BEKU 4894

FINAL YEAR PROJECT

REPORT

DYNAMIC MODELING OF A DOUBLE-PENDULUM GANTRY CRANE SYSTEM

NAME : NOOR FATHIHA BINTI OMAR
COURSE : 4 BEKC
SESSION : 2013/2014
MATRIX NO : B011110149
LECTURER’S NAME : EN. HAZRIQ IZZUAN BIN JAAFAR

18th JUNE 2014
"I hereby declare that I have read through this report entitle "Dynamic Modeling of a Double Pendulum Gantry Crane System" and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Control, Instrumentation and Automation)"

Signature : ........................................

Supervisor's Name : En. Hazriq Izzuan Bin Jaafar

Date : 18 June 2014
DYNAMIC MODELING OF A DOUBLE-PENDULUM GANTRY CRANE SYSTEM

NOOR FATIHA BINTI OMAR

A report submitted in partial fulfillment of the requirements for the degree of Bachelor of Electrical Engineering (Control, Instrumentation and Automation)

Faculty of Electrical Engineering
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2014
I declare that this report entitle “Dynamic Modeling of a Double Pendulum Gantry Crane System” is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : 

Name : Noor Fatiha Binti Omar

Matrix No : B011110149

Date : 18 June 2014
To my beloved mother and father
ACKNOWLEDGEMENT

Firstly, I would like to express my gratitude and appreciation to all those who gave me the possibility to complete this report. Deepest thanks to my supervisor, Encik Hazriq Izzuan Bin Jaafar for his invaluable guidance, stimulating suggestions and encouragement to complete this project. During under his supervision, lot of valuable information is obtained in order to coordinate and complete this project and thesis in the time given.

Special thanks and higher appreciation to my parents, family and special mate of mine for their cooperation, constructive suggestion and also supports from the beginning until the ends during the period of the project. Also thanks to all of my friends and others, that has been contributed by supporting and helps myself during the final year project progress till it is fully completed.

Last but not least, greater appreciation to BEKC Classmates and Electrical Engineering Faculty UTeM for great commitment and cooperation during my Final Year Project. Besides, I would like to appreciate the guidance given by the panels especially in our project presentation that has improved our presentation skills by their comment and tips.
ABSTRACT

This project presents investigations of dynamic behavior of Double Pendulum Gantry Crane System (DPGCS). The dynamic model system is developed and derived using Lagrange equation. The effects of performances in term of movement of the trolley and payload oscillation of the system are analyzed and discussed. The dynamic model is developed and the extensive results based on derivation are presented in the frequency domains. Simulation results are presented within MATLAB environment to verify the response performances of the system. It shows that several factors may affecting the performance of the DPGCS in terms of hook and load length, input force, hook mass, payload mass and trolley mass.
ABSTRAK

# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>CHAPTER</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DECLARATION</td>
<td>iii</td>
</tr>
<tr>
<td></td>
<td>DEDICATION</td>
<td>iv</td>
</tr>
<tr>
<td></td>
<td>ACKNOWLEDGMENT</td>
<td>v</td>
</tr>
<tr>
<td></td>
<td>ABSTRACT</td>
<td>vi</td>
</tr>
<tr>
<td></td>
<td>ABSTRAK</td>
<td>vii</td>
</tr>
<tr>
<td></td>
<td>TABLE OF CONTENTS</td>
<td>viii</td>
</tr>
<tr>
<td></td>
<td>LIST OF TABLE</td>
<td>xi</td>
</tr>
<tr>
<td></td>
<td>LIST OF FIGURE</td>
<td>xiii</td>
</tr>
<tr>
<td></td>
<td>LIST OF ABBREVIATIONS</td>
<td>xvi</td>
</tr>
<tr>
<td></td>
<td>LIST OF SYMBOLS</td>
<td>xvii</td>
</tr>
<tr>
<td></td>
<td>LIST OF APPENDICES</td>
<td>xviii</td>
</tr>
<tr>
<td>1</td>
<td>INTRODUCTION</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.0 Overview</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1.1 Gantry Crane System</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1.2 Motivation</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>1.3 Problem Statement</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>1.4 Significant of Project</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>1.5 Objective of Project</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>1.6 Scopes of Project</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>1.7 Project Report Outline</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>LITERATURE REVIEW</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.0 Overview</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>2.1 Previous Research on Development of Controller</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>2.2 Previous Research on Dynamical Behavior of</td>
<td></td>
</tr>
</tbody>
</table>
3  METHODOLOGY
3.0  Overview 14
3.1  Project Flow Chart 14
3.2  Lagrangian Equation 16
3.3  Bang-bang Input Solution 17

