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Abnormal Compressor Noise Diagnosis Using Sound Quality Evaluation And Acoustic Array Method

Jinquan Zhang
popway@163.com

Rongting Zhang

Huanhuan Gu

Zhiming Wen

Jia Xu

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Jinquan Zhang*, Rongting Zhang, Huanhuan Gu, Zhiming Wen, Jia Xu

Compressor and Motor Institute of Gree Electric Appliances, Inc. of Zhuhai,
Jinji West Rd., Zhuhai City, 519070, P. R. China
Phone: +86-756-8669017, Fax: +86-756-8668386,
E-mail: popway@163.com
zrt1106@gmail.com
huan746@163.com
madicus@163.com
iworking@foxmail.com

*Corresponding Author

ABSTRACT

A noise abnormal rotary compressor is analyzed with sound quality evaluation method. Sound power level (A), loudness, roughness and sharpness are calculated as objective evaluation parameters, and the results indicate that the abnormal compressor has a poor sound quality compared with a normal one. Acoustic array technique can identify target sound source of complicated shape accurately, and get rich sound field information compared to traditional near-field measurement with a sound level meter. In order to diagnose the abnormal noise, the compressor sound sources are identified and located in full frequency range through acoustic array method. As a result, the key frequencies are diagnosed and the corresponding sources are also located, which provide the effective evidence for the future improvement.

1. INTRODUCTION

With the development of society and rising standards of living in step, inverter rotary compressors are widely used in house-hold air conditioners because of its efficiency, comfort, simple structure, etc. What's more, the noise and vibration of inverter compressors are getting more and more attentions, so how to diagnose the abnormal noise rapidly and correctly is an urgent issue.

Compressor sound quality is the key part of air conditioner NVH (noise vibration and harshness) research, because compressor is the main noise source of air conditioner. Sound quality evaluation is not only the examining measurement for compressor, but also indicates how to improve the sound quality (Jinmin You, et al. 2007). In this article, a noise abnormal rotary compressor is analyzed with sound quality evaluation. Sound power level (A), loudness, roughness and sharpness are calculated as objective evaluation parameters, and the results indicate that the abnormal compressor has a poor sound quality compared with a normal one of the similar capacity.

Frequency spectrum is the traditional noise analysis tool, which can reflect the amplitude and frequency bands of compressor noise. However, this method can't get more details about spatial sound field radiating from compressor (Zhigang Huang, et al. 2010). Moreover we can't identify and locate sound sources with frequency spectrum. Acoustic array technique can identify target sound source of complicated shape accurately. All kinds of sources in compressor are identified and located in full frequency range based on the application of acoustic array method for the purpose of diagnosing and confirming the abnormal noise. According to the sound field visualization graphics, the key frequencies and corresponding sources are located on the compressor surface, which provide the effective evidence for the future improvement.

2. ABNORMAL COMPRESSOR SOUND QUALITY ANALYSIS

Compressor sound quality is an essential aspect of compressor NVH research. Sound quality evaluation is an effective tool to judge the noise quality and provides the direction of improvement about compressor. The researches of sound quality focus on psychological characteristic of people’s hearing and emphasize humanity design a lot. Actually sound quality is a subjective concept and a product’s sound quality mainly reflects the special feelings to people. There are several parameters to evaluate sound quality and loudness, roughness, sharpness are selected as objective evaluation parameters as well as the traditional sound power level (A) in this article.

2.1 Loudness

Loudness is a kind of psychoacoustic parameter, to ears which can indicate the subjective feeling of noise. What’s more, by concerning about the human-being masking effect, it can reflect the properties of acoustic signals more accurately compared with sound power level (A). The unit of loudness is sone and defining 1 sone is that a 1kHz pure acoustic signal of 40dB. Zwicker loudness is adopted as our estimating parameter in this article (LMS Test.Lab Manuals).

