THE DEVELOPMENT OF HIGH PERFORMANCE BAND-STOP FILTER FOR ANTI-SWAY CONTROL OF A GANTRY CRANE SYSTEM

NUR IZANA BINTI HAFIZAN

This thesis is submitted as partial fulfillment of the requirements for the award of the
Bachelor of Electrical Engineering (Electronics)

Faculty of Electrical & Electronics Engineering
Universiti Malaysia Pahang

NOVEMBER, 2009

I declare that thesis entitled The Development of High Performance Band-Stop Filter for Anti-Sway Control of a Gantry Crane System is the result of my own research except as cited in the reference. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ____________________________

Name : NUR IZANA BINTI HAFIZAN

Date : 23 NOVEMBER 2009

ACKNOWLEDGEMENTS

The road to accomplishment of this project has been immensely challenging and need strenuous effort. The lessons learned and experiences gained during the entire process to complete the project I can say is invaluable and memorable.

So for the first and foremost, I would like to express my deepest, sincerest gratitude to my supervisor for this project Encik Mohd Ashraf bin Ahmad for his guidance and advice. Without it, I would never been able to accomplish the objectives of my project. His demands for quality and perfection became a challenge to me to achieve beyond my expectation in this project before.

Secondly, I would like to dedicate my thanks to Encik Ahmad Nor Kasruddin bin Nasir for his time and patience to discuss with me anytime anywhere providing many useful advise and ideas during this project execution are very much appreciated. In addition, special thanks to laboratory staff for their kindness and help in completing this project.

Lastly, I would like to extend my thanks to my family and all fellow colleagues for their continuously support and encouragement throughout this project also those who have contributed directly or indirectly toward the success of this project study.

ABSTRACT

Gantry crane is a load-lifting system consists of three main components which are trolley, bridge and gantry. Gantry can be described as a supporting structure that is rigidly affixed to hold the trolley's movement on and parallel to a bridge. However, due to the heavy and bulky size also swaying of the payload during the movement, gantry crane are difficult to control in such a way that the load reaching the desired destination in minimum time. So, the main purpose of controlling a gantry crane is transporting the load as fast as possible without causing any excessive sway at the final destination by using a two-dimensional gantry crane model and feed forward approach. The applications and performance of Band - stop filter is the technique used in this project to actively control the sway angle of the rope of gantry crane system. The dynamic behaviors are analyzed using CEMTool, SIMTool and MATLAB. An unshaped bang – bang torque input is used to determine the characteristic parameters of the system for the design and evaluation of the Band – stop filter techniques. Project results of the response of gantry crane to the input are presented in time and frequency domains. The effects of the order of the filtered Band – stop filter on the performance of the system are investigated. Finally, a comparative assessment of the amplitude polarities of the system performance is presented and discussed.

ABSTRAK

“Gantry crane” merupakan sistem memindahkan beban yang terdiri daripada tiga komponen utama iaitu troli, penghubung dan gantri. Gantri boleh digambarkan sebagai satu struktur penyokong yang melekat kukuh untuk menampung pergerakan troli dan selari dengan penghubung. Walau bagaimana pun, berdasarkan kepada berat dan saiz yang sangat besar serta hayunan beban semasa pergerakan, “gantry crane” susah untuk dikawal dari segi beban sampai ke destinasi dalam masa yang minimum. Jadi, tujuan utama “gantry crane” dikawal ialah memindahkan beban secepat mungkin tanpa menyebabkan sebarang hayunan melampau di destinasi akhir dengan menggunakan model dua-dimensi “gantry crane” dan pendekatan “feed-forward”. Kebolehan dan keupayaan “Band-stop filter” adalah teknik yang digunakan dalam projek ini untuk mengawal sudut hayunan tali system “gantry crane” secara aktif. Sifat dinamik dianalisis menggunakan CEMTool, SIMTool dan MATLAB. Input “bang-bang torque” digunakan bagi menentukan ciri parameter sistem untuk mereka bentuk dan menilai teknik “Band-stop filter”. Keputusan projek bagi respon “gantry crane” terhadap input ditunjukkan dalam domain masa dan frekuensi. Kesan daripada susunan “Band-stop filter” bagi keupayaan sistem ini diselidiki. Penilaian secara perbandingan polariti amplitud dari keupayaan sistem ditunjuk dan dibincangkan.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