4  MODELING OF A DOUBLE-PENDULUM
GANTRY CRANE SYSTEM (DPGCS)
4.0  Overview 18
4.1  Model of DPGCS 18
4.2  Mathematical Modeling of DPGCS 21

5  RESULTS, ANALYSIS AND DISCUSSIONS
5.0  Overview 34
5.1  Simulation Model of DPGCS 34
5.2  First Phase: Analysis of DPGCS Behavior 36
   5.2.1  Different Payload Mass \( m_2 \) 37
5.3  Second Phase: Analysis of DPGCS Behavior
   with Various Parameters Setting 42
   5.3.1  Different Input Force \( N \) 43
   5.3.2  Different Hook Length \( L_1 \) 49
   5.3.3  Different Load Length \( L_2 \) 54
   5.3.4  Different Hook Mass \( m_1 \) 59
   5.3.5  Different Trolley Mass \( m_3 \) 64
5.4  Result and Analysis 71

6  CONCLUSION AND RECOMMENDATION
6.0  Overview 77
6.1  Conclusion 77
   6.11  Conclusion of First Phase: Analysis of
   DPGCS Behavior 78
6.12 Conclusion of Second Phase: Analysis of DPGCS Behavior with Various Parameters Setting 78

6.2 Recommendation 78

REFERENCES 80
APPENDIX A 84
APPENDIX B 86
APPENDIX C 87
## LIST OF TABLES

<table>
<thead>
<tr>
<th>NO</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Summary for the type of technique use in years (2013-1998)</td>
<td>12</td>
</tr>
<tr>
<td>2.2</td>
<td>Research of dynamic modeling (2013-2009)</td>
<td>13</td>
</tr>
<tr>
<td>4.1</td>
<td>Parameter of the DPGCS</td>
<td>20</td>
</tr>
<tr>
<td>4.2</td>
<td>The system’s variable</td>
<td>20</td>
</tr>
<tr>
<td>5.1</td>
<td>Trolley Displacement with different Payload Mass ($m_2$)</td>
<td>38</td>
</tr>
<tr>
<td>5.2</td>
<td>Hook Swing Angle with Different Payload Mass ($m_2$)</td>
<td>39</td>
</tr>
<tr>
<td>5.3</td>
<td>Load Swing Angle with Different Payload Mass ($m_2$)</td>
<td>40</td>
</tr>
<tr>
<td>5.4</td>
<td>Trolley Displacement with Input Force ($N$)</td>
<td>46</td>
</tr>
<tr>
<td>5.5</td>
<td>Hook Swing Angle with different Input Force ($N$)</td>
<td>47</td>
</tr>
<tr>
<td>5.6</td>
<td>Payload Swing Angle with different Input Force ($N$)</td>
<td>48</td>
</tr>
<tr>
<td>5.7</td>
<td>Trolley Displacement with different Hook Length ($L_1$)</td>
<td>51</td>
</tr>
<tr>
<td>5.8</td>
<td>Hook Swing Angle with different Hook Length ($L_1$)</td>
<td>52</td>
</tr>
<tr>
<td>5.9</td>
<td>Payload Swing Angle with different Hook Length ($L_1$)</td>
<td>53</td>
</tr>
<tr>
<td>5.10</td>
<td>Trolley Displacement with different Load Length ($L_2$)</td>
<td>56</td>
</tr>
<tr>
<td>5.11</td>
<td>Hook Swing Angle with different Load Length ($L_2$)</td>
<td>57</td>
</tr>
<tr>
<td>5.12</td>
<td>Payload Swing Angle with different Load Length ($L_2$)</td>
<td>58</td>
</tr>
<tr>
<td>5.13</td>
<td>Trolley Displacement with different Hook Mass ($m_1$)</td>
<td>61</td>
</tr>
<tr>
<td>5.14</td>
<td>Hook Swing Angle with different Hook Mass ($m_1$)</td>
<td>62</td>
</tr>
<tr>
<td>5.15</td>
<td>Payload Swing Angle with different Hook Mass ($m_1$)</td>
<td>63</td>
</tr>
<tr>
<td>5.16</td>
<td>Trolley Displacement with different Trolley Mass ($m_3$)</td>
<td>66</td>
</tr>
<tr>
<td>5.17</td>
<td>Hook Swing Angle with different Trolley Mass ($m_3$)</td>
<td>67</td>
</tr>
<tr>
<td>5.18</td>
<td>Payload Swing Angle with different Trolley Mass ($m_3$)</td>
<td>68</td>
</tr>
<tr>
<td>5.19</td>
<td>Behavior of Double Pendulum Gantry Crane Model with Different Parameter Setting</td>
<td>69</td>
</tr>
</tbody>
</table>
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>NO</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Industrial Gantry Crane System (GCS)</td>
<td>2</td>
</tr>
<tr>
<td>1.2</td>
<td>The overview of the crane accident</td>
<td>4</td>
</tr>
<tr>
<td>3.1</td>
