ISLAMIC UNIVERSITY OF TECHNOLOGY, (IUT)

Improvement of high speed rail pantograph control system using PID controller

By

ANAS ALNAWAFLEH (091418) ABDALLAH ALMOGHRABI(091456)

MAHMUD ANDA(081451)

A Dissertation
Submitted in Partial Fulfillment of the Requirement for the
Bachelor of Science in MECHANICAL AND CHEMICAL Engineering
Academic Year: 2012-2013

Department of MECHANICAL AND CHEMICAL Engineering
Islamic University of Technology (IUT)
A Subsidiary Organ of OIC
Dhaka, Bangladesh

A Dissertation on,

Improvement of high speed rail pantograph control system with PID

Submitted By

ANAS ALNAWAFLEH (091418) ABDALLAH ALMOGHRABI (091456) MAHMUD ANDA (081451)

Approved By

Dr. Abdur Razzak Akhanda
Professor & Head of the
Department of MCE, IUT

Dr.Aly Sabry
Thesis Supervisor
Professor
Department of MCE, IUT

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 2013 under the supervision of Dr.Aly Sabry, Professor of the department of mechanical and chemical Engineering. We would like to express sincere gratitude to our thesis supervisor Dr. Prof. Ali Sabry.

We would like to dedicate this thesis to our supervisor Dr. Prof. Mr. Ali Sabri. Without the dedicated help of him, 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

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

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.

1.2 Objectives

The objectives of this project are:

i. To fulfill the requirement for the subject MCE-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 PI &PID controller applied.

.

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.

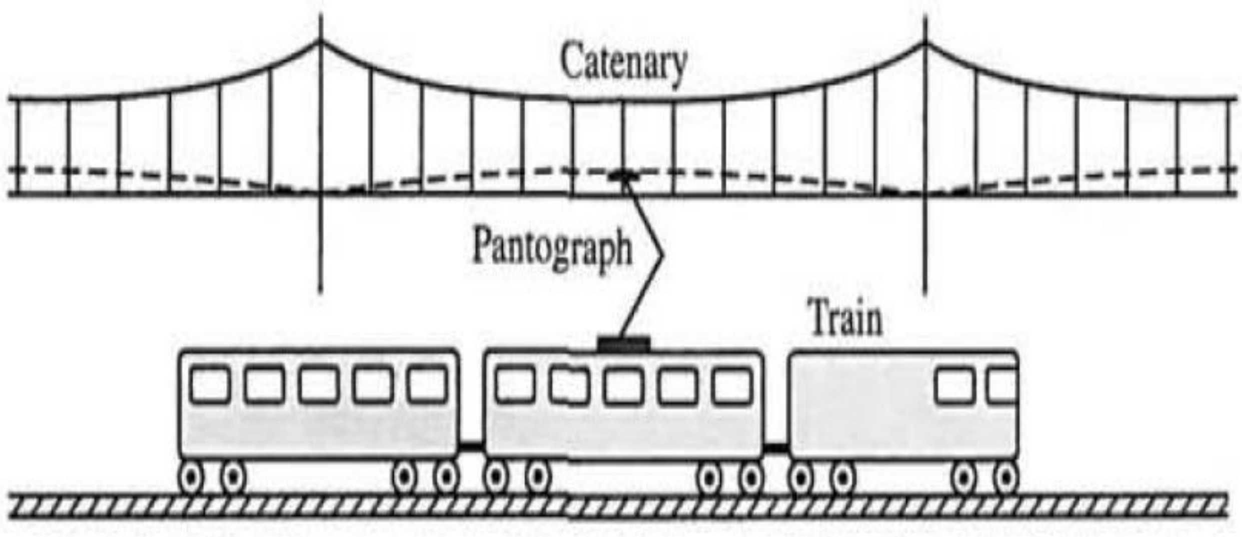


Figure 2.1(b): High-speed rail system showing pantograph and catenary

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.

