

Rotary Compressor Monitoring Using Frequency Analysis Technique

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Abstract— This study was demonstrated condition monitoring of typical domestic rotary compressor with various simulated conditions e.g. normal, blade fault, discharge valve fault and intake port fault. The developed technique was also used to identify mechanical and fluid flow activities in the compression cycle of a rotary compressor. Vibration signals based on crank angle domain could be used to describe compression cycle easier than signals on time domain. Frequency analysis based on power spectral density was able to use to demonstrate various activities in compression cycle and also identify various rotary compressor conditions.

Keywords— Condition monitoring, Rotary compressor, Signal analysis, Frequency analysis technique, Power spectral density, Fast Fourier Transform

I. INTRODUCTION

A compressor is the main component used in many applications in various household and industrial devices such as air-conditioning system, refrigeration system, air-compressor system, etc. The condition monitoring of rotating machine is able to apply for compressor that used in a critical process. It is a useful to know or predict state of compressor in order to prevent a severe damage in compressor. Typical processes in the compression cycle are associated with mechanical activities and fluid flow processes inside a compressor and these depended on type of compressors such as the opening and closing processes of intake and discharge valves, cylinder movement, rotating of shaft, activity of fluid in compression chamber of compressor, etc. There are various types of compressor such as reciprocating compressor, rotary compressor, scroll compressor, and screw compressor. The mechanical and fluid flow activities inside each compressor are different because of the difference of moving parts of each type of compressor.

Condition monitoring of rotating machines has been studied and applied to various type of rotating machines such as diesel engines, pumps, fans, turbine and compressors. Typical monitoring techniques are used various types of sensors to acquire some useful signals from machines e.g. temperature sensor, pressure sensor, microphone, acoustic emission sensor and accelerometer. Thus, the signal processing techniques are used to describe some useful information to predict state of machines.

Condition monitoring of compressors has been studied in the last two decades and applied to screw compressors [1-2], reciprocating compressors [3-5] and rotary

compressors [6-10]. Many monitoring techniques were used to predict state of compressor such as accelerometer [1-2,6-8], acoustic emission [3-5,8] and microphone [9]. To describe some information from signal, signal processing techniques are applied. Typical time domain analysis techniques are used to calculate some statistical and signal parameters such as mean, standard deviation, skewness, kurtosis, maximum, minimum, root mean square, crest factor, etc. However, some detected signal could not give any good parameter to predict between normal and fault conditions. Frequency domain analysis techniques are also basic tools to describe signals such as Fast Fourier Transform (FFT) and power spectral density (PSD). Frequency domain analysis in typical rotating machine (i.e. bearing and gear) is related to rotating speed or and its harmonic. Thus, to use frequency domain analysis, it is necessary to have some background knowledge of machine and signal analysis so that the prediction of machine condition is precise and clearer.

In this study, the typical rotary compressor unit was disassembled and only compressor was used. This type of compressor is used in some domestic refrigerators and air conditioners. The experiment was set up to demonstrate various compressor conditions such as normal, blade fault, discharge valve fault and intake port fault. Vibration signal was recorded on running compressor. Signal processing based on frequency domain technique was used to analyse signal to describe some useful information from compressor and will be detailed in next section.

II. VIBRATION CONDITION MONITORING TECHNIQUES

Vibration monitoring is the most widespread method to determine the state of machine and also can help to reduce loss of production, replacement costs, and other negative effects of deteriorating machine condition. Typical domestic rotary compressor has been studied and used vibration monitoring technique to predict actual overall health of compressor [6-12]. Vibration signal is able to be used to monitor and describe mechanical and fluid flow activities inside compressor. Typical compression process of the rotary compressor is shown in Fig. 1. There are some moving parts in this compressor such as ring, blade and cam. The processes in the compression cycle are continuous processes. The rotation of the off-center cam compresses the gas in the cylinder of the rotary compressor. The cam is rotated by an electric motor. When the cam spins, it carries the ring with it. The ring rolls on its outer rim around the wall of the cylinder. The compression process in a rotary

compressor consists of intake, compression and discharge phases. The beginning of compression phases is shown in Fig. 1(a). When the intake port opens, the gas flows into intake port as shown in Fig. 1(b). The half completion of intake and compression phases is shown in Fig. 1(c) and the end of compression phase is shown in Fig. 1(d). For discharge phase, when pressure in cylinder at compression phase is greater than the plate valve pressure, the gas flows out from discharge port.

