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A STUDY ON NOISE IDENTIFICATION OF COMPRESSOR BASED ON
2 DIMENSIONAL COMPLEX SOUND INTENSITY

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ABSTRACT
Sound intensity method is well known as a visualization technique of sound field or
sound propagation in noise control. Sound intensity or energy flux is a vector quantity
which describes the amount and the direction of net flow of acoustic energy at a given
position. Especially two dimensional sound intensity method is very useful in
evaluating periodic characteristics of noise source, acoustic sound field analysis, and
characteristics of noise source of rotary compressor and scroll compressor for air
conditioner using complex sound intensity method. Also we proposed a new method of
time domain analysis technique, which is used in evaluating of position of noise source
in rotary and scroll compressor in this paper. This paper showed the advantage,
simplicity and economical usefulness of this method by analyzing the characteristics of
noise source with two dimensional complex sound intensity simultaneously.

1. INTRODUCTION
In the air conditioning compressor, Principal noise sources are fluid noise caused by
pressure pulsation, mechanical noise caused by structure vibration, pipe vibration
noise caused by fluid vibration of the flow in the pipe, resonance in the space,
transmission noise based on internal factors, electromagnetic noise caused by motor
and so on. Resultantly these noises are transmitted to the outside through the shell
regardless of noise generating process. To work out a countermeasure on noise, it
should be analyzed noise generating parts and transmitting paths in relation to
characteristics. But, it is difficult to find out noise transmitting paths and generating
parts in the compressor. But many results of study on compressor noises are
published. In the rotary compressor, there is a paper (K.Sano(1)) analyzing pressure,
noise, vibration characteristics of compressor regarding to variable running condition
using multi channel signal analyzer and many sensors, which are pressure sensor,
accelerometers, microphones, gap sensor are set up in the interior of the compressor
to find out noise generating area. But using many equipments and sensors are very
expensive and it is not suitable for analyzing noise characteristics for conventional
type. H. Iwata(2) published a paper on comparing experiment of noise and vibration
characteristics with computer simulating results in the scroll compressor. It merely
refers to cause of generating noise and not to transmitting paths and characteristics.
Ishii(3)(4)(5)(6)(7) published a paper on experimental methods of analyzing
compressor noise. It explains cause of noise generation and source location from
experiment based on general noise and vibration characteristics. But It cannot explain
the transmitting characteristics because it mainly focus on frequency analysis.
The noise of air conditioning compressor has a non-stationary periodic component. So,
Measuring data should be averaged for a long time and be operated by statistical process. In this viewpoint sound intensity method is suitable for analysis sound field of compressor. Therefore there have been many efforts to analyze and visualize the sound field of compressor, but there are some problems. Generally 1-D sound intensity method, which has been mainly used, is likely to be affected by surroundings, near field. It causes errors. And it is suitable for analyzing sound distribution but has not information of noise source and directional characteristics. And, 1-D method analyze noise field with only magnitude of sound intensity, it cannot evaluate characteristics of noise field of compressor.

In this paper, to overcome the limit of 1-D sound intensity method, 2-D sound intensity method is used. And to analyze characteristics of sound field, complex sound intensity method is introduced. 56000 BTU class scroll compressor and 7000 BTU class rotary compressor are examined to analyze characteristics of sound by using this method.

2. COMPLEX SOUND INTENSITY

2.1 THE PRINCIPLE OF MEASUREMENT OF COMPLEX SOUND INTENSITY

Eq. (1) is the principle of measurement complex sound intensity method, which analyze real and imaginary part of intensity.

\[ I_e = \frac{1}{2} \cdot P(t) \cdot U^*(t) = I + jQ \]  

where, \( P(t) \) is Complex sound pressure, \( U(t) \) is Complex particle velocity. Real part of Eq. (1) is active intensity and imaginary part is reactive intensity. Active intensity is general sound intensity and is sound power propagating acoustic energy. Reactive intensity is corresponded to reactive power in the alternating current circuit. It means periodic energy circulation between sound source and sound field and the acoustic power of not propagating. This complex sound intensity is used to analyze radiation characteristics of sound source, reactive or near field sound field.

\[ AI = \frac{\ln(S_{BB}(f))}{2\pi p \Delta f} \]  

(2)

Active intensity is obtained by imaginary part of cross spectrum as shown in eq. (2).

\[ RI = \frac{SS_{AA}(f)-SS_{BB}(f)}{4\pi p \Delta f} \]  

(3)

At eq.(3) \( S_{AA}(f) \) and \( S_{BB}(f) \) mean auto-power spectrum of A, B microphones respectively.

