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EXPERIMENTAL DETERMINATION OF ACOUSTIC SOURCE DATA FOR FANS

H Bodén, M Åbom & J Lavrentjev

The Marcus Wallenberg Laboratory for Sound and Vibration Research, Department of Vehicle Engineering, KTH S-10044 Stockholm, Sweden

1. INTRODUCTION

For low and intermediate frequencies a ducted fan can strongly interact with the system in which it is mounted. This interaction will cause variations in the acoustic power output of the fan and can in particular lead to higher power output than expected. This type of installation effect is not covered by the standard methods to characterize fans as acoustic sources, because in these methods the acoustic power output is simply measured for one specified acoustic load, see e.g. ISO 5136. In order to calculate the interaction between a fan and the duct system in which it is mounted, a more detailed source characterization is necessary. One possibility is to model fans as acoustic multi-port sources, an idea first suggested by Cremer [1]. During the last decade measurement methods have been developed to determine the multi-port source data in practice. A series of works on the subject have been published by the authors of this paper and it is the aim of this paper to present the main results.

2. MULTI-PORT SOURCE MODELS

General

In general a linear and time-invariant source with a finite number of degrees of freedom can be described as an acoustic multi-port source. This means that, in the frequency (Fourier-) domain, the source can be completely characterised by the following equation which relates the input state **x** to the output state **y**

$$\mathbf{y} = \mathbf{K}_S \mathbf{x} + \mathbf{y}^S, \qquad (1)$$

where **x** and **y** are N-dimensional state vectors, $\mathbf{K}_S$ is the multi-port matrix and the index *s* denotes a source related property. The passive properties of the source are described by $\mathbf{K}_S$ while the active are completely contained in $\mathbf{y}^S$. When applying equation (1) to characterise the acoustic behaviour of a fluid machine $\mathbf{K}_S$ and especially $\mathbf{y}^S$ will normally depend on the machines operating condition; thus our linear model only applies at a fixed operating point.

The 1-port source model

For fluids machines where the external acoustic load only can vary at one of the openings, or the openings are acoustically uncoupled from each other so that they can be treated separately; the 1-port model can be used, if there is a plane wave state in the connected duct.

In the frequency domain an acoustic 1-port can be completely described by a source strength p_+^s and a source reflection coefficient R_s

$$p_+ = R_S p_- + p_+^S, \tag{2}$$

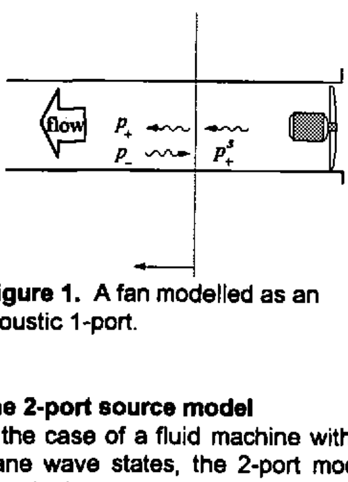

Figure 1. A fan modelled as an acoustic 1-port.

where p_+ and p_- are the travelling pressure wave amplitudes for the plane wave in the positive/negative direction at the reference cross-section (see Fig. 1). In the literature the source model for 1-ports is often expressed in terms of a source strength (p^s or q^s) and a source impedance (ζ_S)

The 2-port source model

In the case of a fluid machine with two active openings where there are plane wave states, the 2-port model should be used. In the frequency domain the system can then be described by the equation

$$\begin{pmatrix} p_{a+} \\ p_{b+} \end{pmatrix} = \mathbf{S}_s \cdot \begin{pmatrix} p_{a-} \\ p_{b-} \end{pmatrix} + \begin{pmatrix} p_{a+}^s \\ p_{b+}^s \end{pmatrix}. \tag{3}$$

Here p_+ and p_- are the travelling pressure wave amplitudes for the plane wave in the positive/negative direction at the reference cross-sections *a* and *b* (see Fig. 2) and $\mathbf{S}_S$ is the scattering-matrix for the source. To obtain a formulation valid for both periodic and random types of signals one can introduce the source cross-spectrum matrix $\mathbf{G}^{s}_{+} = \mathbf{p}^{s}_{+}(\mathbf{p}^{s}_{+})^{c}$ where the superscript *c* denotes the complex conjugate and transpose of a matrix.

