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# MEASUREMENT AND CHARACTERISATION OF SOURCES OF STRUCTURE-BORNE SOUND

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## 1. INTRODUCTION

In 1978 Kihlman called for methods of prediction of structure-borne sound from source and foundation data [1] and since then, there has been a steady increase in research activity in the scientific and engineering communities. The problem remains, however, that structure-borne noise is not as well understood as that resulting from airborne sources.

The lack of progress is a result of the inherent complexity overall and, in particular, the difficulty in achieving a structure-borne source characterisation. In present developments of a source characterisation, two tacit assumptions are being made.

The first is that the structure-borne source is the machine in its entirety. This results from how machines are assembled and marketed. For example, a manufacturer of a heat pump is concerned with its performance as a unit in which there may be several vibrationally active components, whereas the manufacturer of the compressor inside is concerned with that component only.

The second assumption is that the characterisation is analogous to that for airborne sources i.e. it is described as part of the source-path-receiver representation.

These assumptions are exemplified by the ISO Working Group WG22, concerned with a standard for structure-borne sound sources [2]. The group has given a set of criteria for standards which will allow comparison of machines, comparison with set limits, data for prediction and planning, and data and methods for design. Some of these criteria are more important than others to the various parties involved which can be categorised as follows:

Consumers and manufacturers concerned with comparing the performance of their products.

The legislative community primarily concerned with setting limits and in providing recommendations for measurement and rating.

Practitioners interested in data for prediction and planning.

Manufacturers, through their product engineers, who seek data which informs design.

An additional obstacle to progress results from confusion with respect to terminology which is not helpful for any of the groups and their interaction.

## 2. TERMINOLOGY

**Activity** is a map of the result of all internal vibration producing mechanisms, such as impacts, sudden releases of potential energy and parametric excitation [3]. An adequate measure of activity is the velocity of the free source at the proposed contacts [4] although blocked force also has been proposed [5].

**Emission** Q is the required quantity if we are concerned with e.g. far-field radiated noise as a result of the vibrating source, where;

$$Q = \frac{1}{2} \mathrm{Re}\left[\mathbf{F}^{*t}\mathbf{v}\right]$$

**F** is the generalised force vector and **v** that for velocity at the interface of the source and receiver, respectively. Therefore, both forces and velocities are required.

The link between the desirable and the easily obtainable is the **structural interaction** $(\mathbf{Y}_S^{-1} + \mathbf{Y}_R^{-1})$ which requires both the source mobility $\mathbf{Y}_S$ and the receiver mobility $\mathbf{Y}_R$ (or the impedances). In the general case, the emission is given by;

$$Q = \frac{1}{2}\, \mathbf{v}_{SF}^{t} \left(\mathbf{Y}_S^{-1} + \mathbf{Y}_R^{-1}\right) \mathrm{Re}[\mathbf{Y}_R] \left(\mathbf{Y}_S^{-1} + \mathbf{Y}_R^{-1}\right)^{*} \mathbf{v}_{SF}^{*}$$

## 3. PROPOSED METHODS FOR SOURCE CHARACTERISATION

An apparently wide range of methods can now be described in terms of the above terminology. All methods are proposed under the assumption that the machine or machine component is the source entity to be incorporated into a source-path-receiver model.

### Activity methods

The free velocity method is the least controversial and has been developed to a proposed ISO standard [4]. Velocity is measured at the contact points of the yet to be installed machine while it is resiliently suspended and while it is operating normally. Resiliently mounted machines can be measured in-situ since the velocity above the mounts is a good approximation to the free velocity required [6,7].

Measurement is therefore straightforward but the data obtained is only a sub-set of that required for emission. Improvements in design which result in reduced free velocity may not lead to reduced emission in the installed condition since the reduction may be at the expense of an altered structural interaction which promotes vibrational energy flow [8].

Measurement of blocked force offers similar advantages of simplicity and disadvantages of non applicability of data [9]. There is the additional disadvantage that a large inert supporting structure is required and it is generally more difficult to register forces than velocities and there are no accepted methods of registering moments [2].

Ohlrich proposes an equivalent force based on the assumption that the unknown internal excitations of the machine can be represented by a small number of external point forces which drive the casing [10,11]. Verheij et al [12] describe a similar method. Both offer a map of activity in terms of an external force distribution on the machine casing.