Reactive intensity is proportion to gradient of square of sound pressure. As shown in eq. (3), It can be obtained difference between auto-power spectrums of coupled microphones. Reactive intensity is not affected by phase difference (phase mismatch) of this two microphones. On the contrary, the measurement error of active intensity is affected by this phase difference. And phase difference between sound pressure and particle velocity can be found by active intensity and reactive intensity measurement. It is an important factor showing the reactivity of sound field because the phase differences correspond to phase angle of sound impedance. At near sound source, as particle velocity is nearly equal to vibration velocity, so vibration velocity is directly calculated from particle velocity. In this viewpoint, characteristic analysis of near the compressor can be enabled from measuring reactive intensity. Tichy(8), Hidaka(9) explain well the characteristics of complex intensity.
3. Applications of the 2 dimensional complex sound intensity to the compressor

In this paper cross spectrum method is adapted in calculating 2 dimensional sound intensity of rotary compressor. So the resultant 2dimensional intensity was represented as a vector by measuring active and reactive intensity in turn. In this experiment, 2 Microphone probe (B&K 4165 one pair) was used and the space between of the microphones is 12 mm and B&K Pulse system was used to measuring sound intensity.

3.1 Noise of Rotary compressor

The main noise frequencies of rotary compressor exist normally in 2500,3150 and 4000 Hz band (1/3 Octave) as shown in the Fig.1. The measurement grid was used as shown in Fig.2. The these resultant sound intensity vector was shown in Fig.3,4,5 respectively. The location of noise sources of rotary compressor was found in active intensity vector as shown in Fig.3. It is found that the 2500Hz noise source was pump assembly parts. In case of 3150 and 4000 Hz, similar tendency was shown. Therefore It is found that the noise of rotary compressor is mainly radiated from the Pump assembly parts from the active intensity.

In reactive intensity, the direction of reactive intensity of the rotary compressor is similar to the active intensity. This shows that the rotary compressor has periodic characteristics and near field effects is negligible which means no energy has disappeared by any interaction. Generally In the higher frequency of the coincidence frequency of structure, noise radiates freely without energy dissipation (near field effect). In this case, the coincidence frequency of shell is about 1200 Hz, so the above result is considerably valid.

3.2 Noise of scroll compressor

The characteristic of noise radiation of scroll compressor is shown as in Fig.6. The measurement of 2 dimensional intensity of scroll compressor carried out the same way. In this case, lower frequency characteristics had been studied. In active intensity, It can be found that 500 Hz low frequency noise had been radiated from the lower part of motor (welding pin location) as shown in Fig.7. So the main noise source of 500 Hz is welding pin location or lower parts. In the reactive intensity, there are some interactions of sound energy in the upper parts above motor so no sound energy radiated. These tendencies can be approximated to edge-fixed plate. In this case, the center of plate (welding pin location) is excitation source and noise radiated at each fixed edge of plate that is called ‘edge mode’). As shown in Fig. 8, the case of 800Hz is almost accord with that of 500Hz. The sound source is a little upside. Reactive intensity component interferes sound radiations all the direction. It can be found that periodic noise is generated around the mechanical parts from these results.

As shown in Fig. 9, 10, the characteristics of high frequency are very different from those of low frequency. These differences are caused by high frequency components pressure pulsation, non-linear, non-periodic components. Low frequencies generated around the motor part. And high frequencies generated around the mechanical parts.
The difference of sound sources is caused by vibration mode of structure, and noise component caused by unbalance. In the case of comparing reactive intensity components of rotary compressor with those of scroll compressor, periodic noise of scroll compressor is less than that of rotary compressor. It means that pressure pulsation of rotary compressor is stronger than that of scroll compressor, and is a dominant factor. The continuous discharge system of scroll compressor generates less noise than another compressor.