<td>Flow Chart for the methodology of the Project</td>
<td>15</td>
</tr>
<tr>
<td>3.2</td>
<td>Bang-bang Input Force</td>
<td>17</td>
</tr>
<tr>
<td>4.1</td>
<td>Description of the DPGCS</td>
<td>19</td>
</tr>
<tr>
<td>4.2</td>
<td>Position Analysis of DPGCS</td>
<td>22</td>
</tr>
<tr>
<td>4.3</td>
<td>Velocity Analysis</td>
<td>24</td>
</tr>
<tr>
<td>4.4</td>
<td>Simplify of Velocity Analysis</td>
<td>25</td>
</tr>
<tr>
<td>4.5</td>
<td>Velocity Analysis for $V_1$</td>
<td>26</td>
</tr>
<tr>
<td>4.6</td>
<td>Velocity Analysis for $V_2$</td>
<td>26</td>
</tr>
<tr>
<td>5.1</td>
<td>Simulink of DPGCS</td>
<td>35</td>
</tr>
<tr>
<td>5.2</td>
<td>Block Diagram inside the DPGCS Model</td>
<td>35</td>
</tr>
<tr>
<td>5.3</td>
<td>List of Parameters</td>
<td>36</td>
</tr>
<tr>
<td>5.4</td>
<td>Different Payload Mass Setting,</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>(a) 1 kg (b) 5 kg (c) 10 kg</td>
<td></td>
</tr>
<tr>
<td>5.5</td>
<td>Bang-bang Input (5 N) for Different Payload Mass</td>
<td>38</td>
</tr>
<tr>
<td>5.6</td>
<td>Response of Trolley Displacement with Different Payload Mass ($m_2$)</td>
<td>39</td>
</tr>
<tr>
<td>5.7</td>
<td>Response of Hook Swing Angle with Different Payload Mass ($m_2$)</td>
<td>40</td>
</tr>
<tr>
<td>5.8</td>
<td>Response of Payload Swing Angle with Different Payload Mass ($m_2$)</td>
<td>41</td>
</tr>
<tr>
<td>5.9</td>
<td>Simulink of DPGCS with Various Parameters Setting</td>
<td>42</td>
</tr>
<tr>
<td>5.10</td>
<td>Different Input Force Setting</td>
<td>43</td>
</tr>
<tr>
<td></td>
<td>(a),(b) 1 N (c),(d) 5 N (e),(f) 10 N</td>
<td></td>
</tr>
<tr>
<td>5.11</td>
<td>Bang-bang Input (1 N) for Different Payload Mass</td>
<td>44</td>
</tr>
<tr>
<td>5.12</td>
<td>Bang-bang Input (5 N) for Different Payload Mass</td>
<td>45</td>
</tr>
</tbody>
</table>
5.13 Bang-bang Input (10 N) for Different Payload Mass
5.14 Response of Trolley Displacement with Different Input Force (N)
5.15 Response of Hook Swing Angle with Different Input Force (N)
5.16 Response of Payload Swing Angle with Different Input Force (N)
5.17 Different Hook Length Setting (1.15 m, 1.55 m & 2.00 m)
5.18 Bang-bang Input (5 N) for Different Hook Length
5.19 Response of Trolley Displacement with Different Hook Oscillation (L1)
5.20 Response of Hook Swing Angle with Different Hook Oscillation (L1)
5.21 Response of Payload Swing Angle with Different Hook Oscillation (L1)
5.22 Different Load Length Setting (0.15 m, 0.55 m & 1.00 m)
5.23 Bang-bang Input (5 N) for Different Load Length
5.24 Response of Trolley Displacement with Different Load Length (L2)
5.25 Response of Hook Swing Angle with Different Load Length (L2)
5.26 Response of Payload Swing Angle with Different Load Length (L2)
5.27 Different Hook Mass Setting (1 kg, 5 kg & 10 kg)
5.28 Bang-bang Input (5 N) for Different Hook Mass
5.29 Response of Trolley Displacement with Different Hook Mass (m1)
5.30 Response of Hook Swing Angle with Different Hook Mass (m1)
5.31 Response of Payload Swing Angle with Different Hook Mass (m1)
5.32 Different Trolley Mass Setting (1 kg, 5 kg & 10 kg)
5.33 Bang-bang Input (5 N) for Different Trolley Mass 65
5.34 Response of Trolley Displacement with Different Trolley Mass (m3) 66
5.35 Response of Hook Swing Angle with Different Trolley Mass (m3) 67
5.36 Response of Payload Swing Angle Swing Angle with Different Trolley Mass (m3) 68
5.37 Different Input Force (N) 71
5.30 Different Hook Length (LI) 72
5.31 Different Load Length (L2) 73
5.32 Different Hook Mass (m1) 74
5.33 Different Payload Mass (m2) 75
5.34 Different Trolley Mass (m3) 76
LIST OF ABBREVIATIONS

