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SOURCE CHARACTERIZATION IN STRUCTURAL ACOUSTICS

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Abstract - Even though it is often structure-borne sound sources which are the main cause of noise problems, little work has been done so far to characterize such sources compared with the effort made for air-borne sound sources. The need for such characterization and recent work on the subject are discussed.

1 - INTRODUCTION

In many engineering situations, machines are mounted on flexible structures such as ship decks, aircraft fuselages, car or train chassis, building floors etc. When in operation machines may transmit noise and vibrations to the receiving structure, causing unwanted sound and vibration problems close to or remote from the source location. Excessive noise can result in hearing damage and relatively low levels can still result in problems in speech perception, musical appreciation, etc...

In general, procedures for the control of airborne sound are well understood by the engineer, particularly for machines as sources of airborne sound. The analysis and reduction of sound propagation in complex built-up systems has been, since the seventies, one of the major field of applied research in acoustics. Thanks to the increasing possibilities of computers, analysis based on deterministic, statistical and empirical approaches have been possible for systems of increasing complexity thereby offering good approximations to real physical systems.

An important requirement for noise control, design and planning, are invariant source descriptors illustrating the source strength for both airborne and structure-borne emission.
2 - AIR AND STRUCTURE BORNE SOUND SOURCES

For air-borne sound sources, the air-borne sound power generated by the source is used as the source descriptor. Sound power is strictly not a source descriptor since this quantity depends not only on the source strength but also on the acoustic properties of the surrounding space. However, in many cases, the machine as a source of airborne sound can be assumed weakly coupled to the surrounding space and can therefore be characterized by sound power (level) in the absence of fluid loading. The results of tests can be used to quantify the source strength of a machine and this data can be used with confidence for the source in-situ.

The situation is much more problematical for the case of machines as sources of structure-borne sound. The source-receiver interface is often complicated in shape and behaviour and several types of wave can propagate in structures. Also, using sound power in structural acoustics as a source descriptor is not as straightforward as air-borne sound sources. The dynamic properties of the receiving structures can vary considerably. A source strength expressed in terms of surface or point velocity becomes only a particular case, the source may display a constant velocity, a constant force behaviour or sometime intermediate. A source is called a constant velocity or force source if the velocity or the force applied by the source on the receiver is unchanged from one receiver to another (as for air-borne sound sources where results apply to laboratory and field receivers).

3 - SOURCE CHARACTERIZATION

Facing such a disparity of engineering situations, simplified methods of characterization, representative of the typical mounting conditions of particular products or family of products are being investigated /1/, where the final goals of such work are proposals for standardized measurement procedures. Manufacturers are increasingly being made aware of the sensitivity of consumers to both air-borne and structure-borne noise produced by their machines. While tests are at present undertaken in the laboratories of manufacturers, government agencies and consultancies the results produced for structure-borne noise are not reproducible and inter-comparisons are generally not allowed. A lack of knowledge, concerning the limits of applicability of the simplified methods so far proposed remains the main obstacle to the production of standards in this field.

It seems scientifically wise, in such a difficult situation, to look for a general source descriptor, based on a theoretical background, from which possible simplified expressions could be derived together with indicators illustrating the limits of validity of proposed simplified source descriptors. Such a general source descriptor was introduced by the author /2/. It is called the source descriptor S. It is defined as the equivalent power input into the non-operating source required to obtain the velocity of the free source when running. This descriptor depends only on the properties of the uncoupled source, the velocity of the free source and its mobility. It is best suited for multipoint interfaces. The complex power input into the receiver is obtained by introducing a coupling function which depends essentially on the product.
of the source impedance matrix with the receiver mobility matrix for a multipoint interface. Two main quantities govern this function: The ratio of receiver to source diagonal matrices; the ratio of the off diagonal matrix to the diagonal matrix for either the source or the receiver.

The source characterization requires an estimation of receiver to source mobility ratios and simplified measurement methods must provide indicators of such ratios. Standards for point mobility measurements exist for force excitation and progress made recently in moment mobility measurements are encouraging. Despite the fact that more work is required in the development of such measurement techniques, their cost and difficulties should be acceptable for improved engineering practice.

Most machines are mounted on floors, decks, frames, etc., which commonly display beam and or plate-like behaviour. Estimates of mean values of mobility and peak envelopes of such systems can often be derived. Thus, it is possible to rank receivers, in terms of their dynamic properties, with regard to classes of machines. Furthermore, each source or receiver can be regarded as samples drawn from a large population whereby a 'random' variation of their characteristics is to be expected. This means that from a data base, indicators of the behaviour of receivers for a certain type of machine can be defined without too great constraints. Unfortunately, the available data base on receiver dynamic properties is today far too limited.

For example, domestic appliances, especially washing machines are common structural acoustics sources in building. They are normally set on a floor without rigid mounting and they contribute to input structural acoustic power into the floor mainly in bending. It results in noise problems in neighbouring flats. Despite the large disparity of floor dynamic properties, two classes may be considered in relation with washing machines, concrete and wooden floors. In the first case, normal forces and bending moments may be used as simplified source descriptors. The term 'simplified' is perhaps inappropriate since these quantities can not be easily obtained from a direct measurement. In the second case, source and receiver dynamic properties are of the same order of magnitude and consequently, the source descriptor approach is appropriate. It implies free velocity and source mobility measurements.

Even though, source and receiver properties are expected to be handled statistically, since belonging to a population of systems, there must remain in a system description its governing physical characteristics. This means that for multipoint interfaces point and transfer mobilities must be predictable in both magnitude and phase. The interpretation of the magnitude of transfer mobilities has been well summarized in a recent paper by Skudrzyk /3/. The phase on the contrary has not been paid such an interest and its role in conjunction with the transmission of structural acoustic power is more obscure. It is commonly assumed that the phase of transfer mobilities can be termed as a random variable having a uniform distribution between $+\pi$ and $-\pi$ when the distance between the contact points exceeds a governing wavelength. Recent work on the phase of transfer mobility functions /4/ showed that a diffuse field assumption may
be quite erroneous, while qualifying the phase behaviour with an increase of damping and frequency. The phase is a continuous function, when unwrapped, which varies between a statistical estimate for a diffuse field /5/, and the $k_r$ trend of the direct field. Very much information on the diffusity of a field seems hidden in the phase function. Further work is required to estimate the influence of the phase trend on the structural coupling between contact points and consequently on the structural acoustic power transmitted to the receiver.

4 PERSPECTIVES

The potential structural acoustic sources are increasing in number and power with the increased use of mechanisation in domestic and work conditions. The costs of machinery can amount to the main cost of buildings, industrial plants, etc. The lack of standard methods including structure-borne noise control criteria as part of product design can lead to costly overdesign structural acoustics control systems. Also, with the free circulation of goods in the EEC, no comparison on the effective quietness of machinery in competition and no choice of product on the grounds of vibrational quietness are yet possible. The characterization of structure-borne sound sources should be given a higher priority.

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