MODELING AND VIBRATION CONTROL OF A GANTRY CRANE

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A project report submitted in partial fulfillment

of the requirement for the award of the degree of

Master of Engineering

(Electrical - Mechatronics & Automatic Control)

Faculty of Electrical Engineering

Universiti Teknologi Malaysia

MARCH, 2005

To my beloved family,

mum, dad, Faizal and Ani,

thank you for your support and encouragement

that you have given in my life. Also to my fiancée, Saleha,

thank you for understanding me

and the supports that been given

to me in completing this work.

ACKNOWLEDGEMENT

First and foremost, I would like to take this opportunity to thank my project supervisor, Dr. Zaharuddin Mohamed for his invaluable guidance, assistance and support throughout the project. Under his supervision, many aspects regarding on this project has been explored, and with the knowledge, idea and support received from him, this thesis can be presented in the time given.

I also would like to thank Mr. Yusmady Ariffin and Mr. Termiti Sidon, because of their willingness to be as guarantor to secure my scholarship. For all lecturers involved in teaching my course, thanks for the lesson that been delivered. Not forget to all my friends, course mate, and anyone that has provided, whether an idea or support, directly or indirectly, that played a role towards in completing this work. Unfortunately, it is not possible to list all of them in this limited space. Also special thanks to UTM for giving me an opportunity to pursue my course of study. Also for FKE, that has given not only knowledge, but also experiences during my study here.

ABSTRACT

The aim of this project is to model industrial gantry cranes for investigations of dynamic behavior of the system. A gantry crane incorporating a payload is considered. The modeling technique which is easier in terms of mathematical derivation is chosen. Comparison between the mathematical model derived and previous work is conducted to validate the dynamic model. A simulated time response and vibration frequency of the system to an input command is presented. Furthermore, a vibration control scheme based on an open-loop filtering technique is developed. Finally, the effectiveness of the controller is investigated in terms of time response, level of vibration reduction, robustness and the capability of handling a payload.

ABSTRAK

Objektif projek ini adalah untuk melaksanakan permodelan terhadap kren yang disokong oleh rangka besi dengan tujuan untuk mengkaji sifat-sifat dinamik sistem tersebut. Pertimbangan terhadap kren yang melibatkan beban akan dilaksanakan. Kaedah permodelan dipilih daripada beberapa kaedah yang telah dikenalpasti, dimana persamaan matematik bagi sistem tersebut dapat ditunjukkan dalam bentuk yang paling ringkas. Perbandingan di antara model matematik dan kerja-kerja yang telah dilaksanakan pada masa lampau dilakukan. Simulasi berkaitan dengan tindakbalas masa dan frekuensi getaran sistem terhadap masukan akan dikaji. Selain daripada itu, kawalan getaran berdasarkan pada gelung bukaan teknik penapisan akan dibangunkan. Pengawal yang telah dibangunkan akan dikaji keefektifannya dari sudut tindakbalas masa, kadar pengurangan getaran, ketegapannya dan kebolehan untuk membawa beban.

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LIST OF SYMBOLS

A_p	-	maximum pass-band loss
A_s	-	minimum pass-band loss
A_1	-	magnitude response's minimum value when in pass band (dB)
BSF	-	band-stop filter
dB	-	decibels
g	-	gravitational acceleration
H_∞	-	H-infinity
kg	-	kilogram
LPF	-	low-pass filter
l	-	length of bar
m	-	mass
m_c	-	mass of the cart
m_L	-	mass of the load
N	-	Newton
n	-	filter order
PD	-	proportional-derivative

r	-	passband ripple
rad	-	radians
s, sec	-	second
T	-	kinetic energy
$T_{\max}$	-	kinetic energy (maximum)
$T_n(\omega)$	-	Chebyshev polynomial of order n
U	-	potential energy
$U_{\max}$	-	potential energy (maximum)
u	-	applied force at cart
$\dot{x}$	-	cart velocity
$\ddot{x}$	-	acceleration
x_1	-	displacement of cart
θ	-	angle that exists between the bar and vertical axis
$\dot{\theta}$	-	bar's angle rate
ω_c	-	cut-off frequency
ω_n	-	natural frequency
ω_p	-	pass-band cut-off frequency
ω_s	-	stop-band cut-off frequency
ω_1	-	frequency at which the magnitude response first falls below minimum value of magnitude response when in pass band
&	-	and
%	-	percent