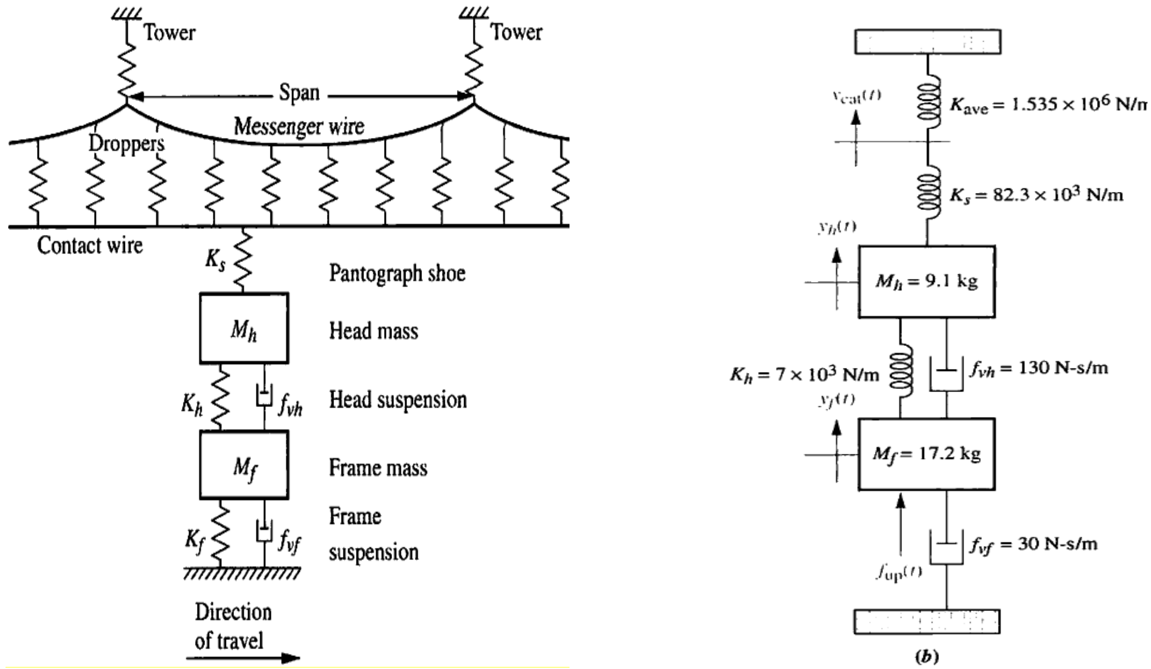


Figure3.1: (a). Coupling of pantograph and catenary (b) simplified representation showing the active control system.

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.

