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Identifying Noise and Vibration of the Discharge Stage in the Rotary Compressor Based on Angle Domain Analysis Method

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ABSTRACT

In the noise and vibration test of the rotary compressor, the peak value of noise and the corresponding frequency can be identified according to the analysis of frequency spectrum. But it can not be obtained that the noise is in which rotation angle range according to the analysis of frequency spectrum, which can be obtained according to the equal angles sampling system. In this paper, the noise and vibration of rotary compressor under different operating frequency in angle domain can be measured using the multi-pulse method, which divides a working cycle into many equal angles. According to comparing the spectrum of noise and vibration of discharge stage and the one of the other stage, the main frequency range of noise and vibration of discharge stage can be obtained.

1. INTRODUCTION

In the noise and vibration test of the rotary compressor, the peak value of noise and the corresponding frequency can be identified according to the analysis of frequency spectrum. But it can not be obtained that the noise is in which rotation angle range according to the analysis of frequency spectrum, which can be obtained according to the equal angle sampling system and the rotary angle range in which the noise appears can be found accurately. Then it can help to reduce the compressor noise.

Rotation angle analysis method can also be called crank angle tracking measurement system^[1-3]. It can be used to analyze the noise characteristic of different rotation angle stage of the rotary compressor. It includes single-pulse method and multi-pulse method.

The single-pulse method is based on that the rotating speed is constant in a circle, on the contrary, the multi-pulse single method is based on that the rotating speed is various in a circle. Using multi-pulse signal method it can be analyzed accurately that the spectrum information at certain rotary angle when the fluctuation of rotating speed is large in a circle. In this paper, the noise and vibration signal of rotary compressor under different operating frequency in angle domain can be measured using the multi-pulse method, which divides a working cycle into many equal angles. According to comparing the spectrum of noise and vibration of discharge stage and the one of the other stage, the main frequency range of noise and vibration of discharge stage can be obtained.

2. PRINCIPLE OF CRANKSHAFT ANGLE ANALYSIS

2.1 Signal Collection

The measurement signal is usually in time domain. According to obtain the noise and vibration signal of different crankshaft angle, it is needed that the measurement data is the function of the crankshaft angle which is the independent variable. The signal collection and analysis method of the rotary system is^[3]:

- A. Collecting measurement signal which is the function of the time;
- B. Collecting equal angle signal according to signal process.

The basic measurement of crankshaft angle analysis includes the following a few signals at least:

- (1) The original time signals needed to measure, such as noise signal, vibration signal and so on;
- (2) The angle time signal, which is emitted in equal angle in a circle, is used to distinguish different angle stage in a circle;
- (3) The period trigger signal emitted synchronously with work circulation (such as top order signal), is used to confirm the start angle time.

Identifying the main range of noise and vibration of discharge stage in the compressor is the main aim, which can be provided to research the principle of the noise. In this paper, the noise and vibration of rotary compressor under different operating frequency in angle domain can be measured using the multi-pulse method, which divides a working cycle into many equal angles.

2.2 Signal Process

The measuring signal is collected at certain sampling frequency. The principle of the crankshaft angle analysis can be seen in Figure 1.

