GANTRY CRANE SYSTEM: INVERSE DYNAMIC ANALYSIS METHOD

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"I hereby declare that this report is the result of my own work except for quotes as cited in the references."

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Date : 18/05/2009

"I hereby declare that I have read this report and in my opinion this report is sufficient in terms of the scope and quality for award of Bachelor of Mechanical Engineering (Design and Innovation) With Honours."

Signature : ....

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Date : 18-5-09

Dedicated to my family especially my parent, brother, sisters and all of my friends.

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ABSTRAK

'*Inverse dynamic analysis*' merupakan kaedah mudah untuk mengurangkan getaran dan sudut ayunan kepada kren rangka. Bahagian masukan untuk sistem kren rangka adalah menggunakan '*Inverse dynamic analysis*'. Persamaan input diperolehi daripada reaksi output yang dikehendaki supaya pengkaji dapat memilih kelajuan dan bentuk reaksi yang diperlukan supaya berada dalam had maksima sesuatu sistem. Fungsi eksponen kuasa tiga akan digunakan sebagai output disebabkan oleh sifat kestabilan asimptotnya. Simulasi mengenai sistem kren dengan sistem order keempat telah dijalankan. Dengan menggunakan teknik ini, parameter yang perlu dikaji adalah kedudukan troli dan sudut ayunan beban. Reaksi bagi kedudukan troli dan sudut ayunan beban akan ditunjukkan menggunakan perisian MATLAB. Dari keputusan simulasi didapati pengurangan kadar getaran yang memuaskan telah diperolehi menggunakan teknik yang diperkenalkan.

ABSTRACT

The inverse dynamic analysis is a simple method that is used for reducing the vibration and swing angle for the gantry crane system. The input of the crane is using inverse dynamic analysis. The shaped input function is derived from the specified output function so that the designer can choose the speed and shape of the motion within the limitations of the drive system. Third order exponential function is used as the desired output due to its asymptotic behavior. The simulation has been done to the gantry crane system which is fourth order system. In the proposed method the parameters that need to be defined is the position of the trolley and sway angle of the mass. Simulated responses of the position of trolley and sway of the mass are presented using MATLAB software. From the simulation results, satisfactory vibration reduction of a crane system has been achieved using the proposed method.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

M	- Trolley mass
m	- Payload mass
l	- Length of the hoisting rope
F_x	- Input force
G	- Gravitational acceleration = $9.81ms^{-2}$
G	- Centre point
S	- Point of suspension
x	- Trolley position
$\dot{x}$	- Velocity
$\ddot{x}$	- Acceleration
θ	- Sway angle
$\dot{\theta}$	- Angular velocity
$\ddot{\theta}$	- Angular acceleration

CHAPTER I

PROJECT INTRODUCTION

This chapter will discussed about the gantry crane system with inverse dynamic analysis. The project introduction, project objective, problem statement, scopes of work, methodology and thesis outline will also be presented.

1.1 Introduction

The fundamental motions of a gantry crane consist of travelling, load hoisting and load lowering. The significant characteristic of a gantry crane is that all motions are performed simultaneously at relatively high speed. When the crane is starting or stopping, it will induce the undesirable swinging of the suspended load. This oscillation can caused possibly damage to the load and workplace. These oscillations also produce safety hazards and can become dangerous to the people nearby. Until now, various type of control approaches have been used to addressed this problem. The approaches are the open-loop and closed-loop system.

One of the open-loop approaches is input shaping. Input shaping is a feedforward control technique for improving the settling time and the positioning accuracy, while minimizing residual vibrations, of computer-controlled machines. Another open-loop method is the optimal control which calculates a motion trajectory.

The closed-loop system is used to reduce end-point vibration. The closed loop system is benefit from the inherent advantages of feedback, such as insensitivity to parameter variations, noise attenuation and disturbance rejection. A closed loop control system based on the dynamic model of the gantry crane of relatively fixed coefficients of gantry mass and friction. The controller algorithm is that of a state variable feedback system, where gantry position and cable rope swinging angle is regulated [1]. System inversion based method reverse the process by specifying the system output function and deriving the input.