2.2 Roughness

Roughness describes people’s feelings about transient change of acoustic signals. It is related with modulation frequency, modulation ratio, central frequency and sound pressure level. Of all these factors, modulation frequency and modulation ratio have the most obvious influence on roughness. Moreover, it increases with the increase of modulation ratio. The unit of roughness is asper. The roughness of 1kHz modulation pure acoustic signal is 1 asper when the modulation frequency is 70Hz, for the signal whose modulation ratio is 1, sound pressure level is 60dB.

2.3 Sharpness

Sharpness describes the proportion that high frequency components take in noise frequency spectrum. It also shows the harshness degree of noise signals. The unit of sharpness is acum. The sharpness of 60dB bandwidth noise is 1 acum, for the noise whose central frequency is 1kHz and bandwidth is 160Hz.

2.4 Test Data Analysis

Two compressors’ sound quality is compared in this chapter, the normal one has a capacity of 420ml/r and the noise abnormal one has a capacity of 428ml/r. The abnormal compressor sounds boring and unacceptable, but the normal compressor sounds much better. Sound power level (A) of two compressors is shown in Table 1 when operating frequency range is from 40Hz to 80Hz. From the result in Table 1 it can be seen that the main differences between two compressors lie on high operating frequency. So loudness, roughness, sharpness are compared in Figure 1 as objective evaluation parameters of 80Hz operating frequency. The calculated results suggest:

(1) The loudness of normal compressor is much lower than abnormal one;

(2) The roughness of both compressors has nearly the same size;

(3) The sharpness of normal compressor is also lower than abnormal one and it means the abnormal compressor has more high frequency components noise.

Furthermore, the calculated results confirm the coherence of subjective and objective sound quality evaluation. This kind of method is correct and effective for compressor noise quality evaluation.