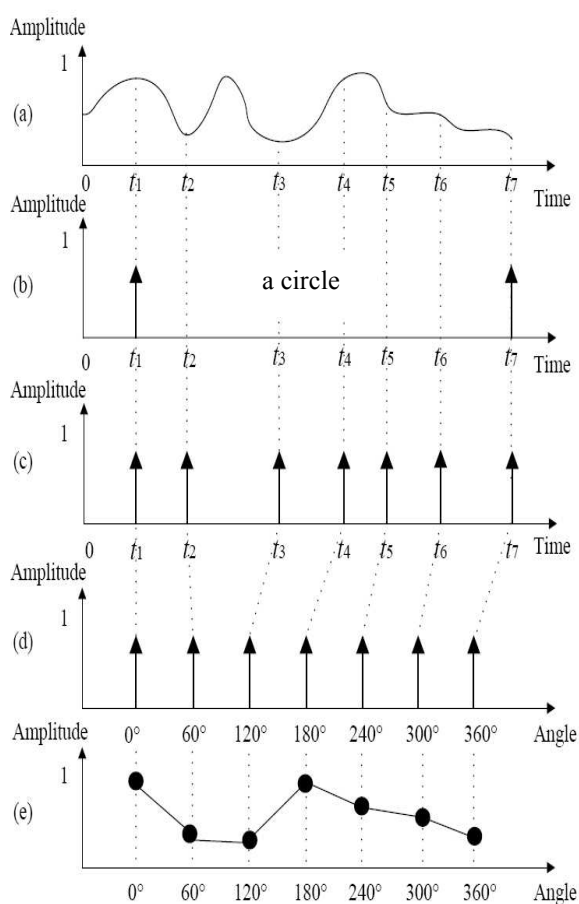


Figure 1: Principle diagram of the crankshaft angle analysis

- (a) Original time signal, (b) top order pulse signal, (c) the time data of each pulse, (d) the angle data of each pulse, (e) the signal correspond to the crankshaft angle

It is given that there are 6 pulses in a working circle from Figure 1. In test the number of the pulse must be decided by the test purpose, the fluctuation of the rotating speed and so on. From Figure 1, it can be seen that according to the time data the relation between the rotary angle and the test data (such as noise signal and vibration signal), which are both the function of the time, can be established. Several period data need to be collected at the same angle domain. So when the data of certain rotary angle domain need to be analyzed, the other data of rotary angle domain

can be set to zero, equaling to set a rectangle window. For example, when the data of the 210-360 degree need to be analyzed, a rectangle window in Figure 2 can be set.

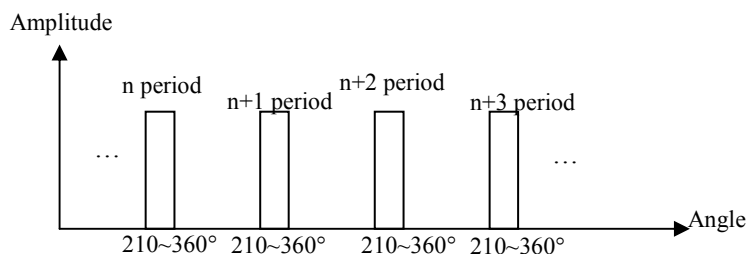


Figure 2: The sketch of the rectangle window

3. DESIGN AND APPARATUS OF THE TEST

3.1 Design of Multi-pulse Sampling System

The position of the crankshaft rotary angle is confirmed based on the fluctuation of the signal, which is measured according to using the eddy current displacement sensor. A gear set is fixed on the crankshaft. When the convex part of the gear set is rotated on the front of the sensor, the distance between them is short, so the signal is small. On the contrary, when the concave part of the gear set is rotated on the front of the sensor, the distance between them is long and the signal is very large, then it can be considered that a pulse is produced here. In this experiment, the structure of gear set, as shown in Figure 3, has 11 dentations. Its design is that a circle is divided equally into 12 dentations, then one of them is thrown away and the size of the widest concave part is as three times wide as the size of the other ten concave parts. It is shown that the middle of the widest concave part is the start point, which is on the position of eccentric of the crankshaft.

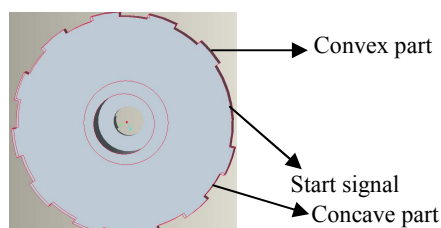


Figure 3: The sketch of the gear set structure

3.2 Measuring of the Crank Angle

Five periods signals measured by the eddy current displacement sensor are shown in Figure 4. The red curves in Figure respect the middle of the widest concave part of the gear set, which is the start point (0 degree) of the crankshaft angle. It can be seen that the signal periodicity is good and 11 peak values of each period is clear, which can satisfy the test request. The signal of every two near red curves is in a working circle period and the angle difference of each two near peaks, except the start peak, is 30 degree.