CHAPTER 1

INTRODUCTION

1.1 CRANE : OVERVIEW

In our environment, there is a necessity to transfer the things like equipment, things etc. from one place to another, whether there are far or not. In the workplace, for example, at construction or industrial sites, ports, railway yards and other similar locations, special equipment is needed to transport the materials. These materials are usually heavy, large and hazardous, which cannot be handling by workers. In order to make the work easier, cranes have been used to lift, move, position or place machinery, equipment and other large objects. There are many types of crane that been used for these purposes, such as tower crane, overhead crane, boom crane, gantry crane and others. Figures 1.1 and 1.2 shows examples of overhead crane and gantry crane, respectively.

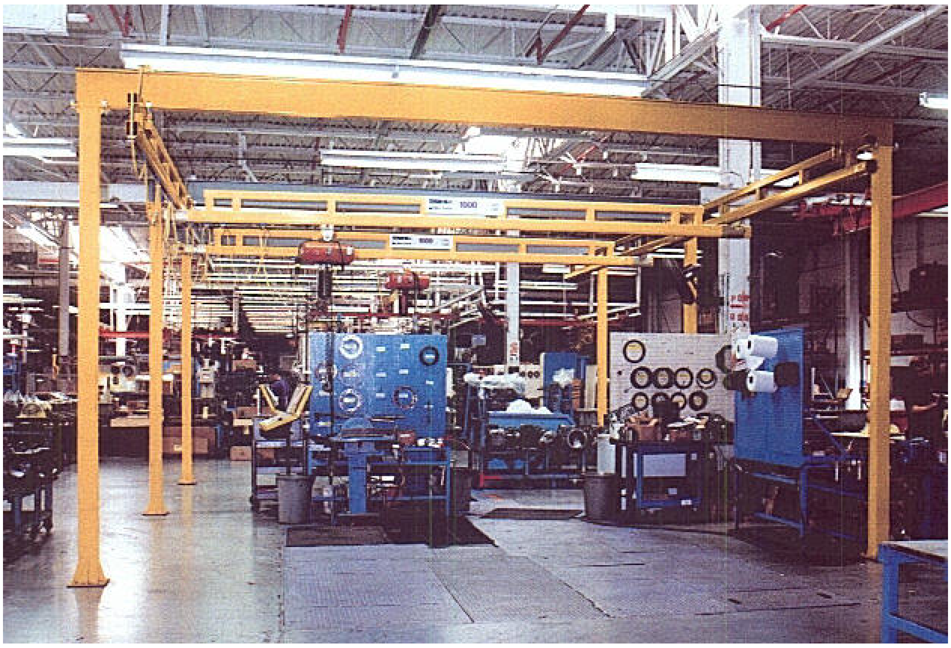

Figure 1.1 Overhead crane

Figure 1.2 Gantry Crane

A crane consists of a hoisting mechanism (usually a hoisting line together with a hook) and a support mechanism. A cable with the load hanged on the hook is suspended from a point on the support mechanism. The support mechanism will moves the hanged load around the crane workspace, while the hoisting mechanism will lifts and lowers the load to prevent the obstacles in the path and locate the load at the desired location.

In handling the crane, safety is the most important point to consider while operating the crane. Hence, the crane must be operated in safe operating manner and procedures. For a crane operator, an experience causing by a crane's accidents can be frightening them. There are many cases and incident regarding on the crane's accidents. For example, in April 1993, the crane becomes unbalanced during two separate incidents at DOE sites in United States of America, which is in Hanford Site and Bryan Mound Site. The first incident occurred in 28th April 1993, where a crane becomes unbalanced while the boom was being lowered. The second incident occurred 2 days later, on 30th April 1993, which while loading the load, the weight of the load caused the crane to tip forward [1]. From these incidents, guidelines have been suggested in using the cranes. Some of the guidelines are:

i. the weight of load must be checked.

ii. crane operations should be supervised by qualified personnel.

iii. crane operators must be familiar with their equipment.

iv. crane operators must be trained and qualified to operate their equipment.

Although the guidelines have been sketched in order to prevent the accident, the other factors also must be considered so that the probability of accidents occurs is small or reduced at an acceptable value. There are many factors that have to be considered: the braking systems, hydraulic and pneumatic components, electrical equipment, operational aids, operating mechanisms, lifting devices, determining load weight, recognizing immediate and potential hazards, control systems and others. In term of control systems, the important issue is how to control the load swing. This is important in order to have a faster operation while maintaining the safety.