DPGCS - Double-Pendulum Gantry Crane System
GCS - Gantry Crane System
LIST OF SYMBOLS

\( m_1 \) - Hook Mass

\( m_2 \) - Payload Mass

\( m_3 \) - Trolley Mass

\( L_1 \) - Hook Pendulum Length

\( L_2 \) - Load Pendulum Length

\( g \) - Gravity Acceleration

\( F \) - Bang-bang Force Input

\( x(m) \) - Trolley Displacement

\( \theta_1 \) - Hook Swing Angle

\( \theta_2 \) - Load Swing Angle

\( kg \) - Kilogram (Mass unit)

\( N \) - Newton (Force unit)

\( m \) - Meter (Distance unit)
# LIST OF APPENDICES

<table>
<thead>
<tr>
<th>APPENDIX</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Gantt chart for Final Year Project 1</td>
<td>84</td>
</tr>
<tr>
<td></td>
<td>(BEKU 4792)</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Gantt chart for Final Year Project 2</td>
<td>86</td>
</tr>
<tr>
<td></td>
<td>(BEKU 4894)</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Turnitin of DPGCS</td>
<td>87</td>
</tr>
</tbody>
</table>
CHAPTER 1

INTRODUCTION

1.0 Overview

This chapter will be discussed about the Gantry Crane System (GCS) dynamic analysis. The project objective, problem statement, scopes of work and methodology will also be presented in this chapter.