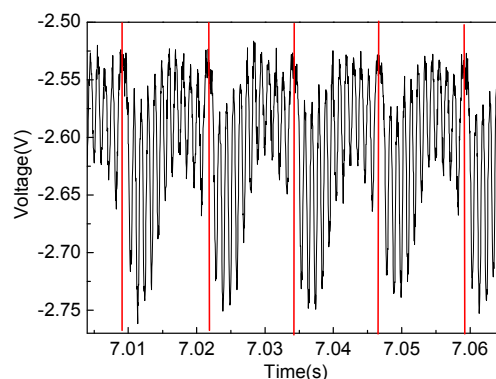
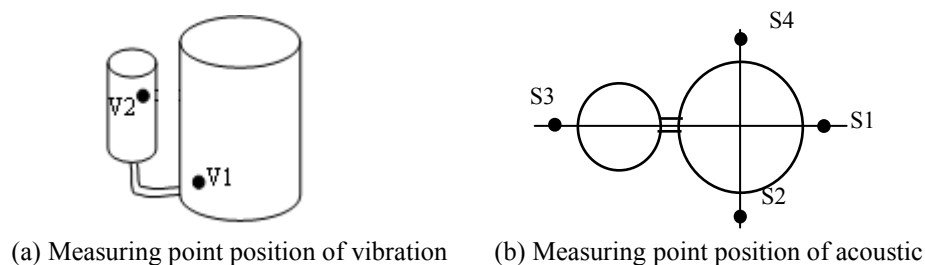


Figure 4: The measuring signal using eddy current displacement sensor

3.3 Equipment of Experiment

The test is measured in hemi-anechoic rooms. The test data is collected using 16-channels LMS Test. Lab System and the sampling frequency is 25600 Hz. The measuring position of the vibration and noise is shown in Figure 5. The measuring point 1 and point 2 of the vibration are located separately on the medium lower part of compressor shell near the discharge of the top-flange and on the medium higher part of the accumulator, as shown in Figure 5(a). According to reduce the measuring error which induced by the time delay in rotary angle analysis, the distance of the measuring point of acoustic is about 30cm from the compressor surface in horizon direction and about 42mm from the bottom of the compressor in vertical direction. The measuring point 1, 2 and 4 are on the side of the compressor main body and the measuring point 3 is on the side of the accumulator, as shown in Figure 5(b).



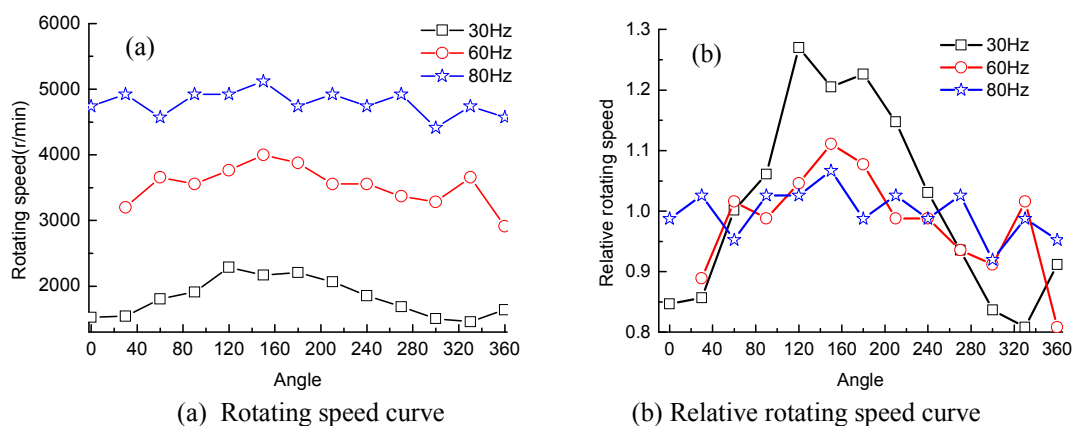
(a) Measuring point position of vibration (b) Measuring point position of acoustic

