ISLAMIC UNIVERSITY OF TECHNOLOGY, (IUT)

Performance comparison among MIMO techniques at different interference levels for LTE

By

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A Dissertation
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Department of Electrical and Electronic Engineering
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A Subsidiary Organ of OIC
Dhaka, Bangladesh

A Dissertation on,

Improvement of high speed rail pantograph control system with PID

Submitted By

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Preface:

The undergraduate thesis, "Improvement of high speed pantograph control system with PID" has been written for the completion of Bachelor of Science degree at Islamic University of Technology, Bangladesh. This thesis work and writing has been done during the year 2012 under the supervision of Mr. Kasibu Khairul Islam, Professor of the department of Electrical and Electronic Engineering. We would like to express sincere gratitude to our thesis supervisor Dr. Prof. Mr. Kasibu Khairul Islam.

We would like to dedicate this thesis to our parents and our supervisor Mr. Kasibu Khairul Islam and Dr. Prof. Mr. Ali Sabri of Mechanical and chemical Engineering (MCE) Department of IUT. Without the dedicated help, we would not be able to complete this work. We are also grateful to all of our will-wishers, who provided their perpetual support towards accomplishing this task successfully.

CONTENTS:

LISTS OF SYMBOLS:

Kp	-	Proportional coefficient
Ki	-	Integral coefficient
kd	-	Derivative coefficient
PID	-	Proportional-integral-derivative
K_s	-	Shoe spring
K_{ave}	-	Average spring
M_h	-	Head mass
M_f	-	Frame mass
K_f	-	Frame spring
y_f	-	Frame force
y_{cat}	-	Catenary force
y_h	-	Head force

CHAPTER 1

Introduction:

1.1 Background of project

There is a wide variety of electric traction systems around the world, which have been built according to the type of railway, its location and the technology available at the time of the installation. Many installations seen today were first built up to 100 years ago, some when electric traction was barely out its diapers, so to speak, and this has had a great influence on what is seen today.

In the last 20 years there has been a gigantic acceleration in railway traction development. This has run in parallel with the development of power electronics and microprocessors. What have been the accepted norms for the industry for, sometimes, 80 years, have suddenly been thrown out and replaced by fundamental changes in design, manufacture and operation. Many of these developments are highly technical and complex, the details of which are therefore beyond the scope of these texts.

Because these changes have been so rapid, there are still plenty of examples of the original technology around and in regular use, so I have covered these in my articles. This is useful, since it helps the reader to get to grips with the modern stuff

To begin with, the electric railway needs a power supply that the trains can access at all times. It must be safe, economical and user friendly. It can use either DC (direct current) or AC (alternating current), the former being, for many years, simpler for railway traction purposes, the latter being better over long distances and cheaper to install but, until recently, more complicated to control at train level.

Transmission of power is always along the track by means of an overhead wire or at ground level, using an extra, third rail laid close to the running rails. AC systems always use overhead wires, DC can use either an overhead wire or a third rail; both are common. Both overhead systems require at least one collector attached to the train so it can always be in contact with the power. Overhead current collectors use a "pantograph", so called because that was the shape of most of them until about 30 years ago. The return circuit is via the running rails back to the substation. The running rails are at earth potential and are connected to the substation.

On modern high speed trains current collection from the overhead line is assured by a pantograph that have to assure a steady mechanical and electrical contact between overhead line and the power equipment of the train. Dynamical interaction between the moving pantograph and the flexible structure of the overhead line cause heavy fluctuations of the contact forces between the sliding surfaces of sliding bows and contact wire. Loss of contact between pantograph and catenary produces excessive wear and over heating of sliding surfaces and reduced mechanical and electrical reliability of catenary, pantograph, train power equipment. As visible in figure 1, pantograph "contact shoes" are placed on "sliding bows" that are linked to the "head" of the "mobile frame" trough a "suspension system" with several degree of freedom that is usually deigned in order to reduce contact force fluctuations due to the pantograph-catenary interaction. The "moving frame" is usually a four bar linkage (other kinematical scheme used for symmetric pantograph are less diffused for high speed trains) whose kinematical behavior is optimized in order to obtain a vertical trajectory of the "head" on which are placed "contact shoes". Angular alignment between the "head" and the ground is usually assured by an "auxiliary rod". Auxiliary rod is linked to a member of the four bar linkage at one end. The constraint between the

head and the auxiliary rod is variable according the different design of the pantograph, however three solutions are more often used:

• A rotoidal joint

• Rotoidal joint and a spring/damper controlled compliance to reduce kinematical errors

• A cam constraint (Ansaldo ATR95)

The static force needed to lift up the pantograph and assure a known static force is assured by a pneumatic actuator. Transmission ratio between actuator and the mobile frame is often optimized in order to obtain a constant transmission ratio from the pressure inside the actuator to the static force between sliding surfaces. At the hand one or more dampers are usually place between the "mobile frame" and the "lower frame" that is constrained by the electrical insulators to the roof.

Dampers have mainly two functions:

• Increase the mobile frame damping in order to prevent resonant/anti-resonant motion of the frame itself that can negatively influence the response of suspension system under the sliding bow.

• Dissipate mechanical energy and limit the speed of the mobile frame when the pantograph is lifted up or collapsed from/to the train roof

Figure: picture of a pantograph system operating for a high speed train.

In this project, we will improve the control system of the pantograph system by using a controller. Different controller can be use for this purse but in our project PID (proportional-integral-derivative) is used to get a better output.

A project on Improvement of high speed pantograph control system with PID has carried out by Yssef Ali Sabri (082416), Mamadou Thiam (113415), Mohamed Abdullahi students of Bachelor of science in Electrical and Electronic Engineering (BscEE).The main objective of this project is to show how actually ,with the new technology in place, lightning and surge are protected in a roof mounted solar panel. To perform this we will literally focus on the part of the theory because of the none availability of the materials .But in the other way it can be the first steps to think about how to implement this use of solar energy in the sunny countries.

1.2 Objectives

    The objectives of this project are:
i. To fulfill the requirement for the subject EEE-4800, Engineering Project.
ii. To explorer and apply the knowledge gain in lectures into practical applications.
iii. To control the pantograph of high speed train with PID controller using MATLAB application.
iv. To compare and analyze the result between the simulation result without PID controller and with PID controller applied.
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CHAPTER 2

LITERATURE REVIEW:

2.1 Pantograph and catenary system

A pantograph is a device that collects electric current from overhead lines for electric trains or trams. The most common type of pantograph today is the so called half-pantograph (sometimes 'Z'-shaped), as shown in Fig.2.1, which has evolved to provide a more compact and responsive single arm design at high speeds as trains get faster. The electric transmission system for modern electric rail systems consists of an upper load carrying wire (known as a catenary) from which is suspended a contact wire as shown in Fig.2.1 The pantograph is spring loaded and pushes a contact shoe up against the contact wire to draw the electricity needed to run the train. As the train moves, the contact shoe slides along the wire and can set up acoustical standing waves in the wires which break the contact and degrade current collection. Therefore, the force applied by the pantograph to the catenary is regulated to avoid loss of contact due to excessive transient motion.

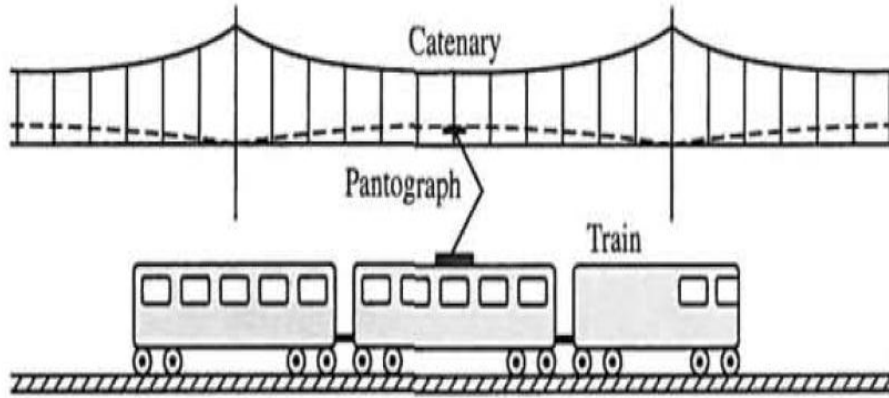Figure 2.1: (a) The (asymmetrical) 'Z'-shaped pantograph. This pantograph is single-arm.