1.2 GANTRY CRANE

Generally, crane can be defined as a machine used for lifting and lowering a load vertically and moving it horizontally and that has a hoisting mechanism as an integral part of it. As mentioned before, a crane type has varies, depend on their application: automatic crane, cab-operated crane, cantilever gantry crane, floor-operated crane, gantry crane, jib crane, mobile crane, overhead traveling crane, power-operated crane, pulpit-operated crane, remote-operated crane, semigantry crane, wall-mounted crane and wall-mounted jib crane. In this project, the work will be focused on a gantry crane.

Gantry crane is similar to an overhead crane, except that the bridge for 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 that the load can achieve the desired location. A real crane may allow a cart movement of 80 to 90 meters [2], regarding on the desired load location.

1.3 MOTIVATION, RATIONAL, SIGNIFICANCE AND NEED FOR THE STUDY

From the previous works, it seems that most researchers have given a lot of efforts in developing a control algorithms and designing controllers that can be used and realized in nature. This includes the study related on how to reduce the vibration, especially in crane, where the controllers that been designed are mostly to control the load swing. Since this is relatively simple and well defined problem in dynamics and control, it is surprising that, it has not been solved exactly, where an exact solution is here understood to be a control strategy that guarantees complete success in a finite time. Most of the crane controllers that have been developed until now have been far from satisfactory. Once tested in actual operation, there found to be ineffective and thus were left unused. This may due to the standard control feedback strategies that are not well suited to this problem. Therefore, the problem of controller synthesis for a crane is still under consideration.

Regarding on this matter, in this study, it seems interesting if multiple point of view can be taken in modeling the crane. For this purpose, gantry crane has been chosen in order to achieve the aim. This will involves in determining the relation between the cart' mass, load's mass and the load swing, in order to looking after the effect of the cart and load's mass to the load oscillation. Because the operation of the gantry crane is related with the movement of the cart and load, the effect that cause a vibration will be, whether from the acceleration that been applied at the cart, or the load and cart's inertia that been exists because the movement of these objects.

1.4 OBJECTIVES AND WORK METHODOLOGY

The objectives of this project can be divided as following:

- To obtain a mathematical model of the gantry crane for further analysis (including to study the system's natural response, transient behavior etc.).
- To verify the derived mathematical model through comparison with previous work and simulation on the model.
- To investigate the effects of system parameters such as load on the dynamics behavior of the system.
- To design and develop control algorithms for gantry crane based on filtering techniques.
- To investigate the performance of the control technique in term of vibration reduction and robustness.

In term of work methodology, it can be summarized as in Figure 1.3.

