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CHARACTERISATION OF STRUCTURE-BORNE SOUND SOURCES: ACTIVE COMPONENTS AND ASSEMBLED SYSTEMS

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ABSTRACT

The paper starts from first principles in posing the basic question as to why a source characterisation is needed. It is argued that for suppliers and installer who work independently the characterisation must both be independent and allow prediction of installed levels. Suppliers and installers who work closely together on specific products require source characterisations only for diagnostic purposes and there is no absolute requirement for independence. Independent characterisations, particularly free velocity are reviewed, and are clearly distinguished from measurement methods since they remain valid whether or not they can be directly measured. Thus, it is argued that all measurement methods should allow one of the independent characterisations to be extracted.

1 - INTRODUCTION

This paper is to serve as an introduction to the special session on Characteristics of Sources of Vibration, and its objective is to revisit the basic questions as to why source characterisations are required for structure-borne sound sources. It is not the intention to provide a comprehensive review, which has been dealt with by other authors [1], [2].

Initially, since there is no commonly agreed vocabulary, it is necessary to define some terms. A **supplier** is the supplier of a source of structure-borne sound. The **source** could be a component in a larger machine (eg a lawn mower motor) or an entire assembled machine such as an air-handling unit. Whatever the source, we assume it to be installed by an **installer** in a larger **receiver structure**, and the assembly of the source and the receiver structure will be referred to as the **installation**, Figure 1.

The noise of the operating source, modified by installation, is the **overall noise output** of the installation, which could be expressed as a sound pressure, sound power, or another structure-borne sound indicator.

2 - WHY CHARACTERISE SOURCES?

According to Ten Wolde and Gadefelt [1] in their often-quoted seminal article such characterisations are necessary for:

- comparison of sources for a particular purpose
- comparison of sources with set limits
- input data for noise planning
- design of quieter machines

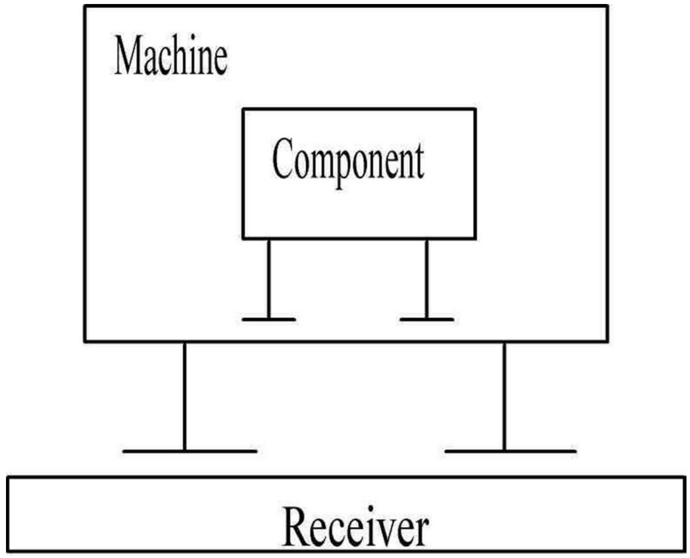

Figure 1: 2 types of installations.

These four goals are usually all obtainable simultaneously for airborne sources, but as is well known, the situation for structure-borne sound sources is more complicated. Each item has a different interpretation depending on whether it is viewed from the suppliers or installers point of view. Secondly the interpretation depends on whether the source is "dedicated" to a particular receiver structure or is "independent", Figure 2. It is helpful to clarify these two situations.

"Dedicated" sources exist typically in the automotive and aerospace industries. Here the source is developed for one, or at most a handful of particular receivers and is only ever sold as part of an installation. Hence the supplier has prior knowledge of the receiver. "Independent" sources are typified in the case of small fans and motors with high production runs. The range of receiver structures for the same source could vary widely and will generally be unknown to the supplier.

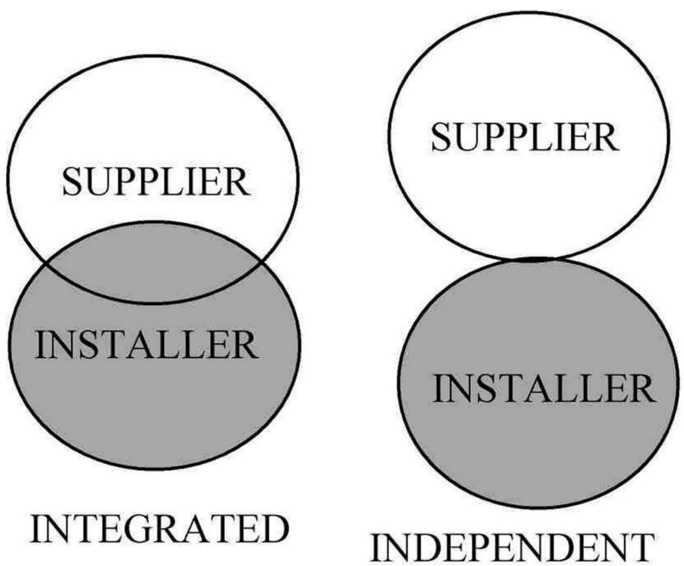

Figure 2: 2 types of supplier/installer relations.

