AUTOTUNED FUZZY-PROPORTIONAL-INTEGRAL-DERIVATIVE CONTROLLER FOR CASCADE LOAD-SHARING COMPRESSOR

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DEDICATION

Specially dedicated to my beloved wife, Sharmini Marilyn and beautiful children, Marissa Anne Nicholas and Mirabelle Tresa Nicholas for being my joy and strength throughout this journey. The journey would not have started without amma and daddy for their love and care.

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ABSTRACT

This thesis focuses on a control scheme of a load sharing parallel compressors commonly utilised in process industries. Typical control systems for parallel compressors in the industry, consist of a pre-set anti-surge control and loading-sharing control scheme. In this parallel compressor system, the characteristics of individual compressors are never the same, i.e. a stronger compressor will tend to take in more flow, causing the other compressor to lose its compressibility and causes it to fall into a surge region. The challenge occurs due to the proven nature of the whole system which exhibits control interactions between the components. Therefore, in this thesis, an optimised double feedback control i.e. a self-tuner fuzzy cascade PID controller and automatic self-tuning fuzzy PID anti-surge controller, is proposed. The implementation of PID controllers is due to its simplicity and robustness, and its wide applicability in the existing process industry. On the other hand, adapting fuzzy tuners on PID controllers is proven can improve the performance of the conventional PID, and since fuzzy logic control box can be embedded to an existing distributed control system (DCS) in the process industry, the implementation is imminent. For the proposed controller, the cascade PID controller can preserve the linear structure of the PID. Meanwhile, the fuzzy logic controller able to continuously tune each of the PID parameter to adapt to rapid changes of the load sharing and surge control of the parallel compressors. The performance of the proposed controller design is evaluated with respect to the conventional cascade PID controller. The performance evaluation is performed in terms of the system's transient response i.e. rise time, overshoot and settling time as well as the system's stability using Simulink. The simulation results showing that the proposed fuzzy logic cascade PID controller can respectively achieve 72%, 88.2% and 92.9% improvement in reducing rise time, settling time and percentage overshoot as compared to the conventional cascade PID. From the results obtained, it can be concluded that the proposed controller design has a better adaptation and performance on the parallel load sharing compressors compared to the conventional cascade PID control.

ABSTRAK

Tesis ini memfokuskan pada skema kawalan pemampat selari pembahagian beban yang biasa digunakan dalam industri proses. Sistem kawalan khas untuk pemampat selari dalam industri, terdiri daripada skema kawalan anti-lonjakan dan pembahagian pemuatan yang telah ditetapkan. Dalam sistem pemampat selari ini, ciri-ciri pemampat individu tidak pernah sama, iaitu pemampat yang lebih kuat cenderung mengambil lebih banyak aliran, menyebabkan pemampat yang lain kehilangan kebolehmampatannya dan menyebabkannya jatuh ke kawasan lonjakan. Cabaran itu berlaku kerana sifat keseluruhan sistem yang terbukti menunjukkan interaksi kawalan antara komponen. Oleh itu, dalam tesis ini, dicadangkan kawalan suap balik berganda yang dioptimumkan, iaitu pengawal *self-tuner fuzzy cascade* PID dan pengawal anti lonjakan *self-tuning fuzzy* PID automatik. Pelaksanaan pengendali PID disebabkan kesederhanaan dan ketahanannya, dan penerapannya yang luas dalam industri proses yang ada. Sebaliknya, menyesuaikan *fuzzy tuner* pada pengawal PID terbukti dapat meningkatkan prestasi PID konvensional, dan kerana kotak kawalan *fuzzy logic* dapat disisipkan ke *Distributed Control System* (DCS) yang ada dalam industri proses, maka pelaksanaannya akan segera dapat dilakukan. Untuk pengawal yang dicadangkan, pengawal PID lata boleh mengekalkan struktur linear PID. Sementara itu, pengawal *fuzzy logic* dapat menala secara berterusan setiap parameter PID untuk menyesuaikan diri dengan perubahan pantas pembahagian beban dan kawalan lonjakan pemampat selari. Prestasi reka bentuk pengawal yang dicadangkan dinilai dengan merujuk pengawal PID lata konvensional. Penilaian prestasi dilakukan dari segi tindak balas sementara sistem iaitu *rise time*, *overshoot* dan *settling time* serta kestabilan sistem menggunakan Simulink. Hasil simulasi menunjukkan bahawa pengawal *cascade fuzzy logic* PID yang dicadangkan dapat mencapai peningkatan 72%, 88.2% dan 92.9% masing-masing dalam mengurangkan masa kenaikan, masa pengenapan dan peratusan terlajak berbanding dengan PID lata konvensional. Dari hasil yang diperoleh, dapat disimpulkan bahawa reka bentuk pengawal yang dicadangkan mempunyai penyesuaian dan prestasi yang lebih baik pada pemampat pembahagi beban selari dibandingkan dengan kawalan PID lata konvensional.