Figure 2.1(b): High-speed rail system showing pantograph and catenary

2.2 Control theory

Control theory is an interdisciplinary branch of engineering and mathematics that deals with the behavior of dynamical systems. The desired output of a system is called the *reference*. When one or more output variables of a system need to follow a certain reference over time, a controller manipulates the inputs to a system to obtain the desired effect on the output of the system.
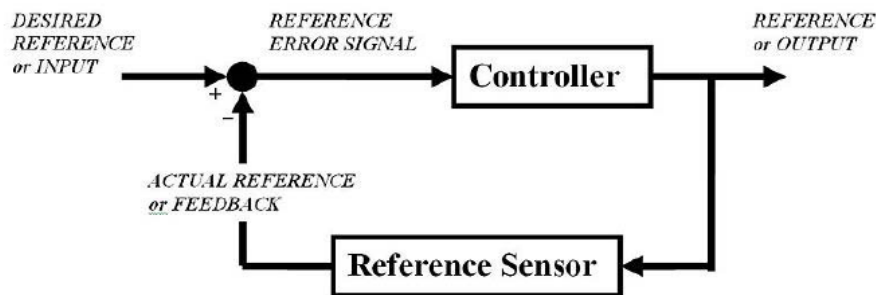

Figure 2.2: Concept of the Feedback Loop to Control the Dynamic Behavior of the Reference

If we consider an automobile cruise control, it is design to maintain the speed of the vehicle at a constant speed set by the driver. In this case the system is the vehicle. The vehicle speed is the output and the control is the vehicle throttle which

influences the engine torque output. One way to implement cruise control is by locking the throttle at the desired speed but when encounter a hill the vehicle will slow down going up and accelerate going down. In fact, any parameter different than what was assumed at design time will translate into a proportional error in the output velocity, including exact mass of the 6 vehicle, wind resistance, and tire pressure. This type of controller is called an open-loop controller because there is no direct connection between the output of the system (the engine torque) and the actual conditions encountered; that is to say, the system does not and cannot compensate for unexpected forces. For a closed-loop control system, a sensor will monitor the vehicle speed and feedback the data to its computer and continuously adjusting its control input or the throttle as needed to ensure the control error to a minimum therefore maintaining the desired speed of the vehicle. Feedback on how the system is actually performing allows the controller (vehicle's on board computer) to dynamically compensate for disturbances to the system, such as changes in slope of the ground or wind speed. An ideal feedback control system cancels out all errors, effectively mitigating the effects of any forces that may or may not arise during operation and producing a response in the system that perfectly matches the user's wishes.

2.2.1 Open-loop transfer function

A generic open-loop system starts with a subsystem called an input transducer, which converts the form of the input to that used by the controller. The controller drives a process or a plant. The input is sometimes called the reference, while the output can be called the controlled variable. Other signals, such as disturbances, are shown added to the controller and process outputs via summing junctions, which yield the algebraic sum of their input signals using associated signs. For example, the plant can be a furnace or air conditioning system, where the output

variable is temperature. The controller in a heating system consists of fuel valves and the electrical system that operates the valves.

The distinguishing characteristic of an open-loop system is that it cannot compensate for any disturbances that add to the controller's driving signal (Disturbance 1 in Figure 4. For example, if the controller is an electronic amplifier and Disturbance 1 is noise, then any additive amplifier noise at the first summing junction will also drive the process, corrupting the output with the effect of the noise. The output of an open-loop system is corrupted not only by signals that add to the controller's commands but also by disturbances at the output (Disturbance 2 in Figure 4). The system cannot correct for these disturbances, either. Open-loop systems, then, do not correct for disturbances and are simply commanded by the input. For example, toasters are open-loop systems, as anyone with burnt toast can attest. The controlled variable (output) of a toaster is the color of the toast. The device is designed with the assumption that the toast will be darker the longer it is subjected to heat. The toaster does not measure the color of the toast; it does not correct for the fact that the toast is rye, white, or sourdough, nor does it correct for the fact that toast comes in different thicknesses.
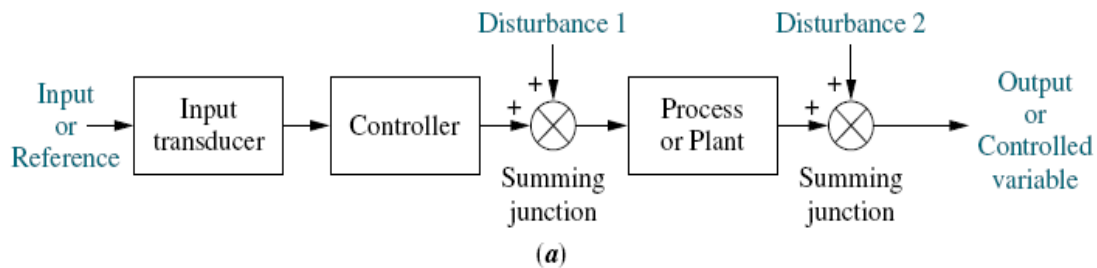

Figure 2.2.1: Open-loop transfer function

$$G(s) = \frac{C(s)}{R(s)}$$

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2.2.2 Closed-loop transfer function

The output of the system *y(t)* is fed back through a sensor measurement *F* to the reference value *r(t)*. The controller *C* then takes the error *e* (difference) between the reference and the output to change the inputs *u* to the system under control *P*. This is shown in the figure. This kind of controller is a closed-loop controller or feedback controller. This is called a single-input-single-output (*SISO*) control system; *MIMO* (i.e. Multi-Input-Multi-Output) systems, with more than one input/output, are common. In such cases variables are represented through vectors instead of simple scalar values. For some distributed parameter systems the vectors may be infinite-dimensional (typically functions)
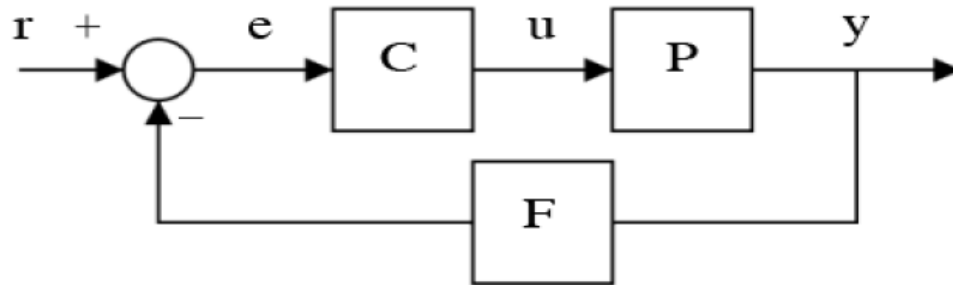
Figure 2.2.2: Close-loop controller or feedback controller

If we assume the controller *C*, the plant *P*, and the sensor *F* are linear and time invariant (i.e.: elements of their transfer function *C(s)*, *P(s)*, and *F(s)* do not depend on time), the systems above can be analyzed using the Laplace transform on the variables. This gives the following relations:

$$1)\ Y(s) = P(s)U(s)$$

$$2)\ U(s) = C(s)E(s)$$

$$3) \; E(s) = R(s) - F(s)Y(s)$$

Solving for $Y(s)$ in term of $R(s)$ gives:

$$Y(s) = \left(\frac{P(s)C(s)}{1 + F(s)P(s)C(s)}\right) R(s) = H(s)R(s)$$

The expression $H(s) = \left(\frac{P(s)C(s)}{1+F(s)P(s)C(s)}\right)$ is referred to as the close-loop

transfer function of the system. The numerator is the forward (open-loop) gain from r to y, and the denominator is one plus the gain in going around the feedback loop, the so-called loop gain. If, $|P(s) \gg 1C(s)|$, i.e. it has a large norm with each value of s, and if $|F(s) \approx 1|$, then $Y(s)$ is approximately equal to $R(s)$. This means simply setting the reference controls the output.

2.2.3 PID controller

PID Control (proportional-integral-derivative) is by far the widest type of automatic control used in industry. Even though it has a relatively simple algorithm/structure, there are many subtle variations in how it is applied in industry. A proportional–integral–derivative controller (PID controller) is a generic control loop feedback mechanism widely used in industrial control systems. A PID controller will correct the error between the output and the desired input or set point by calculating and give an output of correction that will adjust the process accordingly. A PID controller has the general form

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

Where K_p is proportional gain, K_i is the integral gain, and K_d is the derivative gain.

The PID controller calculation involves three separate parameters; the Proportional, the Integral and Derivative value. The Proportional value determines the reaction to the current error, the Integral determines the reaction based on the sum of recent errors and the Derivative determines the reaction to the rate at which the error has been changing. The weighted sum of these three actions is used to adjust the pantograph controller and make it more effective.

2.3 MATLAB

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. Typical uses include:

• Math and computation

• Algorithm development

• Data acquisition

• Modeling, simulation, and prototyping

• Data analysis, exploration, and visualization

• Scientific and engineering graphics

• Application development, including graphical user interface building

MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. This allows you to solve many technical computing problems, especially those with matrix and vector formulations, in a

fraction of the time it would take to write a program in a scalar non-interactive language such as C or For tran. The name MATLAB stands for matrix laboratory. MATLAB was originally written to provide easy access to matrix software developed by the LINPACK and EISPACK projects. Today, MATLAB engines incorporate the LAPACK and BLAS libraries, embedding the state of the art in software for matrix computation.

MATLAB has evolved over a period of years with input from many users. In university environments, it is the standard instructional tool for introductory and advanced courses in mathematics, engineering, and science. In industry, MATLAB is the tool of choice for high-productivity research, development, and analysis.

MATLAB features a family of add-on application-specific solutions called toolboxes. Very important to most users of MATLAB, toolboxes allow you to learn and apply specialized technology. Toolboxes are comprehensive collections of MATLAB functions (M-files) that extend the MATLAB environment to solve particular classes of problems. Areas in which toolboxes are available include signal processing, control systems, neural networks, fuzzy logic, wavelets, simulation, and many others.