Figure 5: The sketch of measuring point position

4. RESULT DISCUSSION

4.1 Rotating Speed Curve in a Working Circle

When the compressor working frequency separately is 30Hz, 60Hz and 80Hz, as shown in Figure 6, the rotating speed of different angle stage is the average speed of every 30 degree angle domain, which is obtained by the angle time signal and the original time signal. From Figure 6(a), it can be found that the fluctuation of rotating speed in a working circle is obvious at low frequency operation, at the same time, the fluctuation at high frequency operation is not so clear. So the relative rotating speed which is equal to the rotating speed dividing average rotating speed at different operating frequency is obtained as shown in Figure 6(b). From Figure 6(b), it can be seen that with the compressor working frequency changing higher, the fluctuation of rotating speed in a working circle is relatively smaller.



(a) Rotating speed curve

(b) Relative rotating speed curve

Figure 6: Rotating speed on different operating frequency

4.2 Rotary Angle Characteristic Analysis of the Vibration Measuring Points

In test the vibration is evaluated by the acceleration level. Because the discharge stage is intermittent, the range of the discharge stage is about 210~360 degree. According to comparing the amplitude and frequency spectrum of vibration of the discharge stage with the other stage, the angle range compared should be agreed with each other. So the range of 0~150, 60~210, 210~360 degree are collected to analyze^[4-5]. The normal acceleration of the vibration is only considered which directly influences the compressor radiation noise. The normal vibration acceleration

characteristic of the rotary angle domain based on the 1/3 octave spectrum at different working frequency is shown in Figure 7.