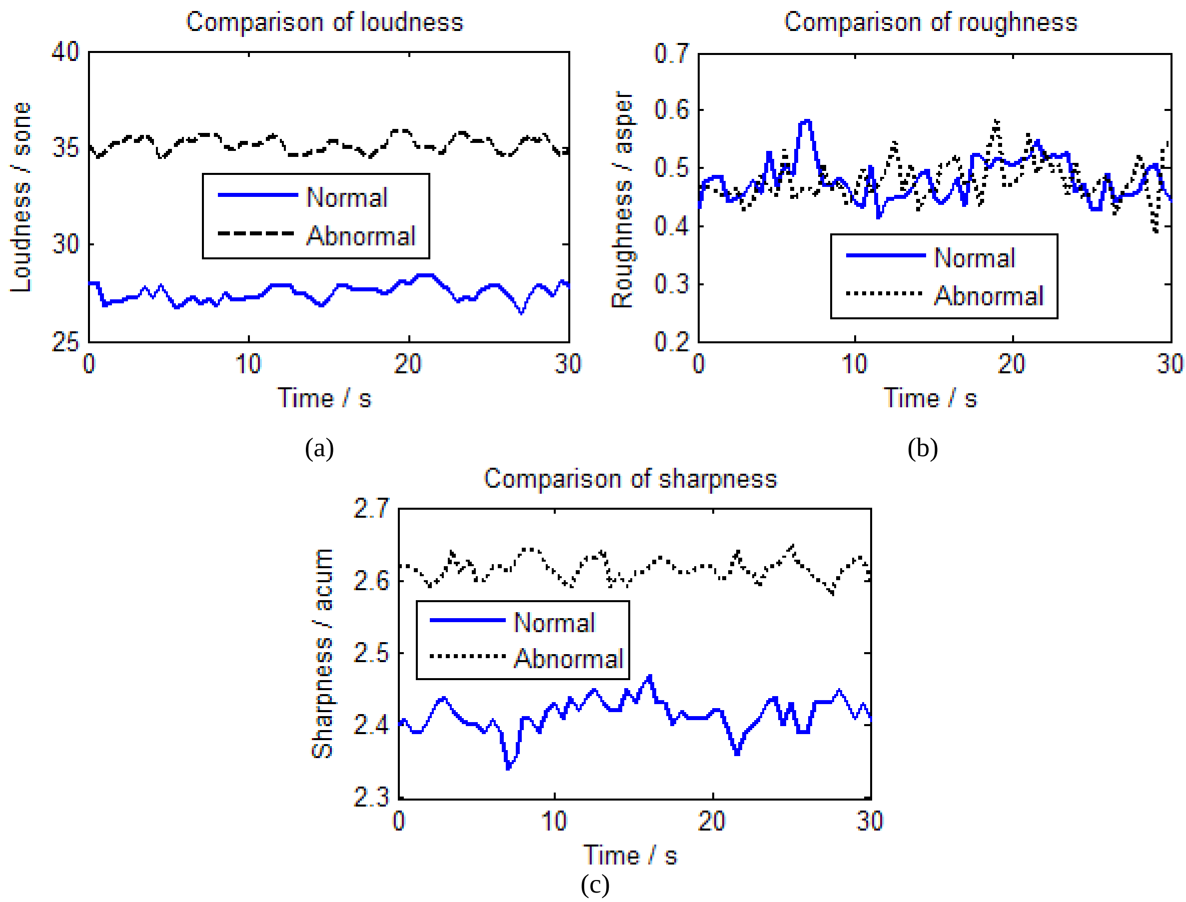


Figure 1: Objective evaluation parameters comparison of two compressors
(a) Loudness; (b) Roughness; (c) Sharpness

Table 1: Comparison of sound power level (A) of two compressors

Operation Frequency /Hz	40	60	80
Sound power level /dB (Normal)	72.1	76.8	78.5
Sound power level /dB (Abnormal)	74.0	79.3	83.1
Sound power level decrement /dB	1.9	2.5	4.6

The loudness and sharpness of normal and abnormal compressors are shown in Figure 2 and Figure 3 respectively when operating frequency range is from 40Hz to 80Hz. Loudness of both compressors increases gradually with the increasing of compressor operating frequency described in Figure 2. However sharpness decreases with the increasing of operating frequency described in Figure 3, and this is quite different from loudness.

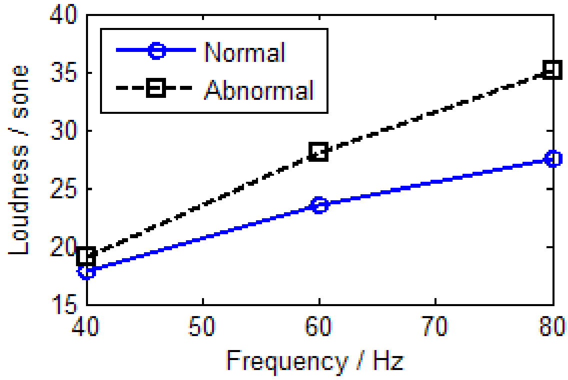


Figure 2: Loudness comparison in various frequencies

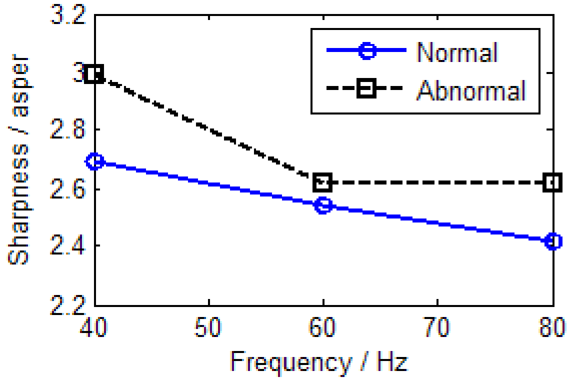


Figure 3: Sharpness comparison in various frequencies

3. ACOUSTIC ARRAY METHOD PRINCIPLE

Acoustic array method is an advanced technique, which can accurately estimate the distribution on source surface, find the sound source location and get the field's dominative feature through making use of spatial acoustic field signals radiating from the target objects. The technique is particularly suitable for analyzing noise sources location from medium to high measurement frequency sources. With a fairly low number of microphones, acoustic array method can provide the finest possible resolution (Jinquan Zhang, et al. 2009 and 2010).