When you start MATLAB, the MATLAB desktop appears, containing tools (graphical user interfaces) for managing files, variables, and applications associated with MATLAB. The following illustration shows the default desktop. You can customize the arrangement of tools and documents to suit your needs.
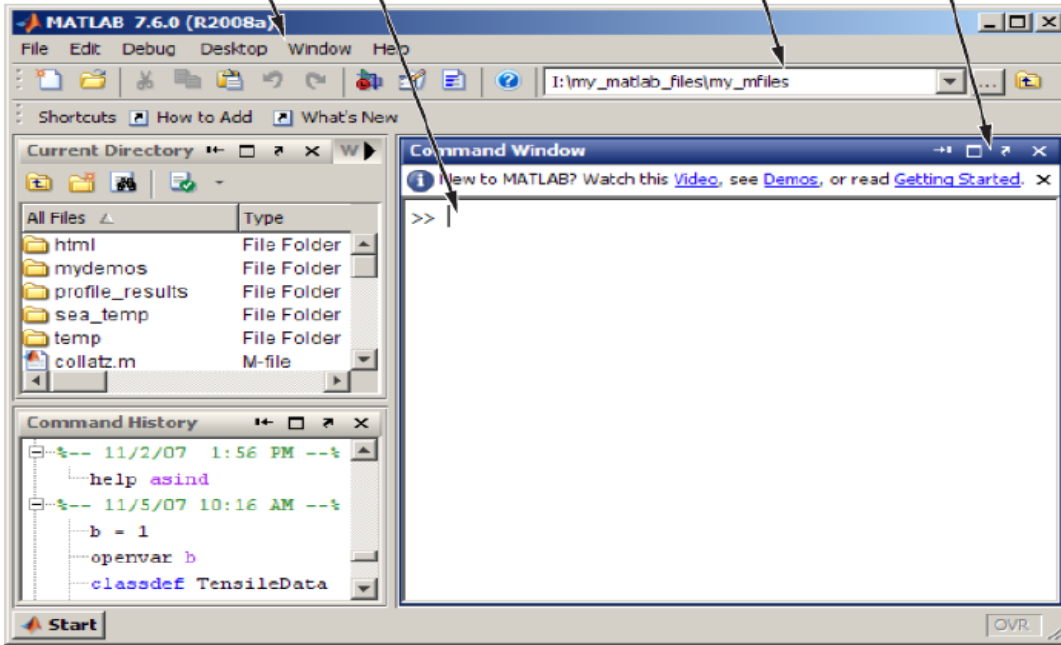
Figure 2.3: MATLAB default command window

CHAPTER 3

METHODOLOGY

3.1 System Description

Fig.3.1 shows the pantograph and the catenary coupling. The contact between the head of the pantograph and the catenary is represented by a spring. The output force is proportional to the displacement of this spring, which is the difference between the catenary and pantograph head vertical positions. A simplified model is shown in Fig.3, where the catenary is represented by the spring, K_{ave}. A functional block diagram in Fig.4 shows the following signals: the desired output force as the input; the force,F_{up}, applied to the bottom of the pantograph; the difference in displacement between the catenary and pantograph head; and the output contact force. It also shows block representing the input transducer, controller, actuator generating F_{up}, pantograph dynamics, spring described above, and output sensor.
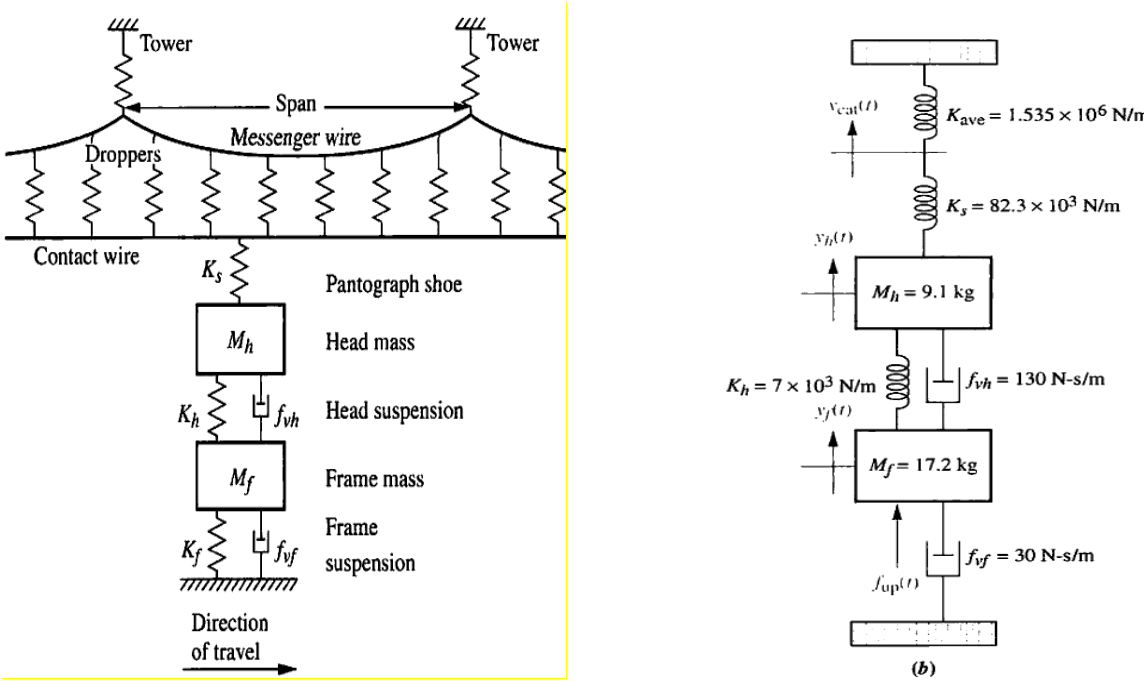
Figure3.1: (a). Coupling of pantograph and catenary   (b) simplified representation showing the active control system.

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3.2 Free body diagrams

A free-body diagram is a sketch of an object of interest with all the surrounding objects stripped away and all of the forces acting on the body shown. The drawing of a free-body diagram is an important step in the solving of mechanics problems since it helps to visualize all the forces acting on a single object. The net external force acting on the object must be obtained in order to apply Newton's Second Law to the motion of the object.
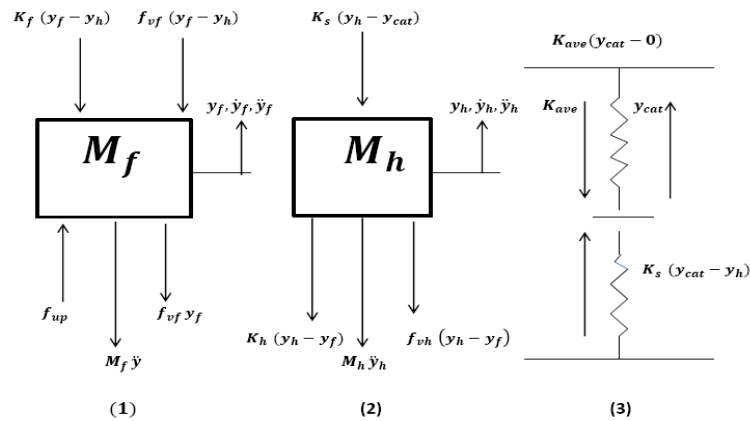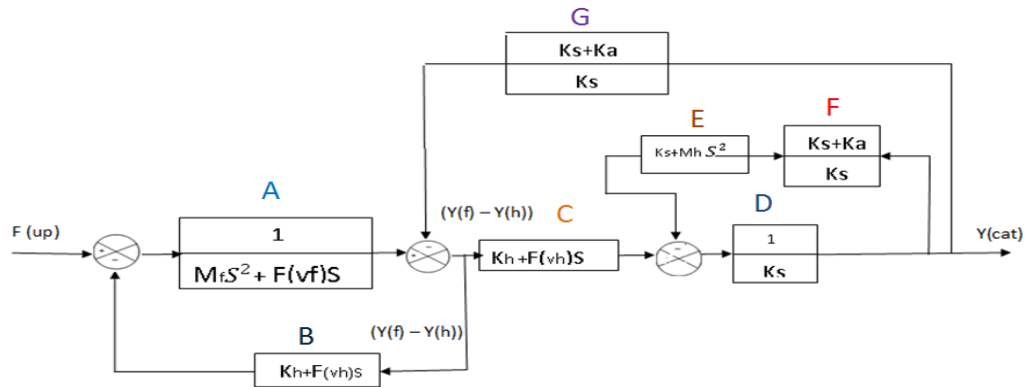

Figure 3.2: free body diagrams

3.3 Writing the Equations

1) $$F_{up} - F_{vf} - K_h(Y_f - Y_h) - F_{vh}(Y_f - Y_h) = M_f s^2 Y_f$$

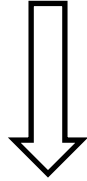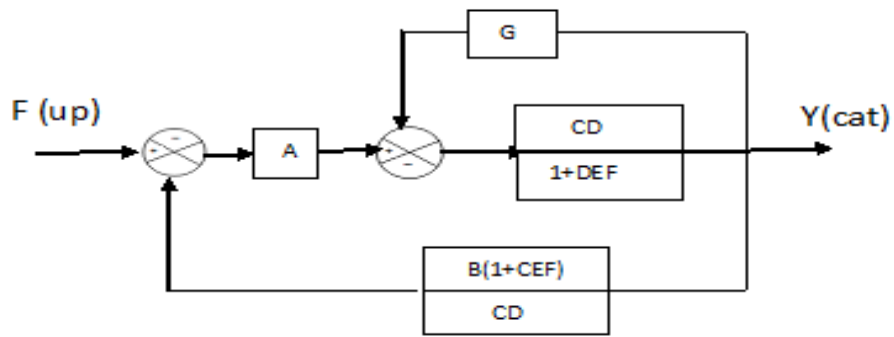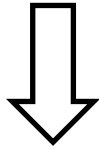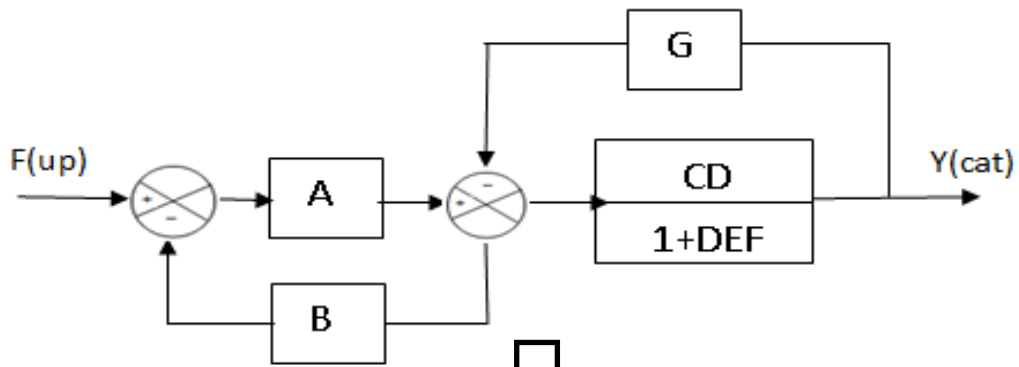2) $$K_h - (Y_f - Y_h) - F_{vh}(Y_f - Y_h) - K_s - (Y_h - Y_{cat}) = M_h s^2 Y_h$$
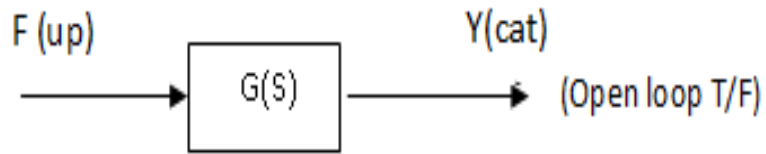
3) $\quad K_s Y_h - (K_s - K_{ave})Y_{cat} = 0$

