3D CRANE SYSTEM

By

Umi Hani Mustafa

Dissertation submitted in partial fulfillment of
the requirement for the
BACHELOR OF ENGINEERING (Hons)
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Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Electrical & Electronics Engineering Programme
Universiti Teknologi PETRONAS
In partial fulfillment of the requirement for the
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Approved by,

____
(Dr Mohd Noh b Karsiti)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
June 2004

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

UMI HANI MUSTAFA

ABSTRACT

This is a research and analysis project on studying the 3D Crane System. The 3D Crane System is widely used for industrial purposes to move cargo, goods and supplies. But one of the problems is when the payload/pendulum is swinging too oscillatory. Thus, it could give the impact on the safety of personnel who controlling the crane and public servant around the crane area.

The goals of this project are to analyse and study the dynamic behavior of 3D Crane System and to design and test a control strategy to improve the performance of the crane system. Through this project, the performance of the crane system is measured in terms of stability of the crane especially on the pendulum oscillation and accuracy of the crane movement to the desired position. In this project, only one control strategy had been designed, which is tuning the PID controller parameters. Thus, tuning the PID parameters expected to reduce the oscillatory of the payload and improving the performance of the crane system. Some tuning methods analysis had been used in order to obtain the tuning parameters of PID controller which are Ziegler Nichols Method and Ciancone Correlations Tuning Method. To obtain the PID tuning parameters, many experiments had been done by varying the gain to obtain the best response (constant amplitude). From the response, using the tuning method, the tuning parameters for PID controller is obtained. All the tuning parameters for each axis obtained were set into respective PID controller and combined it into 3 axis controller. The final response shows the response from actual cart position from 3 axis and response of angle payload in x and y axis. Conclude that, the objective of this project is met where the performance of the response of cart position and angle of payload is better compare before undergoing the tuning PID controller. The scopes of this project include literature review on 3D crane system and Matlab simulation by varying PID tuning parameters. The purpose of this simulation is to see the response curve based on tuning parameters obtained and compare with the response curve before the PID is tuned. Therefore, the performance of the crane system can be observed either better or not.

ACKNOWLEDGEMENT

Deciding to pick a final year topic is the easy part. Actually, starting and, more importantly, finishing the process is another story. Although there is only one author's name in the cover of this particular report, it would have been impossible to accomplish this work without the help and support of many other people throughout the months of deadlines, schedules juggling, mislead sleep, and a complete lack of social life.

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Special thanks to En. Azhar, Technician in charge in Control Lab. He had given a big help in providing equipment, troubleshoot the crane when it have a failure and materials needed in conducting the simulation and experiments. His support and guidance will always be appreciated. A special appreciation is also conveyed to Nur Atikah Abu Bakar, Mr. Fawnizu Azmadi b Hussein, Mr. Azman Zainuddin and Mr Rosdiazli for assistance and guidance towards completing this project.

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INTRODUCTION

1.1 Background of Study / Project Goal

In the present day in industrial world, 3D Crane System widely used in lifting and to move the cargo, goods and supplies. The 3D Crane System have three-dimensional motion where it is controlled by three control DC motors to move in ***x***, ***y*** and ***z-axis*** direction. It is a non-linear electromechanical system having complex dynamic behavior. The control of the crane is achieved by using Matlab / Simulink environment, RT-DAC3 acquisition board and RTWT (Real-Time Window Target) software driver [1].

In this project, by using a 3D crane model by Inteco as a gantry of this project, a few analyses have been done through some experiments to see the response and instability of the crane. From the analysis and added with some studies on dynamic crane system, some problems have been identified that causing the instability of the crane include the high oscillation of the payload and less precision of the cart position to the desired position.

Therefore, to solve the problem, the Author need to design a control strategy and test the design control strategy on lab 3D Crane System. In this project, only one control strategy had been designed, which is tuning the PID controller parameters where the PID controller is played a main role. Therefore, tuning the PID parameters expected to reduce the oscillatory of the payload and improving the performance of the crane system. Some tuning methods analyses have been determined to obtain the tuning parameters of PID controller. Therefore, for this control strategy, the Author focuses on analysis and tuning the parameter of PID controller.

Therefore, the main goal of this project is to design a few control strategies and test it on lab 3D crane system to improve the performance of the crane system.

1.2 Objectives and Scope of Study

1.2.1 Objectives

The objective of Final Year Project is to develop a framework, which will enhance skills in the process of applying knowledge, expanding thought, solving problems independently and presenting findings through minimum guidance and supervision.

However, the detail objectives of this project listed as below:

- Main objective is to design a control strategy, which expected to produce a ***better performance*** of the 3D Crane **Inteco** crane system. Therefore, need to figure out what causes that affect the performance of the crane system.
- In order to meet the main objective, need to learn and understand what the dynamics of the crane system.
- Need to familiarize the Matlab environment in controlling the crane system and familiarize & study the function of RTWT in controlling the crane.
- From that, need to identify the problem encountered that causing the instability of the crane system.
- Need to determine and tune the parameter of the PID controller in reducing the instability of the crane system.
- Finally, need to produce and propose what is the best control strategy in order to produce the best performance of the crane system if it applied in real life.

1.2.2 Scope of Study

Two timeframe has been given in order to complete the task given.

For the last semester, scope of study is going to be conducted is theoretical studies. For this semester, scope of study that is going to be conducted is simulation implementation by using Matlab Simulink Block. Table 1 shows plan work to complete the project.

Table 1.1: Work Plan

Theoretical Studies	• Identification of disturbances that contribute non-linearity of crane system • Identification of method used to reduce the disturbances in crane system. • Determination of tuning parameters of PID Controller for all axes.
Simulation Stage	• Simulate based on the parameters calculated of PID Controller. • Do the simulation on all axis (x, y and z axis) • Finally, own controller had been designed.

1.3 Problem Statement

1.3.1 Problem Identification

A few problems have been identified is briefed as below.

1. The crane problem is illustrated in Figure 1 (in the appendix section) where the pendulum is hanging in the down (equilibrium) position from the cart. Swinging is induced in the pendulum as the cart is moved back and forth by the DC motor. The situation being studied as the crane is moved from one point to another. The velocity and angle of the pendulum swing may become very large or the duration of the swing is too long.

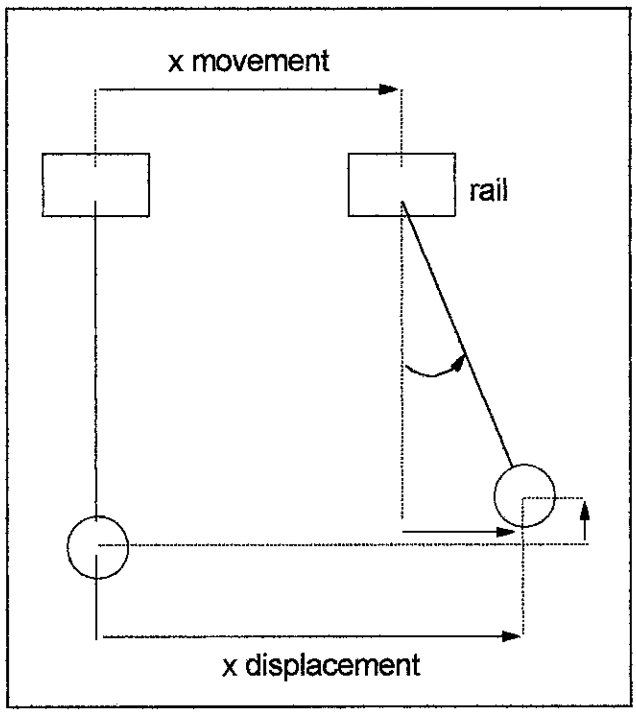


Figure 1.1: The Movement of the Crane System

2. The efficiency of movement of x, y and z-axis driver to a certain position in terms of smoothness and preciseness is a crucial element characteristic of a 3D crane. Therefore, the percentage of efficiency in the 3D crane model must be low in order to improve the crane performance.

3. The motion of a hanging payload swinging accordance to a moving wheel in x, y and axis will produce an overshoot. In order to reduce the angle of overshoot produced, an analytical solution is to be conducted.

4. Cart friction and air friction are identified as a part contributor in reducing the linearity of the crane system. Therefore, dynamic compensators need to be designed in order to reduce and compensate the linearity error.

5. Static friction also contributes an error in linearity and stability of the crane system. Static friction is frictions exist between static cart and initial cart started to accelerate. Thus, produce an overshoot that will be increasing the angle of pendulum swinging and effect the stability of the crane system.

1.3.2 Significant of the Project

Gantry system is a common problem seen in modeling and controlling of overhead cranes used at shipping ports and construction sites to move cargo and supplies. When the payload/pendulum swinging is too oscillatory, the impact on the safety of the personnel who controlling the crane and public servant around the crane area must be looked at. The cargo and supplies moved also damaged due to instability of the crane in moving the payload.

1.4 Organisation of Report

In this report, it has been divided into four chapters. There are:

- CHAPTER 2: LITERATURE REVIEW

  From this chapter, briefs on crane system description. More information on the dynamics of the crane system and dynamics of PID Controller.

- CHAPTER 3: METHODOLOGY / PROJECT WORK

  Methodology describes the sequence of project work, designation and implementation starting from the gathering of information till the simulation stage.

- CHAPTER 4: RESULTS AND DISCUSSION

  Briefs and a bit discussed on result obtained based on experiment of tuning the PID parameters.

CHAPTER 2

LITERATURE REVIEW AND/OR THEORY

For the purpose of conducting this research, the Author had done some literature review to gain enough fact in order to proceed with the research. There are many types of information available to strengthen the facts produced. Most of information that is available regarding to the 3D crane system is mostly from the User Guide from Inteco crane model [2].

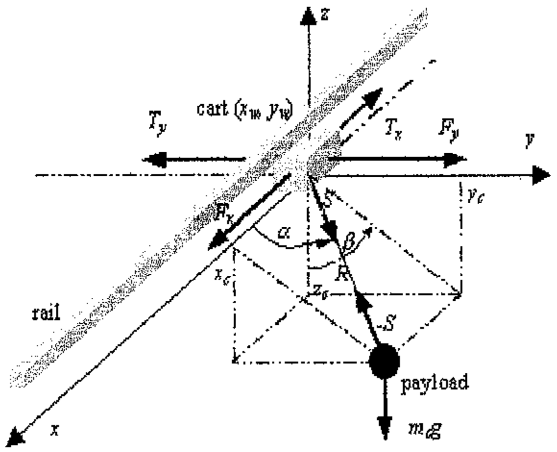
Since the main goal is to design a control strategy for the crane system, the Author needs to analyse the motion and response of the crane system through some experiment that have been conducted. However, the Author needs to understand on the dynamics of the 3D crane system because it helps the Author to understand what the cause of high oscillation of the payload and less preciseness of the cart position.

2.1 Dynamics of The Crane Model [2]

Dynamics of the crane model has been described and listed below is a description of five measured quantities that has been described in this model.

- x_w = the distance of the rail with the cart from the center of the construction frame.
- y_w = the distance of the cart from the center of the rail.
- R = the length of the lift-line.
- α = angle between the x-axis and the lift-line.
- β = angle between the negative direction of the z-axis and the projection of the lift-line to the yz plane.

Figure 2.1 shows a crane model diagram and symbol definition that has been obtained from the User Manual 3D Crane (Inteco).



- m_c - mass of the payload
- m_w - mass of the cart
- m_s - mass of the moving rail
- x_c, y_c, z_c - components of the payload position vector
- S - gravity force of the payload
- x_w, y_w - components of the cart position vector (z_w = 0)
- F_x - force driving the cart
- F_y - force driving the rail & cart
- T_x, T_y - friction forces corresponding to motions in the x and y directions
- R - length of the lift-line

Figure 2.1: Symbol Definition of Crane Diagram

From **Figure 2.1**, crane equation is derived based on denotation of state representation shows in **Table 2.1**.

