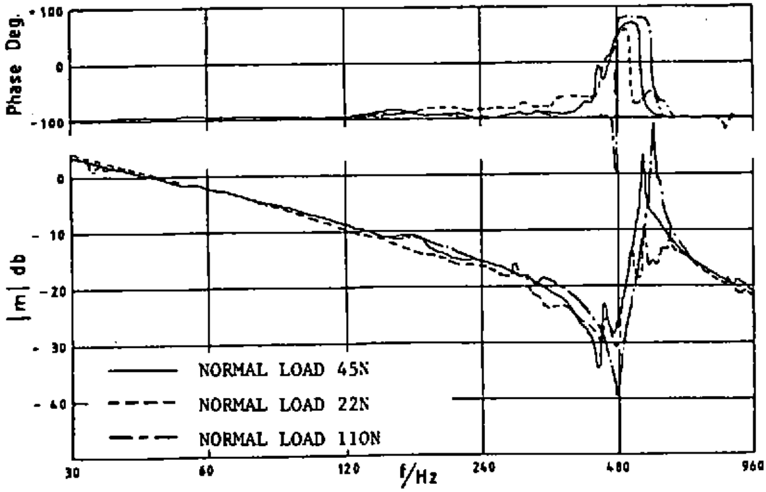

Fig. 3. Typical point mobility responses.