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LIST OF ABBREVIATIONS

PID	-	Proportional-Integral-Derivative
DCS	-	Distributed Control System
LNG	-	Liquefied Natural Gas
LPG	-	Liquefied Petroleum Gas
SLL	-	Surge Limit Line
SCL	-	Surge Control Line
SISO	-	Single Input Single Output
MIMO	-	Multi Input Multi Output
FLC	-	Fuzzy Logic Controller
IPS	-	Instrument Protective System

LIST OF SYMBOLS

$\boldsymbol{\tau}$	-	Minimal error
Q_s	-	Flow
β	-	Beta Ratio
ρ	-	Compression Ratio
h_s	-	Differential pressure
U_{gc}	-	Universal gas constant
e	-	Error
Δu	-	Change of control signal
Δe	-	Change of error
ρ	-	Density
ΔP	-	Differential pressure across orifice
C	-	Orifice coefficient
€	-	Valve coefficient
R	-	Ideal gas constant of proportionality
n	-	Number of moles
mw	-	Molecular weight
t	-	Time or instantaneous time
V	-	Volume
v	-	Velocity

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CHAPTER 1

INTRODUCTION

1.1 Background of Research

In process engineering industry, the processes involved are designed to improve certain standards in fulfilling current customers' requirement. In the oil and gas industry, load sharing and anti-surge control schemes in compressors are common scenarios. In this research, the integration control of load sharing and anti-surge control in refrigeration compressors are explored and analysed. The control scheme proposed is based on cascade control and feedback control using conventional PID. The control scheme is then further improved using fuzzy logic for automation and self-tuning.

Having a parallel operating compressor for process refrigeration has a significant advantage of the ability to cover a larger spectrum of cooling load requirements. The challenge is as the compressor operates over a period of time, the wear and tear of the compressor deteriorates, leading to a condition where one of the compressors being 'stronger' than the other, thus having the potential in taking more flow than the 'weaker' one. The application of a load sharing philosophy will be able to address this situation. Various methods can be applied such as sequence for starting/ stopping of compressor, flow balancing or compressor surge margin control.

Typically, in the industry, when one of the compressors is at the surge control line, a pre-set load sharing controller design will be executed. At this point, both the compressors will not be able to manage the throughput and will lead to possibility of both the compressors going into cyclic condition due to surge. Hence causing a change in the suction pressure which causes the other compressor to react.

Therefore, in this research, the integration of the existing control scheme with the proposed control design will be conducted, hence obtaining a balance on load sharing hence ensuring that both compressors are well protected.

1.2 Problem Statement

Existing control systems for a parallel compressor typically consist of a pre-set anti-surge control and loading-sharing control scheme. In parallel compressors system, a stronger compressor will tend to take in more flow, causing the other compressor to lose its compressibility and causes it to fall into a surge region. Various approaches for the optimisation of parallel compressors and network of compressors have been previously explored and researched. The interest in this has been challenging due to the proven nature of the control targets in a parallel compressor system which exhibits control interactions between the different control loops.

Constraints arises from operational requirements of the compressor, such as limits on the rotating speeds and safety criteria of the compressor. The state of instability in the compressors only allow a small stable operating range which is limited at low and high mass flow rates by surge, rotating stall or a combination of both. Rotating stall and surge have been a problem since the creation and usage of these rotating equipment in the process industry [1]. Active surge control is an active research field to improve the performance and efficiency of the compressors [2]. Surge phenomena are described together with the dynamics operations of the compressors using active surge control schemes only by single operation compressors [3].

PID controllers are a widely utilised algorithm in the process control industry. However, performance loss was exhibited when applied to a system with non-linear characteristics. This can be overcome by applying a properly tuned PID-controller. For systems which require fast changes and responses, PID controllers have difficulties to maintain the required controllability range. Changes in process conditions and equipment condition may require frequent tuning of the controllers. In this research, current techniques utilising fuzzy controller and its extension on conventional PID controller is proposed. The proposed controller can preserve the linear structure of the PID and capable in improving the overall performance of the compressor system. The proposed PID features proposed is self-tuning to adapt to rapid changes of the load sharing and surge control.

1.3 Objectives of Research

The main objectives of this research are:

1. To develop a PID control scheme for a parallel load sharing refrigerant compressor.
2. To develop and optimised PID control approach using automated fuzzy self-tuning control.
3. To analyse the performance of the proposed control scheme by comparing to the conventional PID control scheme.

1.4 Scopes of Research

To achieve the objectives of this research, there are several scopes that need to be determined. Firstly, the research is conducted to develop the transfer function of the temperature-pressure load sharing cascade control and compressor anti-surge based on reference from research paper and available industrial compressor and heat exchanger datasheet. The mathematical model is derived from the reference paper using the available process data from the compressor datasheet and heat exchanger datasheet. The controller block is built for temperature-pressure cascade control scheme using conventional PID and compressor anti-surge PID control scheme using Simulink. In addition, the conventional PID controller is optimised using fuzzy control to automatically tune the controller under fluctuating process condition leading to non-linear conditions using Simulink. The limitation of the research assumed that the simulated compressor is fixed speed single stage centrifugal compressor, pressure drop across the compressor, heat exchangers and other related components were negligible. The compressor refrigeration inflow and outflow rate are same therefore the refrigerant level is maintained constant in the heat exchanger. The boundary on the simulated control scheme was limited to 2 compressors operating in parallel for a refrigeration process.

1.5 Thesis Outline

This thesis is divided into several chapters which are introduction, literature review, research methodology, result and discussion as well as conclusion and recommendation. The first chapter, Introduction, elaborates the essential background and summary of related work in heat exchangers, compressor anti surge control and load sharing control. The chapter includes the research objectives which are the aim of this research, as well as scopes of the research conducted. Chapter 2 describes the literature review of load sharing and anti-surge compressor control, process industry heat exchangers, PID controller and fuzzy logic control. The review includes identification of research gaps that are further exploited in this research. In addition, there is also a review of fuzzy logic tuned PID controller. Chapter 3 focuses more on the research methodology of this research, the sequence of the research, mathematical modelling of the compressor system, heat exchanger and transfer function of the proposed control scheme. This chapter explains the flow of the research in detail. In chapter 4, results and discussion of the proposed work is represented. The results obtained are represented in step change response and implementation on Simulink simulation. Finally, in chapter 5, the conclusion of this research and the recommendation and future works is discussed.

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