Table 2.1: State Representation

$M = m_w^2 + m_c m_s + m_w m_s + m_c m_w$	$u_1 = F_x$	$N_x = u_1 - T_x$
$M_y = m_w + m_s$		
$N_x = F_x - T_x$	$u_2 = F_y$	$N_y = u_2 - T_y$
$N_y = F_y - T_y$	$u_3 = F_z$	$N_z = u_3 + g - T_z$
$V_5 = c_5 s_5 x_8^2 x_9 - 2x_{10} x_6 + g c_5 c_7$		
$V_6 = 2x_8 (c_5 x_6 x_9 + s_5 x_{10}) + g s_7$	$x_1 = x_w$	$x_6 = \dot{x}_5 = \dot{\alpha}$
$V_6 = s_5^2 x_8^2 x_9 + g s_5 c_7 + x_6^2 x_9$	$x_2 = \dot{x}_1 = \dot{x}_w$	$x_7 = \beta$
	$x_3 = y_w$	$x_8 = \dot{x}_7 = \dot{\beta}$
$A = m_w^2 + m_w m_s + m_c m_w \sin^2 x_5 \sin^2 x_7 + M_y m_c \cos^2 x_5$	$x_4 = \dot{x}_3 = \dot{y}_w$	$x_9 = R$
$s_n \equiv \sin x_n$	$x_5 = \alpha$	$x_{10} = \dot{x}_9 = \dot{R}$
$c_n \equiv \cos x_n$		

$$\dot{x}_1 = x_2$$

$$\dot{x}_2 = N_1 + \mu_1 c_5 N_3$$

$$\dot{x}_3 = x_4$$

$$\dot{x}_4 = N_2 + \mu_2 s_5 s_7 N_3$$

$$\dot{x}_5 = x_6$$

$$\dot{x}_6 = \left(s_5 N_1 - c_5 s_7 N_2 + \left(\mu_1 - \mu_2 s_7^2\right) c_5 s_5 N_3 + V_5\right) x_9$$

$$\dot{x}_7 = x_8$$

$$\dot{x}_8 = -\left(c_7 N_2 + \mu_2 s_5 c_7 s_7 N_3 + V_6\right)\left(s_5 x_9\right)$$

$$\dot{x}_9 = x_{10}$$

$$\dot{x}_{10} = -c_5 N_1 - s_5 s_7 N_2 - \left(1 + \mu_1 c_5^2 + \mu_2 s_5^2 s_7^2\right) N_3 + V_7$$

The dynamics of the crane system helps the Author understands the system model based on the dynamics denoted. From the system model obtained, the Author can determine the controlling parameters which are to be controlled.

2.2 Dynamics of The PID Crane Controller

The objective the Author to study and analyse the dynamics of the PID controller is that, to gain understand how the PID controller helps in reducing the oscillatory of the payload and increasing the preciseness of the cart position to the desired position.

To study and analyse the dynamics of the PID controller, the Author needs to determine a few types of error exist in the crane system to confirm that the PID controller is the only controller that controls the errors occurred.

Therefore, a few disturbances have been identified which are cart friction, air friction, noise and error produced between desired position and manipulated position. In **Figure 2.2** shows a instability of crane response.

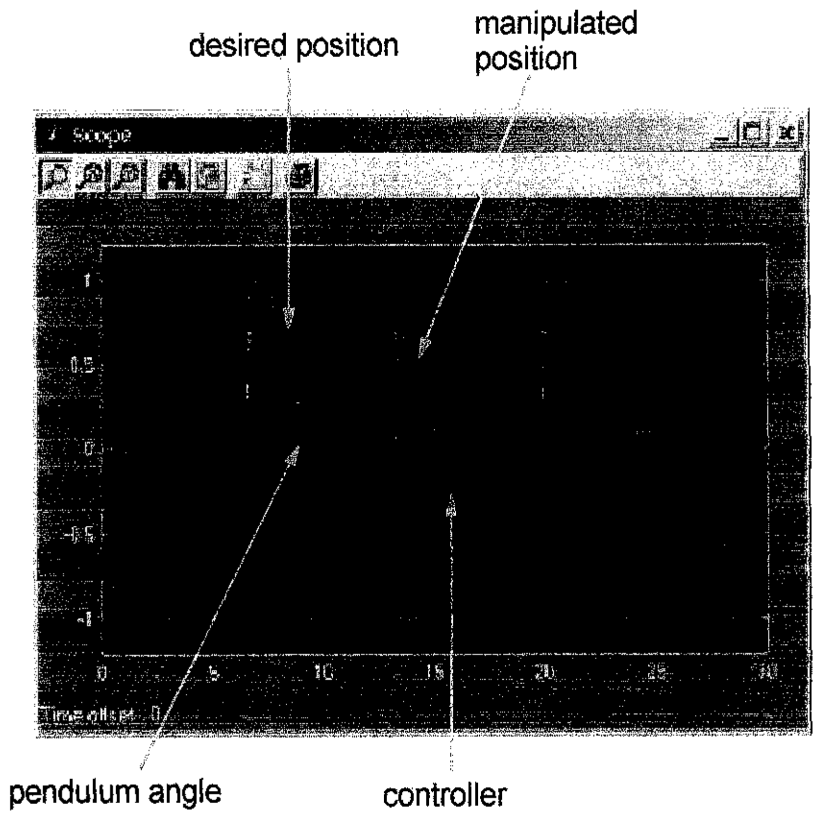


Figure 2.2: Data visible of crane response.

Therefore, in order to control the crane as per required, PID Controller has been chosen to solve the problem of disturbance.

The PID control rule is very common in control systems. It is the basic tool for solving most process control problems. The transfer function of basic PID controller has the form

$$u(t) = K_p e(t) + K_i \int_0^{\tau} e(t)d\tau + K_d \frac{d}{dt}(e(t))$$

where u(t) is the control output and the error, e(t), is defined as

e(t) = desired value – measured value of quantity being controlled.

The control gains K_p, K_d and K_i determine the weight of the contribution of the error, the integral of the error, and the derivative of the error to the control output. The simulink block of PID Controller is built based on equation above shows in **Figure 2.3**.

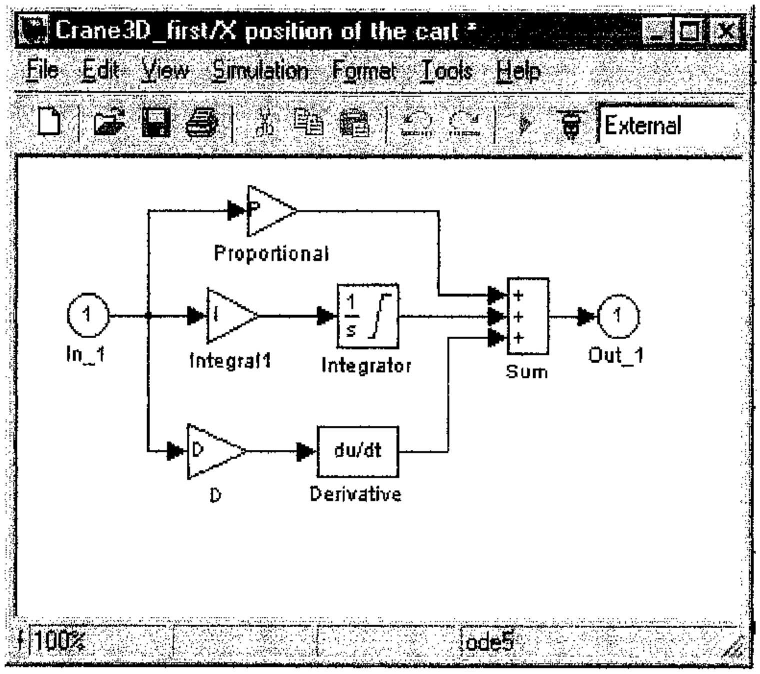


Figure 2.3: Simulink Block of PID Controller

CHAPTER 3

METHODOLOGY / PROJECT WORK

In this project, the Author stresses on designing a control strategy, which is tuning the parameter of the PID controller. Firstly, the Author need to determine the main caused that causing the instability the crane system performance. The main caused are oscillation of the payload during movements to certain direction, and less preciseness for cart position to the desired position. Therefore, a few experiments have been conducted to get the best response curve of the payload oscillation and the cart position. Follows are the methodology in determining the best tuning parameters using Ziegler-Nichols analysis for x, y and z-axis. In the final analysis, the Author shows the results of the response combining the three axis tuning parameters.

Before the analysis is started, the Author needs to know the exact position of the PID controller in the crane system simulink model. Below in Figure 5 [1] shows the simulink model of the crane system.

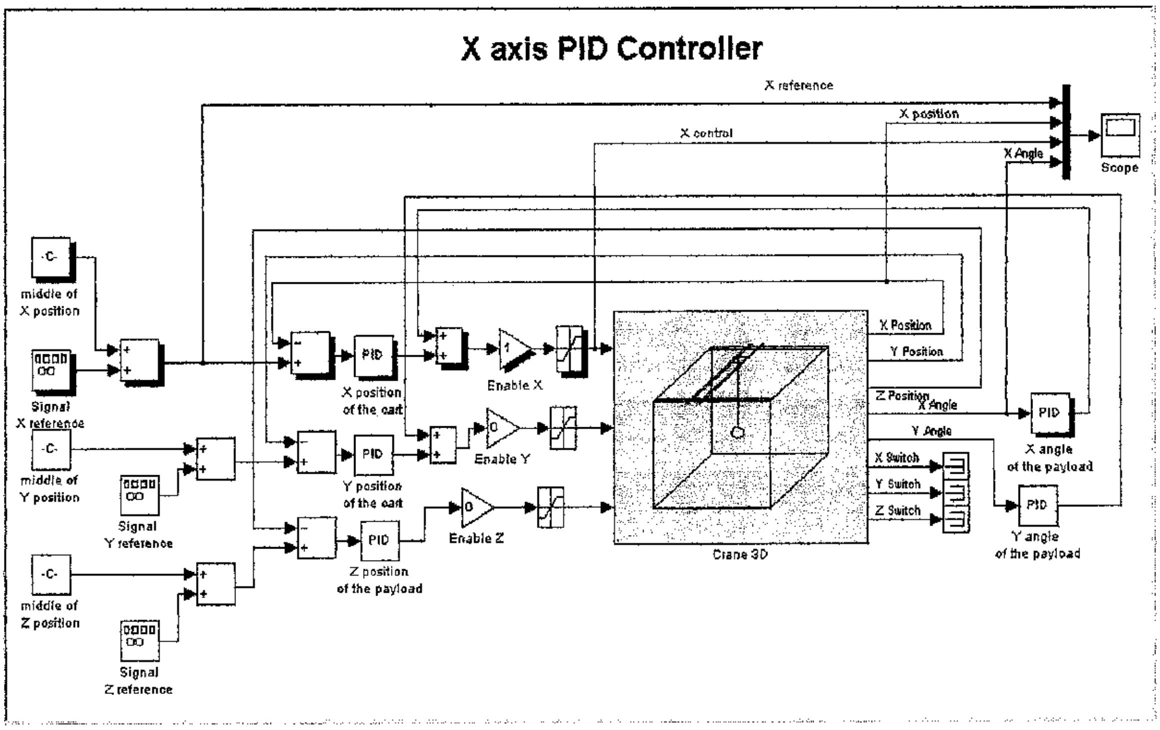


Figure 3.1: Simulink Model of the Crane System

Based on the simulink model shown in **Figure 3.1**, shows that the first PID controller is located at the input of cart position where the function of the PID controller is to control the cart position to follow the desired position. The second PID controller is located at the output of the crane system where to control the oscillatory of the payload.

Therefore, from the simulink model, the Author had been determined that the crane system is closed loop system. Thus, the analysis conducted is based on the closed-loop system analysis. There are a few methods analysis had been used in determining the tuning parameters for PID controller for cart position and PID controller for oscillation of the payload which are; *Ciancone Tuning Correlations* and *Ziegler Nichols Closed Loop*. The best choice of method used is based on response curve obtained that conforming most closely to the characters of the curve and easiest way in determining the tuning parameters. Refer to **Figure 3.2** in the Appendix section, shows the response of the curve for actual of cart position and oscillation of the payload in the X-axis direction. Since the characteristic of the cart position curve is looks like more to process reaction curve, the Ciancone Tuning Correlations Method is suitable to be used. While for oscillation of the payload curve, the curve is quite oscillatory and has a long settling time. Therefore, the Ziegler Nichols Closed Loop Method is suitable to be used.

3.1 Tuning Parameters for PID Controllers in X-Axis Direction

For X-axis direction, the cart and rail are moves together to the desired position. Therefore, the oscillatory of the payload doesn't make any effect on the response curve for the cart position to move to desired position.

In this section, two set of tuning parameters of PID controllers had been determined, PID controller of cart position and PID controller of payload angle.

3.1.1 Determining the Tuning Parameters for PID Controller of Cart Position.

The main objective of these experiments is to reduce the offset between cart position to the desired position to reach the minimum by controlling Proportional controller of PID controller of cart position. At the same time, the PID controller of payload angle is set to zero for all P, I and D controllers.