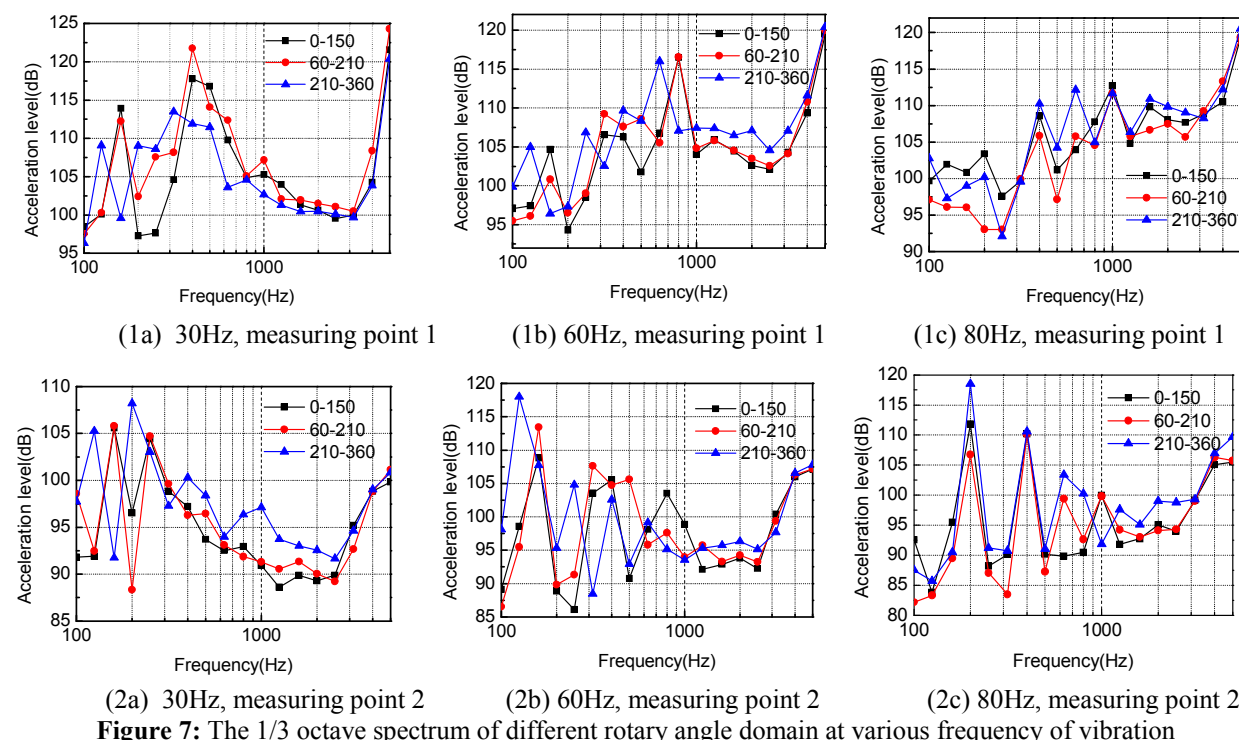


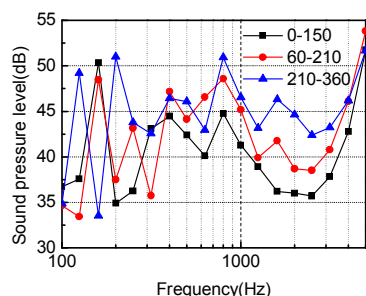
Figure 7: The 1/3 octave spectrum of different rotary angle domain at various frequency of vibration

It can be seen that the vibration at discharge stage (210~360 degree) is usually the biggest, especially the central frequency from 1000Hz to 3000Hz. The reason is, the valve is suddenly open, which induce the spray of fluid and result in the vibration response at middle and high frequency. From the measuring 1(on compressor shell) and point 2(on accumulator) it can be found that the middle and high frequency vibration on the shell is large than low frequency at different working frequency, especially high working frequency, on the contrary, the vibration on the accumulator of low frequency is larger than high frequency.

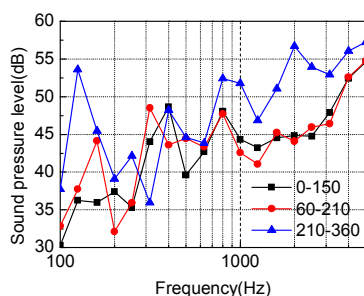
4.3 Rotary Angle Characteristic Analysis of the Noise Measuring Points

Because there is some distance (30cm in experiment) between the microphone and compressor or accumulator surface, it needs some time that the noise transmits to receiver. According to rough calculation the angle in this transmitting time (80Hz working frequency) is about 25degrees. In practice calculation the time delay should be corrected. But the source is not from one point of the compressor or accumulator surface, so the correction is approximate. In this paper, the analyzed angle range (150 degrees) is larger than the correctional angle (less than about 25 degrees), so the difference between the original spectrum characteristic and the correctional is small^[4]. The time delay is not correction in this experiment.

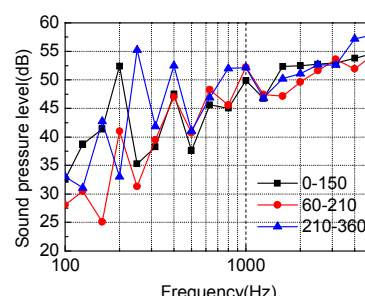
The noise characteristic of the rotary angle domain based on the 1/3 octave spectrum at different working frequency is shown in Figure 8.