1.2 Objective

The objective of this project is to specify an input function by using the inverse dynamic analysis for gantry crane that can move as robustness, quickly, accurately and safely as possible without vibration from an initial position to target position.

1.3 Problem Statement

Gantry cranes are widely used for factories, transportation, nuclear installation and also construction. The crane has to move the load as fast as possible without causing any excessive movement at the final position or during it moves. However, moving the payload using the crane is not an easy task especially when strict specifications on the swing angle and on the transfer time need to be satisfied [2]. The swing motion when payload is suddenly stopped after a fast motion can be reduced but very wasting time. Moreover, the gantry crane needs a skilful and experience operator to control manually for stopping the swing immediately at the right position. Beside this, the operator also needs time to wait the string stop from vibration after movement the load. The vibration is a serious problem in a mechanical system [1]. A gantry crane system with inverse dynamic method can be used to solve this problem

1.4 Scopes of Work

While doing the project, the scope of work plays a very important role. There is a guideline which student should attain to fulfill the requirement of project. The scopes of work are listed as below:

i) To study the dynamic behavior of gantry crane
ii) To study the inverse dynamics analysis method
iii) To design an input function for the system
iv) To evaluate the performance of the system with designed input

1.5 Report Structure

This thesis is a documentation to deliver the generated idea, the concepts applied, the activities done, and the final year project product produced. The thesis consists of six chapters.

Chapter I is about some background of the project. Furthermore, the objective of project, problem statement, scopes of work, and thesis outline also will be presented.

Chapter II contain literature review about the precise position control, rapid rest-to-rest motion and the several techniques of input shaping that will reduce the vibration for the gantry crane.

Chapter III discuss on research methodology used for the whole project. It also contain flow chart of project to make it more clear and easy to understand.

Chapter IV illustrate the inverse dynamic analysis on second order system. This method will reverse the process by specifying the system output function and deriving the input.

Chapter V follows with the design and modelling of the gantry crane system including the derivation of equations of motion for a gantry crane. The application of the input shaping design using inverse dynamic analysis to fourth-order gantry crane system will also be presented here.

Simulation results, analysis and discussion of the performance of the technique are presented in Chapter VI.

Finally, Chapter VII is the conclusion of the project. It also includes the application of the project and the recommendation that can be implemented in the future.

CHAPTER II

LITERATURE REVIEW

Precise position control and rapid rest-to-rest motion is the desired objective in a variety of applications. The requirement of precise position control implies that the residual vibration of the structure should be zero or near zero. Literature review is done in this chapter to make a review of the several techniques of input shaping that will reduce the vibration and part of it is discussed below.

2.1 Input Shaping Techniques

Input shaping is a simple and effective method for reducing the residual vibration when position lightly damped system. One very useful form of command shaping is input shaping. Input shaping is applicable in real time, and input shapers can be designed to have any desirable robustness level. Input shaping is designed to reduce, or eliminate, command-induced system vibration [3]. A desired reference command given to a flexible system will, in general, result in residual vibration. Input shaping is ability to cancel vibration as destructive interference of sinusoidal waves [4]. If two sinusoids of the same magnitude, same frequency and correct phase shift between them are added together, the resulting combination will have no oscillations. This effect can be seen in Figure 2.1.