Therefore, a few experiments have been conducted in determining the best Proportional gain in order to obtain the best response of the cart position where the offset between the actual cart position to the desired position is reached to the minimum value. Refer to **Figure 3.3** (attached in the Appendices section), shows the best response from one of the experiments conducted.

Therefore, in determining the tuning parameter for PID of cart position, the Ciancone Correlations Tuning Method is used. The S, θ, δ, and Δ values is determined based on the response obtained (**Figure 3.3**).

$S = 0.28$

$\theta = 0.13$

$\Delta = 0.37$

$\delta = 0.38$

Then, based on the formula of Ciancone Correlations, the value of K_p, τ and Fraction Dead Time is obtained. The calculation is shown as follows:

$$K_P = \frac{\Delta}{\delta} = \frac{0.37}{0.38} = 0.9737$$

$$\tau = \frac{\Delta}{S} = \frac{0.37}{0.28} = 1.32$$

$$\text{FractionDeadTime} = \frac{\theta}{\theta + \tau} = \frac{0.13}{0.13 + 1.32} = 0.089$$

Finally, based on Fraction Dead Time obtained, the value of K_C, T_I and T_D is determined by referring to the Fraction Dead Time Graph (Appendix 1) in the Appendices section.

$$K_C K_P = 1.1$$

$$K_C = \frac{1.1}{K_P} = \frac{1.1}{0.9737} = 1.1297$$

$$\frac{T_I}{\theta + \tau} = 0.25$$

$$T_I = 0.25(\theta + \tau) = 0.25(0.13 + 1.32) = 0.36$$

$$\frac{T_D}{\theta + \tau} = 0$$

$$T_D = 0$$

Table 3.1: Tuning Parameters for PID Controller of Cart Position

K_C	T_I	T_D
1.1297	0.36	0

3.1.2 Determining the Tuning Parameters for PID Controller of Payload Angle

In obtaining the tuning parameters for PID of payload angle, Ziegler Nichols Tuning Method is the best method is chosen. A few experiments have been conducted in order to get the best Proportional gain where the oscillation of the payload angle is tend to reach the steady state fastest and have a minimum amplitude of oscillatory. Refer to **Figure 3.4** (attached in the Appendices section), shows the best response of payload angle from one of the experiments conducted.

Therefore, in determining the tuning parameter for PID of payload angle, the Ziegler Nichols Closed Loop Method is used. The K_U and T_U values is determined based on the response obtained (**Figure 3.4**).

$\mathbf{K_U} = 1$

$\mathbf{T_U} = 9.42$

Tuning parameters K_U and T_U obtained are calculated referring to Appendix 2. Values of tuning parameters are defined in **Table 3.2**.

Table 3.2: Tuning Parameters of PID Controller

Control Mode	Calculation	Tuning Parameters
P only	$K_C = 1.5\ K_U = 1.5\ (1)$	$K_C = 1.5$
P+I	$K_C = 0.45\ K_U = 0.45\ (1)$ $T_I = T_U / 1.2 = 9.42 / 1.2$	$K_C = 0.45$ $T_I = 7.85$
P+I+D	$K_C = 0.6\ K_U = 0.6\ (1)$ $T_I = T_U / 2 = 9.42 / 2$ $T_D = T_U / 8 = 9.42 / 8$	$K_C = 0.6$ $T_I = 4.71$ $T_D = 1.18$

Finally, tuning parameters for both PID controllers had been determined. However, control mode chosen is Proportional only because the control performance of the proportional controller satisfies the desired control performance goals. Meaning that the response obtained is reached more stability using this control mode compared using other's control mode.

3.1.3 Final Response Curve Using Tuning Parameters Calculated

Using the tuning parameters that have been determined and set into respective PID controller, the response curve result from both PID controllers can be referred to **Figure 3.5** (in the Appendix section).

3.2 Tuning Parameters for PID Controllers in Y-Axis Direction

For Y-axis direction, only cart is moves to the desired position. Therefore, the oscillatory of the payload does make any effect on the response curve for the cart position to move to the desired position.

In this section, two set of tuning parameters of PID controllers had been determined, PID controller of cart position and PID controller of payload angle.

3.2.1 Determining the Tuning Parameters for PID Controller of Cart Position.

The main objective for these experiments is basically same as previous experiment which is to reduce the offset between cart position to the desired position to reach the minimum by controlling Proportional controller of PID controller of cart position. At the same time, the PID controller of payload angle is set to zero for all P, I and D controllers.

Therefore, a few experiments have been conducted in determining the best Proportional gain in order to obtain the best response of the cart position where the offset between the actual cart position to the desired position is reached to the minimum value. Refer to **Figure 3.6** (attached in the Appendices section), shows the best response from one of the experiments conducted.

Therefore, in determining the tuning parameter for PID of cart position, the Ciancone Correlations Tuning Method is used. Because of the difficulty in evaluating the slope, especially when the signal has high frequency of noise, times at which the output reaches 28 and 63 percents of its final value is taken. Thus, the θ, δ, and Δ values is determined based on the response obtained (**Figure 3.6**) shown as follows.

$$\theta = 0.2$$

$$\Delta = 0.12$$

$$\delta = 1.075$$

$$t_{28\%} = 0.17$$

$$t_{63\%} = 0.3$$

Then, based on the formula of Ciancone Correlations, the value of K_p, τ and Fraction Dead Time is obtained. The calculation is shown as follows:

$$K_P = \frac{\Delta}{\delta} = \frac{0.12}{0.14} = 0.857$$

$$\tau = 1.5(t_{63\%} - t_{28\%}) = 1.5(0.3 - 0.17) = 2.647$$

$$\text{FractionDeadTime} = \frac{\theta}{\theta+\tau} = \frac{0.2}{0.2+0.435} = 0.315$$

Finally, based on Fraction Dead Time obtained, the value of K_C, T_I and T_D is determined by referring to the Fraction Dead Time Graph (Appendix 1) in the Appendices section.

$$K_C K_P = 1.1$$

$$K_C = \frac{1.1}{K_P} = \frac{1.1}{0.857} = 1.283$$

$$\frac{T_I}{\theta+\tau} = 0.7$$

$$T_I = 0.7(0.2+0.43478) = 0.444$$

$$\frac{T_D}{\theta+\tau} = 0.01$$

$$T_D = 0.01(0.2+0.43478) = 0.006 \cong 0$$

Table 3.3: Tuning Parameters for PID Controller of Cart Position

K_C	T_I	T_D
1.283	0.444	0

3.2.2 Determining the Tuning Parameters for PID Controller of Payload Angle

In obtaining the tuning parameters for PID of payload angle, Ziegler Nichols Tuning Method is the best method is chosen. A few experiments have been conducted in order to get the best Proportional gain where the oscillation of the payload angle is tend to reach the steady state fastest and have a minimum amplitude of oscillatory. Refer to **Figure 3.7** (attached in the Appendices section), shows the best response of payload angle from one of the experiments conducted.

Therefore, in determining the tuning parameter for PID of payload angle, the Ziegler Nichols Closed Loop Method is used. The K_U and T_U values is determined based on the response obtained (**Figure 3.7**).

$\mathbf{K_U} = 2$

$\mathbf{T_U} = 7.4$

Tuning parameters K_U and T_U obtained are calculated referring to Appendix 2. Values of tuning parameters are defined in **Table 3.4**.

Table 3.4: Tuning Parameters of PID Controller

Control Mode	Calculation	Tuning Parameters
P only	$K_C = 1.5\ K_U = 1.5\ (2)$	$K_C = 3.0$
P+I	$K_C = 0.45\ K_U = 0.45\ (2)$ $T_I = T_U / 1.2 = 7.4 / 1.2$	$K_C = 0.9$ $T_I = 6.167$
P+I+D	$K_C = 0.6\ K_U = 0.6\ (2)$ $T_I = T_U / 2 = 7.4 / 2$ $T_D = T_U / 8 = 7.4 / 8$	$K_C = 1.2$ $T_I = 3.7$ $T_D = 0.925$

Finally, tuning parameters for both PID controllers had been determined. However, control mode chosen is Proportional only because the control performance of the proportional controller satisfies the desired control performance goals. Meaning that the response obtained is reached more stability using this control mode compared using other's control mode.

3.2.3 Final Response Curve Using Tuning Parameters Calculated

Using the tuning parameters that have been determined and set into respective PID controller, the response curve result from both PID controllers can be referred to **Figure 3.8** (in the Appendix section).

3.3 Tuning Parameters for PID Controllers in Z-Axis Direction

For Z-axis direction, the cart and rail are not move in the vertical and horizontal direction. In this experiment, the cart and rail static and only payload is moves up and down direction. Therefore, the movement of the payload up and down direction doesn't make any effect on the response curve especially on oscillatory of the payload.

In this section, two set of tuning parameters of PID controllers had been determined, PID controller of cart position and PID controller of payload angle.

3.3.1 Determining the Tuning Parameters for PID Controller of Cart Position.

The main objective of these experiments is to reduce the offset between actual payload position to the desired payload position to reach the minimum by controlling Proportional controller of PID controller of cart position. At the same time, the PID controller of payload angle is set to zero for all P, I and D controllers.

Therefore, a few experiments have been conducted in determining the best Proportional gain in order to obtain the best response of the cart position where the offset between the actual payload position to the desired payload position is reached to the minimum value. Refer to **Figure 3.9** (attached in the Appendices section), shows the best response from one of the experiments conducted.

Therefore, in determining the tuning parameter for PID of cart position, the Ciancone Correlations Tuning Method is used. The S, θ, δ, and Δ values is determined based on the response obtained (**Figure 3.9**).

$$S = 0.1386$$

$$\theta = 0.1298$$

$$\Delta = 0.144$$

$$\delta = 0.144$$

Then, based on the formula of Ciancone Correlations, the value of K_p, τ and Fraction Dead Time is obtained. The calculation is shown as follows:

$$K_P = \frac{\Delta}{\delta} = \frac{0.144}{0.144} = 1$$

$$\tau = \frac{\Delta}{S} = \frac{0.144}{0.1386} = 1.03896$$

$$\text{FractionDeadTime} = \frac{\theta}{\theta + \tau} = \frac{0.1298}{0.1298 + 1.03896} = 0.111$$

Finally, based on Fraction Dead Time obtained, the value of K_C, T_I and T_D is determined by referring to the Fraction Dead Time Graph (Appendix 1) in the Appendices section.

$$K_C K_P = 1.1$$

$$K_C = \frac{1.1}{K_P} = \frac{1.1}{1} = 1.1$$

$$\frac{T_I}{\theta + \tau} = 0.25$$

$$T_I = 0.25(\theta + \tau) = 0.25(0.1298 + 1.03896) = 0.292$$

$$\frac{T_D}{\theta + \tau} = 0$$

$$T_D = 0$$

Table 3.5: Tuning Parameters for PID Controller of Cart Position

K_C	T_I	T_D
1.1	0.292	0

3.3.2 Determining the Tuning Parameters for PID Controller of Payload Angle

Since the movement of the payload in up and down direction does not give any effect on the oscillatory of the payload, therefore, the PID controller at the payload angle is not utilized. Thus, the Author set all zero in P, I and D controller at the payload angle.

3.3.3 Final Response Curve Using Tuning Parameters Calculated

Using the tuning parameters that have been determined and set into respective PID controller, the response curve result from both PID controllers can be referred to **Figure 3.10** (in the Appendix section)

3.4 Test All the Tuning Parameters Obtained to All PID Controller in All Axis.

All the tuning parameters for each axis that have been obtained are set into respective PID controller and combined into the simulink model of the crane system as shown in **Figure 3.11** (attached in the Appendix section). The response is shown in **Figure 3.12** (attached in the Appendix section).

3.5 Tool Required

- **Real-Time Workshop**

  Real-Time Workshop of an extension of capabilities found in Simulink and Matlab to enable rapid prototyping of real-time software application on a variety of systems. Real-Time Workshop, along with other tools and components from The Math Works, provides

  - Automatic code generation tailored for a variety a target platforms
  - A rapid and direct path from system design to implementation.
  - Seamless integration with Matlab and Simulink.
  - A simple graphical user interface.
  - An open architecture and extensible make process.

- **Matlab and Toolboxes**

  Integrate with the Real-Time Workshop. Means that, it come with one package together with Real-Time Workshop in conducting the crane.

- **Simulink Stateflow Blockset**

  Integrate with the Real-Time Workshop. Means that, it come with one package together with Real-Time Workshop in conducting the crane.