3.4.1 Block Diagram reduction

3.4.1. a) Open-loop transfer function

F(up)

G

A

CD
1+DEF

Y(cat)

B

F (up)

G

A

CD
1+DEF

Y(cat)

B(1+CEF)
CD

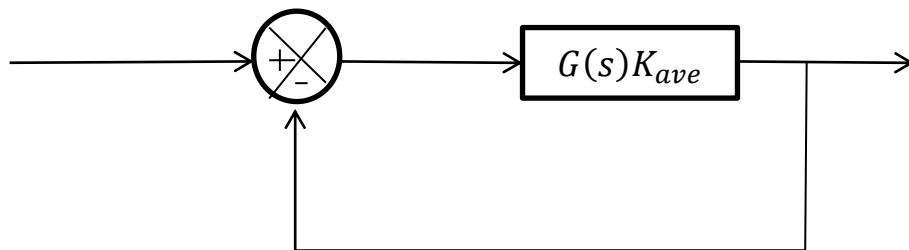G(S)

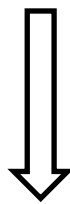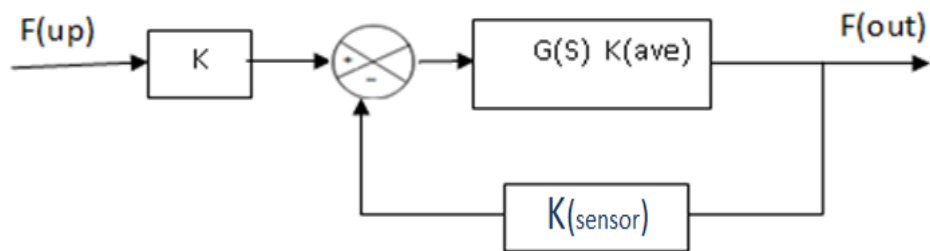F (up)

ACD
DEF+CDG+ABC(1+CEF)
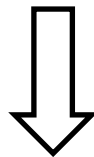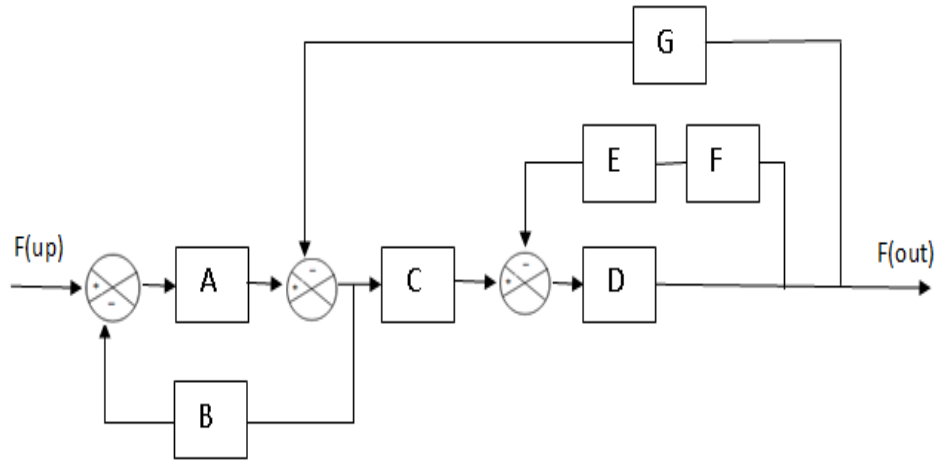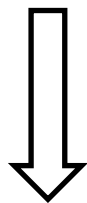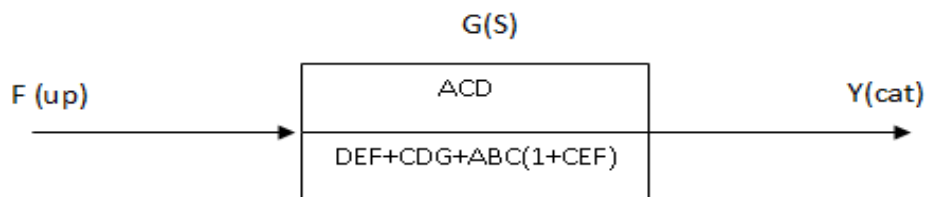
Y(cat)

$$G(s) = \frac{Y_{cat}}{F_{up}} \quad \longrightarrow \quad \text{open-loop transfer function}$$

$$G(s) = \frac{0.044227s + 2.2762395}{s^4 + 23.669s^3 + 9784.9003s^2 + 81190.038s + 3493193}$$

3.4.1. b) Close-loop transfer function

$$T(s) = \frac{KG(s)K_{ave}}{1 + KG(s)K_{ave}}$$

$$T(s) = \frac{KG(s) \times 15.53}{1 + KG(s) \times 15.53}$$

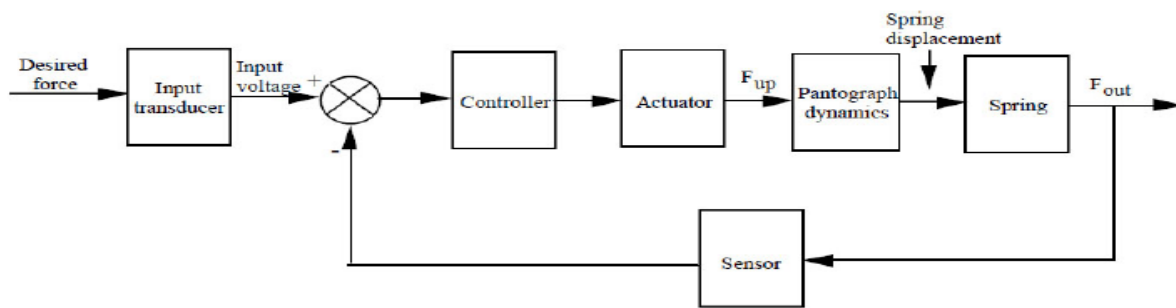3.4 Block Diagram of active control system of pantograph

Figure: Functional block diagram of pantograph active control system

3.5 Determine range of K using Routh Table

$$T(s) = \frac{KG(s)K_{ave}}{1 + KG(s)K_{ave}}$$

The denominator of $T(s)$, $1 + KG(s)K_{ave}$ is called characteristic equation.

3.5.1 Finding the characteristic equation

$$1 + KG(s)K_{ave} = s^4 + 23.669s^3 + 9784.90093s^2 + 81190.038s + 3493192.9$$
$$+(6488Ks + 34.95K)$$

$$= s^4 + 23.669s^3 + 9784.90093s^2 + (81190.038s + 6488Ks)$$
$$+3493192.9 + 34.95K$$

3.5.2 Routh Table

S^4	1	9784.90093	3493192.9+34.94
S^3	23.669	81190.038+0.6488k	
S^2	150,408.7821-0.6488k		82680382+826.995k
S^1	$-\dfrac{0.4k^2+125,334.775k+1.024\times10^{10}}{150,408.7821-0.6488}$		
S^0	82680382.75+826.995		

For column1 $-\infty < K < 23182.113$

For column2 $-12845 < K < 1.8862$

For column3 $-99,976.88 < K < +\infty$

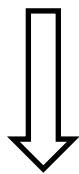$0 < K < 188000$

$$K_{max} = 188000$$

With choice of $K = 188000$, the open-loop transfer function become:

$$s^4 + 23.669s^3 + 9784.9003s^2 + 203158.97s + 1.009 \times 10^7$$

Substitute $S = jw$

$$w^4 - j23.669w^3 - 9784.9003w^2 + j203158.97w + 1.009 \times 10^7$$

$$w^4 - j23.669w^3 + 1.009 \times 10^7 + j(-23.669w^3 + 203158.97w)$$

Real part   Imaginary part $w_d = \pm 92.80$

$w_{n1}\sqrt{1 - \varepsilon^2} = w_d$	$w_{n2}{}^2 - (11.787)^2 = w_d{}^2$
$\left(\dfrac{0.07}{w_n}\right)^2 = \left(\dfrac{w_d}{w_n}\right)^2$	$w_{n2}{}^2 - 138.9333 = 92.8^2$
$w_{n1} = 92.800$	$w_{n2} = 93.5455$
$\varepsilon_1 = 7.9575 \times 10^{-5}$	$\varepsilon_2 = 0.126002$
Dominant pole (near to the right half plane)	omitted pole (stable)

3.6 Drawing the Root Locus (see root locus figure in results 4.1)

$$T(s) = \frac{121982.766(s + 53,8499)}{s^4 + 23.669s^3 + 9784.9003s^2 + 200391.438s + 1.006 \times 10^7}$$

No of poles $(n) = 4$

No of zeros$(m) = 1$

No of asymptotes $= m - n = 4 - 1 = 3$

No of intersection with real axis$= -\dfrac{N.V.P - NVZ}{n - m}$

$= -0.00738 + 92.828j - 0.00738 - 92.828j - 11.787 + 32.07j - 11.787$
$$-32.07j - 53.849$$

$\qquad = 25.812$

Angle of asymptote $= \dfrac{180 \pm K360}{n - m}$, $k = 0,1,2$

$$=+60,-60,180$$

3.7 Active pantograph with PID controller

3.7.1. **Ziegler-Nichols Tuning**

In 1942 Ziegler and Nichols, both employees of Taylor Instruments, described simple mathematical procedures, the first and second methods respectively, for tuning PID controllers. These procedures are now accepted as standard in control systems practice. Both techniques make a priori assumptions on the system model, but do not require that these models be specifically known. Ziegler-Nichols formulae for specifying the controllers are based on plant step responses.
Ziegler –Nichols developed two methods and in our project we are using the method known as second method.