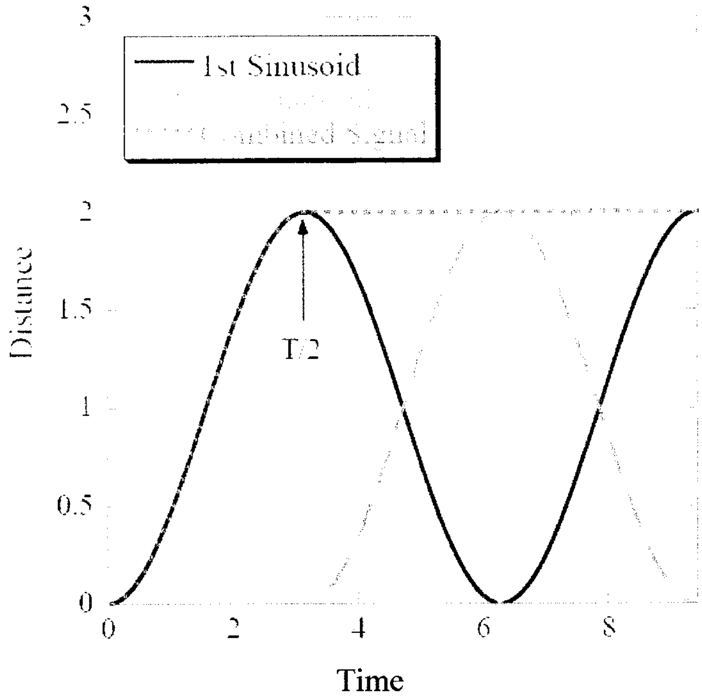

Figure 2.1: Destructive interference

The sequence of impulses, known as the input shaper, is then convolved with a desired reference command to produce a new, modified command that can be used to drive the system.

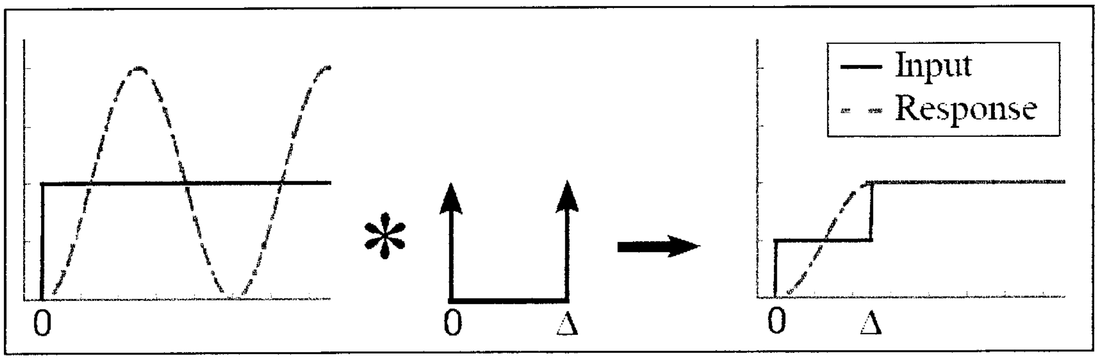

Figure 2.2: Input shaping process.

As shown in Figure 2.2, this modified command will cause the system to move with no residual vibration. The sequence of impulses is chosen such that, when the modified command is applied to the system, certain performance constraints are met. These performance constraints can include the system's desired residual vibration amplitude, robustness to modeling errors, and command rise time, among others.

There are several input shaping techniques which are posicast-based control, Unity Magnitude Zero Vibration Shaper (UMZV), Specified Negative Amplitude shaper (SNA) and Inverse Dynamic Analysis Method.

2.1.1 Posicast-based Control

Posicast was originally proposed by O. J. M. Smith to cancel the oscillatory behavior of lightly damped systems. The control motion is like casting a fly. movement which shown in Figure 2.3 name positive-cast or posicast control [5].

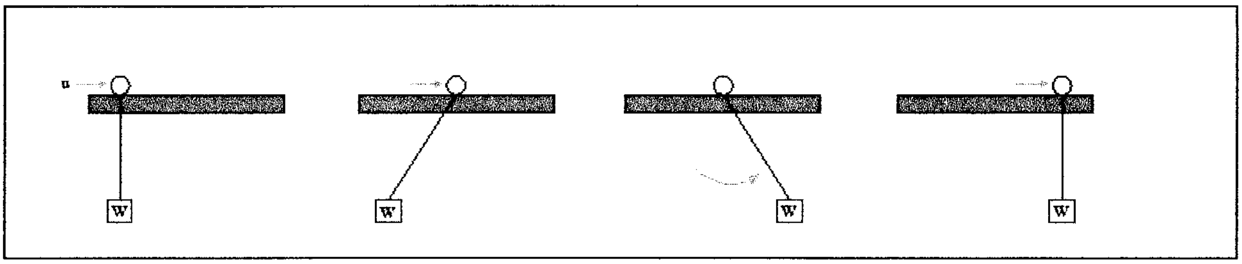

Figure 2.3: Posicast control

In the early 1950, John Calvert developed a time-delay based vibration filter named Signal Component Control. However, his solution did not contain the convenient closed-form description offered by Smith. Since this initial work, there have been many developments in the area of input shaping control.