- **3D Crane Model**

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Response for X-axis

Table 4.1: Tuning Parameters for PID Controller of Cart Position (X-Axis)

K_C	T_I	T_D
1.1297	0.36	0

Table 4.2: Tuning Parameters for PID Controller of Payload Angle (X-Axis)

K_C	T_I	T_D
1.5	0	0

Using the tuning parameters that have been determined and set into respective PID controller, the response curve result from both PID controllers can be referred to **Figure 3.5** (in the Appendix section).

4.1.2 Response for Y-axis.

Table 4.3: Tuning Parameters for PID Controller of Cart Position (Y-Axis)

K_C	T_I	T_D
1.283	0.444	0

Table 4.4: Tuning Parameters for PID Controller of Payload Angle (Y-Axis)

K_C	T_I	T_D
3.0	0	0

Using the tuning parameters that have been determined and set into respective PID controller, the response curve result from both PID controllers can be referred to **Figure 3.8** (in the Appendix section).

4.1.3 Response for Z-axis

Table 4.5: Tuning Parameters for PID Controller of Cart Position (Z-Axis)

K_C	T_I	T_D
1.1	0.292	0

Table 4.6: Tuning Parameters for PID Controller of Payload Angle (Z-Axis)

K_C	T_I	T_D
0	0	0

Using the tuning parameters that have been determined and set into respective PID controller, the response curve result from both PID controllers can be referred to **Figure 3.10** (in the Appendix section).

4.1.4 Final Response Curve Combination of 3-Axis

All the tuning parameters for each axis that have been obtained are set into respective PID controller and combined into the simulink model of the crane system as shown in **Figure 3.11** (attached in the Appendix section). The response is shown in **Figure 3.12** (attached in the Appendix section).

4.2 Discussion

4.2.1 Analysis on the Final Response Obtained

Figure 3.12 shows that the final response obtained based on tuning parameters calculated in the PID controller for x, y and z-axis. In the graph, there are eight responses curve shows the actual cart position of each axis and the oscillation for x and y-axis. This second order system (crane system) exhibits a wide range response. Changes in the parameters of a second-order system can change the form of the response. Based on the response obtained in **Figure 3.12,** there are 3 forms of response exhibits which are underdamped response, undamped response and critically damped response.

In the graph, the actual cart position for y and z-axis shows the same form of response which is underdamped response. It can be recognized from the response obtained that there is an overshooting and oscillating about the steady-state value for a step input. The response is named overdamped because it refers to a large amount of energy absorption in the system. That is why the response is overshooting and a bit oscillating to reach the steady state to follow the desired position. However, the response for both axis (y and z-axis) met the objective of this project which is minimizing the offset or error between the actual cart position and desired position.

For actual cart position response in the x-axis, the form of response is recognized as critically damped. The characteristic of critically damped response can be determined where the response is the fastest to reach the steady state without the overshoot. However, the response obtained for actual cart position in the x-axis, there is offset / error between actual cart position and desired position.

For payload angle response in the x-axis, the form of response looks like an undamped response. However, there is a bit of damping to reach the steady-state as time increases. Therefore, the response can be determined as underdamped response. For payload angle in the y-axis, the response is clearly is underdamped response since the oscillation of the payload is damped to the steady-state.

Basically, in determining the ultimate gain for PID controller in order to determine the best response and best performance, a few trial-and-error experiments have been conducted. The procedure is called continuous cycling. From the best response, using the Ziegler-Nichols and Ciancone Correlations analysis, the tuning parameters of PID controller is determined. In determining the initial best response, the crane system is controlled by a proportional - only controller where the set point perturbed slightly, and the transient response of the controlled variables is observed. When the crane system is stable either overdamped or oscillatory, the gain is increased. The crane system is unstable when the gain decreases. The iterative procedure is continued by changing K_C until after a set point perturbation where the crane system will oscillates with a constant amplitude. This behavior occurs when the crane system has exponential terms with (very nearly) zero values indicating that the crane system is at stability margin. The gain at this condition is the ultimate gain, and the frequency of the oscillation is the critical frequency. Therefore, the Ziegler-Nichols closed-loop tuning correlation is used in calculating the PID constants.

4.2.2 Stability Analysis and Controller Tuning Analysis

At this point, the Author has succeeded in developing a control algorithm (the proportional-integral-derivative controller) and a suitable method has been chosen for tuning its adjustable constants. Through a few experiments that have been conducted, the Author has seen on how feedback control can change the qualities behavior of a process, introducing oscillations in an originally over damped system and potentially causing instability. In fact, the Author shall see that the stability limit is what prevents the use of a very high controller gain to improve the control performance of the controlled variable. Therefore, a through understanding of the stability of dynamic systems is important, because it provides important relationship among process dynamics, controller tuning, and achievable performance. These relationships are used in a variety of ways, such as selecting controller modes, tuning controllers and designing processes that are easier to control.

What do we mean by stable and unstable? How to make our system and control systems to be stable? To answer those questions, the Author had to make a clear and precise definition of how to reach stability to the crane system. The termed *bounded input – bounded output stability*, can be employed in the design and analysis of the crane system. A variable is *bounded* when it does not increase in magnitude to the rail limit as time increases. Bounded inputs for the crane system are the step changes.

Elements in the control loop in the crane system influence the stability and tuning. Clearly, the types of instrument equipment involve in the control loop such as RTW (Real-Time Workshop) and Matlab & Toolboxes and also friction & noise give an affect on the crane system stability and feedback tuning constants. The Author had determined how the process dynamics affect feedback control, specifically the gain and the integral time of a PI controller. The amplitude ratio of the response obtained generally decreases for process elements as the frequency increases. Therefore, smaller time constants and dead times lead to a larger allowable controller gain. The smaller values of the time constant and dead times lead to a smaller integral time which gives a stronger effect on a control action. The previous result obtained in the Result section clearly demonstrates that the Fraction Dead Time and time constant obtained from the response produced a larger controller gain and smaller integral time, thus affect on the feedback tuning and stability.

Basically, the key relationship between tuning and fraction dead time is investigated for Ziegler Nichols PID Tuning. Clearly, the relationship can be referred in the Methodology section where these relationships are consistent with a common-sense interpretation of the feedback controller relationships. As previously mention that the fraction dead time and time constant influence the dynamic performance of the crane system. Since in this project, disturbance contribute a main factor that causing the instability of the system. Thus, the gain controller generally decreases as the fraction dead time increases. The dimensionless derivative time is zero for small fraction dead time and increases for longer dead times to compensate for the lower controller gain. The dimensionless integral time remains in a small range as the fraction dead time increases.

The stability was not explicitly considered in the Ciancone method, although tuning that gave unstable, still have an offset between actual cart position and desired cart position, or oscillatory systems would have a large IAE (Integral of Absolute Value) and thus would not have been selected as optimum. Just simply refer to the Final Response (shown in **Figure 3.12**) that combined three axes simultaneously. Note that the Ciancone gain values are lower, partly because of the objectives of robust performance with model errors and partly because of limitation on manipulated-variable variation with a noisy measured controlled variable [5].

Each mode of the PID controller affects the stability of the feedback system. Increasing the magnitude of the controller gain and decreasing the integral time tends to destabilize the feedback systems.

Many other tuning methods have been developed, generally based on either stability margins or time-domain performance. A summary of the methods is presented in **Table 4.1**, which gives the main objectives of each method used in this project.

Table 4.7: Summary of PID tuning methods

Tuning method	**Stability objective**	**Objective For CV(t)**	**Objective For MV(t)**	**Model error**	**Noise on CV(t)**	**Input SP = set point D = disturbance**
Ciancone	None explicit	Min IAE	Overshoot and variant with noise	±25%	Yes	SP and D individually
Ziegler Nichols closed-loop	Implicit margin for stability (GM $\approx$ 2)	4:1 decay ratio	None	None explicit	No	n/a

CHAPTER 5
CONCLUSION AND RECOMMENDATION

This project takes time on analysis on performance of crane system, identification of disturbances that contribute a non-linearity of crane system and identification of appropriate method to be used to obtain tuning parameters to control stability of crane system. There is only one control strategy that had been completed which is designing the PID tuning parameters.

In designing the PID tuning parameters, trial-and-error experiments have been conducted to obtain the best response that meet the objective of the project. From the response obtained, the tuning parameters are calculated. To this point, two controller tuning methods have been presented. The Ciancone correlations were based on a comprehensive definition of control performance in the time domain, whereas the Ziegler-Nichols closed loop method were based on the stability margin. Using these methods, the fraction dead time and time constant played a main role to give a better control performance. The more and longer time constants and dead times lead to detuning of the PID controller and that fewer and shorter time constants dead times lead to larger controller gain, smaller integral time, and stronger feedback action. Therefore, the stronger feedback action will give better control performance.

Basically, the Author has succeeded to achieve the objective of the project which is to give a better performance of the crane system compared with the original system for each axis. The oscillation of the payload is reduced to the minimum and the cart position follows the desired position even it takes a few second to complete its settling time. However, combination of 3-axis of PID controllers are shown a drastic characteristic in terms of performance of the crane system. It can be referred to the results obtained. Theoretically, the performance of the final response should be have a minimum oscillation and slow in the movements. However, due to some reasons, the final response fails to meet the objective of the project. Though, it stills the best performance from the crane system by using some analysis.

The final response can be improved by using a Bode analysis where the model system is determined. From the system model, transfer function of the system can be determined and therefore the location of zero and pole using a root locus analysis can be built. Thus, the dynamics behavior can be observed. Using this analysis, the excellent display of the effect of the tuning constants on the exponential terms and therefore on stability can be observed. In summary, application of general stability analysis method to feedback control systems demonstrates that the roots of the characteristic equation determine the stability of the system. If all roots have negative real parts, the system is bounded input-bounded output stable; if any root has a positive or zero real part, the system is unstable.

This particular project will prove the importance of tuning methods (stability analysis) in giving the stability on the system. Thus, give a better control performance. Note that, using this stability analysis, the substantial incentives exist for maintaining the system variable at a stable operating conditions. Thus, prevent damaging the system by excessive or over limited some variable.

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[3] Chen-I Lim, December 1999, “Thesis of Development of Interactive Modeling, Simulation, Animation, and Real Time Control Tool for Research and Education. A Framework for Real-Time Hardware Control – Arizona State University”

[4] Norman S.Nise, Third Edition, “Control Systems Engineering”

[5] Thomas E. Marlin, Second Edition, Process Control – Designing Processes and Control Systems for Dynamic Performance