The principle of acoustic array is introduced through the basic Delay-and-Sum method. According to time difference between each microphone receiving sound wave with reference microphone, the measured signals are individually delayed and then summed. As a result the expression for acoustic array method for identifying sound sources at a finite measured distance becomes:

$$\mathrm{B}(\mathbf{r},\omega) = \sum_{m=1}^{M} \omega_m p_m(\omega) e^{-j\omega\Delta_m(\mathbf{r})} \tag{1}$$

where ω_m are a set of weighting coefficients applied to the individual microphone signals. M is the number of microphones in measurement array. The individual time delays Δ_m are chosen with the aim of achieving selective directional sensitivity in a specific direction and can be obtained with the form:

$$\Delta_m(\mathbf{r}) = \frac{|\mathbf{r}| - r_m(\mathbf{r})}{c} \tag{2}$$

where $\mathbf{r}$ is the distance vector between sound source and reference microphone. $r_m(\mathbf{r})$ is the distance from microphone m to sound source. c is the propagation speed of sound.

4. EXPERIMENTAL MEASUREMENT AND DATA ANALYSIS

Objective sound quality parameters, including sound level (A), loudness, roughness and sharpness, have been discussed above in chapter 2. The results confirm the poor sound quality of abnormal compressor. Next the noise problem of compressor must be found, thus acoustic array method is a good tool to locate and image dominative abnormal noise frequency.

4.1 Layout Form of Microphone Array

This experiment is carried out in semi-anechoic chamber, where background noise is below 20dB. The measurement array is shown in Figure 4, including 300 measurement points surrounding the abnormal compressor. There are 10 microphones in vertical layout shown in left figure and 30 microphones in horizontal layout encircling compressor shown in right figure below. The distance between compressor and microphone array is 6cm. The space between two nearby microphones is 3cm in vertical layout. Defining 30° ~330° corresponding to column 1~21 with a 15° space angle degree and defining 360° ~540° corresponding to column 22~30 with a 22.5° space angle degree of two nearby columns in horizontal layout. Any microphone can be taken as reference one in the array by one-shot measurement.

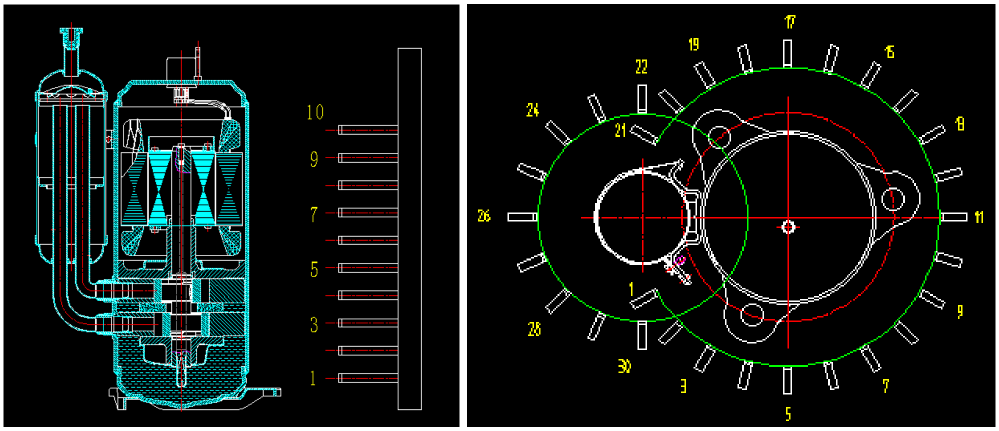


Figure 4: Layout form of microphone array

When operating frequency is 60Hz, the 1/3 octave spectrum comparison of normal and abnormal compressors can be seen in Figure 5, where the green one on behalf of abnormal compressor's noise spectrum and the blue one on behalf of normal compressor. The key differences of spectrum lie on central frequency range from 2500Hz to 5000Hz. So more attention should be paid to that frequency range.