LIST OF EQUATIONS

LIST OF SYMBOLS

CHAPTER 1

INTRODUCTION

1.1 Introduction of Research

A crane has been used for a long time to move a load from one location to another. In general, crane is a machine used for lifting and lowering a load vertically and moving it horizontally with it hoisting mechanism. Crane has varieties of types like automatic crane, gantry crane, cantilever gantry crane and overhead crane. For this project, the work will be focused on development of high performance Band-stop filter to control sway of a gantry crane system because as the loads moves, the crane must be controlled to ensure the load reaches the location needed with less or without sway. The sway occurs at a certain level require the operation stop until the sway disappears.

The control objective is to control and reduce residual sway angle of pendulum by using feed forward approach. An unshaped bang – bang torque input is used to determine the characteristic parameters of the system for the design and evaluation of the band – stop filter techniques. Experiment results of the response of gantry crane to the input are presented in time and frequency domains. The effects of the order of the filtered Band – stop filter on the performance of the system are investigated. At the end of this project, a comparative assessment of different orders of Band-stop filter of the system performance is presented and discussed.

1.1.1 Gantry Crane System

The two dimensional gantry crane system with its payload considered in this project is shown in Figure 1.1. x is the horizontal position of the cart, l is the length of the rope, θ is the sway angle of the rope, M and m is the mass of the cart and payload respectively. In this project, the cart and payload can be considered as point masses and are assumed to move in two dimensional, x-y planes. The tension force that may cause the hoisting rope extend is also ignored. For this project, the length of the cart, l = 1.00 m, M = 2.49 kg, m = 1.00 kg and g = 9.81 m/s² is considered.

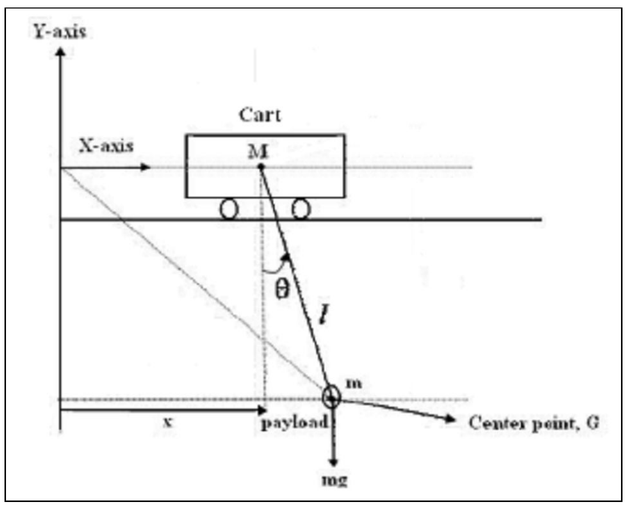

Figure 1.1: Description of the Gantry Crane System

Gantry crane shown in Figure 1.2 is similar to an overhead crane except for the bridge that carrying the trolley or trolleys is rigidly supported on two or more legs running on fixed rails or other runway. To implement the operation, the crane operator will seat inside the cart and move the cart with the load hanged with it, so, the load can achieve the desired location. A real crane may allow a cart movement of 80 to 90 meters regarding on the desired load location.

Figure 1.2: Gantry Crane

1.2 Problem Statement

A crane has been used to move a load from one location to another location. For this lifting performance, accurate and efficient equipments are required. In other word, when the load moves, the crane must be controlled so that the load reaches the location needed with less or without swinging. In operating crane, the swing that occurs similarly to pendulum motion which is at certain level, the operation must be stopped until the swing disappears.