APPENDICES

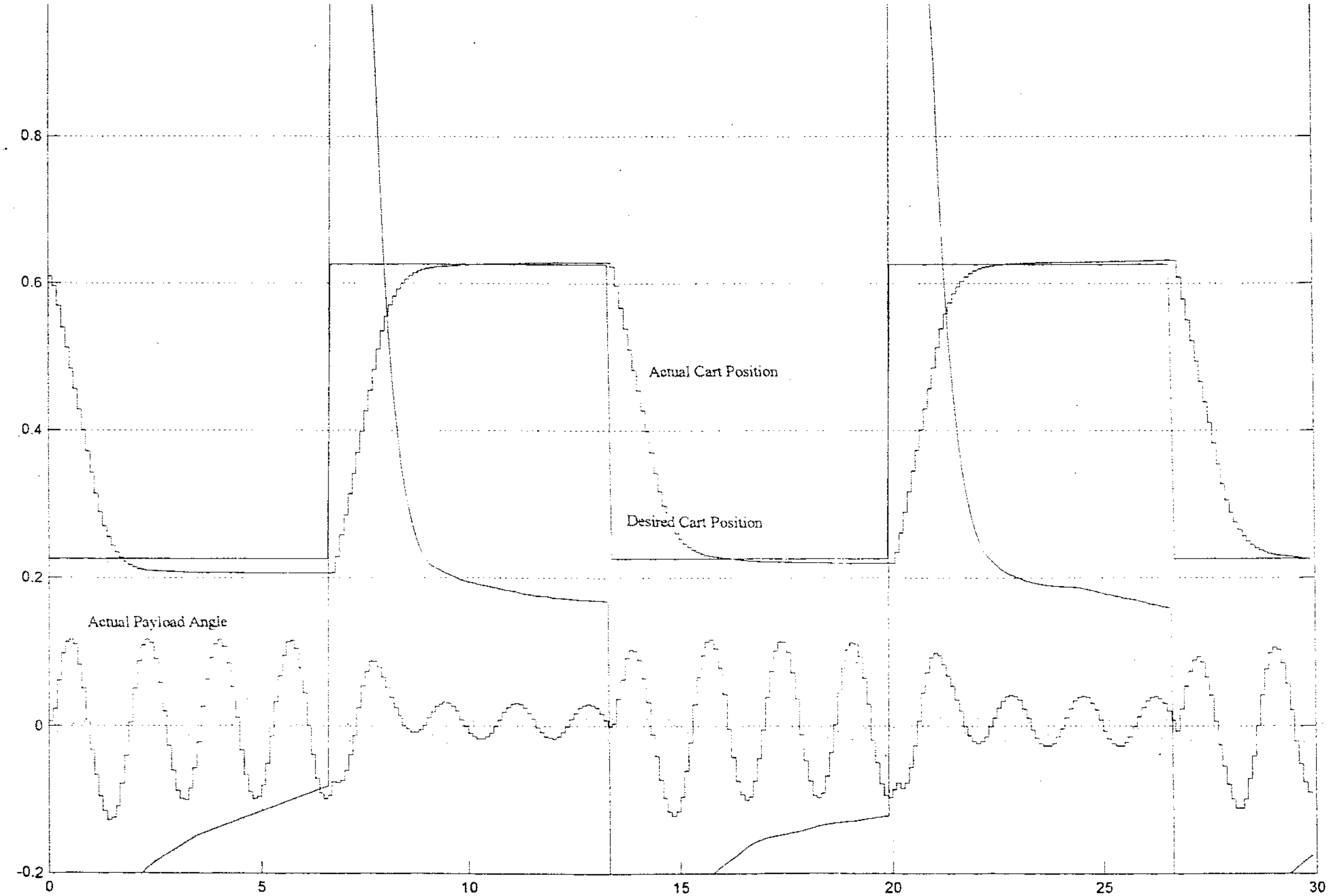


Figure 3.2: Response Curve of the Crane System

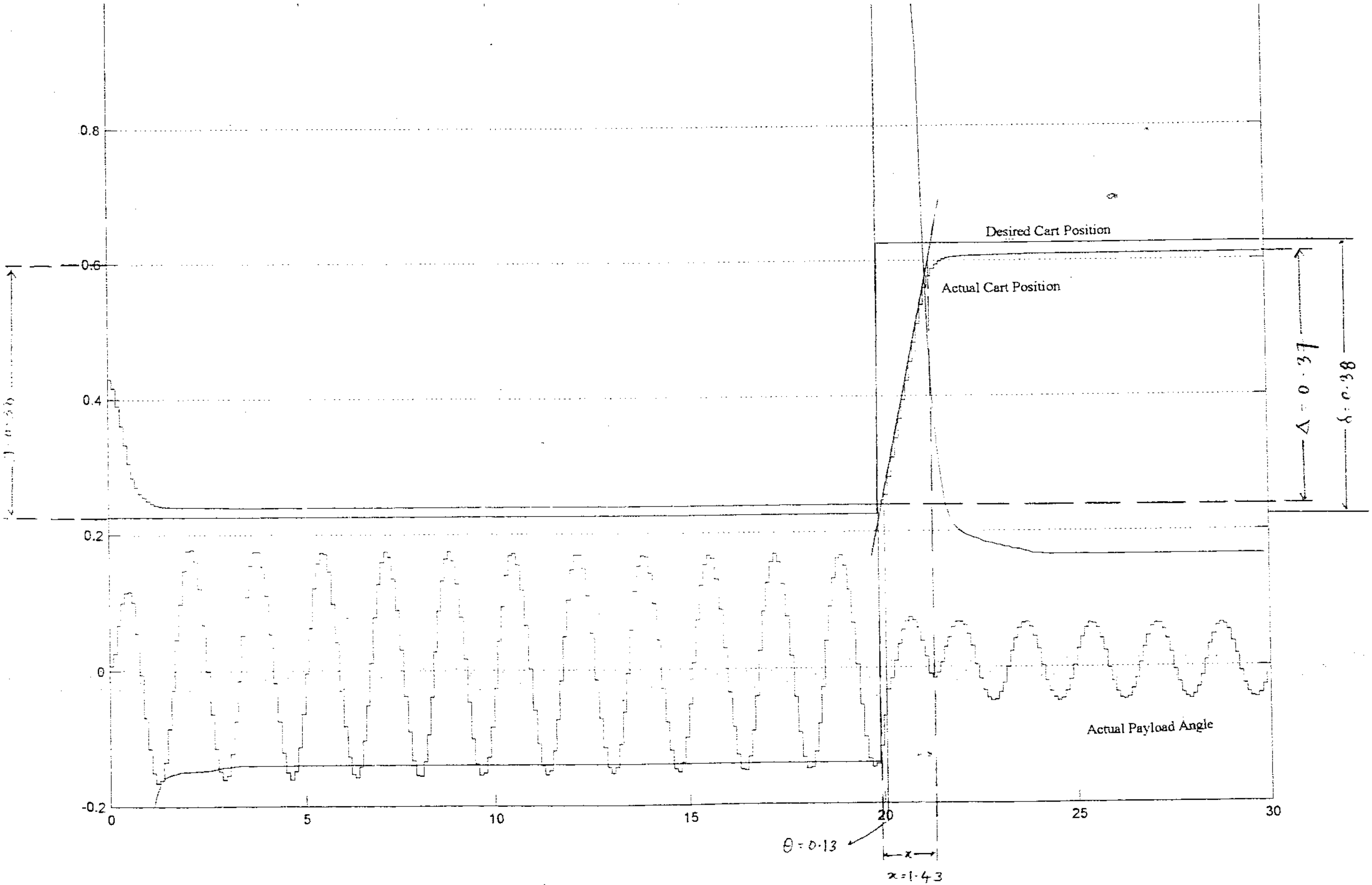
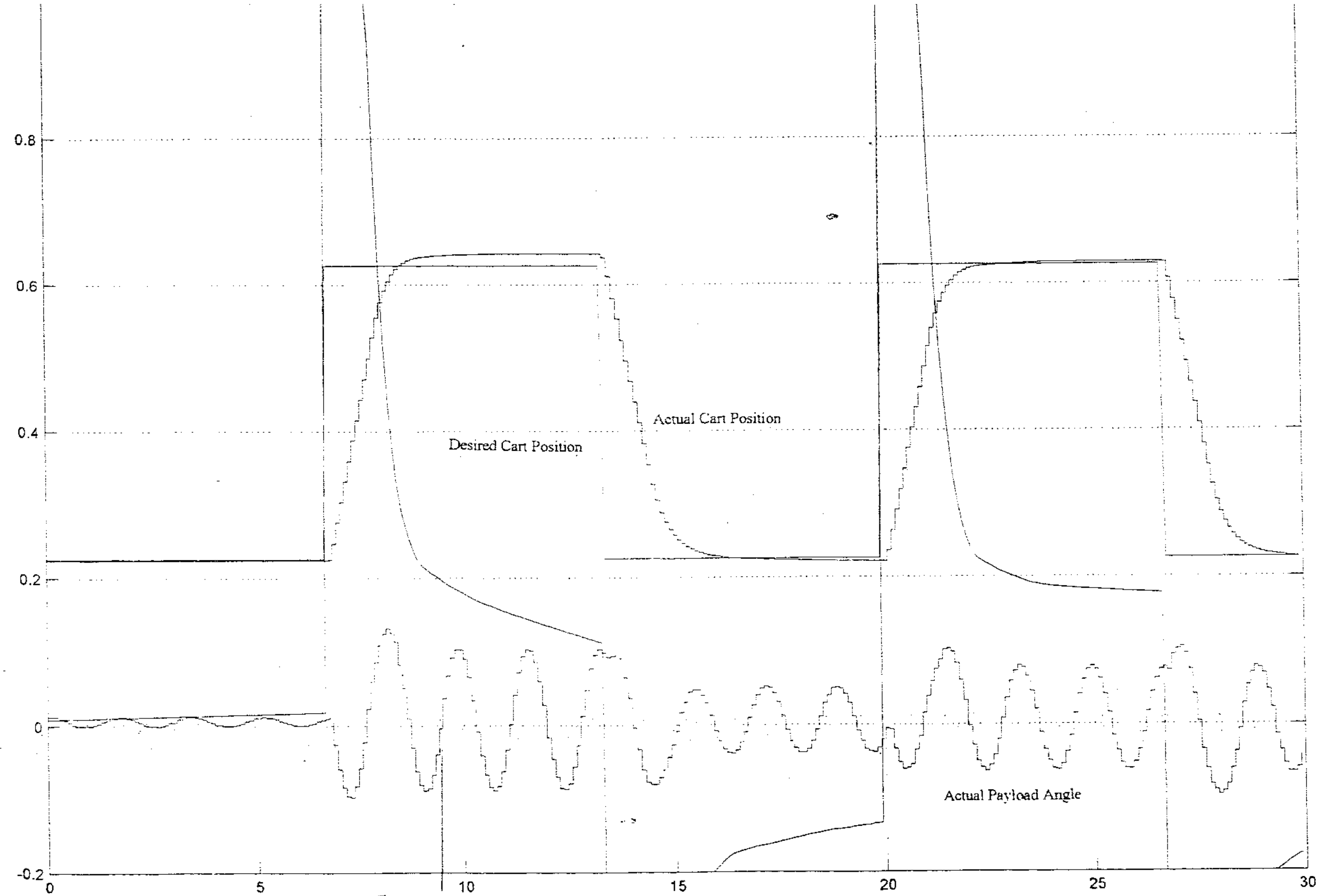


