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CALCULATION OF TIME HISTORIES FROM A SUBDIVIDED SOUND SOURCE

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ABSTRACT

The objective of this study is to characterize the time history of partial sources. To be able to establish the relationship between receiver and source the transfer functions were measured reciprocally. To optimize the desired inverse of the measured transfer function matrix, singular value decomposition and Tikhonov regularization was used. Different receiving positions in two different environments have been studied to evaluate the reliability of calculated time histories. The result for one environment is presented by comparison of the calculated spectrum for one of the partial sources in relation to the measured source strength spectrum. The calculations were made with data from the receiving positions, and transfer functions between them and the partial sources. The result display how the size of the regularization-parameter, reduces the differences between measured and estimated source strength spectra.

1 - INTRODUCTION

A sound source, for example an IC Engine, can be seen as a combination of different partial sources. To reach the receiver the sound passes through several different transfer paths, where each influences the perception of the sound. Analyses of transfer functions between source and receiver may give a possibility to describe and separate the time-histories of the partial sources. Knowledge of how these transfer functions affect the perceived sound from the partial sources may facilitate improvements of sound quality.

2 - METHODOLOGY

The methodology is divided in two parts. One describes how the data was collected (Experimental) and one describes the calculation procedures. (Theoretical)

2.1 - Experimental

The measurements were performed in an hemi-anechoic room. An omni-directional sound source was used for reciprocal measurements of the transfer functions (see Fig. 1). To obtain omni-directional behavior of the sound source, its orifice needs to be much less then the wavelength of the sound radiated ($k \times a \ll l$).

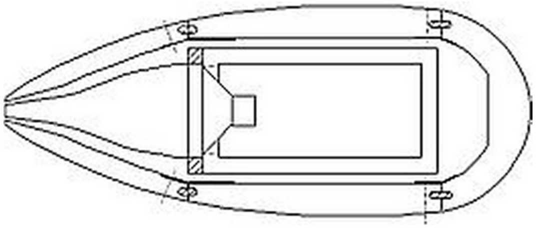

Figure 1: Omni-directional sound source with tuned loudspeaker-box to reduce anti-resonance of the inverted horn and smooth outer shell to minimize the diffraction of the emitted sound.

To give a measure of the source strength [1], a 1/4-inch microphone B&K 4135 was positioned in front of the orifice. The radiation from the used sound source was, however, not perfectly omni-directional. To fulfil the requirements for reciprocity, an anechoic termination was arranged behind the source (Fig. 2).

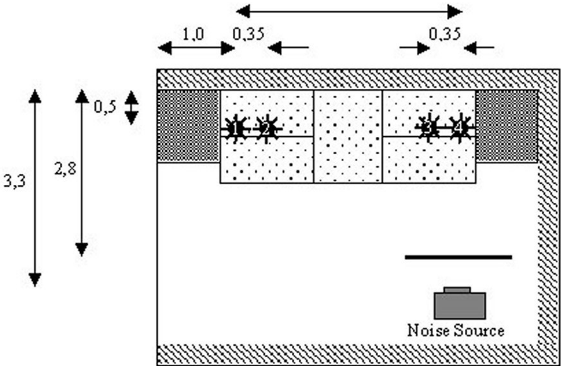

Figure 2: Measurement set-up with four positions of the omni-directional sound source and a sound barrier in front of the noise source (wedges are positioned around the sound sources).

The standard deviation of the sound source for different angels starting in front of the orifice and ending 180° behind the source is shown in Fig. 3.

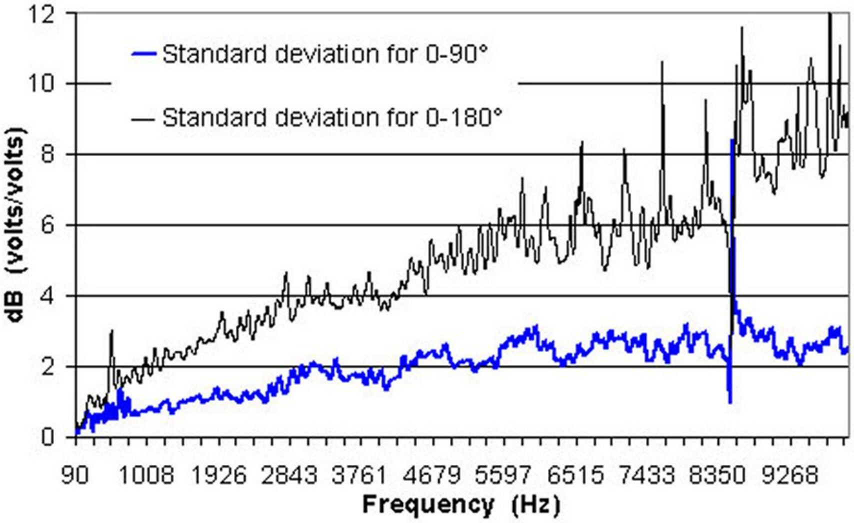

Figure 3: Standard deviation of sound pressure for different angles.