The load swing not only may cause an accident but also resulting in direct loss, the cost which is realized by lost performance. Besides, it will cause a damage to material that been handled. Until now, most of the cranes are being controlled manually by crane's operators. It is better if the operation of the crane can be done automatically which can reduce the possibilities that occurs like the human's mistake or careless. Regarding on the problem, this project will focus on the implementing of high performance band-stop filter in order to find the best solution for anti-sway control of a gantry crane system. The designed control model then test on Swing-up Inverted Pendulum System hardware and if success, this designed control may applied to the real gantry crane system.

1.3 Objectives

The objectives of this project are to:

i. Develop a Band-stop filter algorithm for anti-sway control of a gantry crane system.
ii. Investigate the performance of a gantry crane system with different orders of Band-stop filter technique.

1.4 Scope of the Project

The scopes of this project are:

i. Study the dynamic modeling of anti-sway control of a gantry crane system.
ii. Design the input filter which is an algorithm by using second, third and fourth order of Butterworth Band-stop filter.
iii. Simulate the design using MATLAB7 which is the effectiveness way of the approach.
iv. Develop the algorithm in a real plan with an experiment studies using CEMTool software.
v. Analysis the designed control model by using the Swing-up Inverted Pendulum System hardware.

1.5 Expected Results

This project is expected to:

i. Implement the performance of a gantry crane system with different orders of Band-stop filter technique.
ii. Do the investigation of sway effects of a gantry crane system.
iii. Compare the performance of second, third and fourth order of Band-stop filter.

1.6 Dissertation Organisation

This thesis consists of five chapters and it is organized as follow:

Chapter I is the introduction of the thesis and includes the background of the project, objectives, scope of the project, expected results followed by methodology.

Chapter II presents the literature review on various technical and online papers besides the articles about the modeling and the anti-sway control methods of the gantry crane.

Chapter III informs about methodology of this project. In this chapter, simulation of a gantry crane model is simulates by using MATLAB simulink. Then, the unshaped bang – bang torque input design. When there is input, the control model design used Butterworth Band-stop filter in SIMTool is verified.

Data in time response and frequency response of controller design are collected and analyzed.

Chapter IV explains the results and analysis of anti-sway control. Band-stop filter designs with different orders are explained. Project result are analyzed and presented graphically.

Chapter V is conclusion. Overall conclusion of this project stated in this chapter together with some future recommendations.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Gantry crane is a load-lifting system consists of three main components which are trolley, bridge and gantry. Gantry can be described as a supporting structure that is rigidly affixed to hold the trolley's movement on and parallel to a bridge. The gantry extends downwards from the bridge to the ground where it can be mobilized on wheels or set of tracks. The motion of the gantry on the ground, the trolley on the bridge and the hoisting of the payload provide the three degrees of freedom of the payload.

Most of the anti-sway control of the gantry crane is performed manually by skillful human operators who combine their intuition, experience and skill to manipulate a load hanging on a hoisting cable by stopping the trolley near the desired position. Then, they are letting the payload to stop oscillating gradually by a further gentle movement of the trolley. The response of these systems to external disturbances is also oscillatory in nature. The swaying phenomenon introduce not only reduce the efficiency of the crane but also cause safety problem in the complicated working environment. For this reason, the payload sway angle should be kept to minimum; otherwise, large payload sway angle during transportation may cause damage to the payload itself, surrounding equipment or even personnel [1].

2.2 Input Shaping

Methods for controlling the cranes can be roughly divided into feedback and feedforward approaches. Feedback methods are often the most desirable means of eliminating vibration [2]. Input shaping has proven to be an especially practical and effective method of reducing vibrations in flexible systems. This statement supported by several previous researches. It is known that giving the system an impulse will cause it to vibrate; Garrido et al. [2] applied a second impulse to the system in the right moment so the vibration by the first impulse is cancelled. Singhose et al. [3] suggested only knowledge of the system natural frequency and damping ratio is required. The shaping method involves convolution of desired input with a sequence of impulses to produce an input function that reduces vibration.