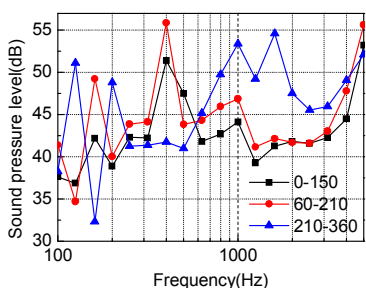
(1a) 30Hz, measuring point 1



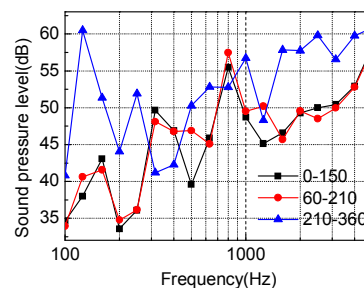
(1b) 60Hz, measuring point 1



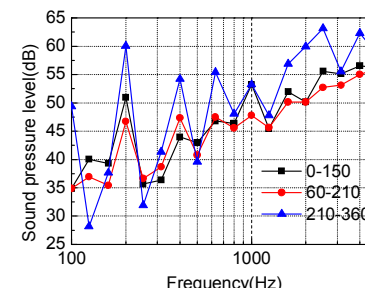
(1c) 80Hz, measuring point 1



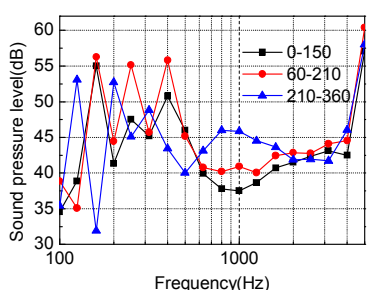
(2a) 30Hz, measuring point 2



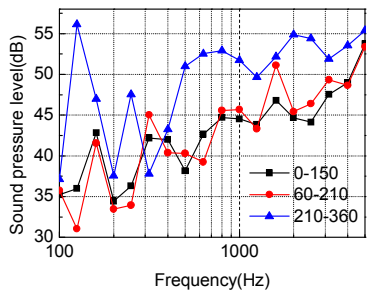
(2b) 60Hz, measuring point 2



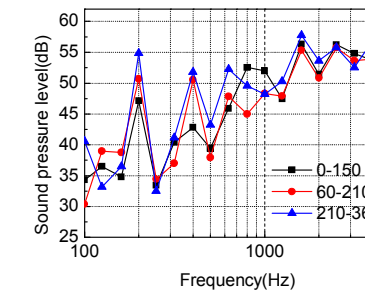
(2c) 80Hz, measuring point 2



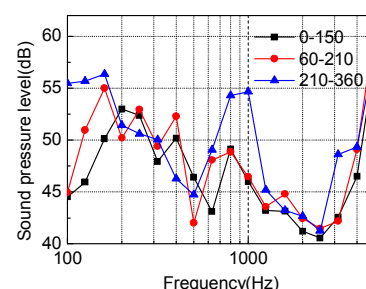
(3a) 30Hz, measuring point 3



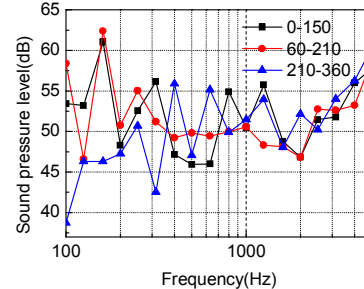
(3b) 60Hz, measuring point 3



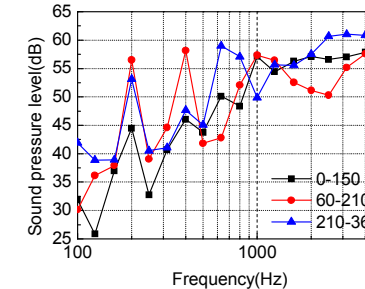
(3c) 80Hz, measuring point 3



(4a) 30Hz, measuring point 4



(4b) 60Hz, measuring point 4

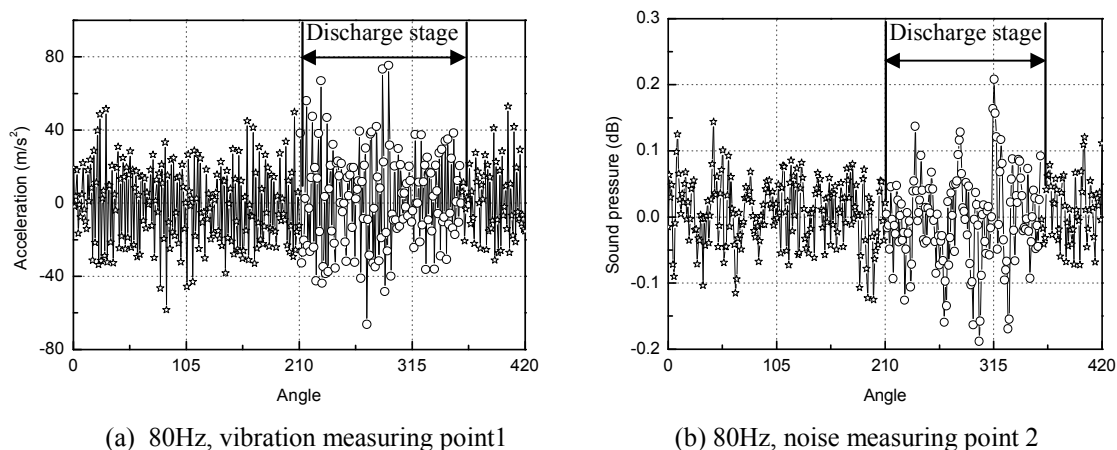


(4c) 80Hz, measuring point 4

Figure 8: The 1/3 octave spectrum of different rotary angle domain at various frequency of noise

From Figure 8, firstly, it can be seen that under different operating frequency the sound pressure in discharge stage up 600Hz is higher than the other stage such as suction stage and compressing stage, especially in range of middle frequency 800~1000Hz and 1600~3000Hz, which means the discharge noise is the main component of the noise spectrum. Secondly, with the operating frequency of the compressor increasing, the amplitude of the discharge noise increases as well, but other kind of noise increases more quickly, which conduces that with the rotary speed of the compressor increasing, the percent of the discharge noise at high speed is lower than that at low speed. Finally, it can be found that the discharge process has a weakly effect on the measuring point near the accumulator.

When the operating frequency of compressor is 80Hz, the data of the vibration measuring point 1 and the noise measuring point 2 in time domain are shown in Figure 9. The acceleration and sound pressure with the angle change are separately shown in Figure 9(a) and 9(b). It can be seen that the pulse data curve at discharge stage is severe than the other stage, which is agreement with the result of frequency spectrum in angle domain.



(a) 80Hz, vibration measuring point 1

