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THE USE OF TWO-DIMENSIONAL AUTOCORRELATION OF VIBRATION SIGNAL FOR FAULT DETECTION OF RECIPROCATING COMPRESSORS

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ABSTRACT

Reciprocating compressors are the oldest kind of compressors designed for mass production. These compressors still become- the best choice for several industrial application due to their advantages that give high compression ratio and low mass flow. There are many cases of reciprocating compressors faults, such as fault in valve, wrist-pin, and crankpin bore on connecting rod. In this paper, fault detection of such compressors due to exhaust valve and pin bore faults will be presented based on the vibration signal. At first, time domain and frequency domain will be the basic method for analysis and then it will be completed by spectrogram and two-dimensional autocorrelation. The patterns of vibration signals were analyzed and compared through their vibration signatures. Vibration signatures could give informations related to impending faults in the compressors. Therefore, the fault diagnostics of compressor could be realized.

Keywords: *Autocorrelation, compressor, fault detection, spectrogram.*

1. INTRODUCTION

Reciprocating compressors are the oldest kind of compressors designed for mass production. Until today, such compressors still become the first choice in several industries due to of their advantages that capable in providing high compression ratio and low mass flow.

Reciprocating compressors have a wide range in size from fractional cfm to 15,000 cfm (25,485 m3/h) with discharge pressures as high as 60,000 psig (413,790 kPa). The majority of applications fall in the pressure range of 10 to 300 psig (690 to 2,069 kPa) and capacities less than 2,500 cfm (4,250 m3/h). Single-acting compressors (which compress gas on one side of the piston only) have their widest application below 50 hp (37 kW). Larger compressors are usually double-acting, it meansboth sides of the piston are used to compress the gas) [1].

There are so many fault cases in reciprocating compressors. It is about 36% of faults is usually occurs because of faulty valve [2]. A good valve should have several parameters such as good sealing, how fast the valve will open and close, flow area and low flow resistance, low impact, and the ability to resist from high impact force and high temperature. But, a valve which cannot resist force in wide operation condition usually leaked at low compression ratio and decrease lifetime of valve in high pressure operation [3].

The other components of reciprocating compressors which have high chance to be faulted are crankpin bore and wrist pin. Those components are susceptible to wear because of continuous friction with another component, in this case with crankshaft and piston. Therefore, an early detection should be performed to prevent the fault level become more serious at reciprocating compressors.

2. BASIC THEORY

Short Time Fourier Transform

Time-Frequency analysis combines the signal in time domain and frequency domain so that the transient events such as impacts which are occur in very short time could be well observed. This analysis can monitor an event in a machine at certain time and frequency. This method is known as short-time Fourier transforms (STFT). STFT defined as [4]:

$$S(f,t)=\int_{-\infty}^{\infty} x(t)w(t-\tau)e^{-j2\pi ft}dt \quad (1)$$

where w(t) is windowing which move along measurement time. This window can be finite length like Hanning window or infinite length like Gaussian window.

The amplitude of power spectral is presented in decibel (dB) as follows

$$x(t)=10\log\frac{P}{\mathrm{P_r}} \quad (2)$$

where P is power measurement and P_r is power reference.. Plot of STFT is then called as spectrogram.

Autocorrelation

Autocorrelation defined as correlation between observation of one or more variable. Autocorrelation is the correlation from a time series data for different time lag. At detection of images and patterns, autocorrelation was used to view the periodicity in vibration signals [5].

3. METHOD

Research method is compiled as a guide to conduct the research work. Figure 1 shows a flowchart diagram for fault detection of reciprocating compressors based on vibration signal extraction.

