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# EXPERIMENTAL INVESTIGATIONS OF COMMAND SHAPING TECHNIQUES FOR ANTI-SWAY CONTROL OF DOUBLE PENDULUM GANTRY CRANE SYSTEM

# (KAJIAN PENYIASATAN TEKNIK PEMBENTUKAN ARAHAN UNTUK KAWALAN ANTI-AYUNAN BAGI SISTEM GANTRI KREN DWI-PENDULUM)

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# ABSTRACT


## EXPERIMENTAL INVESTIGATIONS OF COMMAND SHAPING TECHNIQUES FOR ANTI-SWAY CONTROL OF DOUBLE PENDULUM GANTRY CRANE SYSTEM

***(Keywords: input shaping, double pendulum and sway motion)***

The sway motion of crane can be successfully suppressed by properly shaping the reference command. Input shaping is a one type of feed-forward shaping method that is based on linear superposition. In this project, we present the impact of double pendulum type overhead crane (DPTOC) system on the effectiveness of input shaping. An unshaped bang-bang input force is used to determine the characteristic parameters of the system for design and evaluation of the input shaping control techniques. The input shapers with the derivative effects are designed based on the properties of the system. The response DPTOC system to shaped input is experimentally verified in time and frequency domain. The performance of the input shaper is examined in terms of sway angle reduction and time response specification. Experimental results demonstrate the effectiveness of the proposed approach in reducing the sway motion of crane system.



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# ABSTRAK

## KAJIAN PENYIASATAN TEKNIK PEMBENTUKAN ARAHAN UNTUK KAWALAN ANTI-AYUNAN BAGI SISTEM GANTRI KREN DWI-PENDULUM

***(Kata Kunci: Pembentukan input, dwi-pendulum dan gerakan ayunan)***

Gerakan ayunan kren boleh dikurangkan dengan membentuk perintah rujukan yang sepatutnya. Pembentukan input adalah jenis salah satu sistem suap hadapan membentuk kaedah yang didasarkan pada superposisi linear. Dalam projek ini, kami menyajikan kesan pembentukan input terhadap sistem kren dwi-pendulum. Daya bang-bang input tanpa bentuk digunakan untuk menentukan ciri-ciri parameter sistem untuk reka bentuk dan penilaian teknik kawalan pembentukan input. Pembentukan input dengan kesan derivatif dirancang berdasarkan sifat-sifat sistem. Sambutan sistem kren dengan pembentukan input ditentusahkan secara eksperimen dan dipersembahkan dalam domain masa dan frekuensi. Prestasi pembentukan input disiasat dalam hal pengurangan sudut ayunan dan spesifikasi waktu respon. Keputusan kajian menunjukkan keberkesanan pendekatan yang dicadangkan dalam mengurangkan gerakan ayunan sistem kren.

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# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction

Overhead crane is important machinery that has been used at construction or industrial site to transfer the material. In order to make work easier, overhead cranes have been used to transfer the material that are usually heavy, large and hazardous which cannot be handling by worker. In handling the crane, safety is the most important aspect to consider while operating crane. It also has a problem when carrying the heavy load, the overhead crane tents to be unbalance causing its cart to sway excessively.

There are many cases and incident regarding on the crane's accident. For example, in April 1993, the crane becomes unbalanced during two separated incidents at DOE sites in United State of America, which is in Hanford Sites and Bryan Mound Site. For the first accidents happened in 28$^{th}$ April 1993, where a crane becomes unbalanced while the boom was being lowered and two day later in 30$^{th}$ April 1993, which crane loading the load, the weight of the load caused the crane to tip forward. Relate to this accident, effective controller need to be applied into the crane system to meet safety requirement and smooth operation.

Input shaping is a feed forward control technique for improving the settling time and positioning accuracy, while minimizing residual vibrations of computer controlled machines. Input shaping is a strategy for a generation of time-optimal shaped commands using only a simple model, which consist of the estimate of natural frequency and damping ratio so, input shaping is a simple method to reduce the sway of double pendulum type overhead crane (DPTOC) system. It offers several clear advantages over conventional approaches for trajectory generation [1].

i) Designing an input shaping does not require an analytical model of the system; it can be generated from simple, empirical measurements of the actual physical system [1].
ii) Input shaping does not affect the stability of the closed loop system in any way. It simply modifies the command signal to the system so that all moves, regardless of length, are vibration free [1].

