Proceedings of The Institute of Acoustics

MEASUREMENT TECHNIQUES FOR ASSESSING THE CONTRIBUTION OF INDIVIDUAL SOURCES TO THE NOISE LEVEL IN A MULTIPLE SOURCE ENVIRONMENT

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INTRODUCTION

Many industrial environments suffer from high noise levels at certain points where the exact origins of the noise are difficult to assess due to the large number of sources present and the exist nce of a highly reverberant sound field. The use of coherence techniques to calculate the contribution of individual sources to the sound energy at the point in question should enable an intelligent choice to be made of those machines which should be treated in priority to lower the noise to acceptable levels. The principal problems involved in this type of measurement technique are the selection of the source reference signals required to condition the output noise signal, the choice of the measurement conditions and the interpretation of the results. In cases where the sources are linked in some way or it is difficult to obtain source reference signals which are truly independent of each other it is necessary to make use of processing techniques for partially coherent sources [1]. Previous investigations have shown that a degree of coherence between the sources can result in large errors in the estimation of the contribution of each source, even if the correct partial coherence techniques are used, when the source reference signals are contaminated [2]. Fortunately it is possible to obtain maximum and minimum estimations of the source contributions which indicate the maximum possible error in the results. This paper reports the results of a preliminary investigation using partial coherence techniques to identify noise sources in the turbine hall of a Nuclear Power Station. A more detailed study is now being initiated on other source configurations to improve the accuracy of the estimations.

PRINCIPLES OF COHERENCE TECHNIQUES

For a system (Figure 1) excited by a source which may be considered to be completely independent of other noise sources, the relation between the input source autospectral density G_{11} and the output autospectral density G_{yy} is defined by transfer function H_{1y} and the cross spectral density between the input and the output G_{1y}

$$G_{1y} = H_1 . G_{11} \tag{1}$$

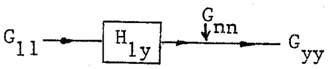

Figure 1

G_{nn} represents the output noise due to the other sources which are assumed to be uncorrelated with source 1.
The squared coherence function γ^2_{1y} represents the proportion of the energy in

the output due to the input 1

$$\gamma_{1y}^2 = \frac{|G_{1y}|^2}{G_{11}\ G_{yy}} \tag{2}$$

The energy due to source 1 at the output is then given by the coherent output power

$$(G_{yy})_1 = \gamma_{1y}^2 . G_{yy} \tag{3a}$$

$$= |H_{1y}|^2\ G_{11} \tag{3b}$$

When several sources contribute to the output noise level, providing the inputs are independent, the effects of each input may be calculated independently.

In real industrial noise source situations it is necessary to obtain a source reference signal representing the vibrations or noise radiation of each source. This may be obtained by means of an accelerometer placed on the machine structure,or a near field microphone. If the vibrations or noise measured by these transducers are partially correlated with the other sources then erroneous results will be obtained for the transfer functions and coherent output powers. In a two source situation for example (Figure 2)

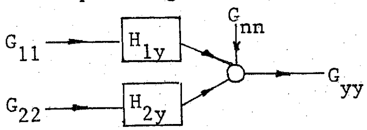

Figure 2

the coherence between inputs 1 and 2 will no longer be zero so the cross spectra between input 1 and the output will include effects due to the transfer between input 2 and the output

$$G_{1y} = H_{1y}.G_{11} + H_{2y}.G_{12} \tag{4}$$

Similarly

$$G_{2y} = H_{1y}\ G_{21} + H_{2y}G_{22} \tag{5}$$

In general for n inputs

$$G_{2y} = \sum_{j=1}^{n} H_{jy}\ G_{ij} \qquad i=1,n \tag{6}$$

and the correct values of the transfer functions may be calculated using this relationship.

The contribution of each source to the output can be found using the correct values of the transfer function associated with the autospectra of the input sources

$$(G_{yy})_i = |H_{ij}|^2 \quad G_{ii} \qquad (7)$$

In the case where there is inter-source contamination of the reference signals, the contributions calculated by (7) will still be too high, because part of the autospectral energy is due to the neighbouring sources.

An alternative form of analysis [1] models the system using a series of independent inputs where all the parts of the inputs coherent with the first input are assumed to pass through an optimum system represented by the ordinary transfer function between the first input and the output defined by

$$L_{1y} = G_{1y}/G_{11} \qquad (8)$$

The spectra representing the rest of the input-output characteristics are then conditioned to remove the parts that are coherent with the first input leading to a set of residual spectra that are independent of the effects of input 1.

