1994

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NOISE PATH IDENTIFICATION OF ROTARY COMPRESSOR

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ABSTRACT

This paper refers to the noise source identification of rotary compressor by using DSP(Digital Signal Processing) method. It is difficult to know the noise source and path by only measuring the compressor noise radiated from compressor case. An experimental investigation was conducted to characterize the radiated compressor noise by simultaneously measuring the sound pressure level in both internal and external to the compressor and vibration level on the compressor shell. Then coherence and transfer function are obtained from data, and they are compared to estimate effect of each noise source and path.

Nomenclature

- $x_1(t)$: noise measured by microphone inside compressor cavity
- $x_2(t)$: vibration measured by accelerometer on compressor shell
- $y(t)$: noise measured by microphone outside compressor shell
- $G_{11}(f)$: one-sided autospectrum of $x_1(t)$
- $G_{22}(f)$: one-sided autospectrum of $x_2(t)$
- $G_{12}(f)$: cross-spectrum between $x_1(t)$ and $x_2(t)$
- $G_{xy}(f)$: cross-spectrum between $x_1(t)$ and $y(t)$
- $G_{y2}(f)$: cross-spectrum between $x_2(t)$ and $y(t)$
- $\gamma_{12}$: coherence between $x_1(t)$ and $x_2(t)$
- $\gamma_{1y}$: coherence between $x_1(t)$ and $y(t)$
- $\gamma_{2y}$: coherence between $x_2(t)$ and $y(t)$
- $n(t)$: unknown noise

1. Introduction

Recently there are many researchs about vibration and noise reduction in home appliances such as air conditioner, washing machine, refrigerator because consumer increasingly prefer to low-vibration, low-noise production. It is difficult to identify the noise source and noise path of rotary compressor which is important part of air conditioner, because rotary compressor has the complex noise source and noise path.

In this paper noise source of rotary compressor is largely classified three categories. The first is pressure pulsation which is caused by refrigerant gas flow in rotary compressor. The second is shell vibration of rotary compressor which is excited by pressure pulsation in compressor. The last is the other noise source excluding the former noise sources. Because these interact each other, it is difficult to estimate noise source separately which contributes to the total outside noise spectrum. In order to identify the noise source and the noise path, each sensors are built on compressor parts. Coherence and transfer function are obtained and compared how the noise source and the noise path are affecting to compressor noise.

2. Theory

Consider a two-input/one-output model as Fig. 2.1, where two inputs may be correlated. Assume $x_1(t)$, $x_2(t)$ and $y(t)$ can be measured. This system is defined by the basic transform relation.
\[ Y(f) = H_1(f)X_1(f) + H_2(f)X_2(f) + N(f) \]  

(1)

For arbitrary \( n(t) \), the cross-spectral density functions between \( x_1(t) \) and \( y \), and between \( x_2(t) \) and \( y(t) \) are given

\[ G_{1y}(f) = \frac{(2/T) E[X_1(t)^*Y(f)]}{H_1(f)G_{11}(f) + H_2(f)G_{12}(f) + G_{1n}(f)} \]
\[ G_{2y}(f) = \frac{(2/T)E[X_2(t)^*Y(f)]}{H_1(f)G_{21}(f) + H_2(f)G_{22}(f) + G_{2n}(f)} \]  

(2)

When \( n(t) \) is uncorrelated with \( x_1(t) \) and \( x_2(t) \), Eq.(2) becomes

\[ G_{1y}(f) = H_1(f)G_{11}(f) + H_2(f)G_{12}(f) \]
\[ G_{2y}(f) = H_1(f)G_{21}(f) + H_2(f)G_{22}(f) \]  

(3)

where the limiting operation on \( T \) have been omitted to simplify the notation. Therefore

\[ H_1(f) = \frac{G_{1y}(f) \left[ 1 - \frac{G_{12}(f)G_{2y}(f)}{G_{22}(f)G_{1y}(f)} \right]}{G_{11}(f)[1-\gamma_{12}^2(f)]} \]  

(4)

\[ H_2(f) = \frac{G_{2y}(f) \left[ 1 - \frac{G_{21}(f)G_{1y}(f)}{G_{11}(f)G_{2y}(f)} \right]}{G_{22}(f)[1-\gamma_{12}^2(f)]} \]

Where the ordinary coherence function

\[ \gamma_{12}^2(f) = \frac{|G_{12}(f)|^2}{G_{11}(f)G_{22}(f)} \]  

(5)

For the special case of uncorrelated inputs when \( \gamma_{12}^2 = 0 \), the terms \( G_{12}(f) \) and \( G_{21}(f) \) are zero also, and Equation(4) reduced to usually relations for single-input/single-output models. On the contray the case in which \( \gamma_{12}^2(f)=1 \) must be handled separately. A coherence function of unity between \( x_1(t) \) and \( x_2(t) \) implies complete linear dependence. Hence one would consider a linear system existing between them. The implication is that the first input \( x_1(t) \) is actually taking two different paths to arrive at the output \( y(t) \).