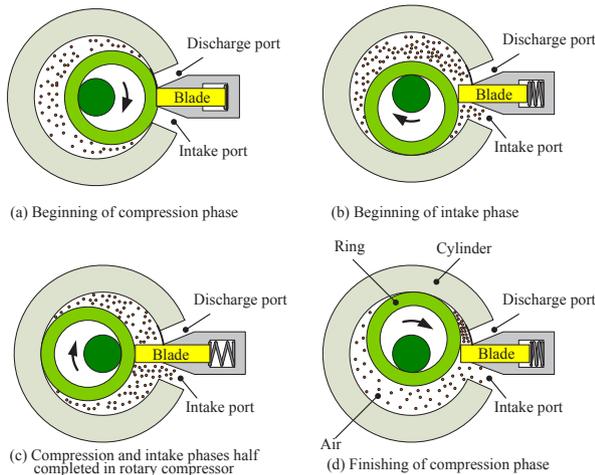


Fig. 1 Compression processes of the rotary compressor

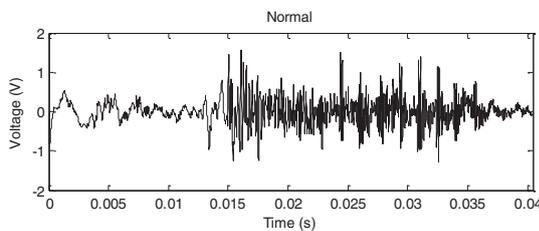


Fig. 2 Example of typical vibration signal acquired at normal condition.

An example of vibration signal detected from a running rotary compressor at normal condition is shown in Fig. 2. It can be seen that amplitudes of the vibration signal vary with time and these amplitudes may be associated with mechanical and fluid flow activities in the compression cycle [6-8]. Vibration signals can be analysed various parameters using time domain technique such as standard deviation, skewness, kurtosis and crest factor [6,8]. This work was used vibration signal to monitor states of a two-stage reciprocating compressor. It was found that the use of single parameter was unable to predict compressor condition. When the comparison of two parameters was used, it was able to predict state of compressor. PSD, one of typical frequency domain technique, was applied to analyse vibration signal acquired from compressor [6,9]. PSD can be used to analyse the main frequency components in vibration signal that related to various activities in the compression cycle.

This study was applied PSD to describe vibration signal acquired from compressor with normal and various fault conditions. Frequency spectrum vs cycles were

displayed in order to compare the main dominant frequency of each compressor condition.

III. EXPERIMENTAL

This study was demonstrated condition monitoring of 9000 Btu, domestic compressor. This compressor unit was disassembled and only compressor was used and was driven by electric motor of speed at 1430 rpm as shown in Fig.3. The working fluid in this study was air. The processes in the compression cycle were investigated including various faults on moving parts of the compressor. Two signals acquired from simulated compressor were vibration signal and revolution signal. Vibration signals were acquired from an accelerometer attached on the compressor housing. Revolution signals were acquired using proximity switch that gave one pulse per revolution. The experimental setup in this study is shown in Fig.4. Both signals were acquired with sampling frequency of 100 kHz and were saved into files for later analysis.



Fig.3 A rotary compressor with an electric motor

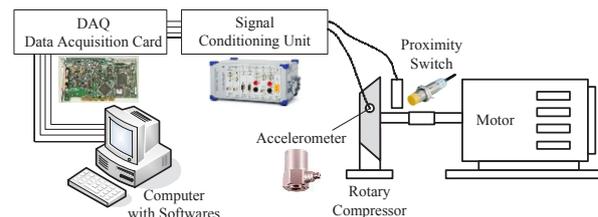


Fig.4 Experimental Setup

Four conditions were demonstrated such as normal, blade fault, discharge valve fault and intake port fault. The blade fault was simulated by introducing a small groove into the blade to allow air to leak past between intake and discharge chambers. The discharge valve fault was simulated by attaching a shim to the plate valve to prevent the valve from closing properly. For the intake port fault, a plate with a small hole with diameter of 5 mm was attached on the intake port to prevent air to pass easily through the intake port.

