UNIVERSITY OF TECHNOLOGY SYDNEY
Faculty of Engineering and Information Technology

INTELLIGENT FAULT DIAGNOSIS OF RECIPROCATING COMPRESSOR USING DEEP LEARNING METHODS

by

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Requirements for the Degree

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Certificate of Authorship/Originality

I, Ying Zhang certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis. This research is supported by the Australian Government Research Training Program.

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Abstract

Fault diagnosis of reciprocating compressors (RCs) based on vibration signals plays a vital role in guaranteeing a high operating reliability in RCs. Conventional maintenance schemes, which are carried out on a regular basis, can lead to unnecessary maintenance and shutdowns. Online health monitoring can monitor the working conditions of RCs continuously and provide more specific information, thus allowing the RC to be maintained as needed.

This PhD research focuses on the development of effective fault diagnosis methods using deep learning methods, thereby greatly advancing traditional health condition monitoring methods. Most traditional data-driven methods analyze the operating conditions using shallow models, which are incompetent at obtaining more confident results. To overcome this problem, a novel scheme based on deep learning models is proposed and applied to RC fault diagnosis. Traditional fault diagnosis methods select and extract features of raw signal with expertise and fuse them with shallow models. However, these methods cannot analyze the characteristics of signal in depth and thus degrade the performance of health monitoring. Deep learning methods are introduced in this research to calculate more representative features self-adaptive from the RC signals to improve fault diagnosis performance. As most fault diagnosis methods are based on vibration signals being the single information source, they cannot reflect the RC operating condition comprehensively. In this research, multi-source signals are collected and analysed for fault diagnosis. A scheme fusing multi-source information is proposed, as well as an auto-denoising network for denoising RC signals self-adaptively.

This PhD thesis consists of seven chapters. Chapter 1 provides research background. Chapter 2 presents a literature review. Chapter 3 proposes a method using intrinsic vibration feature fusion and a Grassmann manifold-based similarity. Chap-

ter 4 introduces the method of RC fault diagnosis using mode isolation-convolutional deep belief networks. Chapter 5 presents the intelligent fault diagnosis method using an optimized convolutional deep belief network. Chapter 6 proposes a novel ensemble empirical mode decomposition-convolutional deep belief network for RC fault diagnosis, and chapter 7 presents the conclusion and discusses future research in this area.

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List of Publications

Journal Papers

J-1. **Zhang, Y.**, Ji, J.C., 2020. Intelligent fault diagnosis of a reciprocating compressor using mode isolation-convolutional deep belief networks. *IEEE/ASME Transaction on Mechatronics*. [Published, DOI: 10.1109/TMECH.2020.3027912]

J-2. **Zhang Y.**, Ji, J.C. and Ma, B., 2020. Reciprocating compressor fault diagnosis using an optimized convolutional deep belief network. *Journal of Vibration and Control*, p.1077546319900115.

J-3. **Zhang, Y.**, Ji, J.C. and Ma, B., 2020. Fault diagnosis of reciprocating compressor using a novel ensemble empirical mode decomposition-convolutional deep belief network. *Measurement*, vol. 156, p.107619.

J-4. Ma, B., Zhao, Y., **Zhang, Y.**, Jiang, Q.L. and Hou, X.Q., 2019. Machinery Early Fault Detection Based on Dirichlet Process Mixture Model. *IEEE Access*, 7, pp.89226-89233.

J-5. **Zhang, Y.**, Ji, J.C., Use of intrinsic vibration feature fusion and a Grassmann manifold-based similarity for intelligent fault diagnosis of a reciprocating compressor, IEEE Transactions on Industrial Informatics. [Under review]

J-6. **Zhang, Y.**, Ji, J.C., Wei, D.B., Wear and fatigue analysis of support ring of reciprocating compressor using a deep belief network-conditional random field method. [Submitted]

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The chapters of this thesis contain materials from 4 papers published or submitted for publication in the journals.

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Contributor	Statement of Contribution	Thesis Chapter
Ying Zhang	Literature review, Conceptualization, Methodology, Validation, Investigation, Manuscript Writing- Original Draft. Overall contribution: 80%	Chapter 4
Jinchen Ji	]Conceptualization, Manuscript Writing- Review & Editing, Supervision. Overall contribution: 20%	

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Bo Ma	Experimental Data Collection Overall contribution: 5%	

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Abbreviation

RC - Reciprocating Compressor

EMD - Empirical Mode Decomposition

IMF - Intrinsic mode function

PCA - Principal Component Analysis

KPCA - Kernel Principal Component Analysis

DBN - Deep Belief Network

GM - Grassmann manifolds

RBM - Restricted Boltzmann Machines

SVD - Singular Value Decomposition

SVM - Support Vector Machine

TD - Time-domain

FD - Frequency-domain

CNN - Convolutional Neural Network

CDBN - Convolutional Deep Belief Betwork

LDA - Latent Dirichlet allocation

AE - Auto Encode

CS - Compressed Sensing

SF - Sparse Filtering

CRBM - Convolutional Restricted Boltzmann Machine

ANN - Artificial Neural Network

EEMD - Ensemble Empirical Mode Decomposition

CC - Correlation Coefficient

WT - Wavelet Transforms

PCM - Probabilistic Committee Machine

GPC - Gaussian Process Classifier

EM - Expectation Maximization

MI - Mode isolation

GMM - Gaussian mixture model

p-V - Pressure-volume