3.7.2 **Ziegler-Nichols second method**

The second method targets plants that can be rendered unstable under proportional control. The technique is designed to result in a closed loop system with 25% overshoot. This is rarely achieved as Ziegler and Nichols determined the adjustments based on a specific plant model.
The steps for tuning a PID controller using the second method is as follows
Using only proportional feedback control:

1. Reduce the integrator and derivative gains to 0.

2. Increase *Kp* from 0 to some critical value *Kp=Kcr* at which sustained oscillations occur. If it does

not occur then another method has to be applied.

3. Note the value *Kcr* and the corresponding period of sustained oscillation, *Pcr*

The controller gains are now specified as follows:

PID Type	K_p	T_i	T_d
P	$0.5\,K_{cr}$	∞	0
PI	$0.45\,K_{cr}$	$\dfrac{P_{cr}}{1.2}$	0
PID	$0.6\,K_{cr}$	$\dfrac{P_{cr}}{2}$	$\dfrac{P_{cr}}{8}$

Table 4: Ziegler Nichols Recipe – Second Method

CHAPTER 4

4.1 Pantograph active control system

- ➢ Unit step function: it is the response of the system using a step function as a test signal (ramp or parabola could be use also to test the system's stability) So the difference between the input and output for a prescribed test input when time is going to infinity is found and called steady state error.
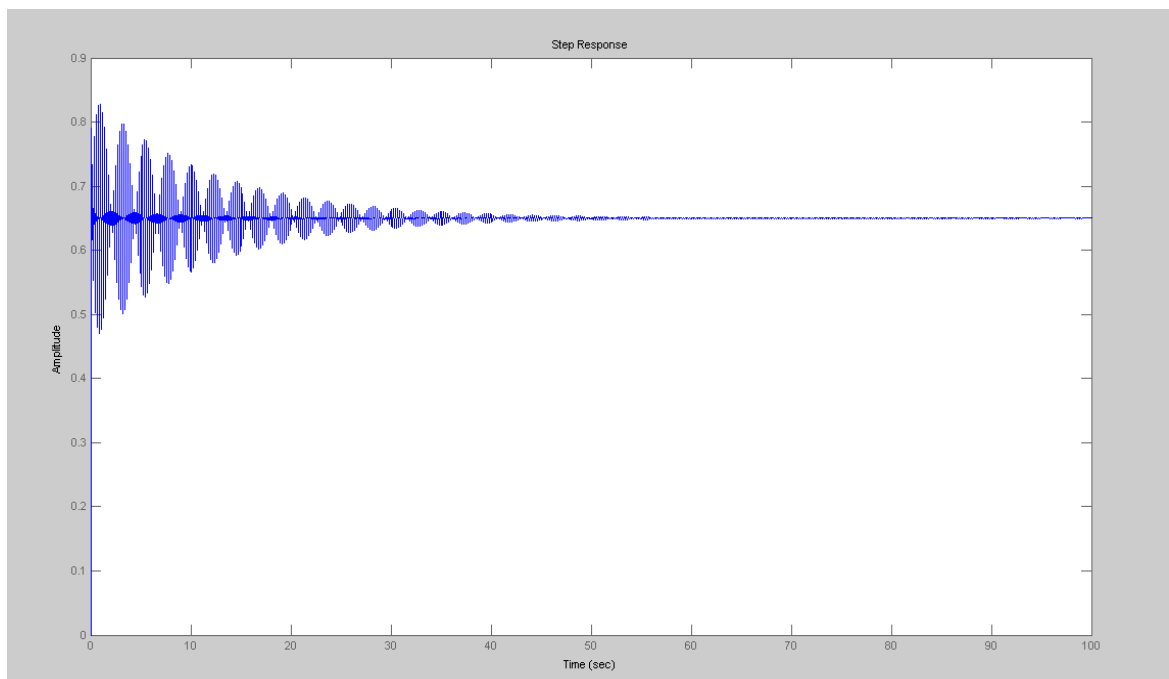
  K=0.1

Figure: Unit step function

Comment: Our unit step function show oscillation at the beginning and then starts damping with 35% steady state error. So we can say the system is not stable.

- ➢ Root Locus :

Root Locus is the finest way to show the stability of a system when the order of the differential equation is more than two.

Root Locus shows how many poles and zeros do we have in the right half plane, in the left half plane or in *jw* axis.
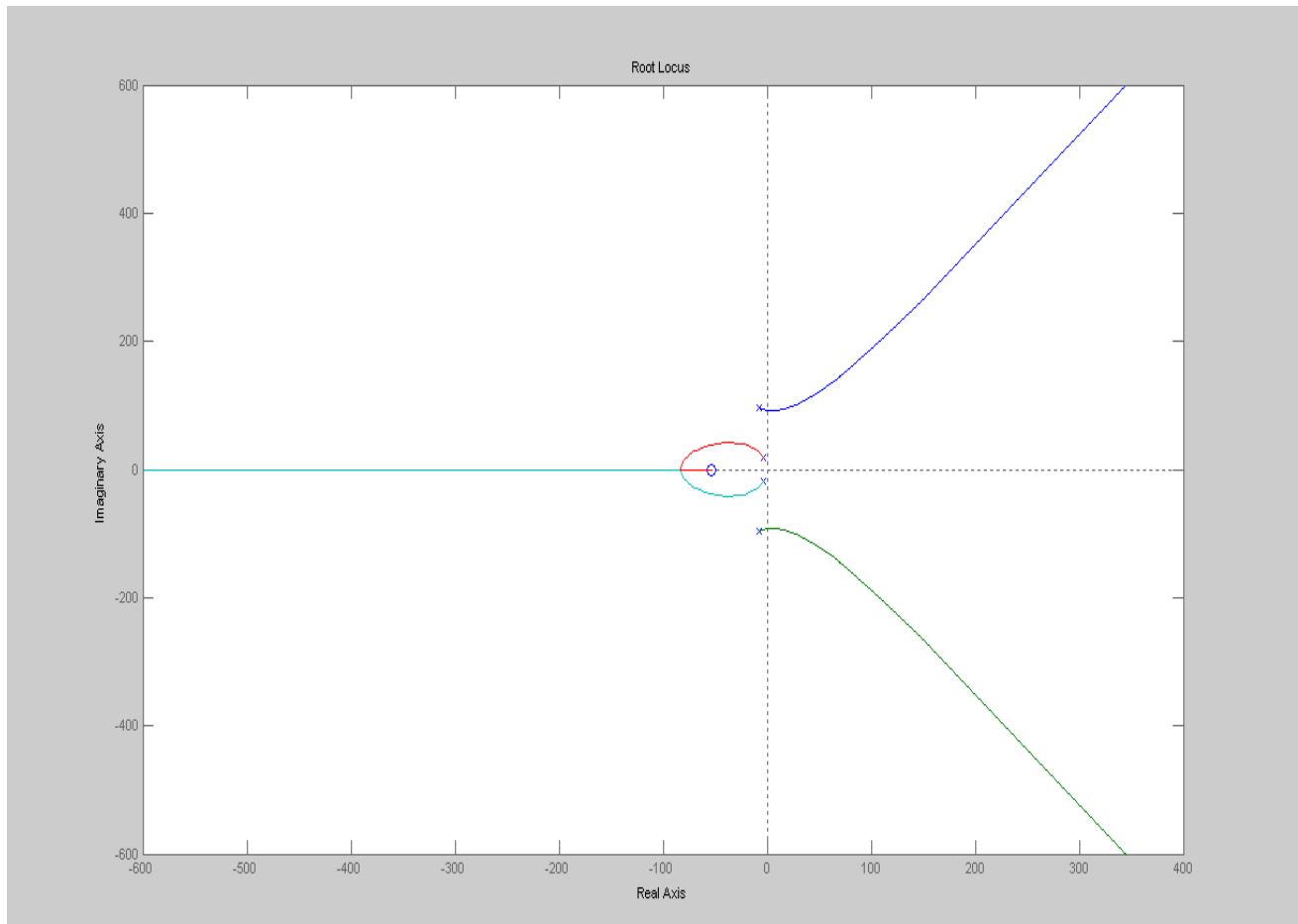

Figure: Root Locus of the system.

We get four poles and one zero, One pole is going to zero, The other one is going to infinity, the two others are going to the right half plane.