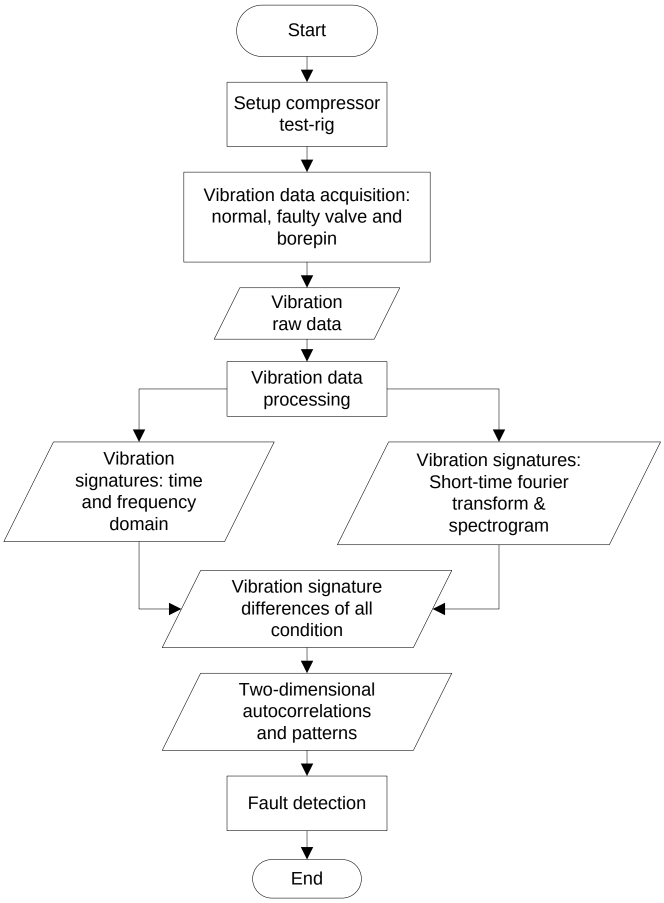


Figure 1. Flowchart of the method

Vibration signatures extraction was conducted from reciprocating compressor with normal condition and fault condition in time and frequency domain. STFT was then performed on vibration signal from experimented conditions and the differences between each condition signatures were analyzed. Finally, two-dimensional autocorrelation analysis was performed to observe the periodicity pattern of each conditions. If the significant difference of each pattern is obtained, so the fault detection will be success.

4. EXPERIMENTAL WORK

Machinery fault simulator (MFS) was used for experimental work of fault detection of reciprocating compressor. The sspecification of tested reciprocating compressor in this experiment is presented in Table 1.

Tabel 1. Compressor specification

Model	MSI 5.2 ML Schulz of America, Inc.
Max. Pressure	120 psig
Power	1 HP

This compressor is driven by an 1 HP electrical motor with a static coupling, as shown in Figure 2. Compressed air then stored in an air tank.

Figure 2. Reciprocating compressor setup on MFS

Data acquisition was conducted by installing two accelerometer sensors on piston cylinder and crankshaft as shown in Figure 3. Vibration signal was acquired by SpectraPad 8 channel i/o and VibraQuest software with frequency limit 3600 Hz and sampling rate 9216 Hz for 2.2 seconds. Total vibration signal data are 20480 samples.

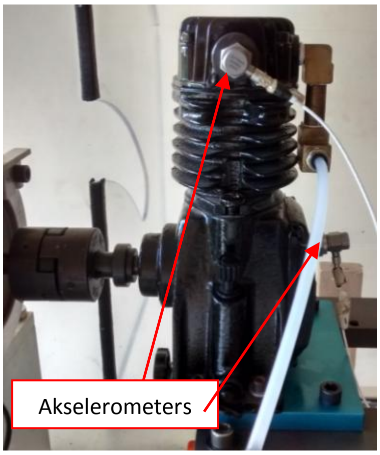
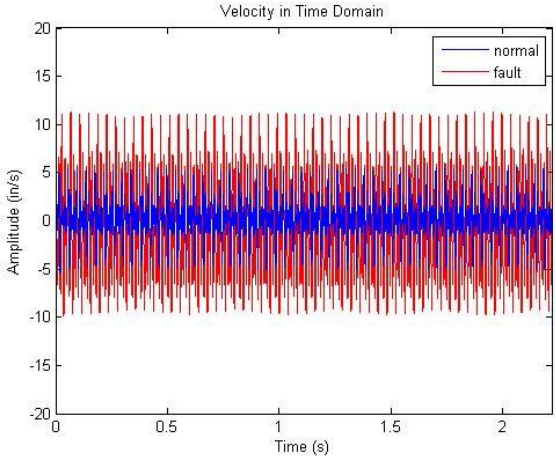


Figure 3. Accelerometer sensor location

5. RESULTS AND DISCUSSION

The acquired vibration signals were processed by MATLAB software for vibration signatures extraction. Time and frequency domains of the signal are depicted in Figures 4. Vibration signal in this figure was acquired at rotational speed of 1500 RPM with 100% load. It can be seen that there are significantly different amplitudes between normal and faulty conditions. Fault that occurs in reciprocating compressor is shown by harmonic frequency 3X with increased amplitude from 0.21 in/sec to 0.73 in/sec.

a.