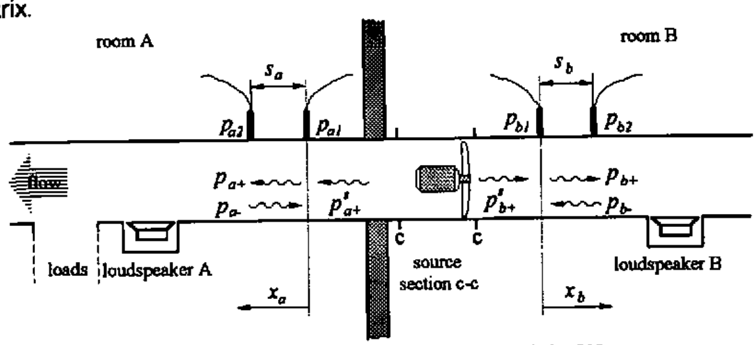

Figure 2. Test rig for measurement of 2-port source data [2].

3. EXPERIMENTAL METHODS

General

The *external source* methods which have been used for fans are two-step methods. First the source impedance or scattering matrix is determined by exciting the source with the sound field from external sources. The same type of methods used for passive systems can then be used. In the second step the external sources are turned off and the source strength is determined by making pressure measurements when known acoustic loads are applied to the source. The main problem with these methods is that in the first step when the external sources are used only the sound field from these sources and not the sound field from the machine under test must be picked up by the pressure transducers. There are different ways to solve this problem, but the most successful is to use different correlation techniques [2,3]. Using correlation techniques an improved estimate of the acoustic pressure from the external source can then be obtained, even if it is contaminated with the sound coming from the machine and flow noise.

1-port source data

The 1-port source data have been measured for an axial flow fan [3] and the maximum sound power has been calculated for the case that there is a perfect match between source and load [4]. When measuring the source impedance using the correlation technique the signal exciting the external source (loudspeaker) has been used as a reference.

2-port source data

The 2-port models have been applied to fans in a number of papers [1,2,5]. Cremer [1], 1971 made a review of some experimental investigations about axial and centrifugal fans treated as multi-port sources. It was, however, very difficult to obtain good measurements using the instrumentation available around 1970. The first investigation using modern instrumentation, FFT-analysers and the two-microphone method for plane wave decomposition was made by Terao and Sekine [5] (1989). Fig. 3 shows an example of a results obtained from measurements on an axial fan using the method described by Lavrentjev et al [2].

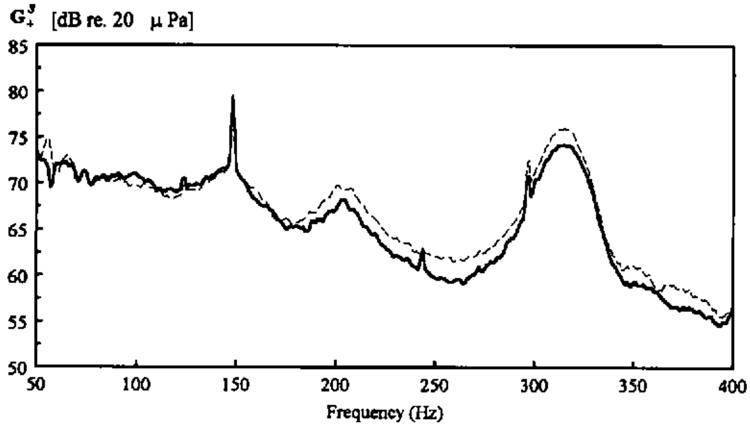

Figure 3. Measured source strength for an axial fan [2]. —— G^s_{a+a+}, --- G^s_{b+b+}.

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