Figure 3.3: Best Response for Cart Position in the X-Axis



$T_u = 9.42$

Figure 3.4: Best Response for Oscillation of Payload in the X-Axis

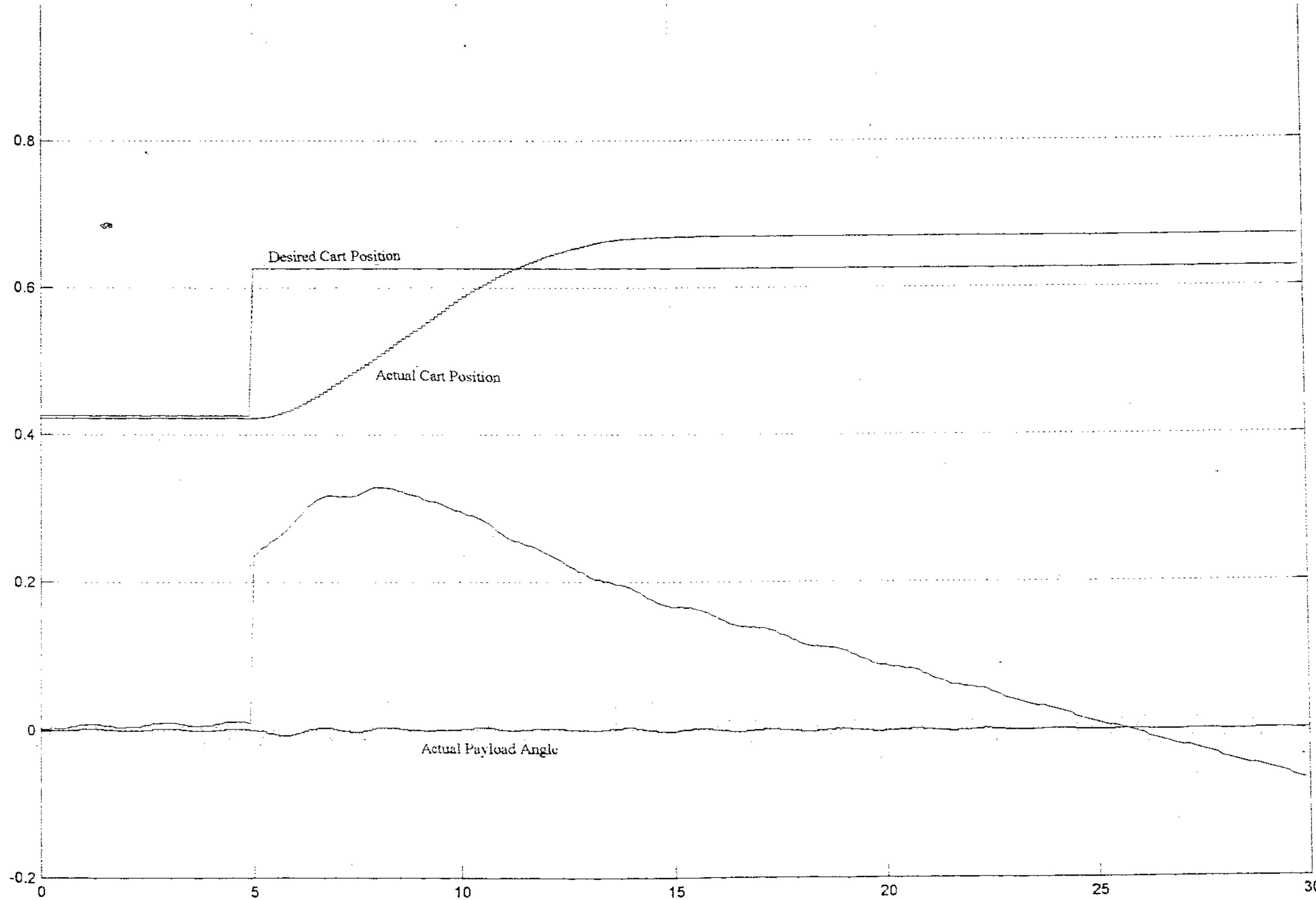


Figure 3.5: Final Response for X-Axis

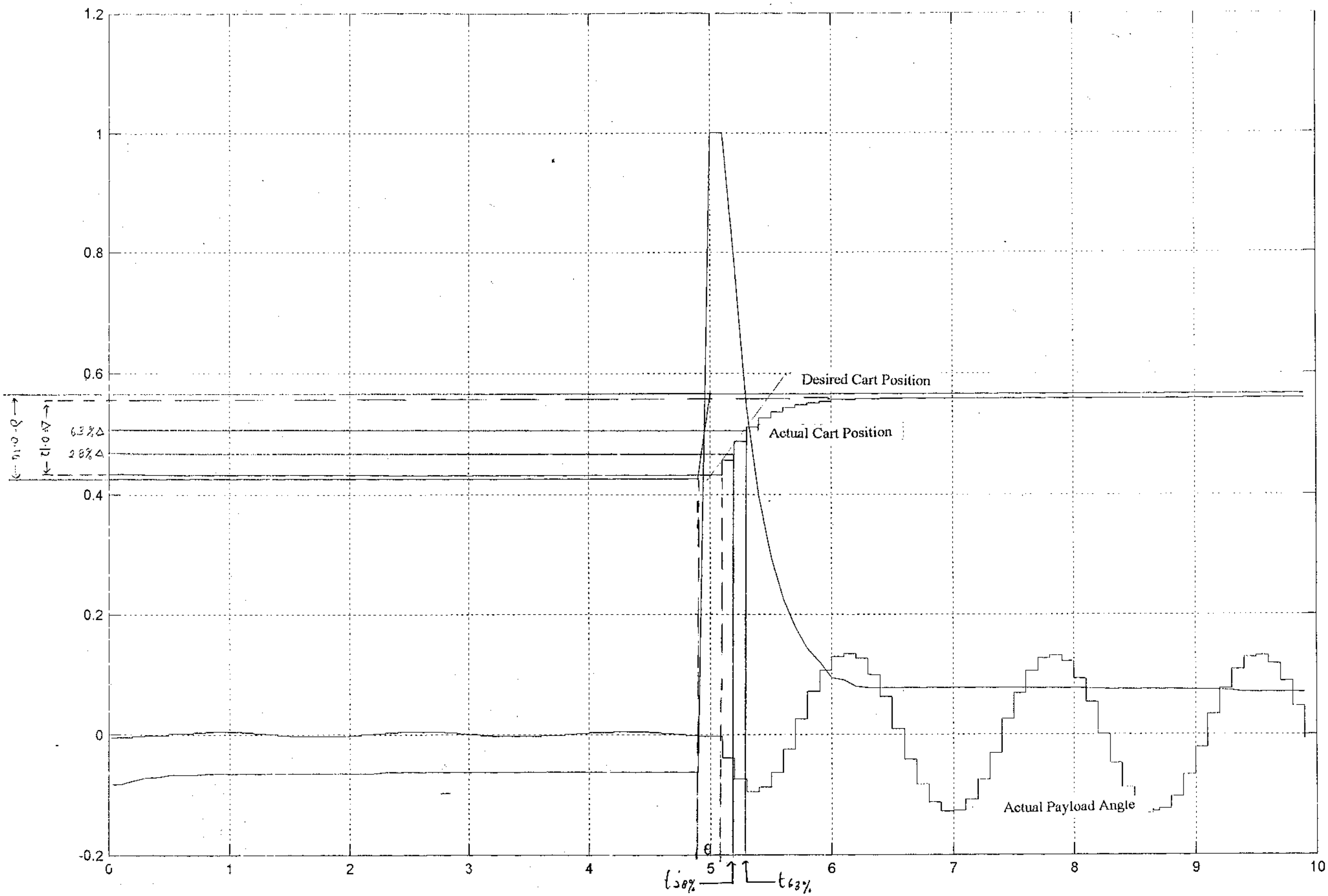


Figure 3.6: Best Response for Cart Position in the Y Axis

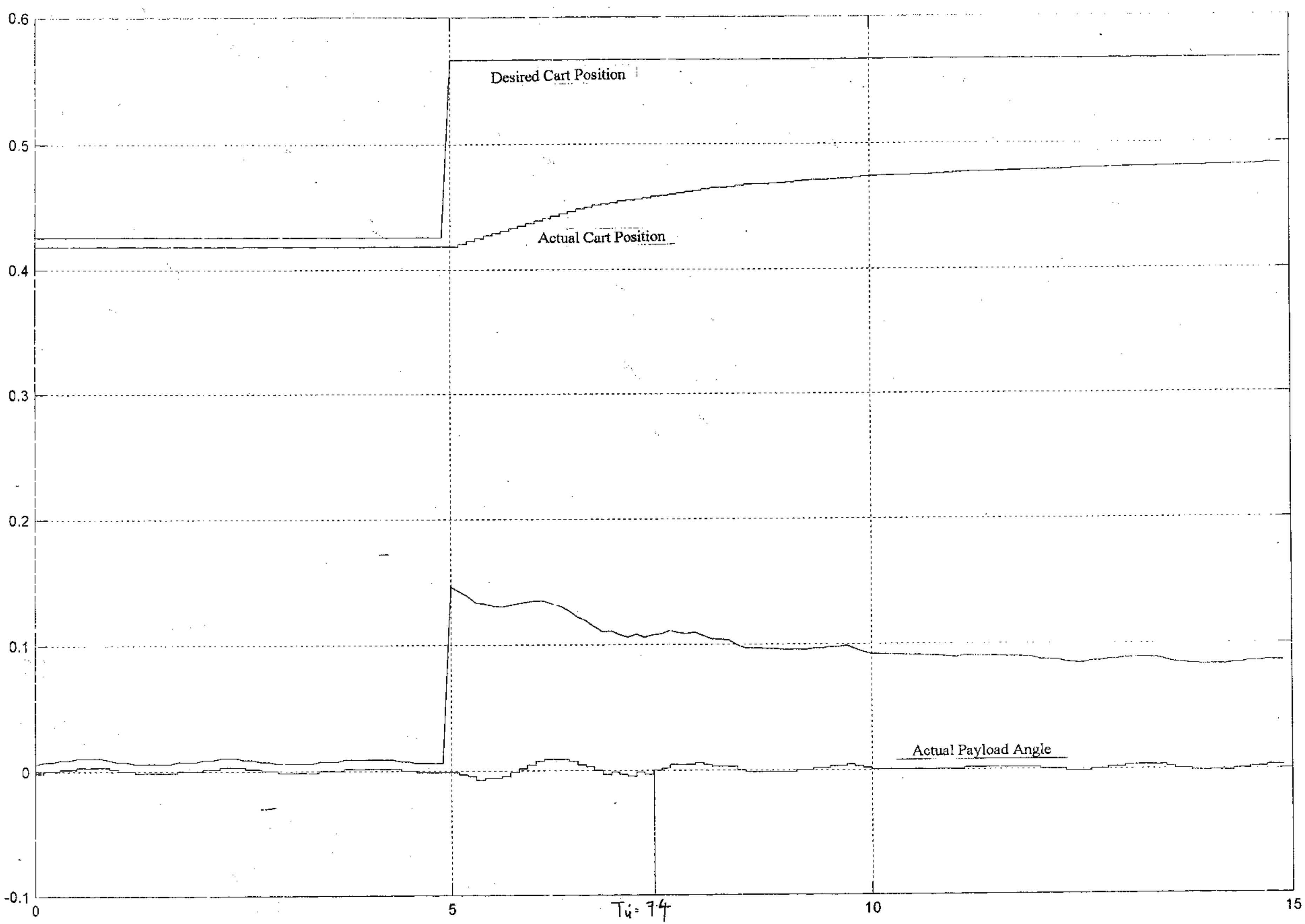


Figure 3.7: Best Response for Oscillation of Payload in the Y-Axis

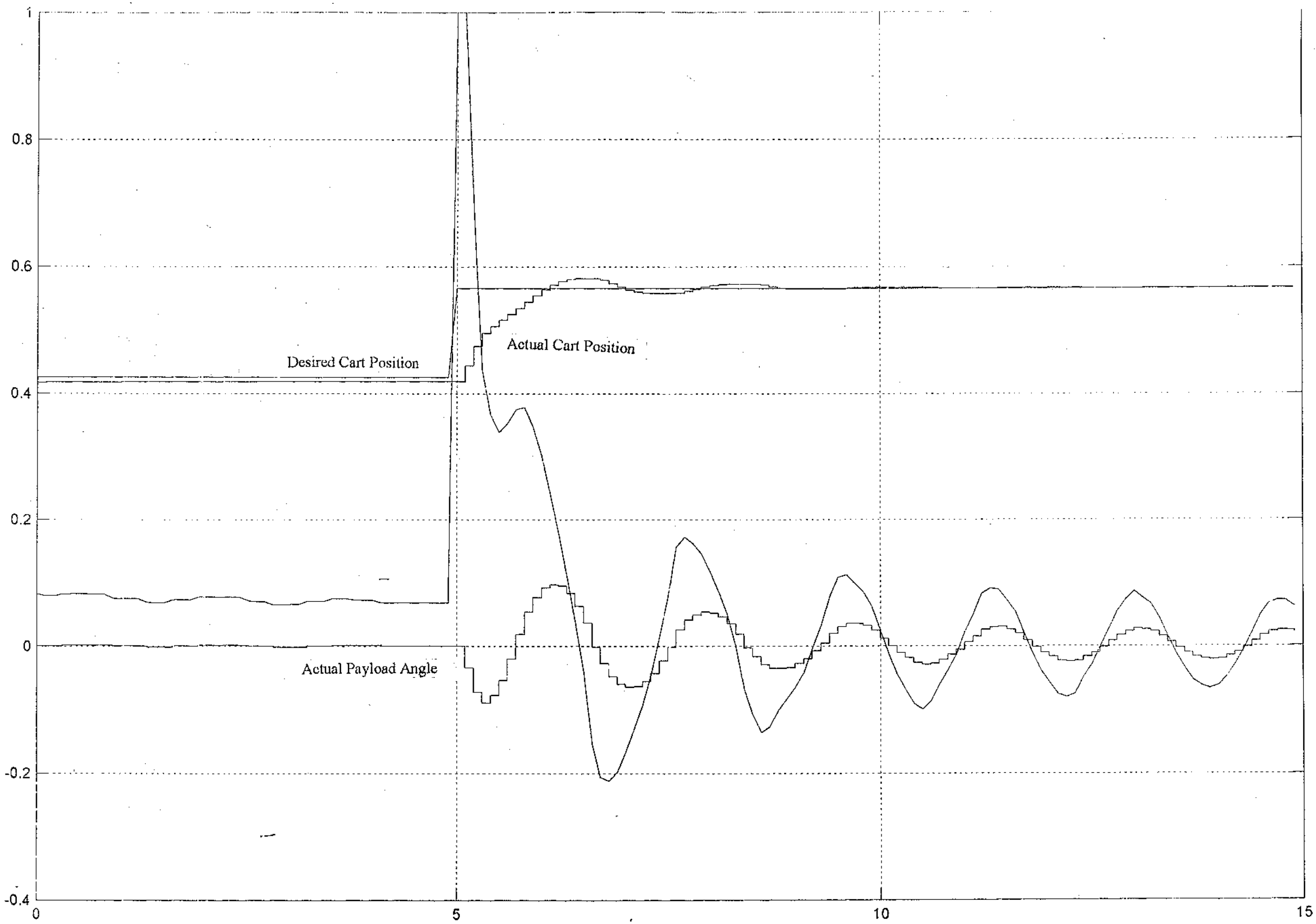


Figure 3.3: Final Response for Y-Axis

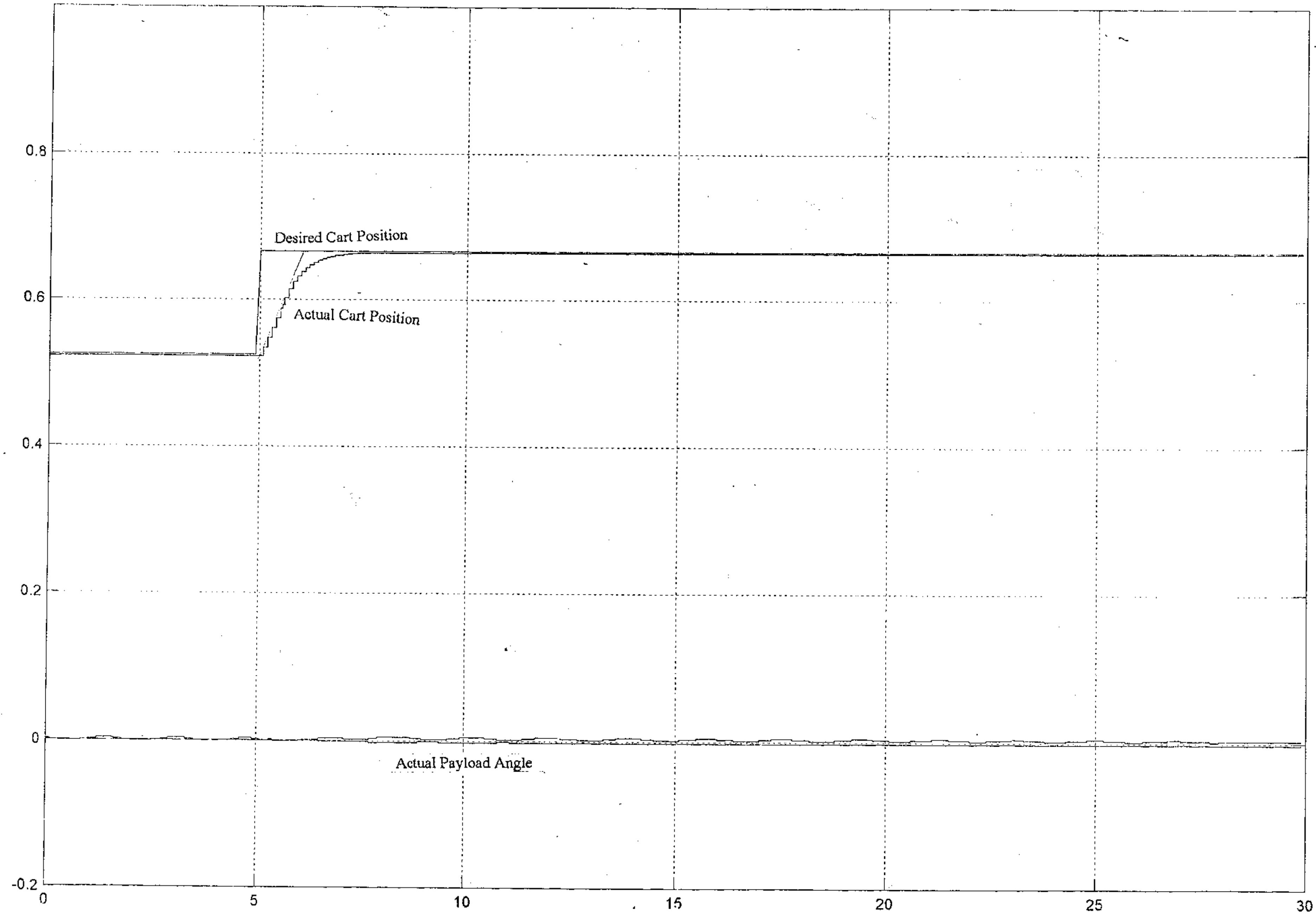


Figure 3.9: Best Response for Cart Position & Oscillation in the Z-Axis

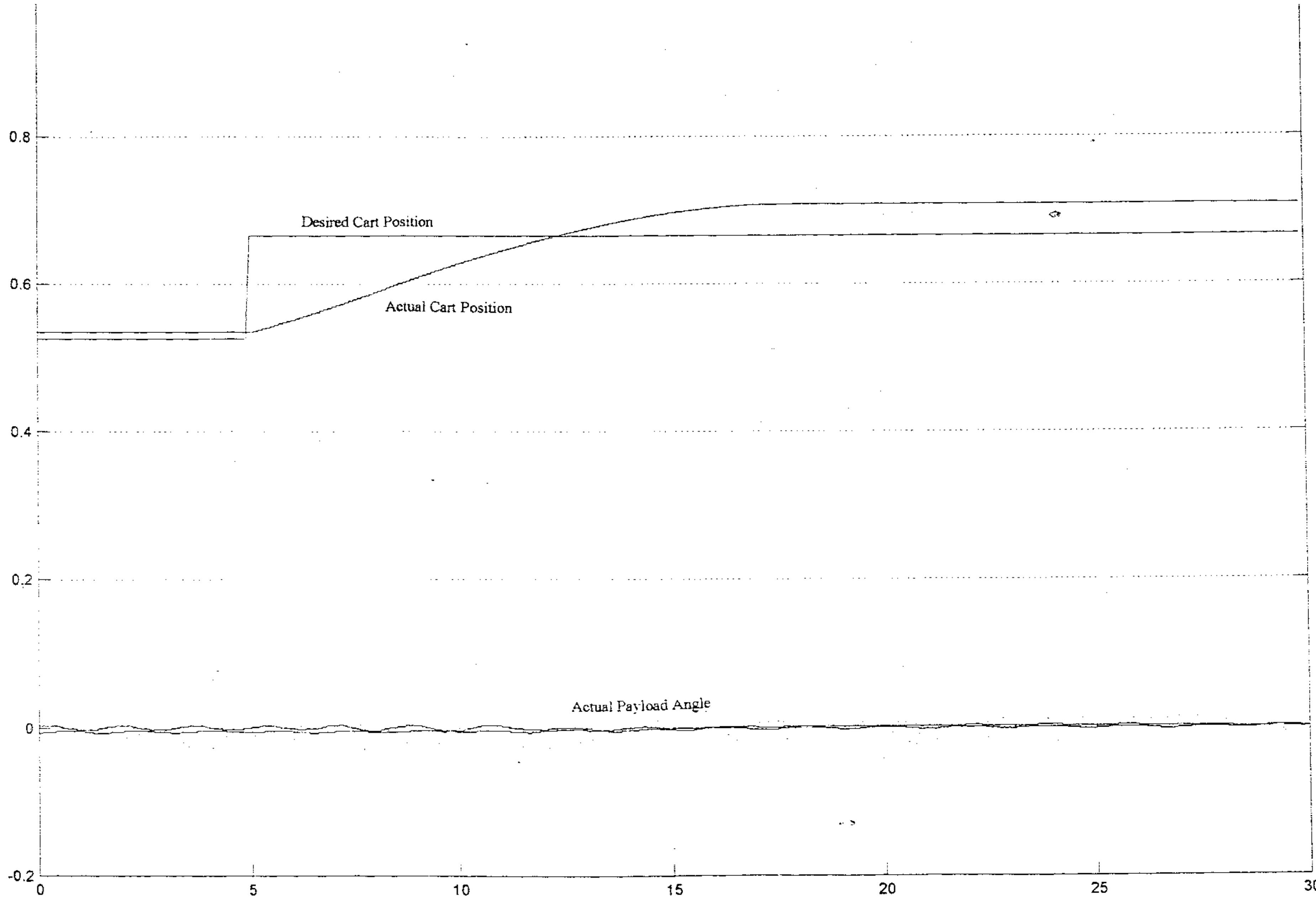


Figure 3.10: Final Response for Z-Axis

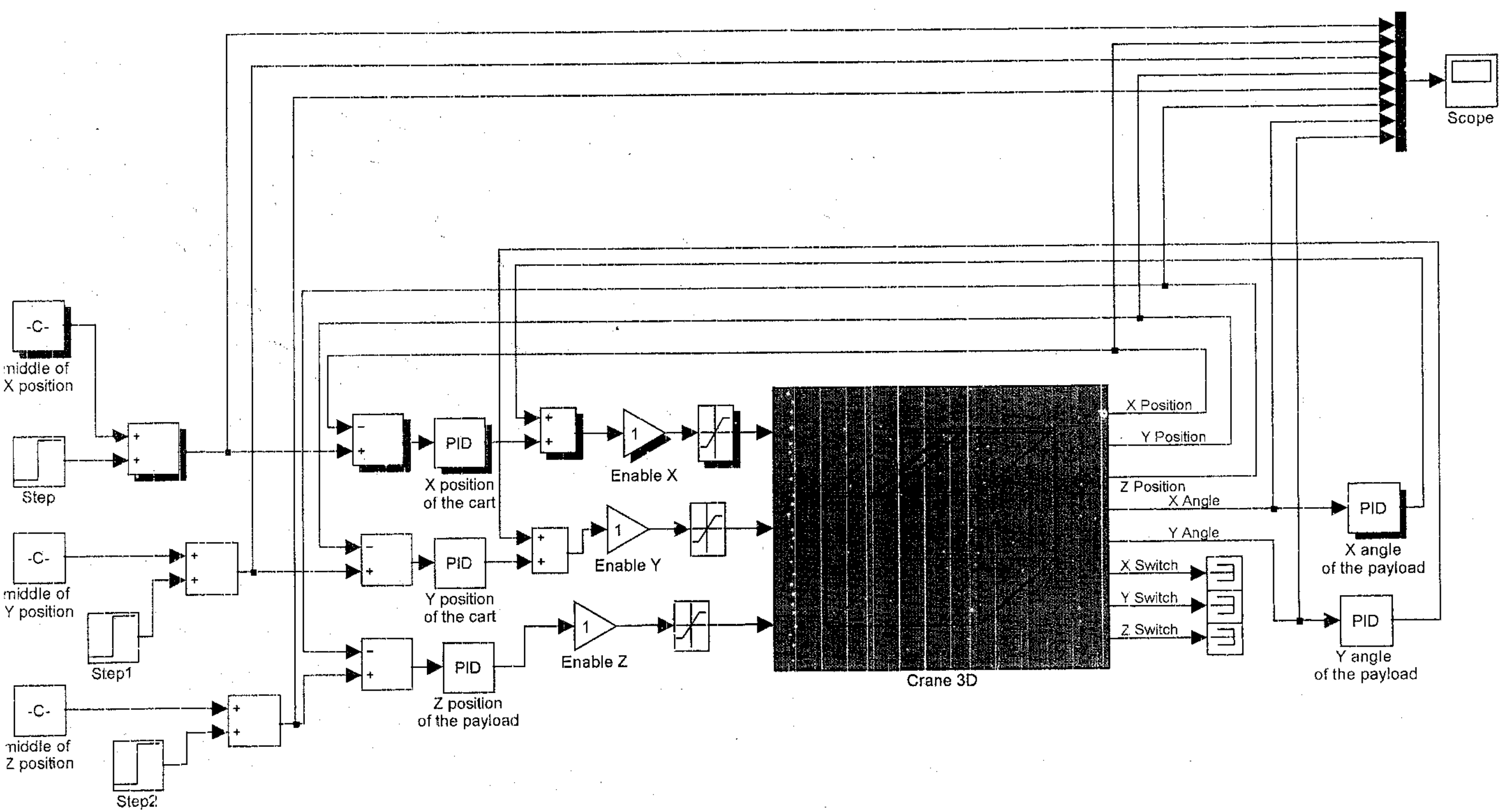


Figure 3.11: Simulink Model Combination 3-Axes

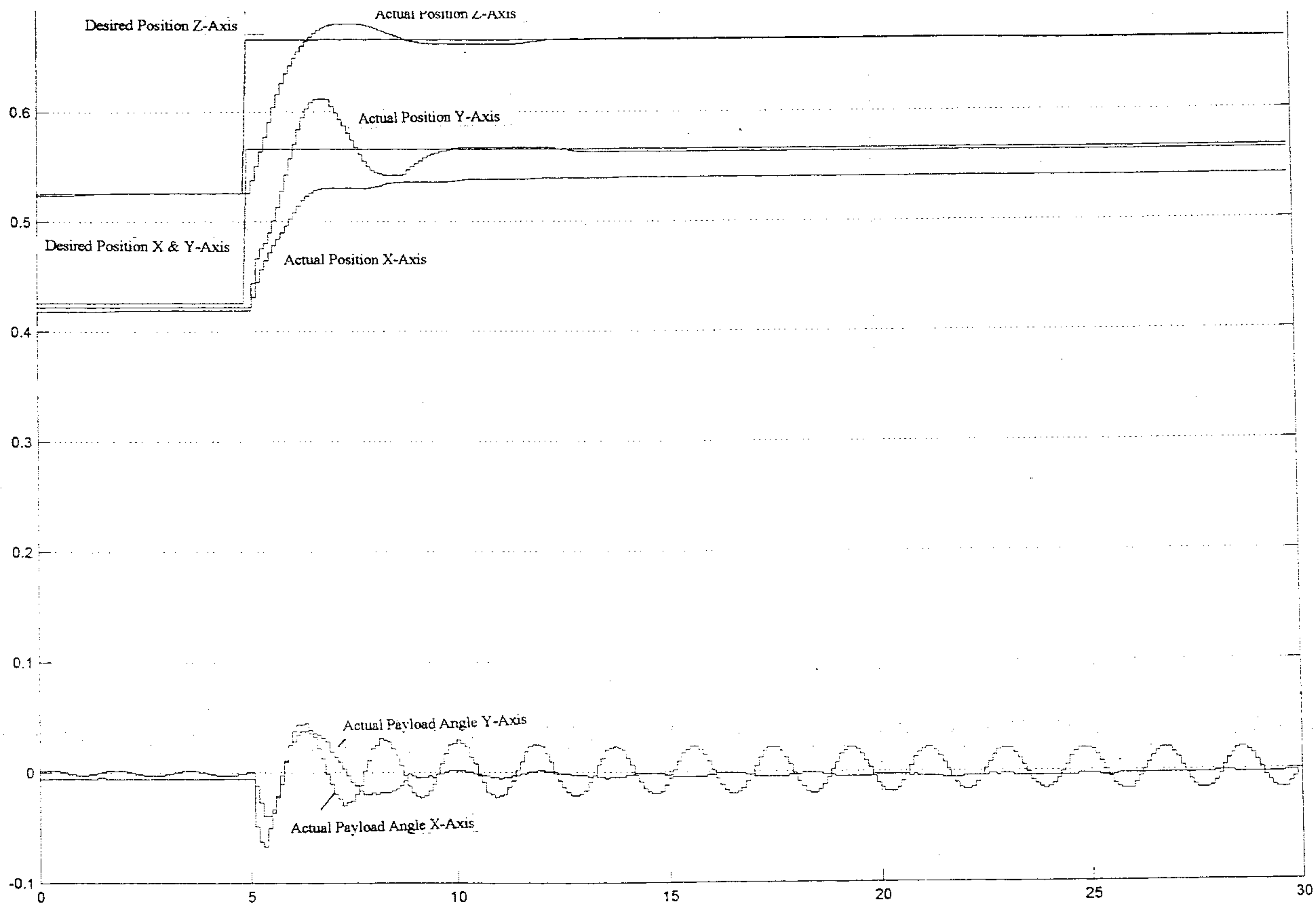
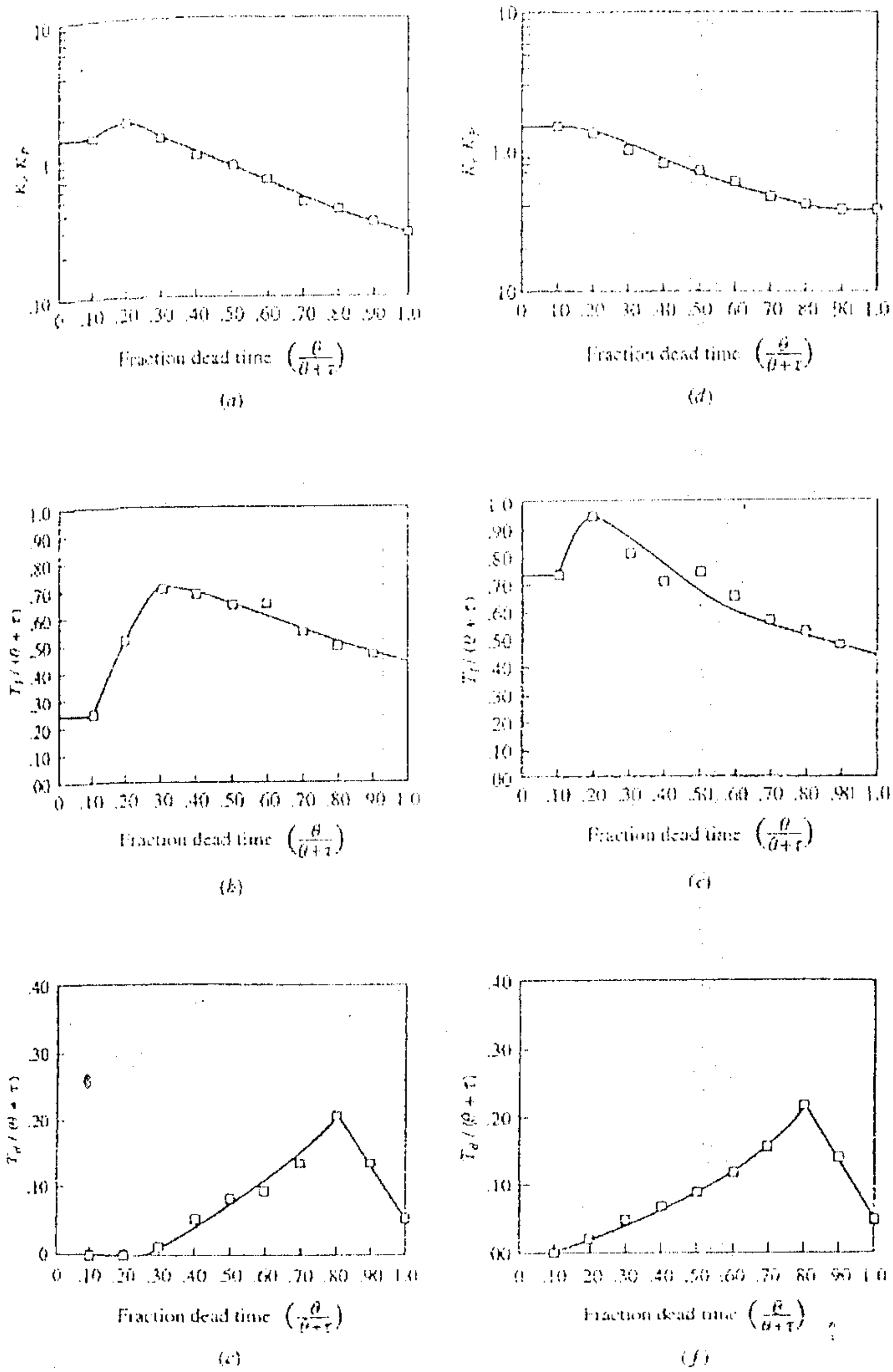


Figure 3.12: Response Curve Combination 3-Axes

APPENDIX 1



Ciancone correlations for dimensionless tuning constants, PID algorithm.

For disturbance response: (a) control system gain, (b) integral time, (c) derivative time.

For set point response: (d) control system gain, (e) integral time, (f) derivative time.

APPENDIX 2

Ziegler-Nichols Rules [4]

Ziegler Nichols have two types of methods to calculate tuning parameters based on response curve. The methods described as below:

1. Method I