Thus G_{22} becomes $G_{22.1}$ where.

$$G_{22.1} = G_{22} - |L_{12}| \; G_{11}$$
$$= G_{22}(1-\gamma^2_{12}) \qquad (9)$$

and L_{12} is the transfer function that would be measured between inputs 1 and 2.

$$L_{12} = G_{12}/G_{11} \qquad (10)$$

also $G_{yy.1} = G_{yy} - |G_{1y}|^2 \; G_{11} = G_{yy}(1-\gamma^2_{1y})$ (11)

and $G_{2y.1} = G_{2y} - L_{1y} \; G_{21}$ (12)

Hence for two inputs the system becomes as in Figure 3

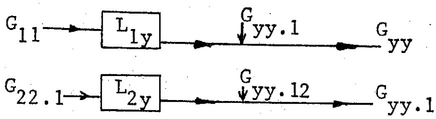

Figure 3

the noise term $G_{yy.1,2}$ can be calculated by using the following relationships.

The transfer function for the second input

$$L_{2y} = \frac{G_{2y.1}}{G_{22.1}} \qquad (13)$$

The partial coherence between input 2 and the output

$$\gamma^2_{2y.1} = \frac{|G_{2y.1}|^2}{G_{22.1} \; G_{yy.1}} \qquad (14)$$

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and $$G_{yy.1,2} = G_{yy}(1-\gamma^2_{1y})\,(1-\gamma^2_{2y.1}) \qquad (15)$$

The multiple coherence $$\gamma^2_{xy} = \frac{(G_{yy}-G_{yy.1,2})}{G_{yy}} \qquad (16)$$

and because L_{2y} is completely independent of input 1 it represents the true transfer function of the system (H_{2y}). H_{1y} may be found using equation (4) which gives

$$H_{1y} = \frac{G_{1y}}{G_{11}} - H_{2y}\frac{G_{12}}{G_{11}} \qquad (17)$$

Using this approach the true transfer functions can be found, but also the multiple coherence indicates the accuracy of the model and the partial coherence function indicates the energy transfer that is due to the second input alone. Multiplication of the partial coherence by the conditioned output spectrum $G_{yy.1}$ gives the energy due only to the independent part of input 2 which sets a lower limit on the contribution of this source. This may be compared with the higher limit calculated by equation (7).

This method may be extented to any number of inputs providing the inputs are not totally coherent with each other. In this case the conditioned autospectra $G_{22.1}$ etc. would be reduced to zero.

APPLICATION TO NOISE SOURCE IDENTIFICATION

The object of this particular investigation was to test the application of coherence techniques to an area of high noise levels around the high pressure turbine of a Nuclear Power Station. The possible noise sources in this area were limited to the high pressure turbine itself, and the four inlet valve assemblies. The number of effective inputs to the system was further reduced by fitting two of the four inlet valve assemblies with acoustic enclosures. The system was initially investigated using accelerometers to provide the source reference signals as it was felt that these would be less likely to be affected by intersource contamination. An accelerometer was fixed to the outer casing of each of the two inlet valve assemblies and to a supporting leg of the turbine. The chosen output measurement point was a microphone situated at head height about 6 metres from the nearest control valve assembly. Initially the caracteristics of the inputs and output were investigated using a dual channel analyzer. It was found that the coherence was relatively low between the inputs except at certain frequencies where the levels reached between 0.4 and 0.7. The coherence between the inputs and the output was also low, indicating the existence of many significant sources coupled with losses in coherence due to the limited duration of the Fourier transform lengths used in the analysis. Due to these limitations the subsequent analysis was performed using a limited frequency range of 0 to 1KHz in order to keep the transform periods as long as possible.

The use of microphones placed near the sources for the reference signals increased the coherence values a little, but not sufficiently to indicate that there was a lot of intersource contamination. The accelerometer and microphone signals were recorded on a 7-track FM recorder for subsequent analysis in the laboratory.

RESULTS

The spectrum of the output microphone signal had relatively few noteworthy peaks in the frequency range up to 1KHz except for a broad peak around 400Hz (Fig. 4). The true transfer functions and the multiple and partial coherence functions were calculated for this range using both the accelerometer and the microphone source reference signals. In each case the acquisitions of the three inputs and the output were performed simultaneously to ensure that the cross spectra were consistent with each other. Measurements had shown that the characteristics of the system varied slightly and even relatively small changes could lead to substantial errors in the calculation if the signals are processed sequentially. The multiple coherence using the microphones was higher than thak using the accelerometers (Figures 5 and 6) therefore the microphone conditioned results are presented here. Even so the multiple coherence was relatively low except in the frequency range around the output response peak at 400Hz. The partial coherence for all three inputs was also relatively high around this peak (Figures 7, 8, 9), but the output power contributed by the first inlet valve had peaks that were higher than the other two sources in this frequency range using both the residual contribution and the transfer function calculations (Figure 10 and 11). It may be concluded that this is the most significant source in this frequency range.

