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THE APPLICATION OF SINGULAR VALUE DECOMPOSITION TO DETERMINE THE SOURCES OF FAR FIELD DIESEL ENGINE NOISE

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SAE Noise and Vibration Conference

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Introduction

- Demand for quieter engines is a constant driving force behind creation of competitive engines
- Determination of dominant noise sources in both the near- and far-fields within an engine is an integral step in development of quieter engines
- A method to assist in noise source identification in the near- and far-fields was desired to reduce the number of time-consuming and expensive fired and motored tests required

Outline

Multiple Input/Multiple
Output (MIMO) System

Transfer Path Estimation
Between Inputs and Outputs

Singular Value Decomposition

SVD Contributions to Near-
and Far-Field Measurements

Multiple Input/Single Output System

Solution of Cross-Spectral Matrix Problem

- A method to calculate transfer paths without including repeated information was required.
- In the following simplified equation, H_1 and H_2 are needed

Well Conditioned S_{xx} Matrix

$$\begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} H_1 \\ H_2 \end{bmatrix} = \begin{bmatrix} S_{1y} \\ S_{2y} \end{bmatrix}$$

Transfer Paths

S_{xy} Matrix

- Solution of this matrix by elementary row operations (Gaussian elimination) was conducted;

$$\begin{bmatrix} S_{11} & S_{12} \\ 0 & S_{22} - \frac{S_{12}S_{21}}{S_{11}} \end{bmatrix} \begin{bmatrix} H_1 \\ H_2 \end{bmatrix} = \begin{bmatrix} S_{1y} \\ S_{2y} - \frac{S_{1y}S_{21}}{S_{11}} \end{bmatrix}$$

Transfer Path Estimation

Independent source spectral characteristics

Transfer Path Estimate Simulation – Full Mixing

Designed and estimated transfer paths

Testing of Engine

- Each near-field measurement is an accelerometer/near-field microphone pair
- There are also 6 cylinder pressure transducers and 4 far-field microphones

Far Field Estimate Power Spectra

Singular Value Decomposition

Separate noise from uncorrelated sources from the data measured by the inputs

$$\mathbf{S}_{xx} = \mathbf{U}\mathbf{\Sigma}\mathbf{V}^H = [\mathbf{u}_1, \mathbf{u}_2, \dots, \mathbf{u}_N] \text{diag}[\lambda_1, \lambda_2, \dots, \lambda_N] [\mathbf{v}_1, \mathbf{v}_2, \dots, \mathbf{v}_N]^H$$

$$U = V$$

$$\lambda_1 > \lambda_2 > \dots > \lambda_N$$

$[\mathbf{S}_{xx}]$ = Cross spectral matrix

N = Number of input

measurements to system

λ_i = Singular value

$\mathbf{u}_i$ = Left singular vector

$\mathbf{v}_i$ = Right singular vector

$\mathbf{u} = \mathbf{v}$ in this case

Conducting a decomposition on the accelerometer or near field microphone spectral density matrices will help us identify the number of uncorrelated sources being measured, and potentially their relative strength.

Golub G H and Loan C F V 1996 *Matrix Computations*, 3rd Edition, (Baltimore: Johns Hopkins University Press).

SVD Example and Decomposition

Color coding example

1st Singular Value
Contribution

2nd Singular Value
Contribution

n^{th} Singular Value
Contribution

%

>75

50-75

25-50

5-25

0-5

$$S_{x_1 x_1} = \underbrace{\mathbf{u}_1 \lambda_1 \mathbf{v}_1^H}_{8\%} + \underbrace{\mathbf{u}_2 \lambda_2 \mathbf{v}_2^H}_{78\%} + \dots + \mathbf{u}_n \lambda_n \mathbf{v}_n^H$$

- Using a color coding scheme depending on the percentage contribution, these can be visualized graphically.
- A more detailed description of this method can be found in Hayward, Bolton & Davies (2012).

SVD, Swept Test, Accelerometers

SVD, Swept Test, Accelerometers

%

>75

50-75

25-50

5-25

0-5

Note: This analysis uses input measurement data – contribution of singular values at output is not used

2nd Singular Value Contribution to:

- Measurement 1
- Measurement 2
- Measurement 3
- Measurement 4
- Measurement 5
- Measurement 6
- Measurement 7
- Measurement 8
- Measurement 9

Frequency [Hz]

Far Field Source Contributions

With calculated transfer paths, far-field time histories can be calculated, and source contributions to the far field can be determined

Near-Field and Far-Field Contribution Comparison Example 1

Near-Field and Far-Field Contribution Comparison Example 2

The analysis below is was conducted on data from a different engine, in a full loaded sweep test, with a different set of transducers

Conclusions

- Transfer paths from input to output measurements can be accurately estimated through solution of a cross-spectral matrix problem.
- Contributions of each independent virtual source to real, physical near-field locations can be determined through singular value contribution plots.
- Utilization of input measurements and estimated transfer paths yield both accurate far-field estimate time histories, and SVD contribution plots demonstrating virtual source contributions in the far-field.
- Analysis of the singular values and their contributions to near- and far-field measurement power spectra allows inferences to be drawn regarding the characteristics of dominant noise sources within the engine.

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Singular Value Decomposition

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