4. TIME DOMAIN ANALYSIS METHOD

Compressor generates periodic noises, vibrations, and pressure pulsations in the compression parts. Time domain analysis method measures noise signals and vibration signals at the same time. And it analyzes the location of generated sound from known characteristics of reference signals. It evaluates the location of noise source by calculating time delay between vibration signal and noise signal from the surface of shell. Frequency component generated from circumferential direction can be found from noise signal. Fig. 11 shows the result of analysis. Fig. 12 shows the results of measured and analyzed noise, which is generated around pumping part without muffler. 2-D sound intensity method was used in measuring vertical components and time domain analysis carried out measurement for circumferential components. Accurate location of noise source can be found using 3-D sound intensity method combined with former 2 methods. These results are 1/3 octave band through all over the frequency band. It is the common result that noises are generated in the discharge parts concentrically. The fact which noises are generated from discharge process all over the frequency means that noises are generated in the domain where terrific pressure pulsation is generated. And it shows indirectly that periodic noises and vibrations are generated. Fig. 13 shows the analyzed results of the generating location of noise using muffler from shell. The muffler is also new noise source and noise source is moved. the location of noise where sound source is dominant can't be moved using muffler. It is confirmed that the major noise source of compressor is pumping part. And most of all, discharge process is important. So, noises can be lowered by decreasing pressure pulsation. Fig. 14 shows that measured SPL(Sound Pressure Level) from x, y direction in the case of with muffler, without muffler in the conventional rotary compressor. X direction means 90 degrees counterclockwise from accumulator. And y direction means 180 degrees counterclockwise from accumulator. And it is measured with microphone 30cm apart from the center surface of compressor shell. Using muffler, noise can be decreased. And another noise source(1250 Hz) is caused by muffler, but it is negligible because of improvement of noise level.

5. CONCLUSION

Intensity method, especially 2-D complex intensity method is very useful to analyze propagation of sound field and characteristics of sound source. In the previous chapter, in comparison with reactive intensity components, signals of scroll compressor are less periodic than those of rotary compressor. Therefore it is clear that pressure pulsation
of rotary compressor is more dominant than that of scroll compressor. In this paper, 2-D complex sound intensity method is useful to find sound source of compressor and to find characteristics of sound field. And combined with time domain analysis method, more accurate location of sound source can be found. Through sound field analysis of compressor with 2-D complex sound intensity, we can conclude as follows.

1. 2-D complex sound intensity method is useful to find out characteristics of sound source in small structure as rotary and scroll compressor.
2. It is found that noise of rotary compressor has strong periodic signal from the analysis result of reactive intensity of rotary compressor.
3. Main noise source of rotary compressor is distributed over cylinder block and it has acoustic mode, the noise of pressure pulsation component is dominant.
4. In the lower shell of scroll compressor, acoustic modes generated by the welding point excitation.
5. It is found that muffler decrease noise level from time domain analysis, and It is very powerful measurement method if it is used combined with 2-D complex sound intensity method.

Reference
(8) J. Tichy, Use of the complex intensity for sound radiation and sound field studies, JASA, Vol. 82, No. 1, pp. 994-1001, 1997
(9) Hidaka, Tachibana, Yano, Sound field analysis with complex sound intensity, Vol. 43, No. 12, 1987, pp. 994-1000
Fig. 1 Noise spectrum of rotary compressor

Fig. 2 Measured point of rotary compressor

(a) Active intensity  (b) Reactive intensity
Fig. 3 Intensity of rotary compressor (2500Hz)

(a) Active intensity  (b) Reactive intensity
Fig. 4 Intensity of rotary compressor (3150Hz)

(a) Active intensity  (b) Reactive intensity
Fig. 5 Intensity of rotary compressor (4000Hz)

Fig. 6 Noise spectrum of scroll compressor

Fig. 7 Intensity of scroll comp. (500Hz)

(a) Active intensity  (b) Reactive intensity
Fig. 8 Intensity of scroll compressor (800Hz)
Fig. 9 Intensity of scroll comp. (3150 Hz)
(a) Active intensity
(b) Reactive intensity

Fig. 10 Intensity of scroll comp. (4000 Hz)
(a) Active intensity
(b) Reactive intensity

Fig. 11 Block diagram in order to analyze noise source in cylinder

With Muffler

Without Muffler

Fig. 12 Noise source without muffler

Fig. 13 Noise source with muffler

Fig. 14 Comparison noise spectrum without and with muffler (X & Y direction)