MODAL TESTING TECHNIQUES

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ABSTRACT. This is the first of a set of three papers which describe the technology of modal testing and its application to vibration problems in rotating machinery. Modal testing embraces the processes involved in the construction of a mathematical model of a structure from test data and over the past 10-15 years, the technology has been developed and used extensively on structures of all types. Although there are particular problems associated with the vibration testing of structures which are actually rotating, these are now being addressed and overcome and there are many instances where the non-rotating components of machines must be investigated, or rotating components tested in a stationary condition, and these will be included in the following sections. This paper summarises the processes and techniques involved in modal testing.

1. Introduction

1.1 MATHEMATICAL MODELS

Today, the demands for machines to be free of vibration-related problems such as fatigue and instability require the development and application of sophisticated design methods. These, in turn, demand the availability of detailed mathematical models which can adequately represent the dynamic behaviour of the structures and components under consideration, and which can be used to predict vibration and stress levels and such important characteristics as fatigue lives and stability margins. These mathematical models are sought from 'theoretical' sources such as finite element models but such is the complexity of most modern machinery, and such is the stage of development of the associated prediction methods, that there is usually a gap between the requirements of the designer and the tools which are available from theory alone. As a result, recourse must be made to experimental, as well as analytical, methods of study for these important characteristics of most machines and their constituent components. The most appropriate experimental techniques may be found in the technology of modal testing.

Modal testing has been evolving for over 40 years although it has only recently come into prominence, and its full potential become accessible, with the advent of instrumentation and computation of sufficient precision and power. The basic concept is simple: it is to extract as much information as possible from the data acquired from vibration tests performed on the structure or machine of interest. More specifically, it may be defined as the process of constructing a mathematical model of the test object by suitable
of its vibration characteristics. This model can then be used for any of a range of applications, from simple observation of the structure's vibration modes to design optimisation by determining modifications to bring about desired changes in its dynamic properties, such as tuning its natural frequencies.

1.2 ESSENTIALS OF MODAL TESTING

An essential feature of modal tests, and one which differentiates them from other types of vibration tests on machines, is that the vibration response which is to be measured must be generated by a known and controlled excitation - not the in-built excitation which every operating machine will exhibit. This means that special provision must be made for such an excitation, using vibration exciters or impactors, and for its measurement.

The data which are then measured, of excitation forces and response levels, are processed and presented in the form of frequency response functions. These, in turn, are analysed in order to identify the underlying modal characteristics of the test structure - often, the required end-product of a modal test. However, a further stage of interpretation is possible - the modelling process - whereby a full mathematical model of the structure is set up, suitable for some of the more advanced applications described in the next section.

1.3 SPECIFIC APPLICATIONS OF MODAL TESTING

Before embarking on the summary of the methods and procedures used in modal testing, it is appropriate to itemise the various applications to which the results may be put, with special reference to the theme of interest here - rotating machinery.

The first application is the 'simple' one of identifying and displaying the major vibration modes of the actual structure - as opposed to theoretical predictions of these same properties. This visualisation of the way(s) in which the structure or machine tends to vibrate can help an engineer to diagnose in-service vibration problems and to establish remedies for them. This is the most common application of modal testing and the least demanding in terms of precision and extent of measured data.

The second application is an extension of the first in that it offers the possibility of comparing such measured modal properties with corresponding data predicted by, say, a finite element (FE) model. Moreover, this comparison process can be extended to correlation and eventual updating of the FE model to produce a validated model for subsequent use in design.

More ambitious, but potentially very useful, is the prospect of using the measurement-derived model to predict the effect of design changes on the machine's vibration properties or - even more helpful - of suggesting what changes need to be made in order to bring about a desired change in the vibration responses. Such changes could include addition of mass or stiffness at strategic points, or the incorporation of a damped vibration absorber. An extension of the same approach, and sharing its requirements for detailed and precise measured data, is the structural assembly application. Here, the mathematical model of a complete structure made up of several components is obtained by combining models of each individual component, some or all of which may have been obtained by a modal testing.

The fourth application has particular relevance to rotating machinery: it being the use of a