So in this project the positive input shaping algorithm will be used to reduce the sway of double pendulum type overhead crane system. The positive input shaping is implemented by convolving a positive sequence of impulse, an input shaper with a desired system command to produce a shaped input. Figure 1.1 and 1.2 show examples of overhead cranes using in industry.

The requirement of precise sway control of overhead crane implies that residual sway of the payload should be zero or near zero. As the performance requirements imposed by the industry become more severe, the need to understand how to model and control the overhead crane becomes an issue of concern. Thus, it becomes necessary to anticipate and control such sway in order to obtain robust and fast response of the overhead crane.

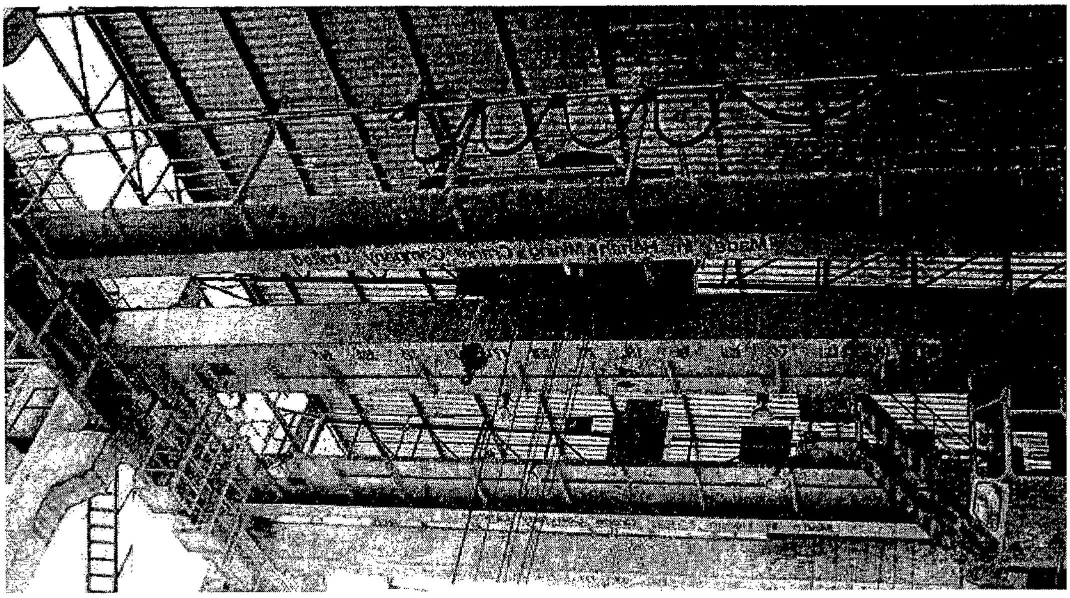

Figure 1.1: Double beam overhead crane (EOT crane)

Figure 1.2: Overhead cranes

## 1.2 Problem statement

When carrying heavy loads, the overhead crane tends to be unbalance causing its cart to sway excessively. This can cause accidents. The accidents which caused by cranes have been recorded [1] and this prove that gantry crane can be hazardous. To solve this problem, input shaping technique is introduced.

## 1.3 Project Objective

The objectives of this project:

i) To develop positive input shaping technique for anti sway control of double pendulum type overhead crane system.

ii) To determined the amplitude and time locations of the impulse in order to reduce the natural frequencies and damping ratio of the system.

iii) To investigate the effects of the difference derivative order of the positive input shaper in terms of level sway reduction and time response specifications.

## 1.4 Project Scope

The scopes of this project:

i) Modeling of overhead crane.
Modeling is needed to present a real system that will be focused in order to do the analysis. Further work involves obtaining the dynamic characteristic and to predict the problem that will occur before the control of the system is implemented.

ii) Design the positive input shaping controller.
Positive input shaping is developed based on positive zero sway (PZS), positive zero sway derivative (PZSD) and positive zero sway derivative-

derivative (PZSDD). Each positive input shaping contains difference value of impulse.

iii) Simulation studies using MATLAB software.

For simulation studies, MATLAB 7.6 is used for input shaping design before it is used for experimental studies.

iv) Experimental studies using CEMTool and MATLAB 7.6 software.

To carry out this project after simulation studies is done; this software will be used to interface the design program with its experimental hardware.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

An overhead crane has been used to lift and move the payload from one location to another place that are usually heavy, large and hazardous which cannot be handling by worker. In operating the overhead crane, when the load moves, the crane must be controlled so that the load reaches the location needed with less or without swinging.