(b) 80Hz, noise measuring point 2

Figure 9: Curve of vibration and acoustic in time domain

5. CONCLUSIONS

In this paper, the noise and vibration of rotary compressor under different operating frequency in angle domain can be measured using the multi-pulse method, which divides a working cycle into many equal angles. According to comparing the spectrum of noise and vibration of discharge stage and the one of the other stage, the main frequency range of noise and vibration of discharge stage can be obtained. It can be obtained from the test that:

(1) From the vibration measuring, the vibration at discharge stage (210~360 degree) is the biggest, especially the central frequency from 1000Hz to 3000Hz. From the measuring 1(on compressor shell) and point 2(on accumulator) it can be found that the middle and high frequency vibration on the shell is large than low frequency at different working frequency, especially high working frequency, on the contrary, the vibration on the accumulator of low frequency is larger than high frequency.

(2) From the noise measuring, firstly, it can be seen that under different operating frequency the sound pressure in discharge stage up 600Hz is higher than the other stage such as suction stage and compressing stage, especially in range of middle frequency 800~1000Hz and 1600~3000Hz, which means the discharge noise is the main component of the whole spectrum. Secondly, with the operating frequency of the compressor increasing, the amplitude of the discharge noise increases as well, but other kind of noise increases more quickly, which conduces that with the rotary speed of the compressor increasing, the percent of the discharge noise at high speed is lower than that at low speed. Finally, it can be found that the discharge process has a weakly effect on the measuring point near the accumulator.

In a word, according to the rotary angle characteristic analysis, the vibration and noise characteristic in different rotary angle can be identified efficiently, which is the base on reducing the noise of compressor.

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