1.1 Gantry Crane System

By the centuries, humans have been facing a problem in lifting and handling heavy materials. There is no other way in solving the problem until the GCS has been introduced. The use of modern machine technology is a step to provide support in the construction, transportation and make daily life become more convenient. The industrial use of GCS are increasing with the demand for greater safety and faster transferring payloads. The uncontrolled payload motions that are suspended will become dangerous if accident occur along transferring payloads. Crane operators must be skilled in handling cranes and have
the appropriate training to control the crane with more secure. The operator have the responsibility to plan carefully and taken the inspection before controlling the crane.

Thus, GCS supports to hold the load at a fixed location to move left or right and high or low. It consists of two or more legs parallel to each other on the bridge as shown in Figure 1.1. The heights of loads are depending on the maximum hook height. Samson and the Goliath have built the largest GCS ever that could each lift up to 840 tons [16].

Many cranes facing the same problem of the inefficiency cause by payload oscillations. It is difficult to manipulate payload accurately, quickly and safely because of the natural sway of crane payload. The purpose of crane controlling is to transfer the load as fast as possible without increasing any excessive sway at the desired position. Moreover, the results in a sway motion gave the terrible response when payload stopped after desired motion. The problem is become more complicated when the payload use a Double-Pendulum Gantry Crane System (DPGCS). It motion is very complex and its dynamic behavior are definitely related to the noise level of whole structure [10]. If the
crane behaves like a single-pendulum, the crane operators can eliminate much of the residual motion by causing a deceleration oscillation that cancel the oscillation induced during acceleration. For the system that behaves like a double pendulum, manual method of eliminating residual vibration becomes very difficult even for the most experienced operators. It may cause an accident if the problem cannot be resolved.

1.2 Motivation

Safety issues are very important because the GCS involved the use of shipping heavy loads. Gantry crane accidents have the potential to cause a serious injury or death to employees and other person involved. Many cases have been reported involving an accident on the gantry crane. This accident occurred is due to failure in handling the crane and may cause load collapse. Even though the person that have been injured in accidents have the legal right to claim compensation for the losses if cause by the negligence of the employer but precaution is better to avoid the injury occurred.

This matter can be supported with incident occurred involving crane which is on May 21, 2013 (Tuesday) at the Gallatin, Tennessee where the crane (Terex/American 165) owned and operated by Mountain States Contractors. According to the inspection report, a construction worker died on previous works. During the incident happen, the crane was collapse and fall on to a moving car. In this accident, nobody was seriously hurt on Highway 109 in Gallatin when the crane was crashed down the car. Gallatin police reported that the strong winds at that time in the afternoon were caused of the accident.

Based on the above issues, another way to curb and prevent this problem from continuing to happens is to study the behavior of cranes system in order to analyze the response performance of the system.
Figure 1.2: The overview of crane accident.
1.3 Problem Statement

i. Gantry crane has been developed to transfer heavy load as fast as possible or in a short period of time without causing any excessive swing at the desired position. However, the trolley acceleration always induces unwanted load swing. If the mass of trolley were increased, swing angle becomes larger. It requires more time to minimize the swing angle.

ii. Most of the gantry crane is manually controlled by the skillful and experience operators in handling cranes in order to make sure the payload stop swaying at correct position. A manual control is one of the factors that cause an accident in case of carelessness in handling the cranes. If the load becomes larger, it may cause accident and also harm people surrounding.

1.4 Significant of Project

i. According to previous researches, a lot of controllers have been designed in order to find the good performance of DPGCS. Most of controllers are used to control the trolley position and payload oscillation. However, the expected result still cannot be solved.

ii. Most industries are used general controller such as PID, Fuzzy Logic, and Input Shaping to overcome and improve the performance response. By development and investigations of dynamic modeling, it will lead us to better understand the behavior DPGCS in terms of performance response.