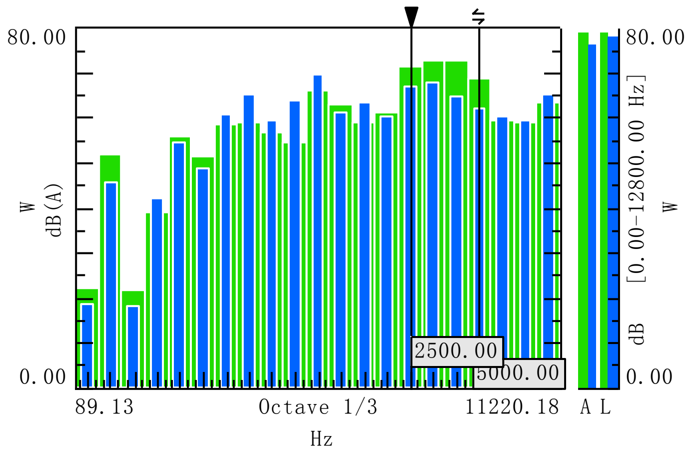


Figure 5: 1/3 octave spectrum comparison of two compressors

4.2 Dominative Frequency Spectrum Investigation near Compressor Main Body

Actually compressor can be divided into two parts, one is main body and the other is accumulation. Both of them are large noise radiating surface, therefore frequency spectrum will be investigated respectively through some dominative measurement points near main body and accumulation. The frequency spectrums of some key measurement points near compressor main body are shown in Figure 6, and all of these spectrums are without A-weighted calculation. Three maximum frequencies are 2761Hz, 3481Hz and 3841Hz.

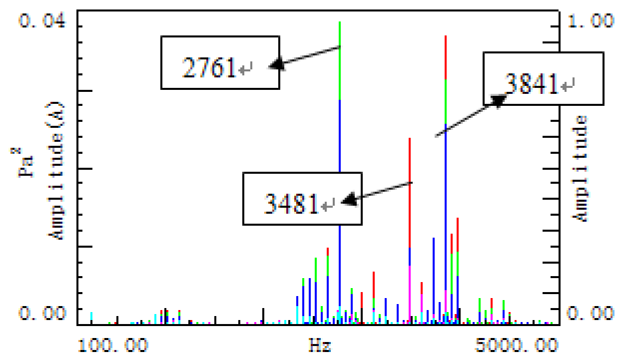


Figure 6: Frequency spectrums near compressor main body

Based on frequency spectrum data seen in Figure 6, the focus of key frequencies is determined, which are 2761Hz, 3481Hz and 3841Hz. According to above mentioned principle and key frequencies, the noise source image can be gotten. Figure 7 (a)~(c) are the noise source images of abnormal compressor corresponding to the three maximum frequencies respectively. Just as the description in chapter 4.1 and Figure 4, 30° ~330° corresponds to source image of compressor main body and 360° ~540° corresponds to source image of accumulation. General speaking, the main sources all locate on main body for the three dominative frequency. In detail, the most important source of frequency 2761Hz and 3481Hz locates in lower cylinder of compressor. Whereas the main source of frequency 3841Hz locates in upper cylinder. Thus designers should pay more attention to optimize both cylinders for compressor noise improving.