In operating the overhead crane, the oscillation that occurs is seemly like a pendulum motion which is at certain level, the operating must be stopped until the swing or oscillation reduced [2]. This happen when the cart in which carries the load will produce a sway which cause the cart and the load to oscillate. One of the incidents occurred in 28th April 1993, where a crane becomes unbalanced while the boom was being lowered [2].

Due to this problem, to prevent the accidents, the controller of positive input shaping technique will be implemented. The timeliness and effectiveness of this manipulation system are important contributors to industrial production. Beyond the basic pendulum mode, crane also has additional dynamic effects such as motor time constants, velocity limits and nonlinear payload dynamics that make them well suited for both introductory and advance study [3].

Today most existing crane control systems are designed to maximize speed, in an attempt to minimize system sway and achieve good positional accuracy in minimum duration. High stiffness can be achieved by using short rope or heavy carrier head. As a result, such cranes are usually heavy with respect to it payload. This limits the speed of operation of transportation, increases size of driving motor and energy consumption [4, 5].

## 2.2 Anti-sway techniques

The vibration or sway is a significant problem in dynamical systems that are required to perform precise motion in presence of structural flexibility. Step motors, robotic arms, flexible manipulators and crane systems are some examples for this category. In reducing the excessive sway of an overhead crane, many researches and paper work had been done in proposing the techniques to overcome the problem. These are some techniques which had been done over the years which include input shaping, filtering technique, and feedback control technique.

### 2.2.1 Input Shaping Technique

Feed-forward control schemes are mainly develop for sway suppression and involve developing the control input through consideration of the physical and swaying properties of the system so that system sways at response modes are reduced [4]. The earliest incarnation of this self canceling command generations was developed by smith [4, 5, and 6]. His posicast control method involved breaking a command of certain magnitude into two smaller magnitude commands, one of which is delayed one-half period of vibration.

Unfortunately, his technique was extremely sensitive to modeling errors [6]. Singer and Seering developed reference commands that were robust enough to be effective on a range of systems [5, 7]. This new robust technique is named as input shaping.

Input shaping is implemented by convolving a sequence of impulses, an input shaper, with a desired system command to produce a shaped input that produces self canceling command signal [4, 8, 9, and 10]. Input shaping is easier to derive and implement than time-optimal control schemes and does not require the feedback mechanisms of closed loop and adaptive controllers [9, 10].

Input shaper is designed by generating a set of constraint equations which limit the residual vibration, maintain actuator limitations, and ensure some level of robustness to modeling errors [11]. Input shaping is a form of Finite Impulse Response (FIR) filtering that places zeros near the locations of the original system's flexible poles. The impulse amplitudes are equivalent to the filter coefficients. The impulse amplitudes and time locations are determined by satisfying a set of constraint equations [8, 9, and 10].

According to Sirri Sunay Gurleyuk, Ozgur Bahadir, Yunus Turkkan and Hakan Usenti which had proposed in their paper Three-Step (TS) input shaping technique state that Zero Vibration (ZV), Zero Vibration and Derivative (ZVD) and Extra Insensitive (EI) are the most common shaper types. Improving the robustness respect to modeling errors requires more impulses [5].

The requirement of positive amplitudes for the input shapers has been used in most input shaping schemes. The requirement of positive amplitude for the impulses is to avoid the problem of large amplitude impulses [4]. The shapers containing negative impulses have tendency to excite unmodeled high modes and they are slightly less robust as compared to the positive shapers besides, negative input shapers require more actuator effort than the positive shapers due to high changes in the set-point command at each new impulse time location [4].

In this project, by related the advantage and disadvantage of the positive input shaping technique and negative input shaping technique, this experimental will use positive input shaping technique as the controller of double pendulum type overhead crane (DPTOC) system.

**2.2.2 Other Techniques**

In the paper entitled Experimental Investigations of Low pass Filter Techniques for Sway Control of a Gantry Crane System by M.A. Ahmad, F.R. Misran, M.S. Ramli, and R.M.T. Raja Ismail it presents investigations into the development of IIR low-pass filter techniques in anti-swaying control of a gantry crane system. According this paper, filtering techniques is developed on the basic of extracting input energy around natural frequencies of the system.

The filters are thus used for pre-processing the input signal so that no energy is fed into the system at the natural frequencies. In this manner, the flexural modes of the system are not excited, leading to a sway-free motion. This can be realized by employing either low-pass (LPF) or band-stop (BSF) filters [12].

In the former, the filter is designed with cut-off frequency lower than the first natural frequency of the system. There are various filter types such as Butterworth, Chebyshev and Elliptic that can be designed and employed [12].