IV. RESULTS

Vibration signals were acquired from the testing compressor with various conditions as mentioned above. Band pass filter was applied to vibration signal to eliminate low and high frequency noises with upper and lower cut-off frequencies between 200 and 9000 Hz. To describe vibration signal clearer, vibration signal was

acquired with revolution signal to allow signal to be resampled with respect to crank position.

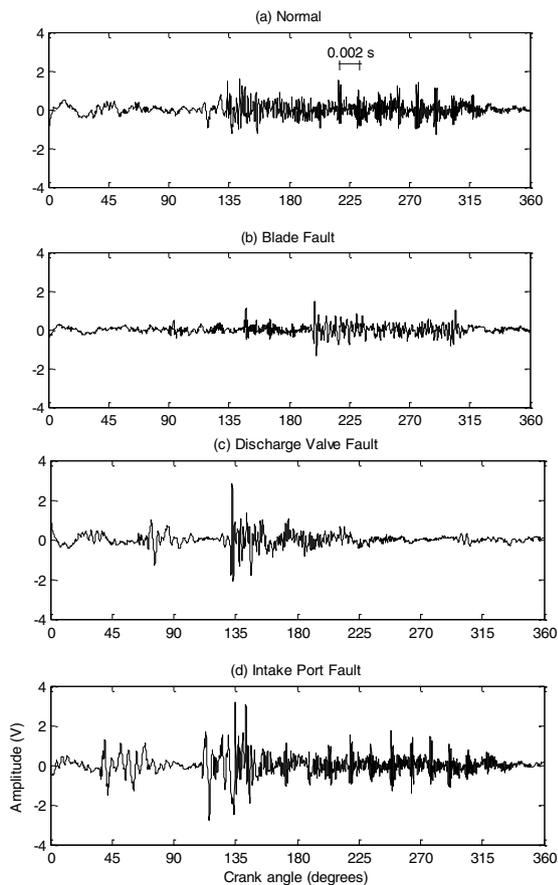


Fig. 5 Example of vibration signals on crank angle domain with various conditions

Examples of vibration signals based on crank angle domain of each simulated condition are shown in Fig. 5. It can be seen that vibration signal can be described easier using crank angle domain. Amplitudes of vibration signal at each condition are different. The activities of intake phase occur between 0 and 135 degrees with small amplitudes which is depended on the simulated conditions. For normal and intake port fault conditions, the events in vibration signal are similar. Only amplitudes of signal of intake port fault condition is greater than of normal condition. The main activities of compressor can be seen clearly after 135 degrees. Various events occur with the same time duration especially in normal and intake port fault conditions. These may be because when air has been compressed to a certain pressure that exceeds plate valve pressure, it leaves through the discharge port. However, these events disappear for blade fault and discharge valve fault conditions. It is difficult to predict precisely of all compressor conditions using vibration signal based on crank angle and time domains. Because of the non-stationary signal nature, amplitudes of acquired signals may vary from cycle to cycle. In addition, the knowledge of signal analysis is needed.

To enhance understanding of vibration signal, frequency domain analysis can be applied. PSD of vibration signals was presented in Fig. 6. Frequency spectrum of signals can be separated into 3 bands at approximately 200-1000, 1000-2500 and 2500-9000 Hz.

PSD of signal of intake port fault condition is greater than other conditions. As a result of smaller intake port, air intake is difficult to flow through intake port to compressor cylinder. This may produce more mechanical and fluid flow activities in the compression cycle.