Deviation of sound pressure with different angles around the omni-directional sound source, give rise to differences between 'true' and measured transfer functions.

The noise source consists of three 4-inch loudspeaker elements mounted in a loudspeaker box. The loudspeakers reproduce the sound of a fuel pump, oil sump and camshaft of a SCANIA diesel engine. The source strength of the individual noise sources was determined by sound intensity measurements over each loudspeaker element.

The transfer functions were measured between the omni-directional sound source in positions one to four, and a microphone positioned half a centimeter from the loudspeaker elements of the noise source. The first node of the blocked sound pressure should therefor appear at a frequency of approximately 17 kHz.

2.2 - Theoretical

The source strength of the omni-directional sound source was calculated from a measurement of sound pressure close the orifice (equation 1).

$$q = \frac{4\pi r}{j\omega\rho_0} p\left(r\right) e^{jkr} \tag{1}$$

The transfer functions were calculated from sound pressure at the partial sources and the source strength of the omni-directional sound source.

$$H_{ij} = \frac{p_i^{'}}{q_j^{'}} \tag{2}$$

The source strength of the partial sources were estimated by a measure of their sound power P and then calculated using equation 3, [2]:

$$Q_{eq}^2 \approx P\frac{2\pi c}{\rho\omega^2} \tag{3}$$

To separate the noise sources an inversion of the matrix of transfer functions H was made. Singular value decomposition [3] and Tikhonov regularization [4] was used for this purpose.

In this case H consists of a three times three matrix with as many layers as the spectral points used. With singular value decomposition, H equals the product of three matrixes USV^T that is defined for each frequency. U and V being orthogonal matrixes and S being a diagonal matrix that contains the singular values of H. To get the inverse of H is these three matrixes altered as in equation 4:

$$H^{-} = VS^{-}U^{T} \tag{4}$$

With Tikhonov regularization the diagonal elements ($1/\sigma$) of S^{-} is changed to ($\sigma/\left(\sigma^2+\beta\right)$) in matrix $S_r{}^{-}$. Optimization of β reduces the effect of the smaller values in S and improves the result of the inverse. The separated signals are then calculated with equation 5.

$$Q = VS_r^{-}U^{T} \times p \tag{5}$$

3 - RESULT & DISCUSSION

It can be seen in the figures 4, 5 and 6 how different choice of the regularization parameter β influences the result of predicted source strength. This choice of regularization parameter is closely connected with the size of the singular values in the matrix. Therefore different choice of parameter gives different results along the frequency axis. There is also a difference in how good that choice of parameter is, among the different partial sources. Therefore there is a need to use an algorithm that in a least square sense reduces the error of the predictions of partial source strengths. Finally, the recorded time signals can be convolved with the Inverse Fourier Transform of the filters created, to receive the time histories of the partial sources.

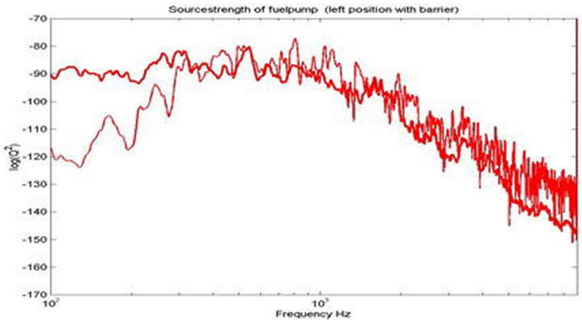

Figure 4: Measured- (thick line) and calculated- (thin line) source strength of fuel pump with regularization parameter β=25000 (a moving average of 20 points is used).

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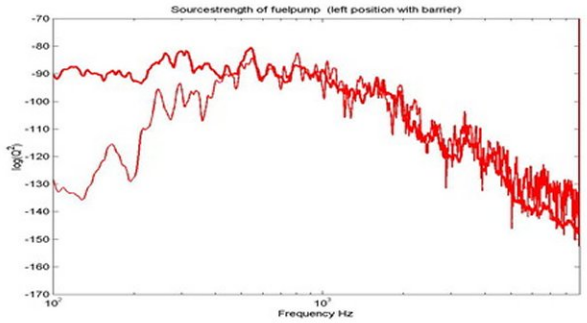

Figure 5: Regularization parameter β=100000 (same conditions as in fig. 4).

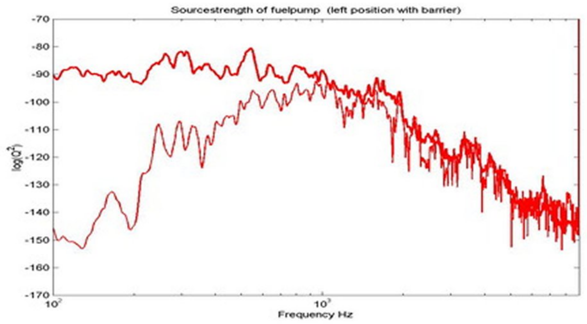

Figure 6: Regularization parameter β=750000 (same conditions as in fig. 4).

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