The ratio of the distance of the two poles to the imaginary axis and the two others is less than infinity.

So we can omit the two poles (Far from the right half plane) and the two remaining are called dominant pole.

We can finally say that our system is unstable via Root Locus.

➢ Nyquist plot:

Nyquist criterion is similar to root locus, it relates the stability of the system of close-loop to the open-loop frequency response and open-loop pole location.
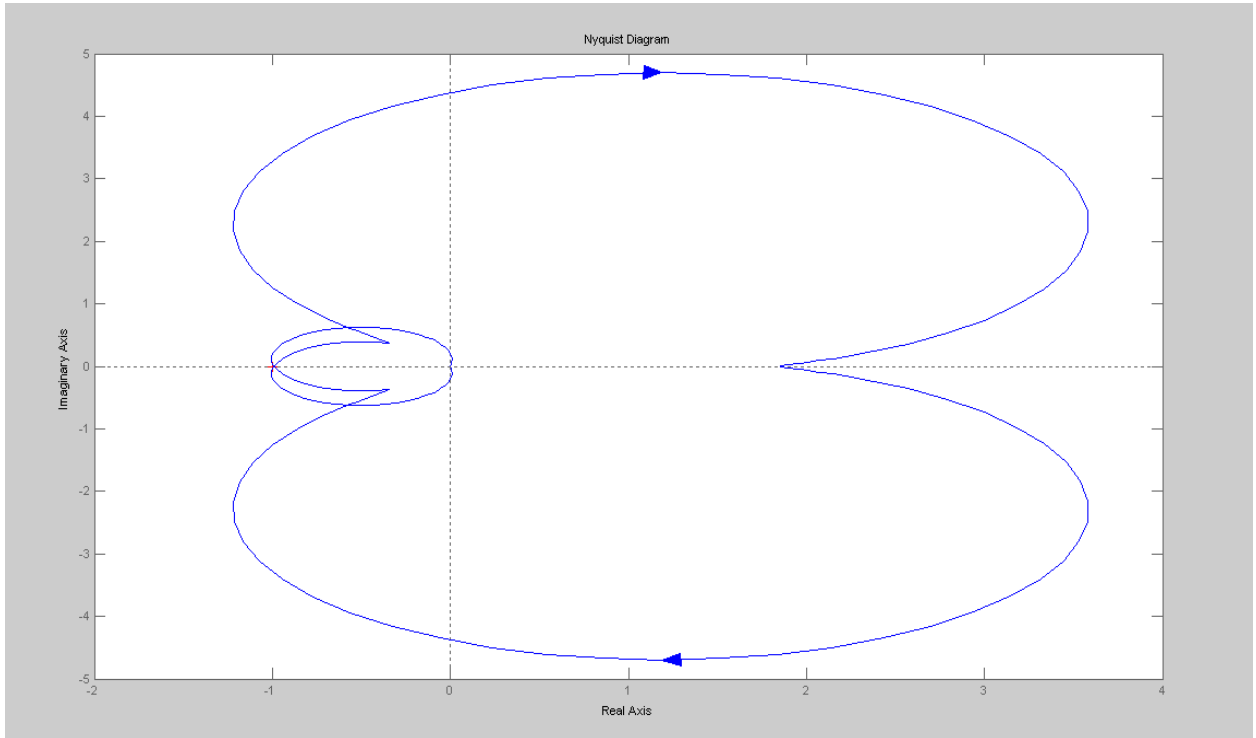

Figure: Nyquist plot of active pantograph control system

The curve starts from omega equal to zero and goes to infinity and then it touches -1 which confirm our previous result via root locus (unstable).

➢ Bode plot

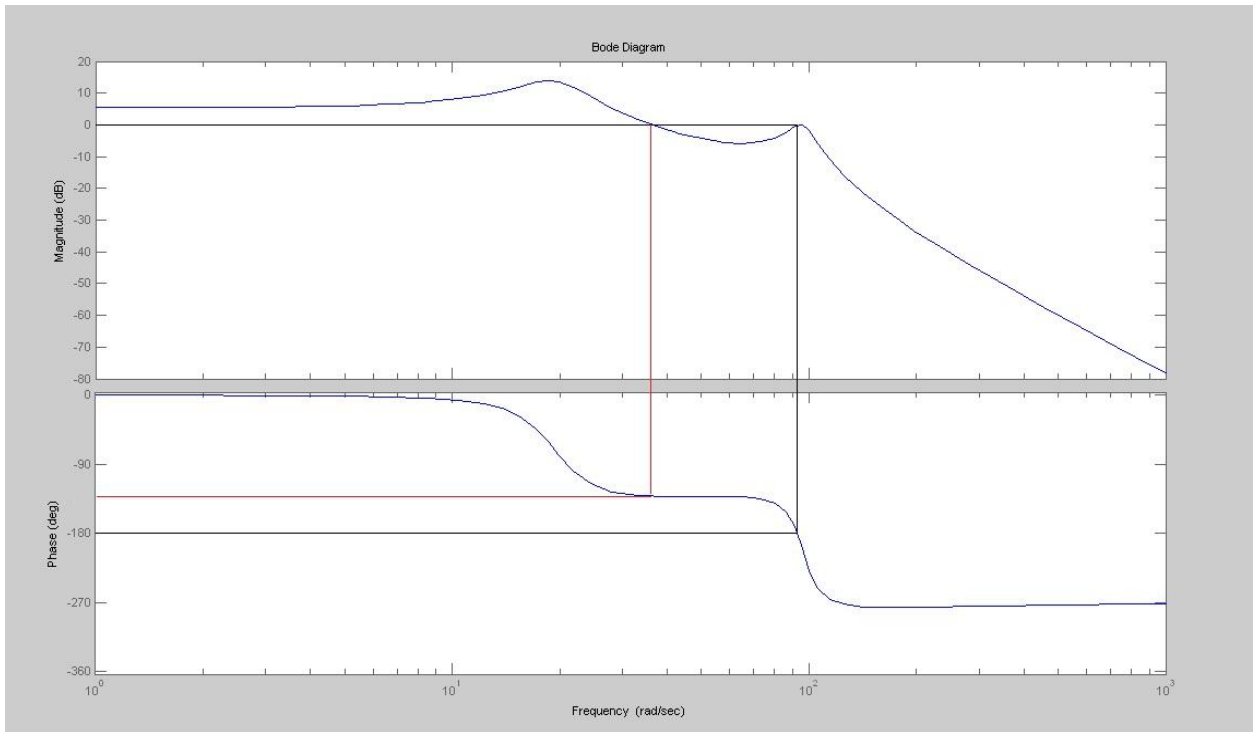Bode plot is the diagram of phase (in degree) versus frequency (in rad/s)

Figure: bode plot of the active pantograph control system.

In here our

Gain margin = zero

Phase margin = 45°

➢ Matlab codes:

- Step function:

```
clear all
close all
num=20.83;
den=[1 101.71 171];
step(num,den)
```

- Root locus:

```
num=[0 0 0 1 -53.58];
den=[1 31.4 18805.32 292.4 172348178];
numa=[0 0 0 1];
dena=[1 4.0068 5.3515 2.3825];
k1=0:1:50;
k2=50:5:200;
k=[k1 k2];
r=rlocus(num,den,k);
```

```
plot(r,('o');
v=[-6 2 -4 4];
axis(v);
hold on
plot(a,'-')
grid;
titlle('Root-locus Plot')
```

4.2 Pantograph active control system with PID controller

➢ Unit step function:

When PID controller is applied on the pantograph active system the result we had found increase. Here, there is no error with 0.09% percentage overshoot and 0.8s settling time.
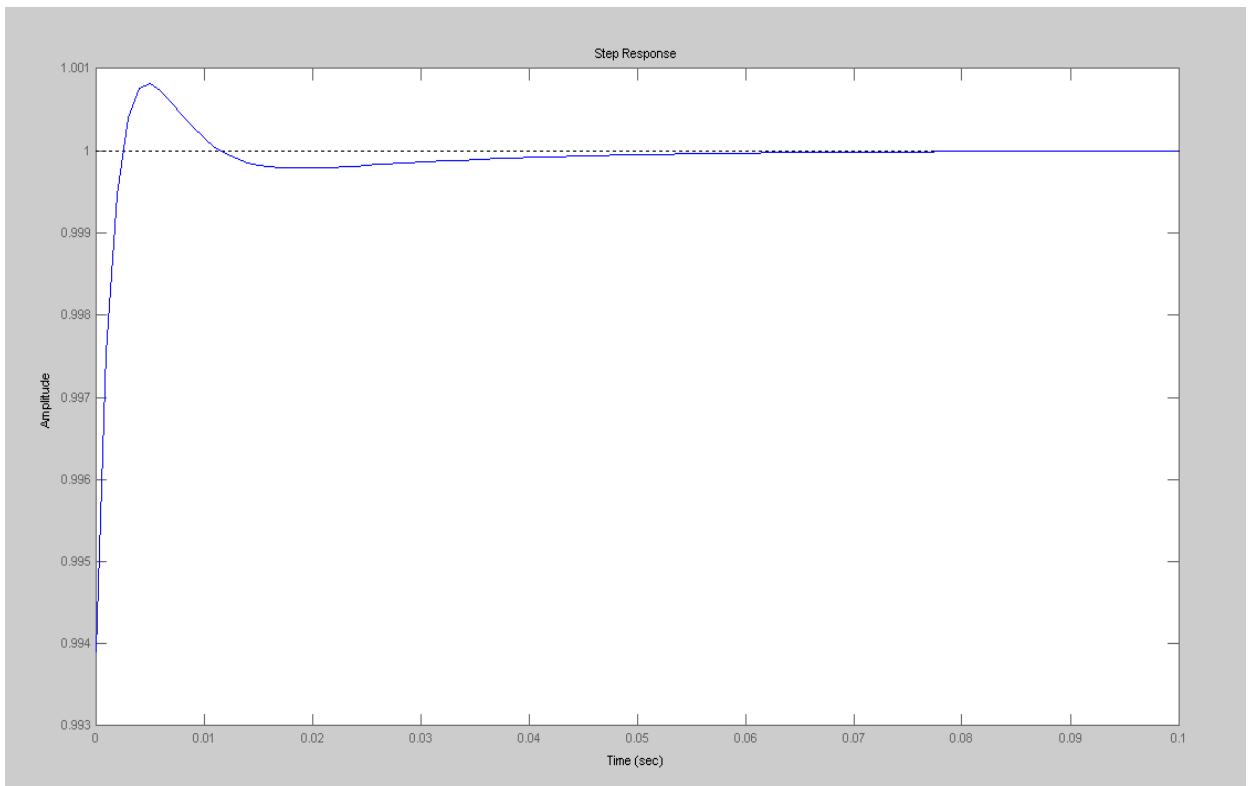

Figure: Unit step function of the pantograph active control system, with PID controller.

