Mechanical Systems and Signal Processing 56-57 (2015) 197–212

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/ymssp

Fault diagnosis of reciprocating compressor valve with the method integrating acoustic emission signal and simulated valve motion

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ARTICLE INFO

Article history:
Received 11 October 2013
Received in revised form
18 January 2014
Accepted 4 November 2014
Available online 6 December 2014

Keywords:
Fault diagnosis
Valve
Acoustic emission
Valve motion
Reciprocating compressor

ABSTRACT

This paper proposes a method of diagnosing faults in reciprocating compressor valves using the acoustic emission signal coupled with the simulated valve motion. The actual working condition of a valve can be obtained by analyzing the acoustic emission signal in the crank angle domain and the valve movement can be predicted by simulating the valve motion. The exact opening and closing locations of a normal valve, provided by the simulated valve motion, can be used as references for the valve fault diagnosis. The typical valve faults are diagnosed to validate the feasibility and accuracy of the proposed method. The experimental results indicate that this method can easily distinguish the normal valve, valve flutter and valve delayed closing conditions. The characteristic locations of the opening and closing of the suction and discharge valves can be clearly identified in the waveform of the acoustic emission signal and the simulated valve motion.

1. Introduction

Reciprocating compressors are widely used in the gas storage, gas transport and petrochemical industries. The efficiency and reliability of a reciprocating compressor strongly depend on the performance of its suction and discharge valves. Valve faults are cited as the most common cause of unscheduled reciprocating compressor shutdown [1]. Moreover, damaged compressor valves can cause costly secondary damage to the other active parts of the compressor. Therefore, an effective and accurate method for valve fault diagnosis is required to help increase the reliability and reduce the maintenance of reciprocating compressors.

Until now, a large amount of methods based on pressure, vibration and acoustic emission (AE) signals have been proposed to help diagnose the various faults in reciprocating compressors and their valves. Once the valve faults occur, the pressure will change accordingly. Due to its accuracy in reflecting the condition of a valve, several approaches have been implemented by analyzing pressure signal to diagnose faults. Pichler et al. [2] and Wang et al. [3] detected reciprocating compressor valves based on the PV diagram. They classified the valve conditions using support vector machines and used the features extracted from the PV diagram as inputs. Manepatil et al. [4,5] studied the modeling and simulation of reciprocating compressor with various valve faults to determine the influence of the faults on performance parameters, and

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http://dx.doi.org/10.1016/j.ymssp.2014.11.002
0888-3270/

Nomenclature

t	time, s
n	rotational speed, rpm
F_g	gas force, N
F_{spring}	spring force, N
h	enthalpy, J
m	mass of the gas, kg
u	internal energy, J
N	number of valves
A_v	flow area of valve gap, m^2
M_v	equivalent mass of valve plate, kg
M_{plate}	mass of valve plate, kg
M_{spring}	mass of valve spring, kg
k	spring rigidity, N/m
y_0	pre-compression value of spring, m
p	pressure, Pa
A	flow area of the valve seat, m^2
c_f	gas velocity, m/s
C_r	rebound coefficient
W	work, J
H	lift of valve, m
Z	valve springs amount
D	diameter of the cylinder, m
S	stroke, m
Q	heat transfer, J
R_g	gas constant, $J/(kg \cdot k)$
T	temperature, K
v	specific volume, m^3/kg
V_c	working volume, m^3
V_0	clearance volume, m^3
x	piston displacement, m
l	length of the connecting rod, m
r	crank radius, m
V_h	swept volume, m^3
y	valve plate displacement, m

Greek letters

θ	crank angle, rad
λ	ratio of crank radius to length of connecting rod
ω	angular velocity of crank, rad/s
α	gas force coefficient of valve
α_v	flow coefficient in valve gap
β	connecting rod angle, rad
κ	adiabatic exponent

Subscripts

c	inside cylinder
i	into cylinder
o	out of cylinder
s	suction
d	discharge

they focused on fault diagnosis of reciprocating compressor with pressure signal. Elhaj et al. [6,7] developed a new numerical simulation method for monitoring the condition of reciprocating compressor and its valves using the crankshaft instantaneous angular speed (IAS) and cylinder pressure waveform. Li et al. [8] diagnosed valve faults in high pressure air compressor using feedforward neural networks based on pressure and temperature signals. However, the simulated cylinder pressure curve is not the most direct way to show the valve conditions and pressure signal measurement is intrusive and difficult to implement. Fault diagnosis of compressor valves based on the vibration and AE signals is considered to be more efficient because it can be accomplished non-intrusively. Yang et al. [9] used artificial neural networks and support vector machines to classify the conditions of reciprocating compressors based on the features extracted from vibration and noise signals by wavelet-transformed. Cui et al. [10] applied the SVM method to diagnose valve faults based on vibration signals using different information entropy features as inputs. Qin et al. [11] also used the SVM method to diagnose valve faults, although they used the features extracted by basis pursuit and wave matching as inputs. Tran et al. [12] proposed an approach to implement fault diagnosis of the faults in reciprocating compressor valves based on vibration, pressure, and current signals, using the Teager–Kaiser energy operator and deep belief networks. Lin et al. [13] diagnosed valve faults using time–frequency partitions of the vibration signals. Reciprocating compressor includes many components moving in both rotary and reciprocating that producing mechanical noise, this cause the signal to noise ratio (SNR) of the vibration signal is low. Therefore, effective signal processing is needed to provide useful information. Different from the vibration signal, the high-frequency AE signal of a compressor valve can clearly describe the working condition of the valve, and its high SNR makes further signal processing easier. Fault diagnosis technology based on the AE signal has been successfully used to detect faults in rotating and reciprocating machinery, such as diesel engines, turbines and reciprocating compressors. EL-Ghamry et al. [14] presented techniques for diagnosing reciprocating machinery using the AE signal. Pandya et al. [15] applied AE data to diagnose faults in rolling element bearing. Wu et al. [16] implemented fault diagnosis of the internal combustion engines faults based on acoustic and vibration signals. Jiang et al. [17] monitored a diesel engine based on the acoustic source characterization of the exhaust system. Wang et al. [18] diagnosed the faults in reciprocating compressor valves using AE signal.

Although the above mentioned fault diagnosis methods have good performance in diagnosing valve faults, they are limited to specific conditions, specific data types and specific machines, and require a library of reference data for each fault. With the help of the simulated valve motion, the exact opening and closing locations of normal valves over various operating conditions can be obtained as references to diagnose valve faults. The valve motion is also the most direct way of assessing the condition of a valve. For these reasons, in this study, the simulation of a reciprocating compressor valve is