The commercial/legal relationship of the companies also tend to reflect the above categories: in the case of dedicated sources, the supplier and installer are frequently highly integrated, possibly even being part of the same company (automotive industry), and independent sources are more often produced by companies independent of the installer. This is probably no coincidence since, in the former case, it is difficult to separate the legal responsibilities. Indeed, it could be argued that the difficulty in separating the source from the receiver is partly why the commercial structures are as they are. Furthermore, in

the "independent" case, structure-borne noise emission data may in part define the contractual relation between the two parties.
Therefore, the structure-borne noise information is not only handled by specialists but also by different actors of the company (marketing, purchase department, drawing office). The source characterisation should then be provided in terms that can be handled by non-specialists.
It is worthwhile to examine the above goals a)-d) rather carefully from the point of view of both the dedicated and independent arrangements.
In the former case, comparison of sources by itself is not meaningful since the source is only ever sold in an installed condition. The only meaningful comparison is of the overall output of the installation, and so an in-situ characterisation is adequate. These comments apply also for comparison with set limits. It is not easy to see the relevance of "noise planning" in this case, and one could argue that it is not required if the source is already characterised in the installed state. Finally, for the design of quieter machines we take this as being synonymous with the design of quieter installations. Here, a means of characterising the source separate to the rest of the installation is required in order to rank order source mechanisms and transmission paths and quantify the effect of changes to the receiver structure. These points are summarised in table 1, where it can be seen that in the case of integrated supplier and installer, the only requirement for source characterisation is for diagnostics leading to a reduction in the overall noise output.
In the case of independent sources the contract between the purchaser of the installation and the supplier of the source should include specifications on noise emission. Thus, the installer must take full responsibility for the overall noise output of the installation, even though the noise producing components maybe entirely supplied by others. In re-examining points a)-d) above we now need to distinguish between the purposes of the supplier and the installer.
a) Comparison of sources: the supplier needs to compare with competitor's products. This places very specific requirements on the characterisation which must:

- be independent of particular installations
- give an absolute measure of source strength (this implies units of power since measures of "activity" eg free velocity are not necessarily proportional to the overall power output of the source)
- be expressible as a single value or spectrum for each source so as to allow comparisons.

To the installer, comparison of sources means something quite different, i.e. it means how the overall noise output from the installation varies from one source to the next. The installer could of course characterise the competing sources himself by testing in-situ, and this is a technique which is currently employed. However, a more flexible approach is to predict installed noise levels from information provided by the supplier. In this case the source characterisation must be:

- independent, and
- in a form allowing prediction of overall noise output from the installation.

b) Similar information is required to enable the installer to compare with set limits such as for noise labelling purposes. Suppliers themselves are also increasingly likely to meet set limits as acceptance criteria from the installers of their sources (current practice in naval applications is the setting of limits for free velocity of e.g. motors and pumps). For this the requirements are similar to those for comparing sources as mentioned above, ie the characterisation must be single valued and independent.
c) Noise planning implies that prediction of installed noise levels will be carried out which is also necessary for comparison of sources as already seen. The supplier must provide appropriate data to serve as input to the installer's prediction model. Input data need not be expressible as a single figure (although to allow comparisons output data must be). The source characterisation must however be both independent, and allow coupling of source and receiver to be accounted for. In the general case the supplier can assume nothing about receiver structure, so two types of data are required for the source, an active and passive part, typically free velocity and mobility.
d) Finally, the design of quieter machines can be considered as a special form of comparison, ie with a reference or unmodified machine. Requirements are as for comparison of sources and differ for suppliers and installers as described above. The requirements are summarised in Table 1.

	SUPPLIER / INSTALLER INTEGRATED	**SUPPLIER / INSTALLER INDEPENDENT**
Examples	*Automotive* *Aerospace* *Production lines*	*Fans/motors/compressors/pumps* *Utilities, turbines* *Building services equipment* *Machine tools*
Comparison of sources and with set limits	In-situ	Supplier requirements: • independence • single figure • absolute measure of source strength Installer requirements: • independence • allows prediction of installed noise
Prediction of installed noise levels	Not required	Requirements: • independence • allows source receiver coupling to be accounted for
Design of quieter machines	Diagnostics requires source characterisation, need not be independent	As for comparison of sources

Table 1: Requirements.

In practice of course many situations lie on a sliding scale somewhere between the dedicated and independent ideals. For example, independent suppliers frequently co-operate with their larger customers for particular installations in which case the receiver structure may be partly known to the supplier, and at the other end of the scale, suppliers of engines for aircraft have contractual obligations which are distinct from those of the installer. The advantage of the integrated arrangement is that technical difficulties of providing independent characterisations can be avoided. The disadvantage is that the responsibilities of the supplier and installer cannot be easily separated.