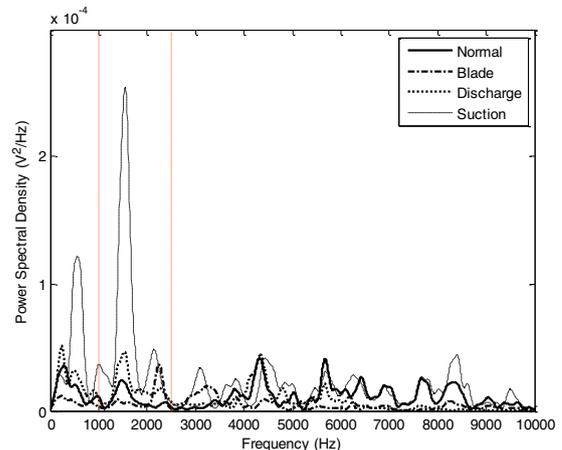


Fig. 6 PSD of vibration signal at various rotary compressor conditions

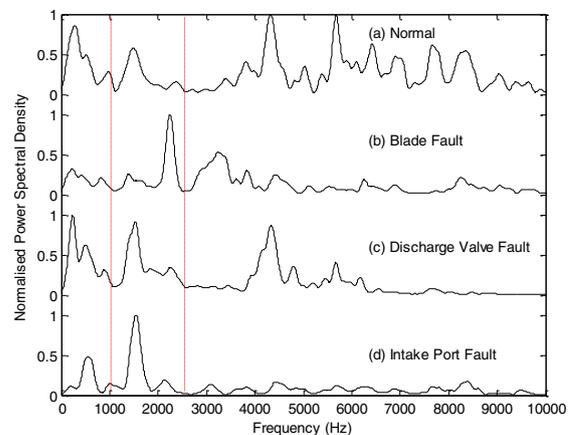


Fig. 7 Normalised PSD of vibration signal at various rotary compressor conditions

In order to gain a more general view of frequency spectrum in vibration signals, PSD of each signal in Fig. 6 was normalised with its maximum power and can be illustrated in Fig. 7. The main frequency bands of vibration signal in each condition can be seen clearly. The first two frequency bands are presented in all compressor conditions with varying magnitudes and dominant frequency components. However, for the third frequency band, it can be seen only at normal and discharge valve fault conditions.

To compare frequency spectrum, normalised PSD of vibration signals of each compressor condition was determined around 100 compression cycles. All normalised PSD are displayed using contour plot. The colour bar represents the signal power levels as shown at the top of the plot in Fig. 8. Frequency components in Hz are shown in y-axis and cycle index is shown in x-axis. The result is divided into 4 groups as follows: normal, blade fault, discharge valve fault and intake port fault. The frequency spectrum of each group is different and may depend on mechanical and fluid flow activities in each compressor condition. There are 3 frequency bands at approximately 200-1000, 1000-2500 and 2500-9000

Hz as same as those in Fig. 7. All frequency bands can be seen clearly in results of compressor at normal and intake port fault conditions. However, the high frequency contents of signal of intake port fault condition (>2500 Hz) give lower magnitudes. For the case of discharge valve fault condition, dominant frequency bands are similar as at normal condition. It is evident that the high frequency contents of signals (>7000 Hz) disappear. For blade fault condition, high frequency band (>4000 Hz) is not presented. It can be noted that the lower frequency component at approximately 500 Hz (~ 0.002 s) in Fig. 8 may be associated with various discharge valve opening event as shown in Fig. 5. The 2nd frequency band at 1500 Hz may be related to the rubbing between moving ring and cylinder. The higher frequency bands (>2500 Hz) may be associated with the fluid flow activities at the discharge phase in rotary compressor.

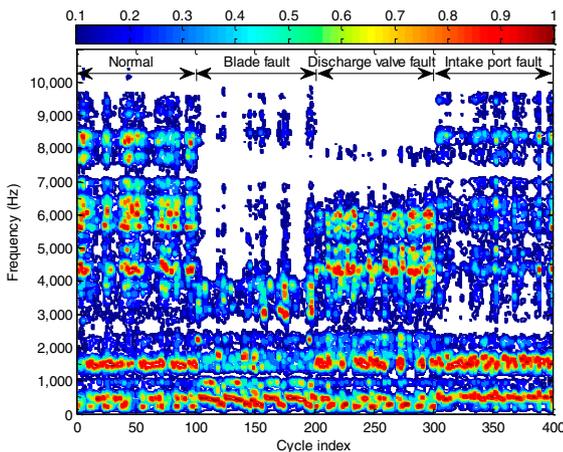


Fig. 8 The contour plot of normalised PSD at various fault conditions

V. CONCLUSION

Vibration monitoring is a useful method to investigate rotating machine as well as a rotary compressor. Four simulated conditions were chosen in this study such as normal, blade fault, discharge valve fault and intake port fault conditions. Vibration signals acquired from all conditions were analysed on time domain, crank angle domain and frequency domain technique. Vibration signal mapped onto crank angle domain could be used to describe compression cycle clearly. The use of contour plot of normalised PSD could be used to identify state of rotary compressor clearer.

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