➢ Root Locus:

The root locus of the pantograph control system had two poles (dominant poles) and one zero. Applying PID controller on the system adds two poles and one zero.

So now, we have three poles and three zero and this result confirm the fact that our system is improved via unit step function.
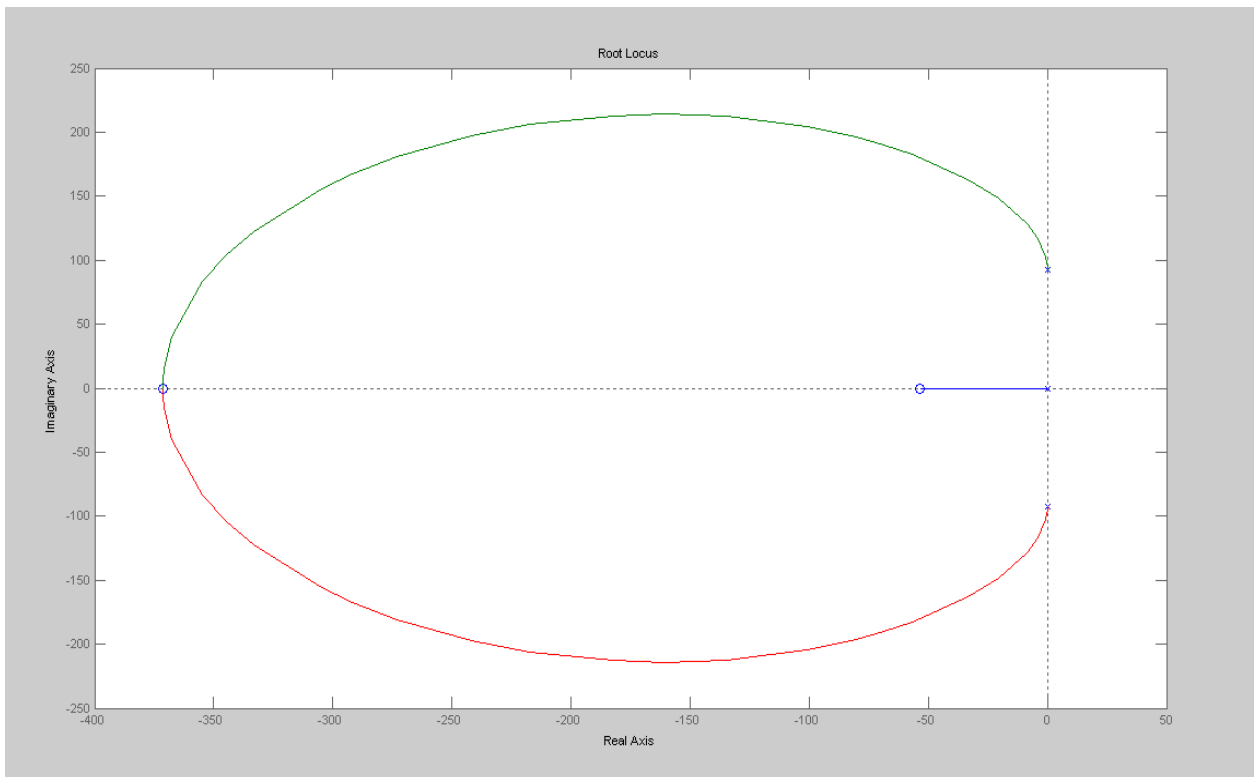

Figure: root locus of the active pantograph control system with PID controller

➢ Bode plot:

Bode diagram or bode plot of the active pantograph control system gives information about the stability of the system. It is just like root locus except it gives no information about the location of the poles.

So we have one pole and two zeros after applying PID controller on the system. Therefore our system still yields three poles and three zero which confirm the result we got via root locus criterion of stability.

Hence we can say that our system is stable with

Gain margin (GM) = 95dB
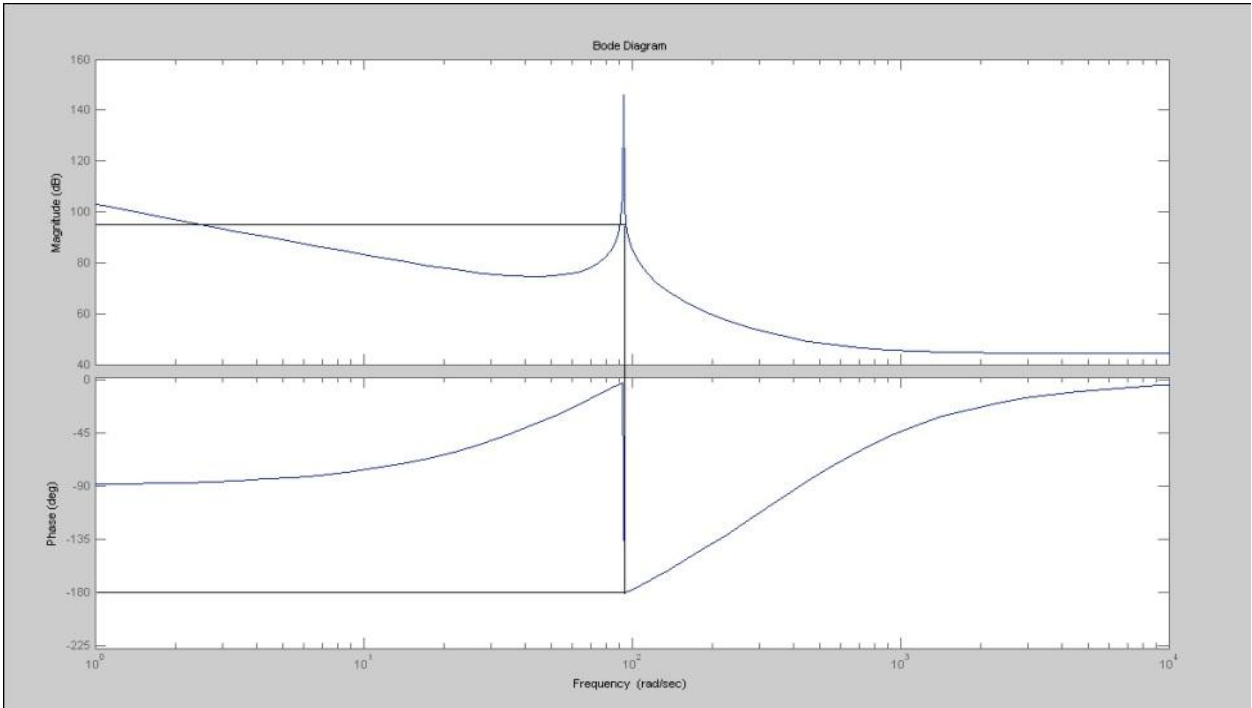
Phase margin (PM) = infinity.

Figure: bode plot of the active pantograph control system with PID controller

➢ Nyquist diagram:

The nyquist diagram of the active pantograph control system show that the curve touches -1 and that made the system unstable. Our diagram below shows that, when PID controller is applied on the system, It neither rotates around -1 nor touches -1.