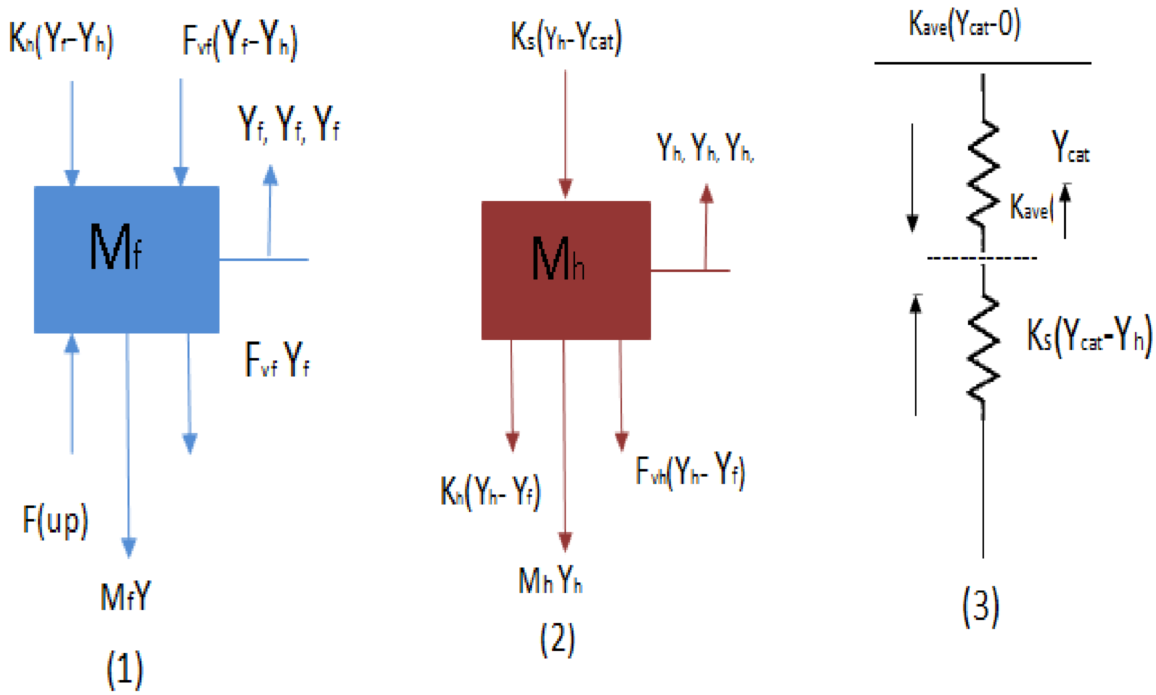


Figure 3.2: free body diagrams

3.3 Block Diagram

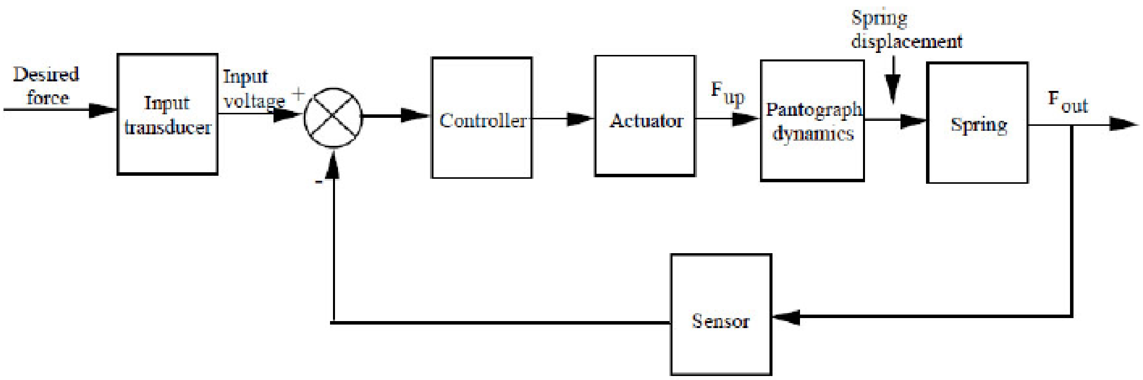


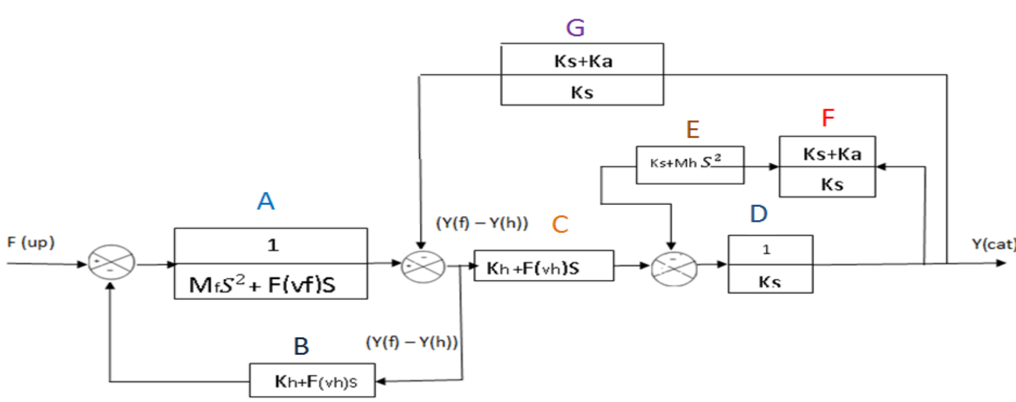
Figure 4: Functional block diagram of pantograph active control system