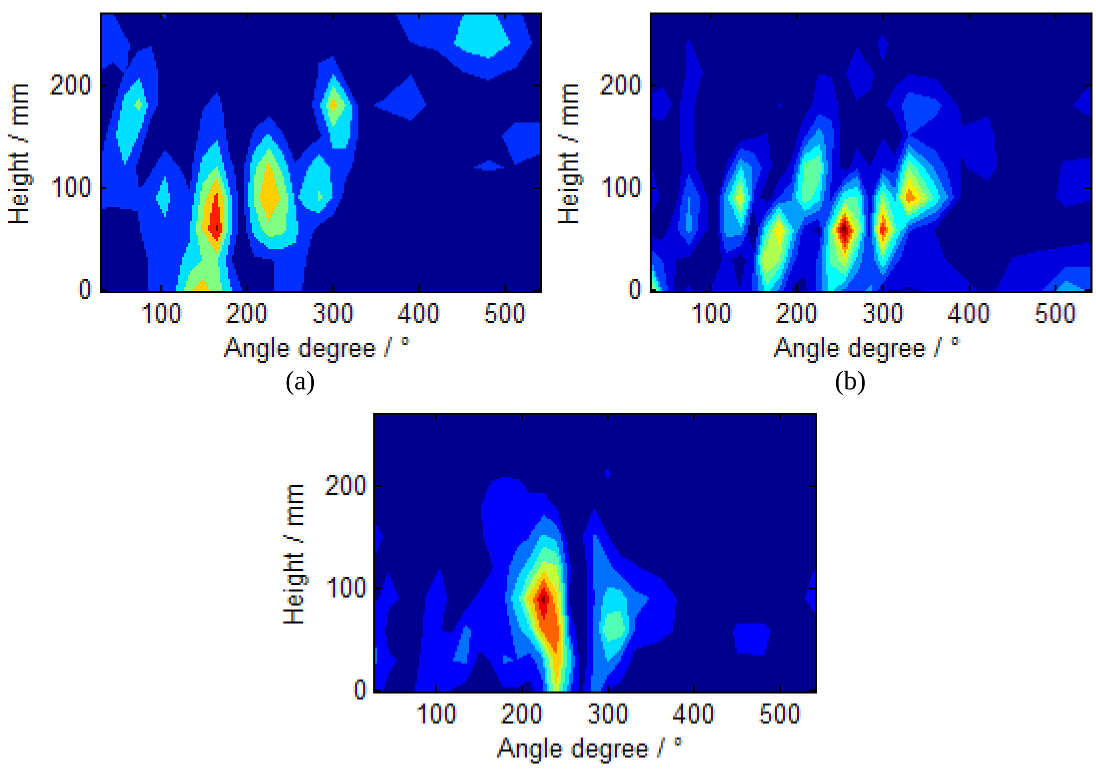


Figure 7: Noise source images of key frequency near main body

(a) 2761Hz; (b) 3481Hz; (c) 3841Hz

4.3 Dominative Frequency Spectrum Investigation Near Accumulation

The accumulation is also an important noise source, so it can't be ignored. The frequency spectrums of several key measurement points near accumulation are shown in Figure 8, and these spectrums are also without A-weighted calculation. Two maximum frequencies are 2745Hz and 5490Hz.

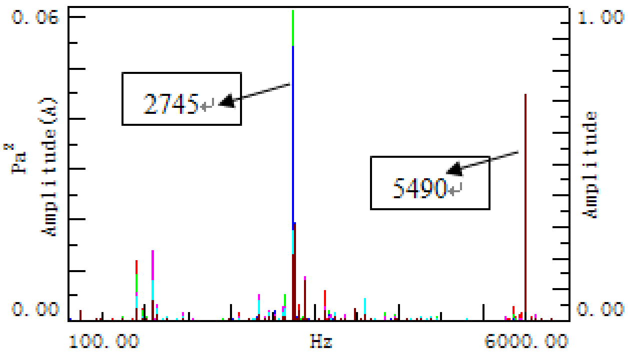
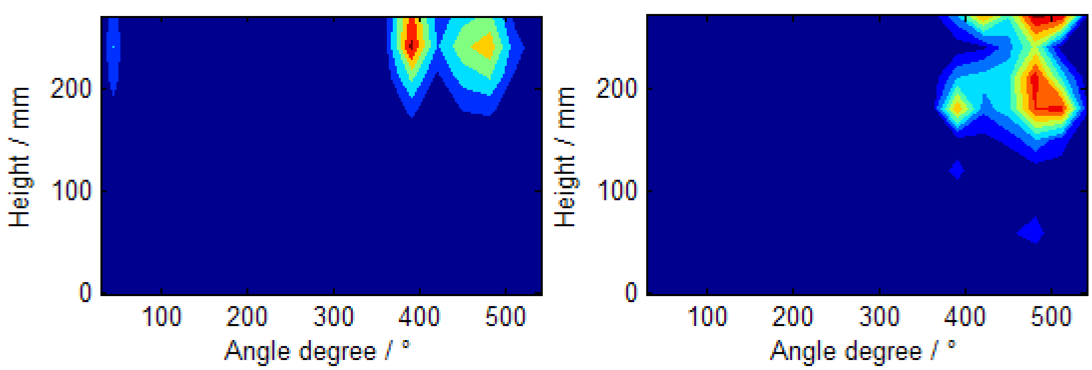