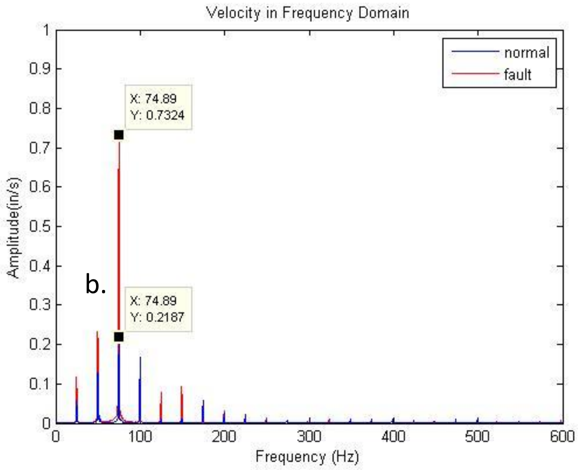


Figure 4. Compressor vibration signal: a. time domain; b. frequency domain

Spectrogram of normal compressor is considered as reference spectrogram is shown in Figure 5. This spectrogram became the main spectrogram for fault detection in reciprocating compressor.

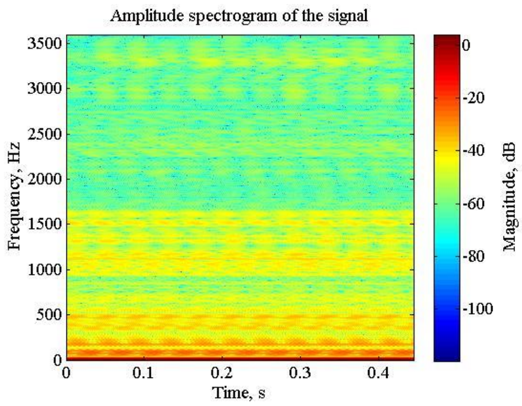


Figure 5. Spectrogram of normal compressor, with 1500 rpm and full load

Figure 6 shows the spectrogram difference calculated from faulty valve condition and reference. There is difference value between test spectrogram with the reference spectrogram, and is called as spectrogram difference matrix [6].

Spectrogram difference that has been obtained is then analyzed using autocorrelation function. Autocorrelation function gives information of the correlation of signal with itself at time and frequency delay.

Two-dimensional autocorrelation of faulty valve is shown in Figure 7. Autocorrelation give higher value than autocorrelation of normal condition. There are several peaks which are relatively uniform along time axis.

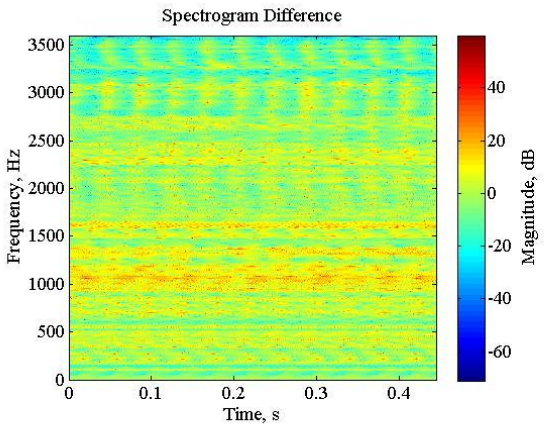


Figure 6. Spectrogram difference matrix with faulty valve as test spectrogram.

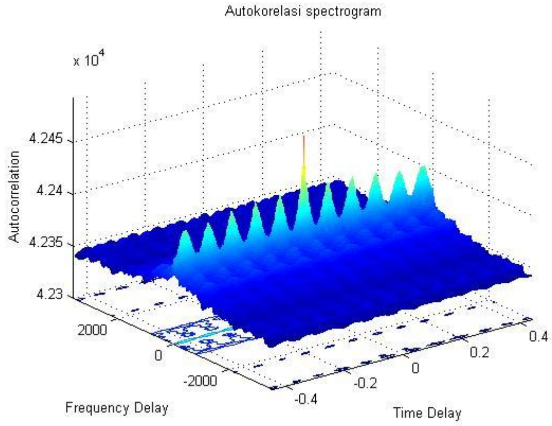


Figure 7. Vibration signal autocorrelation of faulty valve.

6. CONCLUSION

Faulty conditions of reciprocating compressor give higher vibration amplitude than normal condition as shown in time and frequency domain of signal.

At frequency domain, vibration signal of faulty compressor will high at harmonic frequency 3X, which is the characteristic of faulty valve in this compressor.

Two-dimensional autocorrelation of several condition variation gives different character. Load variation give peaks value distribution relatively uniform, while rotational speed variation give peaks value distribution relatively not uniform but still with regular pattern.

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