Posicast was further examined in the early 1960's by researchers trying to minimize vibration in various types including flexible structures, and vibration control. Application of Posicast to nonlinear dynamics has also been proven effective when the nonlinearity is slowly time varying. It is also well-known that Posicast is very sensitive to inaccurate knowledge of the damped resonant frequency such performance sensitivity is common to many feed-forward control methods that rely on dynamic cancellation or model inversion.

2.1.2 Command Shaping

Between the late 50's and the publication of the *Input Shaping* paper by Singer and Seering [6], there was some work on the shaping of input profiles for control of residual vibration [7], [8]. Swigert [8] proposed techniques for the determination of torque profiles which considered the sensitivity of the terminal states to variations in the model parameters. Publication of the *Input Shaping* paper renewed interest in prefiltering reference inputs for robust vibration control, which has resulted in dozens of papers with application to spacecrafts, robots, cranes, chemical processes, etc.

The design will consider two classes of problems. First, involves real-time shaping or time-delay filtering of the reference command to stable systems with the objective of minimizing the residual vibration [9]. The second class of problems considered is the design of controllers for systems with rigid body modes with constraints on the control input [10], [11]. The example of this technique can be seen in Figure 2.4.

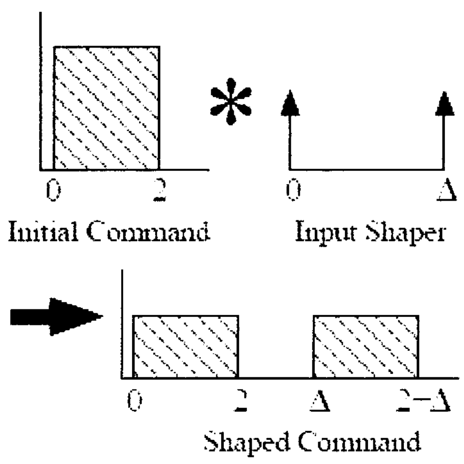

Figure 2.4: Multi pulse shaped input

2.1.3 Convolution (Impulse Shaping)

The most popular technique for input shaping is to convolve a sequence of impulses and various methods for shaping impulse function and examining their robustness has been reported and applied to flexible spacecraft, robots and to the control of swing of suspended objects transported by cranes [12]. Impulse shaping is a feedforward control technique for reducing vibrations in computer controlled machines. The method works by creating a command signal that cancels its own vibration. That is, vibration caused by the first part of the command signal is canceled by vibration caused by the second part of the command.

Input shaping is implemented by convolving a sequence of impulses, an input shaper, with any desired command. The shaped command that results from the convolution is then used to drive the system. See Figure 2.5. If the impulses in the shaper are chosen correctly, then the system will respond without vibration to any unshaped command.

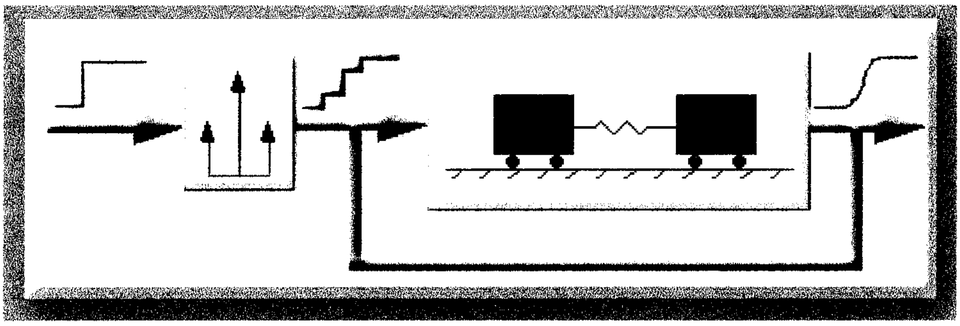

Figure 2.5: An example of impulse shaping technique

The amplitudes and time locations of the impulses are obtained from the system's natural frequencies and damping ratios. Shaping can be made very robust to errors in the system parameters. The impulse sequence is chosen such that in the absence of control input, it itself would not cause residual vibration. Recall that convolution in the time domain is equivalent to multiplication in the Laplace domain. In order to increase the