3.4 Writing the Equations

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

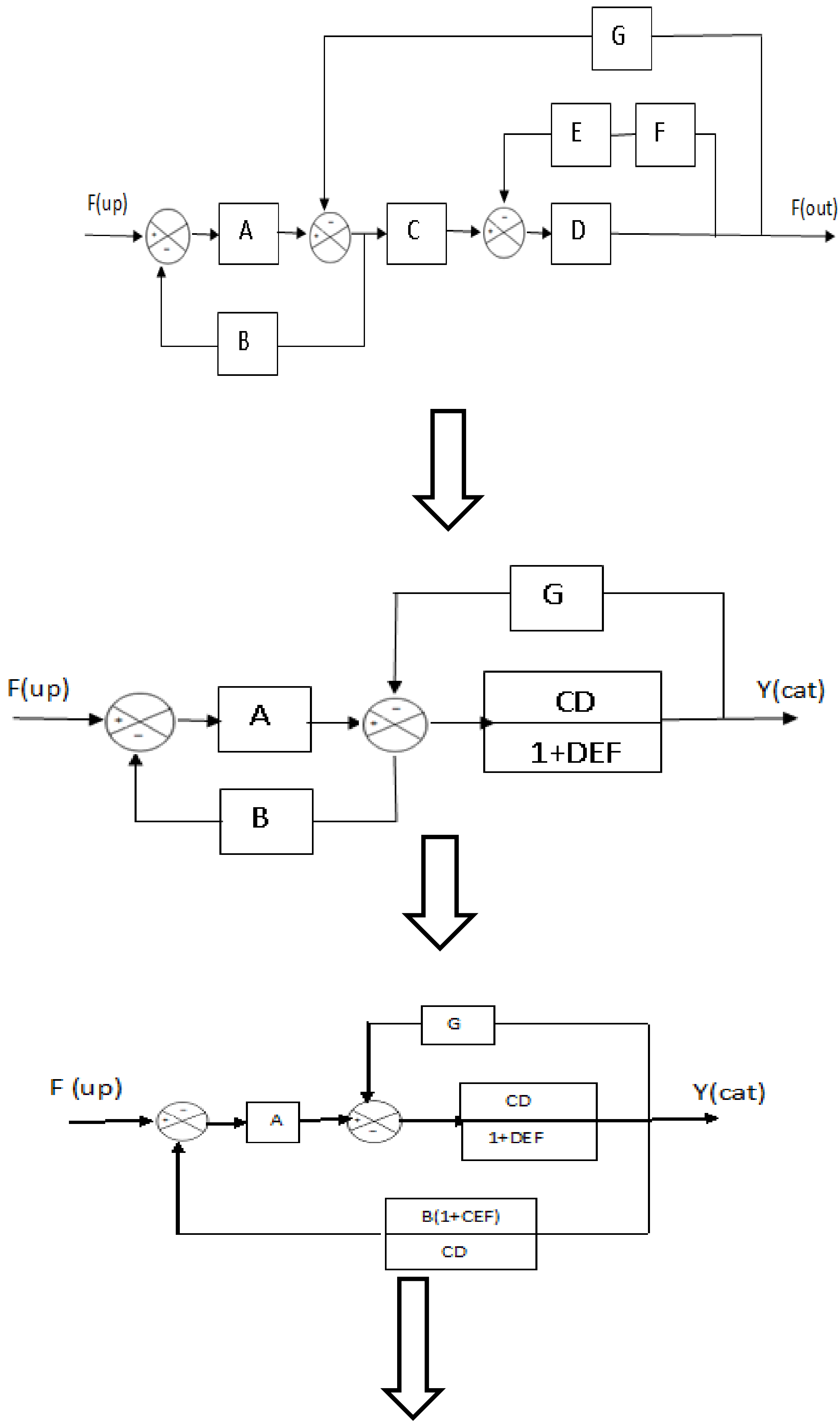
2) $$K_h - (Y_f - Y_h) - F_{vh}(Y_f - Y_h) - K_s - (Y_h - Y_{cat}) = M_h s^2 Y_h$$