CONCLUSIONS

The investigation has shown that it is possible to obtain logical results using a simple model of noise sources in a turbine hall even if the results obtained are difficult to analyze in narrow band form. The method is being further developed to explore the use of a greater number of source signals, longer transform times and alternative forms of presenting the results. It is intended to try and compare the results obtained using masking techniques to validate the accuracy of the method.

ACKNOWLEDCEMENTS

The authors would like to acknowledge the financial and technical assistance of Electricite de France.

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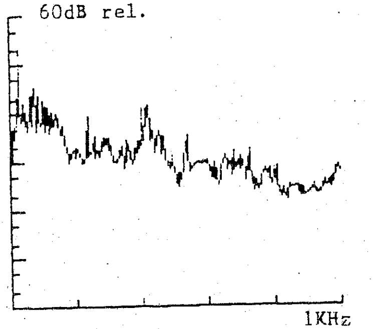

Fig. 4 - Output noise spectrum

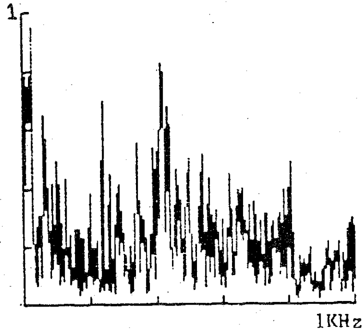

Fig. 5 - Multiple coherence 3 microphone inputs

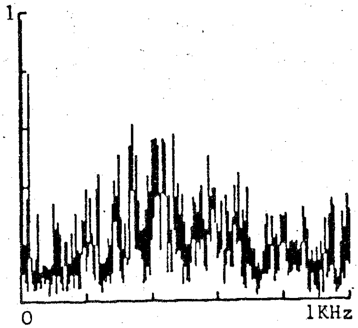

Fig. 6 - Multiple coherence 3 accelerometer inputs

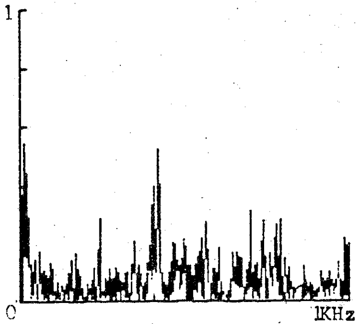

Fig. 7 - Partial coherence turbine

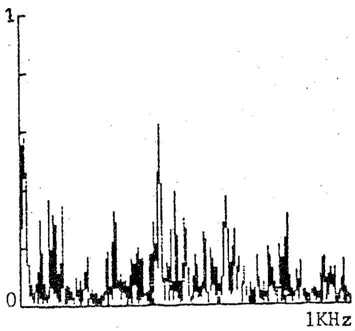

Fig. 8 - Partial coherence 1st inlet valve

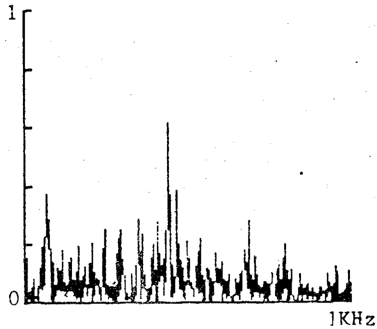

Fig. 9 - Partial coherence 2nd inlet valve

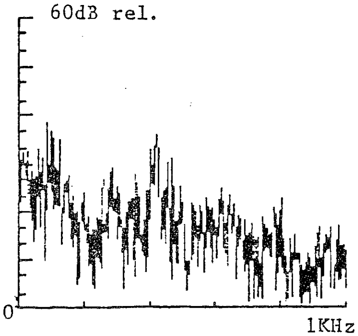

Fig. 10 - Residual contribution 1st inlet valve (partial coherent output power)

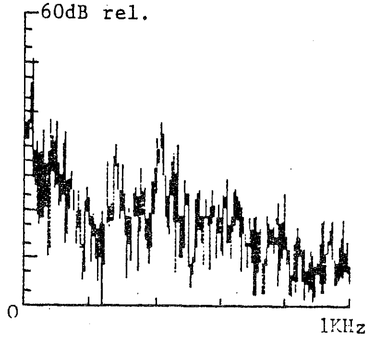

Fig. 11 - Transfer function output power 1st inlet valve