Input shaping is a feedforward technique for reducing residual vibrations in computer controlled machines which does not depend on actuator limits or motion parameters [4]. According to Singhose and Pao [4], instead of using the bang-bang input as the reference signal, the wave form resulting from the convolution is used as the command signal. The shaped input that result from the convolution has a rise time which is longer than the unshaped input by an amount equal to the duration of the input shaper [4]. Singhose and Pao [4], had compared the control methods used between a shaped bang-bang with the response of using the time-optimal flexible-body commands. As a result, they found that input shaping provides vastly increased robustness to modeling errors while being much easier to implement and input shaping generates significantly less transient deflection than does time-optimal control [4]. Input shaping also provides an attractive alternative to time-optimal flexible-body control [4]. Besides, the input shaping is a form of Finite Impulse Response (FIR) filtering that places zeros near the locations of the flexible poles of the original system where the impulse amplitudes are equivalent to the filter coefficients [5].

Singer et al. [5] introduced a new mode of operation called Step Mode (Patent Pending) by using input shaping to make sway less moves. Step Mode issues a fixed length shaped command to the motors so that the crane's load is indexed to a new location without sway. To address both sources of oscillation, a combined feedback and input shaping controller is developed which consists of three distinct modules. First module is a feedback module detects and compensates for positioning error, a second feedback module detects and rejects disturbances while input shaping is used in a third module to mitigate motion-induced oscillation [6]. Moreover, input shaping provides significant reduction in both residual and transient oscillation even when the hoisting distance is a large percentage of the cable length [7].

2.3 Fuzzy Logic Controller

Open loop controllers are sensitive to external disturbances and to parameters variations besides it required control action is bang-bang which is discontinuous. Omar and Nayfeh [8], designed the anti-swing controller based on two techniques, that are a time-delayed feedback from the load swing angle and an anti-swing fuzzy logic controller (FLC). The process from fuzzify the control input and determine the control output according to fuzzy rules, gives a control action in a fuzzy form which is then converted to a crisp value suitable for operating the actuator by a process called defuzzification [8]. Then according to Omar and Nayfeh [8], they concluded that the residual swing angles were smaller when using the fuzzy controller while the settling time was nearly the same when using the delay controller.

A new fuzzy controller for anti-swing and position control of an overhead traveling crane is proposed by Jianqiang et al. [9] based on the Single Input Rule Modules (SIRMs) dynamically connected fuzzy inference model where the trolley position and velocity, the rope swing angle and angular velocity are selected as the input items while the trolley acceleration as the output item. So, Jianqiang et al. [9] stated that control simulation results show that by using the fuzzy controller, the crane is smoothly driven to the destination in short time with small swing angle and almost no overshoot. Different approach, Cho and Lee [10], recommended a new fuzzy anti-swing control scheme for a three-dimensional overhead crane that used to suppress load swing.

2.4 Time Delayed Feedback

The aim of the crane control is to move the load from point to point and at the same time minimize the load swing. These aims have motivated many researchers to develop control algorithms to automate crane operations. Since the load swing is affected by the acceleration of the motion, the researchers have concentrated on generating courses which deliver the load in the shortest possible time besides minimize the swing. So, Omar and Nayfeh [8], had improved the performance of the designed time-delayed feedback controller with introducing an anti-swing Fuzzy Logic Controller (FLC) where the rules of the FLC are generated by mapping the performance of the anti-swing time-delayed feedback controller. The output from the anti-swing controller represents a correction to the position trajectory [8].

2.5 Other Types of Controller

Other than three types of controller discussed, the researchers came out with varieties different idea of anti-sway. One of them is Active Force Control (AFC) is designed and implemented using a two degree-of-freedom (DOF) controller – the outer classic Proportional-Integral-Derivative (PID) control loop provides the commanded signal while the internal AFC loop accommodates the known and unknown disturbances presence in the gantry system [1]. PMAC (Programmable Multi-Axis Controller) which belongs to a family of high-performance servo motion controllers capable of commanding up to eight axes of motion simultaneously with high level of sophistication and the controller board comes with a complete as well as advanced tunable PID algorithm [2].