### Emission methods

Emission is the required quantity but involves detailed data on both the source and receiver structural dynamics as well as source activity. Such data will not be available for installations not yet known. The problem appears immutable but in a limited number of cases, the variation in installation structural dynamics is sufficiently small to allow simulation in test facilities. The INCE Technical Group on computer and business equipment has developed a method for fans and blowers used in computers where the test receiving structure is a damped plate which has a mobility similar to that of an ensemble average of computer panels [13]. An additional necessary condition is that the fan location on the plate must be the same. A source located near an edge of a plate will give a different emission to that located at the centre [14].

### Reception plate and equivalent excitation

The reception plate method is to attach the vibrational source under test, through the proposed contacts and supports, to a passive structure such as a thin plate, the response of which is then measured. The reception plate is designed to yield an average response simply rather than to simulate real conditions, mainly because of the wide range of installations possible [15].

Lu et al [16] propose a perforated plate for compact sources such as small circulation pumps and the implicit assumption is that the receiver mobility is much greater than the source mobility and that a velocity source idealisation holds. This may not be true in the installed condition where the receiving structure may be a thick wall or where source and receiver mobilities are of the same order of magnitude. Also, the relative contributions of moments and forces will be different to that at the centre of a laboratory reception plate; particularly so when attached close to structural discontinuities such as corners and edges in real structures. Therefore, test data may be misleading and a rank ordering of sources will not necessarily be the same as that for the installed condition.

It is not clear whether this method addresses the emission or the activity. The average plate response relates to the former but clearly not to that of the actual installation. Conversely, it relates to the latter but then of a structurally modified source and can be viewed as a measure of displaced activity.

Equivalent excitation methods have been proposed [17-20] where source substitution or reciprocal methods allow an equivalent force to be calculated, usually as a single point. The approach is seductive in its simplicity but there are questions as to the physical significance of representing multiple point and component excitations by a single fictitious excitation. In general, there is some confusion as to whether it is quantifying activity or emission. It would appear to be the former.

The argument is taken further by Ohlrich to propose an equivalent power [21,22] where a distinction is made between surface source power and mount source power. This, at least, recognises that source characterisation should be on a power basis rather than by force or velocity alone.

## 4. STUDIES OF SOURCE CHARACTERISTICS

A different perspective is offered by studying the physical features of sources. In [23] the energy transmission is reformulated in terms of the source descriptor and coupling function. The source descriptor can be interpreted as the latent power at a contact, for a single component of excitation and motion at the interface. It is a function of source characteristics only, has units of power and can be combined with receiver mobility to yield the emission. The practicalities of measurement of been confirmed [24] and it has been employed in studies of the interaction between components and contacts [25]. However, it is not intended as and cannot form a basis for a standardised method.

Ohlrich and Larsen adopt a similar approach in defining a terminal source power but ignore the effect of coupling between contacts [21].

Su et al [26] represent the mobility matrix of a receiver by single upper and lower bounds and the power from a source to a receiver can be obtained by representing the excitation mechanisms at the interface, however complicated, by a single real figure. Again, this cannot be a source characterisation since it depends on the receiver structural characteristics.

In general, the work on the physical features of sources should not be confused with work on standard methods, but the former underpins the latter.

## 5. CONCLUDING REMARKS

This review is cautionary rather than pessimistic. It is by no means complete but offers a categorisation of the principal approaches to structure-borne sound source characterisation.

An attempt has been made to remove some confusion with respect to terminology and aims.

It is argued that the development of a characterisation is constrained by two assumptions concerning the nature of the source. One is that the machine or component must be considered in its entirety, the second, that the characterisation should be analogous to that for airborne sound sources.

Moreover, it is illustrated that the proposed methods fall into either of two categories. The activity methods yield data which are a necessary but not sufficient requirement for source characterisation. Emission methods yield data from which a source characterisation cannot be extracted. Therefore, expectations are too high regarding present proposed test methods. Indeed, in this respect, it is arguable whether addressing a machine in its entirety is a constructive approach.

If the primary aim is to control by design, then an alternative approach is to consider the generating mechanisms within the machine and treat the machine structure as part of the receiver. There are interesting questions, then to be addressed, including how the installation and operating conditions affect these mechanisms and how these mechanisms can be controlled.

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