So, we can conclude that our system is stable now and that brings us to the same conclusion we got with root locus and bode plot.
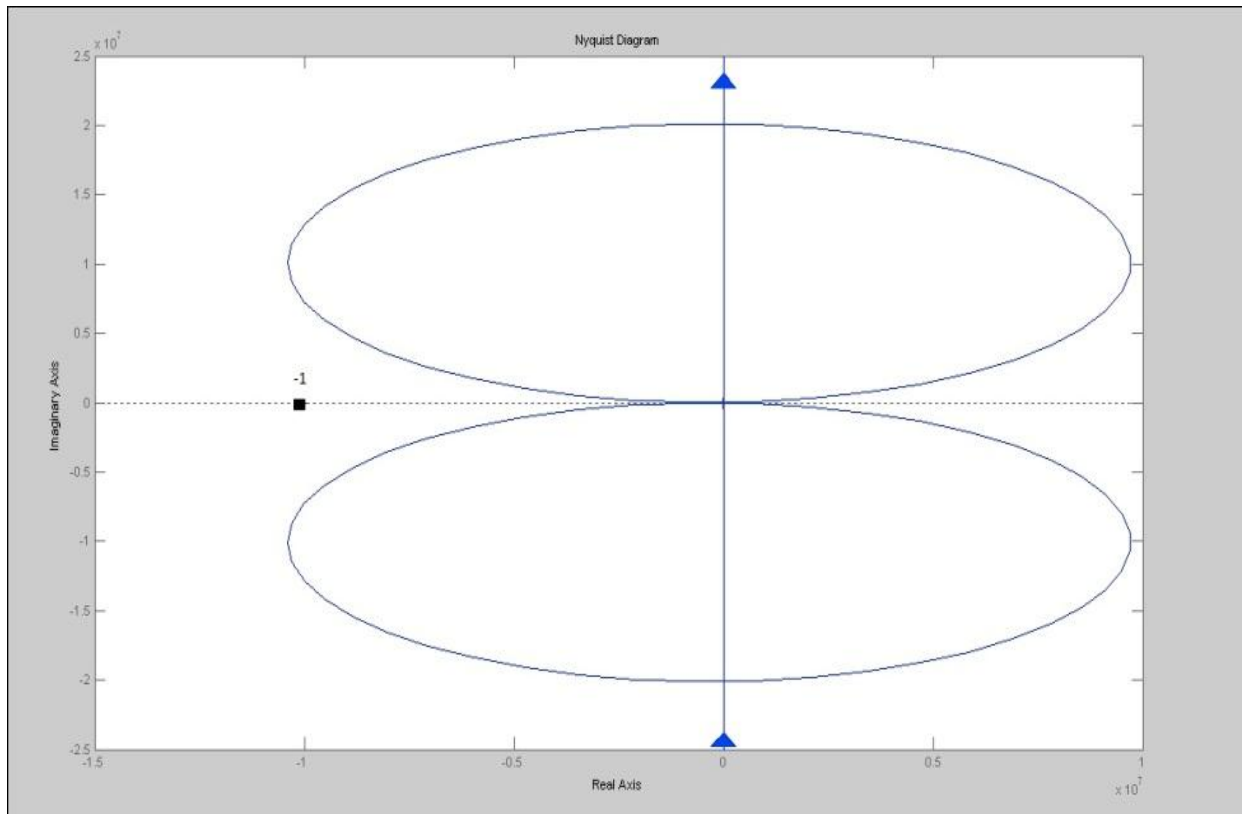
Figure: Nyquist diagram of the active pantograph control system with PID controller.

4.3 Matlab code of unit step function, root locus, bode plot and nyquist diagram and outputs graph (with PID)

```
%P controller
Ku=188145;
omegad=92.82;
zeta=7.95*10^(-5);
omegan=92.83;

%Kp=0.5*Ku;
Kp=0.1;

Kstar=Kp*.7883*1.535*10^6;
ng=Kstar*[1 53.58];
dg=[1 23.589 9784.9 81190.04 3493192.9];roots(dg)
sysg=tf(ng,dg);
nh=[1];dh=[1];
sysh=tf(nh,dh);
sys_cl=feedback(sysg,[1]);

%pzmap(sys);pole(sys);zero(sys);
```

```matlab
%subplot(2,2,1);
rlocus(sysg);
%[Kp,poles]=rlocfind(sysg);
[mag,phase,w]=bode(sysg);
w=.01:100:10000;
%subplot(2,2,2);
bode(sysg);
%[Gm,Pm,Wcg,Wcp]=margin(mag,phase,w);
%subplot(2,2,3);
t=0:0.1:100;
step(sys_cl,t);
%subplot(2,2,4);
%Nyquist Plot
nyquist(sysg);


%impulse(sys_cl,t);
%closed loop poles=-.00738+j92.83,-.00738-j92.83,-11.787+j32.07,-11.787-
j32.07

a1=-0.00738;b1=92.83;a2=11.787;b2=32.07
Kp=0.1
ncl=Kstar*[1 53.58];
dcl=[1 2*(a1+a2) (a1^2+b1^2)+(a2^2+b2^2)+4*a1*a2
2*a1*(a2^2+b2^2)+2*a2*(a1^2+b1^2) (a1^2+b1^2)*(a2^2+b2^2)];
cltf=tf(ncl,dcl);
%subplot(1,2,1);
t=0:0.001:.1;
step (cltf,t);

%desired poles -15+30j,-15-30j,-50+80j,-50-80j,wn=33.54
omegan=92.83
zeta=7.95*10^(-5);zetaomegan=.00738;
napprox=Kstar*[1 53.58];
dapprox=[1 2*zetaomegan omegan^2];
sysapprox=tf(napprox,dapprox);
clapprox=feedback(sysapprox,[1]);
%subplot(1,2,2);
t=0:0.0001:.001;
step (clapprox,t);


%steady state error
ess_p=1/(1+(Kstar*53.58/3493192.9));
OS=100*exp(-zeta*3.1414/sqrt(1-zeta^2));
tp=3.1414/omegad;
Ts=4/zeta/omegan;

Kp=.6*Ku;
%Kp=0.1
Pu=1/omegad;
Ki=2*Kp/Pu;
Kd=Kp*Pu/8;

%Kd=1;Kp=0.1;Ki=omegan^2;
```

```matlab
%Kstar=(Kd*s^2+Kp*s+Ki)/s
numc=[Kd/Kp, 1, Ki/Kp];
denc=[1 0];
numa=conv(napprox,numc);
dena=conv(dapprox,denc);
syspid=tf(numa,dena);
sys_clpid=feedback(syspid,[1]);
[numac,denac]=cloop(numa,dena);
%steady state error
%ess_pid=1/Kv
ess_pid=0
%OS=100*exp(-zeta*3.1414/sqrt(1-zeta^2))
subplot(2,2,1);
rlocus(numa,dena);
w=.01:100:10000;
[mag,phase,w]=bode(numa,dena);
[Gm,Pm,Wcg,Wcp]=margin(mag,phase,w);
Pm;Gm;
subplot(2,2,2);
bode(numa,dena);
title('Step response with Proportional integral derivative Control');
subplot(2,2,3);
t=0:0.001:0.1;
step(sys_clpid,t);
subplot(2,2,4);
nyquist(syspid);


ans =

  -7.7350 +96.0373i
  -7.7350 -96.0373i
  -4.0595 +18.9689i
  -4.0595 -18.9689i


b2 =

   32.0700


Kp =

    0.1000


omegan =

   92.8300


ess_pid =

     0
```
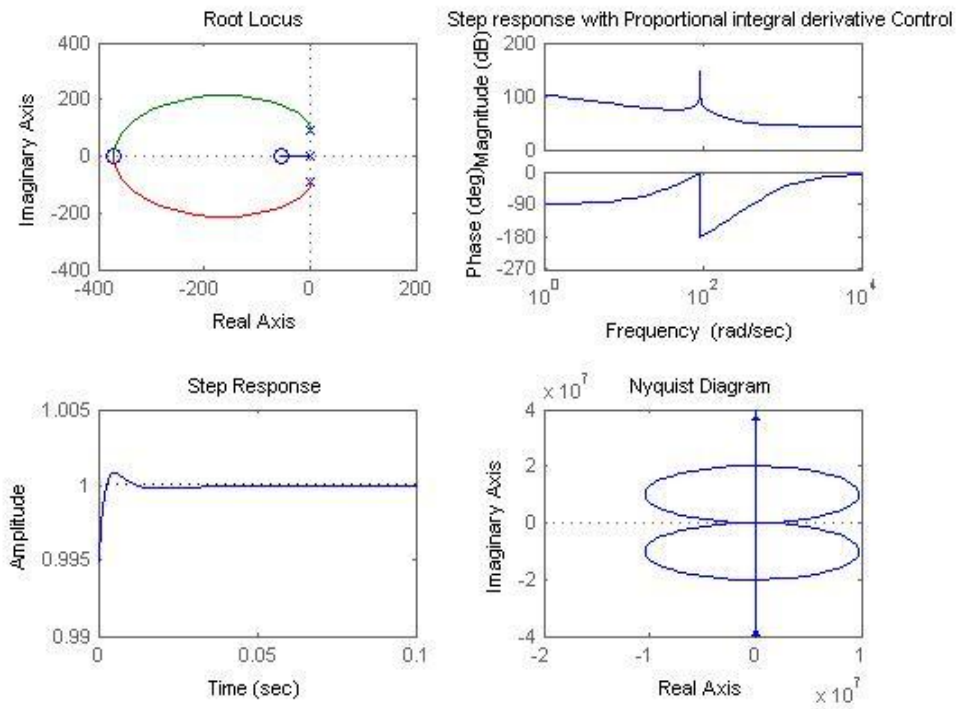
Figure: diagram showing step response, root locus, Bode plot and Nyquist diagram in a same graph.

CHAPTER 5

CONCLUSION:

In this project, the behavior of a simplified model of the control system associated with high-speed rail pantograph has been studied and necessary changes have been made using PID controller from modern control system analysis.

When we first analysis our system we found out that the system is not stable and can be improve.

Our main target was then achieved. We aimed to apply PID controller to the pantograph active system to get a better performance in terms of efficiency. So to tune our PID controller Ziegler-Nichols tuning rules was used.

Ziegler-Nichols tuning rules are mostly useful when the plant's mathematical representation cannot be obtained. It gives the engineers a tuning process starting point with ease. However, these tuning rules are also applicable for those systems with known mathematical models.

As stated before, the Ziegler-Nichols method gives the starting point for the tuning process. Nevertheless, it is critical that an engineer can take it up from there and further tune it (based on experience) so the system can meet the performance specification wanted.

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[1] Control System engineering Sixth Edition by Norman S NISE

[2] Proportional-Integral-Derivative (PID) Controllers Stanisław H. Żak School of Electrical and Computer Engineering

[3] The Design of PID Controllers using Ziegler Nichols Tuning Brian R Copeland March 2008

[3] Wikipedia