This type of tuning methods is used to calculate the closed loop parameters of PID Controller. In general, the parameters calculation is intended to produce a closed loop-damping ratio of ¼. The parameters are obtained when sustained *oscillation* is observed. The value of K_U and period of oscillation, T_U is noted. Below in **Table 1** shows a calculation in obtaining controller parameters.

Table 1: Ziegler-Nichols Closed-Loop Tuning PID Parameters

Control Mode	Parameters
P only	$K_C = 1.5\ K_U$
P+I	$K_C = 0.45\ K_U$ $T_I = T_U / 1.2$
P+I+D	$K_C = 0.6\ K_U$ $T_I = T_U / 2$ $T_D = T_U / 8$

2. Method II

The *process reaction curve* used for identifying dynamics model. This method uses graphical calculation (Figure 2) to determine the parameters for a first-order with dead time model. The values determined from the graph are the magnitude of the input change, δ; the magnitude of the steady-state change in output, Δ; and the maximum slope of the output-versus-time plot, S.

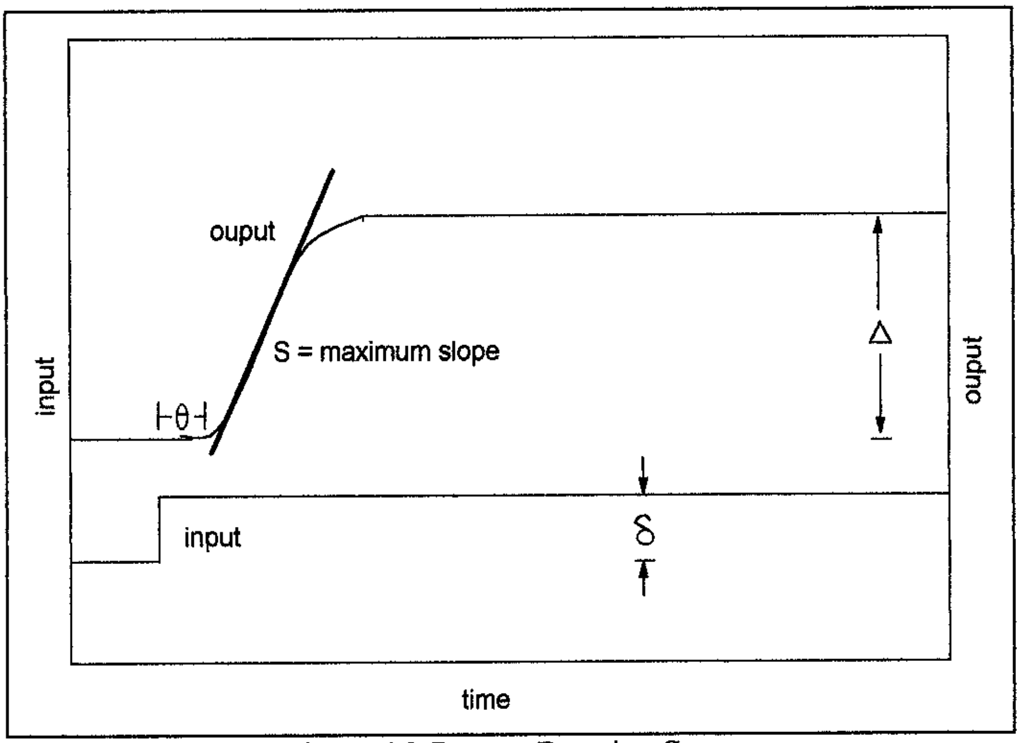


Figure 16: Process Reaction Curve

Thus, model parameters:

$K_p = \Delta / \delta$

$\tau = \Delta / S$

θ = intercept of maximum slope with initial value

Ciancone Correlations Tuning Method

The purpose of tuning correlations is to enable to calculate tuning constant for many process applications that simultaneously without performing the optimization. Correlations for tuning constants will reduce the engineering effort in controller tuning, and, perhaps more importantly, the correlations will show how the controller tuning constants depends on feedback process dynamics.

