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VISUALIZATION OF MEASURED ACOUSTIC FIELDS USING A COMMERCIAL MODAL ANALYSIS CODE

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ABSTRACT

A technique for visualizing the acoustic field around a refrigeration compressor is presented. This technique uses commercially available modal analysis software to animate microphone data measured in an anechoic space. The microphone data cover a surface with one stationary microphone serving as a reference. Examples of resulting patterns are presented.

INTRODUCTION

Because refrigeration compressors are sources of many pure tones, they are often tested in anechoic or hemi-anechoic spaces. During diagnostic stages of the testing, many narrow-band spectra are measured using FFT analyzers. Making sense of all this data becomes a real problem. One way to better understand the sound radiation is to view the sound levels as directivity patterns. Our initial task was to find a convenient way to view these narrow-band directivity patterns with a minimum of additional work. The solution was to use Modal Analysis software, especially Operating Deflection Shape software. This paper presents a justification for this technique and some examples of the results.

METHOD

Sound Pressure Levels are measured on a hemisphere in an anechoic space. In our implementation the measurements are made at a 1.5 meter radius with an angle increment of 22.5°, both around the vertical axis and off the horizontal plane. This results in 65 measurement positions; 16 positions on each of 4 elevations around the compressor and 1 directly overhead. These are free field measurements in the far field. At each location both the power spectrum and the transfer function between the microphone and a reference are saved. Our reference is the overhead microphone, but any coherent reference should work. These measurements are then transferred to a modal analysis system where an Operating Deflection Analysis is performed. The resulting amplitudes and phases at each frequency are displayed as a radial displacement from the measurement point in spherical coordinates. The base structure is the hemisphere of microphone locations.
JUSTIFICATION

Sound tests in hemi-anechoic and anechoic spaces are considered free-field tests and are usually carried out in the far field. This means that we assume the sound waves are radiating outward, perpendicular to the measurement surface. When this technique is used to measure sound power, we also assume that the sound intensity is directly related to the sound pressure. The intensity is integrated over the measurement surface to get the total sound power. The intensity is commonly given as:

\[ I = \frac{P_{\text{rms}}^2}{\rho \cdot c} \]

where:

- \( P_{\text{rms}} \) is the measured pressure
- \( \rho \) is the density of air
- \( c \) is the speed of sound of air

In this equation the only variable is the pressure. In fact when considering the units of Sound Intensity, we find it is a product of a pressure and a velocity. Really what we have is a velocity proportional to the pressure. If we divide out the pressure we find a relationship for the particle velocity:

\[ v = \frac{P_{\text{rms}}}{\rho \cdot c} \]

For this calculation to work for dynamic values, the velocity must be in phase with the pressure. The pressure is a field variable; it has magnitude but no direction. The velocity on the other hand does have a direction; it is propagating perpendicular to the measurement surface. This allows us to view the measured pressure magnitude as a particle velocity in the radial direction. When viewed as a mode shape, the absolute magnitude is unimportant as mode shapes involve only relative amplitudes.

EXAMPLES

On the following pages are examples of measured operating deflection shapes, based on pressure measurements, for compressors of various sizes. The examples were chosen to demonstrate the capability of the method across the frequency range. Compressors ranged from small refrigeration compressors (700 BTU/hr) up to 5 ton air conditioning compressors. Both low and high pressure housings are represented. Frequencies below 200 Hz do not always exhibit nice patterns, especially for the small refrigeration compressors. This is probably due to the poor radiation efficiency at wavelengths that are long relative to the physical size of the compressor. At frequencies below the resonance frequencies of the compressor housing, rigid body motion shows up as an acoustic dipole. Once housing resonant frequencies are reached, the pressure patterns generally match the structural mode shapes of the compressor housing. This holds true even as the frequencies of the housing modes increase as the physical size of the compressor gets smaller.
CONCLUSIONS

A method of presenting narrow-band sound pressure level measurements has been given that relies on commercial modal analysis software. The pressure transfer function between each measurement microphone and some coherent reference is used to display operating deflection shapes at selected frequencies. The motion is displayed as being perpendicular to the measurement surface. This appears to work quite well for free field measurements in the far field at frequencies where the compressors radiates efficiently. Measured operating deflection shapes based on sound pressure show an excellent correlation to structural mode shapes of the compressor housing.

REFERENCES

Beranek, Leo L; *Noise and Vibration Control*; McGraw Hill Book Company; New York, NY; 1971
Example Operating Deflection Shapes from Sound Pressure Measurements

Undeformed Surface

4 Node Circumferential Mode 588 Hz

Rigid Body Dipole 538 Hz

6 Node Circumferential Mode 1200 Hz

Rigid Body Bounce 688 Hz

8 Node Circumferential Mode 3580 Hz
Example Operating Deflection Shapes from Sound Pressure Measurements

10 Node Circumferential 1920 Hz

Dome Rocking at 4760 Hz

Dome Resonance at 2030 Hz

Dome Saddling at 4560 Hz

Dome Resonance at 3900 Hz

Combination Mode at 1160 Hz