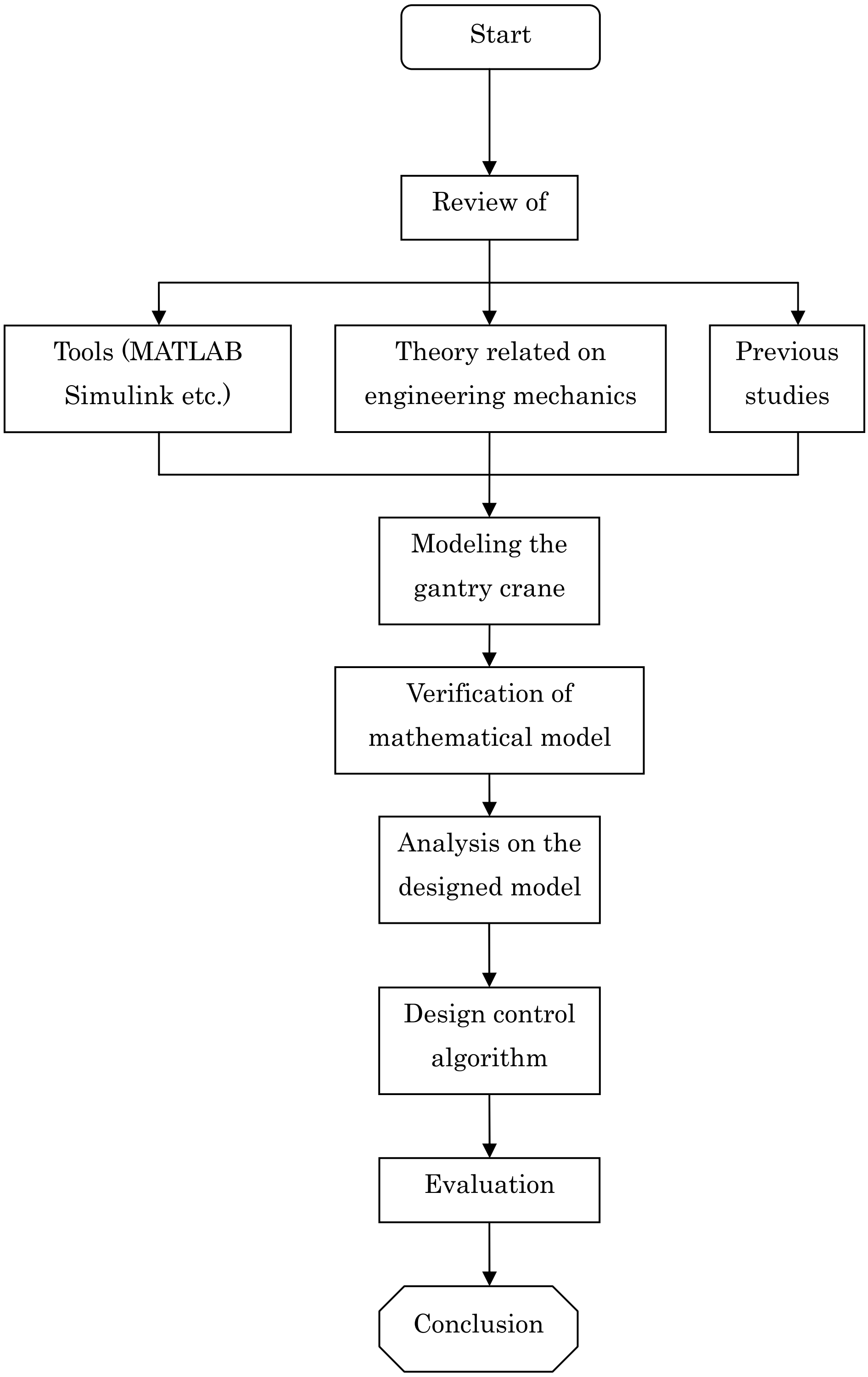

Figure 1.3 Work methodology

1.5 THESIS OUTLINE

This section will give an outlines of the structure of the thesis. The following is an explanation for each chapter.

Chapter 2 discusses the previous work that been done around the world about the crane, in term of modeling, or designing the crane. Literature that been done will cover, for instance, modeling, control algorithm design and others. At the end of the chapter, conclusion regarding on previous work that have been surveyed will be showed.

Chapter 3 deals with the gantry crane model, where the mechanical drawing and description related on it will be explained. In addition, the assumption and limitation that been added to the model will be described.

Chapter 4 will discuss along the line regards to model the gantry crane, where mathematical expression will be derived and will be showed. For this work, consideration will be given to the gantry crane with one degree-of-freedom, which its cart and load movement is only along single axis. The derivation will lead to forming the state equation, and the critical aspects, for example, natural frequency will be focused. Furthermore, the derived equation will be compared with previous work and also simulation in order to validate the model. Other than that, the characteristic of gantry crane will be explored through simulation, where the simulation will take many factors that seems can give an effect to the gantry crane.

Chapter 5 will discuss about control algorithm design for controlling gantry crane. In this topic, consideration is given to develop an algorithm to reduce oscillation of the load. The method that will be proposed is using command shaping via filtering technique, where the method is generally based on open-loop control. Analysis regarding on performance of designed controller will be conducted, and evaluation will be implemented.

Chapter 6 contains conclusion regarding on the topics and recommendation for future works.

evaluate the performances of the gantry crane. With this implementation also, the other aspects perhaps can be observed in order to improve the design.

Finally, is to add other consideration in design, such as to take account the mass of the bar (which relates calculation regards of moment of inertia of the bar and its effect in the system); effect from environment (wind etc). For instance, with adding the mass of the bar, the moment inertia of the bar also need to be considered, which also have its role in load oscillation. As we know, since the body has a definite size and shape, an applied nonconcurrent force system may cause the body to both translate and rotate. This will lead to consideration of adding moment of inertia in calculation, which is a measure of the resistance body to angular acceleration. Regarding on this fact, it is quite beneficial if the other consideration is taken in our design.

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