3 - INDEPENDENT SOURCE CHARACTERISATIONS

Since above discussion emphasises the importance of independent characterisations, in this section such characterisations are reviewed. The figure below shows there to be four ways of mounting a source independently of the receiver: free, blocked, to a "mirror" structure, and to a "conjugate" structure. These apply equally for point and area contact. The last two are conceptual mountings only as such receiver structures could never be realised in practice. Furthermore, the blocked condition is also difficult or impossible to achieve in practice. Thus, only free velocity is ever likely to give a realistic possibility of measurement.

Thus we must draw a clear distinction between a source characterisation and a measurement method. It is one of the central points of this paper that the above characterisations remain valid whether or not they can be directly measured. A source which can never be operated independently of a receiver still has a free velocity and blocked force. Indeed, if they are to provide an independent characterisation then all measurement methods must provide a means to relate the measured quantities to one of the above.

4 - MEASUREMENT METHODS

If it can be measured, then free velocity is an uncontroversial independent source descriptor. However, practical problems in running the source realistically under load when freely suspended often preclude direct measurement so an indirect method is required where the source is attached to some sort of

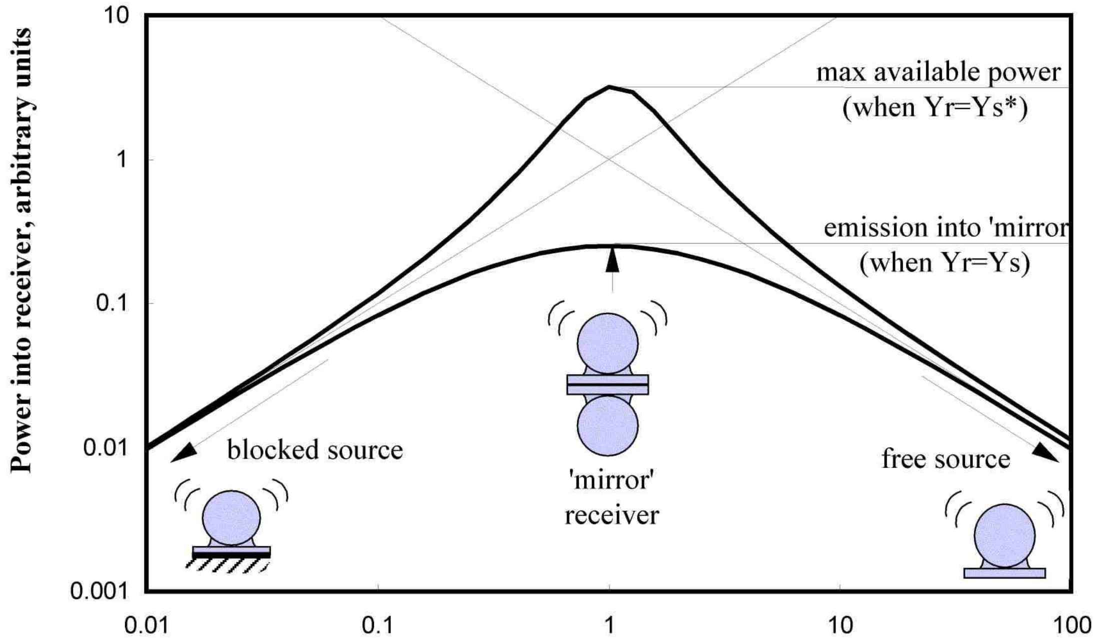

Figure 3: Ratio of receiver to source mobility magnitude, —Yr/Ys—.

receiver. In this case the question then becomes how can the structural dynamic influence of the receiver structure be extracted from the test results to yield an independent characterisation. This means that the emphasis shifts from the source to the source/receiver interface and the problem becomes on of modelling the effect of one on the other. These technical difficulties have forced engineers into various ingenious alternative strategies for indirect measurement. No attempt will be made here to provide an overview, although some of the approaches will be presented in the session. In nearly all of the approaches the independence of the source characterisation is inevitably compromised to some extent by practical constraints. This is a fact of life, although there is a danger that in compromising we lose sight of the fact that such compromises are forced rather than being desirable. It is only by continually reminding ourselves of the reasons for the characterisation that we will be able to achieve the correct balance.

5 - CONCLUDING REMARKS

Noise design procedures for components of machines (source), machines (receiver or source), plants, buildings, transportation devices (receivers) are required to achieve optimal environmental, occupational, technical and economic benefit. In order to progress in this direction both fundamental research and engineering work on source characterisation should be strongly encouraged. Having in mind that the related data can belong to specifications in a contract within two industrialists, the acoustic specialist should not forget that the handling of technical specifications need to be associated with decision making tools (data and knowledge base, risk analysis, loss control strategy) for a good management and communication in industrial investments projects. An industrialist is always concerned by a global approach of its specific classes of problem. He is less concerned by a specific technical approach of a general problem.

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