Figure 8: Frequency spectrums near accumulation

According to above mentioned two key frequencies, the noise source images are gotten. Figure 9 (a) and (b) are the noise source images of abnormal compressor corresponding to the frequency of 2745Hz and 5490Hz respectively. As the description above, 360° ~540° corresponds to source image of accumulation. From Figure 9, it can be seen that both source images of 2745Hz and 5490Hz locate on surface of accumulation and the compressor main body has even no source distribution. It most probably proves that the accumulation exists phenomena of sympathetic vibration. So the next step should focus on optimizing the structure of accumulation to avoid occurring sympathetic vibration.



(a) (b)

Figure 9: Noise source images of key frequency near accumulation
(a) 2745Hz; (b) 5490Hz

4.4 Solutions Can Be Taken

The main noise sources are located accurately from the analysis of dominative frequency near main body and accumulation respectively. So the reason of abnormal noise lies on the inappropriate design of cylinder and accumulation. In next period, the two parts should be optimized for noise improvement. There are two suggestions for optimization: one is to add appropriate Helmholtz resonator on both upper and lower cylinders to reduce discharge noise; the other is to optimize the structure of accumulation to avoid occurring sympathetic vibration.

5. CONCLUSIONS

In this paper, a noise abnormal rotary compressor is analyzed based on sound quality evaluation method. Loudness, roughness, sharpness are selected as objective evaluation parameters as well as the traditional sound power level (A). The results indicate that the abnormal compressor has a poor sound quality compared with a normal one. This kind of method is correct and effective for compressor noise quality evaluation.

The acoustic array test for abnormal compressor is achieved and rich sound field information is gotten. Through sound field visualization, the compressor sound sources are identified and located according to several dominative frequencies achieving by some key measurement points in microphone array. Furthermore, the cause of noise problem is diagnosed depending on the location of main source. And the reason of abnormal noise lies on the inappropriate design of cylinder and accumulation. Two suggestions, which are adding appropriate Helmholtz resonator on cylinder and optimizing the structure of accumulation, are given for optimization to reduce noise in next period.

REFERENCES

YOU Jinmin, CHEN Tianning, HE Limei. Subjective and Objective Evaluation of Compressor Sound Quality and Correlation Research [J], Journal of Fluid Machinery, 2007, 35(11).

Zhigang Huang, Hong Guo, etc. 2010 Purdue Compressor Technology Conference, 1392-1397. The Diagnosis and Optimization of Scroll Compressor Noise Based on the Theory of Near-Field Acoustical Holography.

LMS Test.Lab Manuals.

ZHANG Jinquan, BI Chuanxing, CHEN Xinzhao. Research on Array Pattern and its Application in Sound Source Identification by Using the Beamforming Method [J], Journal of Noise and Vibration Control, 2009, 29(03).

ZHANG Jinquan. Study on Noise Source Identification and Sound Field Visualization Based on Beamforming Techniques [D]. Hefei University of Technology, Master Dissertation, 2010.