3. Experiment setup

Fig. 3.1 shows compressor jig which is used for our study. In order to measure noise level inside compressor, 3 microphones(FCB) are built in compressor. 3 accelerometers(B&K) are built on compressor shell to obtain shell vibration data and 3 microphones(B&K) are located outside compressor to estimate outside noise level.

4. Comparison of each acquisition data
Fig 4.1 shows spectrum of each state measured by inside microphone, accelerometer, outside microphone. Outside noise spectrum has peaks at 0.8,1.6,3.3kHz region. Analyzing each data, inside noise has much power in low frequency and outside noise has much power in low and 3-4KHz. What is interesting is that in comparison with inside noise and outside noise, inside noise has much power in low frequency(0-2kHz) and has small power in high frequency(3-4kHz) but outside noise has relatively much power in high frequency(3-4kHz) than low frequency. These facts indicate that it is difficult to know the noise source by simply comparing noise spectrum between inside noise and outside noise.

5. Coherence and transfer function between each data
Fig 5.1 (a) shows coherence between inside noise and compressor shell vibration. Analyzing the coherence, it is founded in the spectrum that coherence at 0.8 and 1.6kHz bands are nearly 1, which indicates that compressor shell vibration is caused by inside noise power. But at 3-4kHz region coherence between inside noise and compressor shell vibration is relatively low in comparison with low frequency region, which indicates that compressor shell vibration is excited by not only inside noise power but also other unknown power source.

Fig 5.1 (b) shows coherence between shell vibration and outside noise. coherence is high at 0.8kHz and 1.6kHz, which informs that compressor shell vibration power contribute to outside noise. Besides coherence at 3-4kHz is relatively high in comparison with fig 5.1 (a) and fig 5.1 (c).

Fig 5.1 (c) shows coherence and transfer function between inside noise and outside noise. Like Fig 5.1 (a), coherence at 0.8and 1.6 kHz is high, which shows that outside noise is caused by inside noise but at 3-4kHz region coherence is considerably low in contrast with fig 5.1(b).

From above the data it is natural to say that outside noise in low frequency is mainly affected by inside noise power but high frequency (3-4kHz) is affected by compressor shell power as well as inside noise power.

6. Experiment using speaker exciting compressor
In case of Rotary compressor, shell vibration is caused by various sources such as pressure pulsation inside compressor, transmitted force from spot welding points at cylinder part and unknown vibration source. In order to identify effect of only pressure pulsation, a speaker is attached to the bottom shell of compressor. Fig 6.1 shows spectrum level of three measuring parts, inside noise and shell vibration, shell vibration and outside noise, and inside noise and outside noise, which shows relativity of each signals. It is founded that the coherence between outside noise and other signals is high at 3.15kHz, which informs the outside noise at 3-4kHz is affected by shell vibration.

7. Modal testing
Fig 7.1 shows cavity resonance of compressor and Fig 7.2 shows structural resonance of compressor shell. In Fig 7.1, as cavity resonance is obtained in the air, it must be shifted 0.73kHz and 1.5kHz in the R22 refrigerator gas. In Fig 7.2, structural resonance frequency is 3.2kHz, which indicates that at 3-4kHz the outside noise radiated from compressor is caused by structural resonance.

8. Conclusion
(1) The outside noise in the low frequency is affected by inside noise caused by refrigerant gas pulsation. So cavity shape should be carefully considered when compressor is designed.
(2) The outside noise in high frequency(3-4kHz) is affected by compressor shell vibration which is excited by inside noise as well as the other source.

Reference
1. Bendat & piersol, "Random data"
Figure 2.1 Two-input/one-output Model

Figure 3.1 Experiment setup

(a) $G_{II}(f)$
(b) $G_{ZZ}(f)$
(c) $G_{yy}(f)$

(a) $G_{II}(f)$: one-sided autospectrum of noise inside compressor
(b) $G_{ZZ}(f)$: one-sided autospectrum of shell vibration
(c) $G_{yy}(f)$: one-sided autospectrum of noise outside compressor

Figure 4.1 Autospectrum
(a) coherence between inside noise and shell vibration

(b) coherence between shell vibration and outside noise

Figure 5.1 coherence between outer noise and other signal

(a) $G_{11}(f)$: one-sided autospectrum of noise inside compressor

(b) $G_{22}(f)$: one-sided autospectrum of shell vibration

(c) $G_{yy}(f)$: one-sided autospectrum of noise outside compressor

Figure 6.1 Autospectrum in speaker excitation
(a) coherence between inside noise and shell vibration

(b) coherence between shell vibration and outside noise

(c) coherence between inside noise and outside noise

Figure 6.2 coherence between outer noise and other signal

Figure 7.1 cavity resonance of compressor shell

Figure 7.2 coherence and transfer function of compressor shell