This correlation provides values for K_C, T_I and T_d based on the values in a process dynamic model. The general approach is to select a model structure and determine the dimensionless parameters that define the closed-loop dynamics response.

The Ciancone correlations consist of the following steps:

1. Ensure that the performance goals and assumptions are appropriate.
2. Determine the dynamic model using and empirical method (e.g. process reaction curve), giving Kp, θ and τ.
3. Calculate the fraction dead time, $\theta / (\theta + \tau)$.
4. Select the appropriate correlation, disturbance or set point; use the disturbance if not sure (refer to Appendix 1).
5. Determine the dimensionless tuning values from the graphs for K_cK_p, $T_I / (\theta + \tau)$, and $T_d / (\theta + \tau)$.

PID Controller

The PID control rule is very common in control systems. It is the basic tool for solving most process control problems. The function of each controller (P, I & D Controller) is discussed in Table 1.

Table 6: Function of Each P, I and D Controller

Parameter	Function
Proportional, P	1. Provides rapid adjustment of the MV 2. Does not provide zero offset. 3. Speeds dynamic response 4. Can cause instability if tuned improperly
Integral ,I	1. Achieves zero offset 2. Adjust the MV in a slower manner than P mode, thus giving poor dynamic performance. 3. Can cause instability if tuned improperly
Derivative, D	1. Does not influence the final steady state value of error 2. Provides rapid correction based on the rate of change of the controlled variable 3. Causes undesirable high frequency variation in MV.