3) $$K_s Y_h - (K_s - K_{ave}) Y_{cat} = 0$$

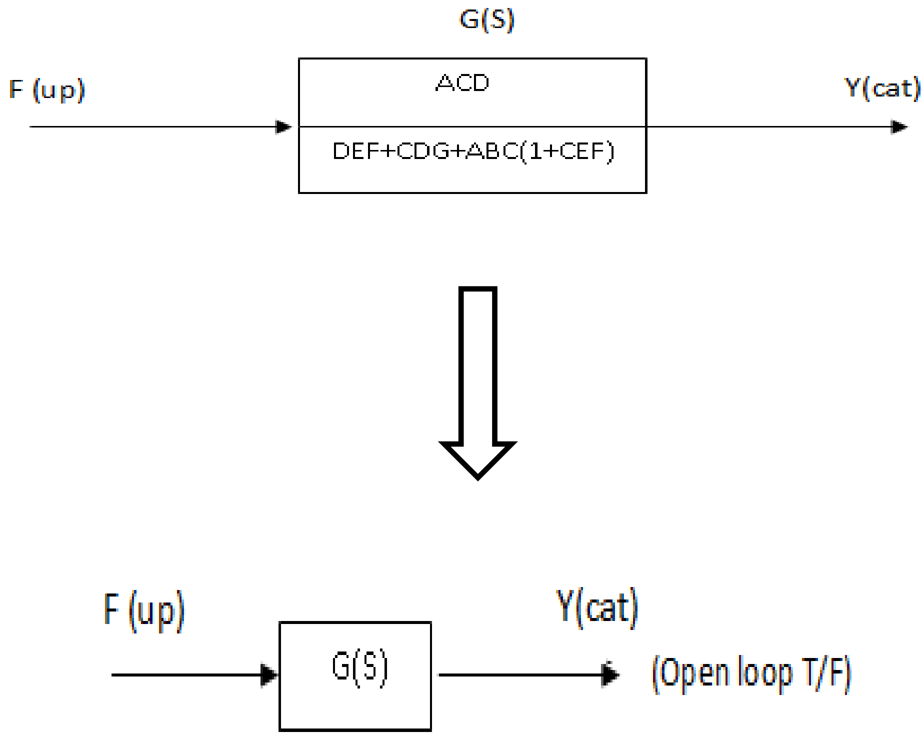


3.4.1 Block Diagram reduction

3.4.1. a) Open-loop transfer function



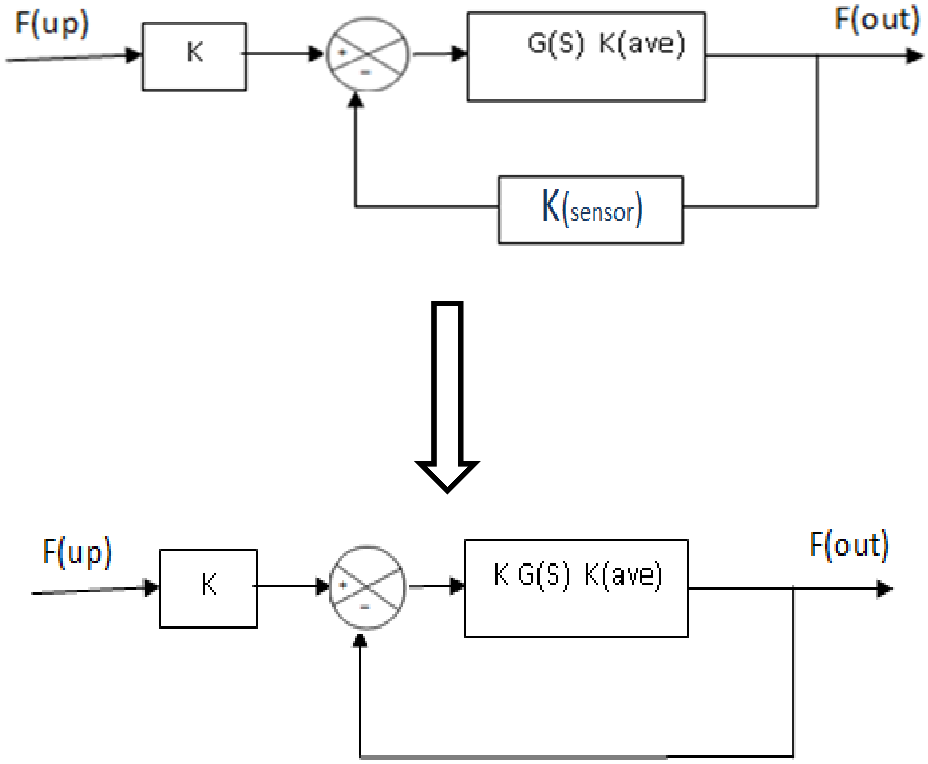
G
E
F
F(up)
A
C
D
F(out)
B
G
F(up)
A
CD
1+DEF
Y(cat)
B
G
F (up)
A
CD
1+DEF
Y(cat)
B(1+CEF)
CD



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

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

3.4.1. b) Close-loop transfer function



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

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

3.5 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+34.94k
s^3	23.669	81190.038+0.6488k	
s^2	150,408.7821-0.6488k		82680382+826.995k
s^1	$-\dfrac{0.42k^2 + 125{,}334.775k + 1.024 * 10^{10}}{150{,}408.7821 - 0.6488}$		
s^0	82680382.75+826.995k		

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 $w_d = \pm 92.80$

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

3.6 Drawing the rootlocus

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

No of poles $(n) = 4$

No of zeros$(m) = 1$

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

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

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

$-32.07j - 53.849$

$= 25.812$

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

=+60,-60,180

CHAPTER 4

RESULTS:

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

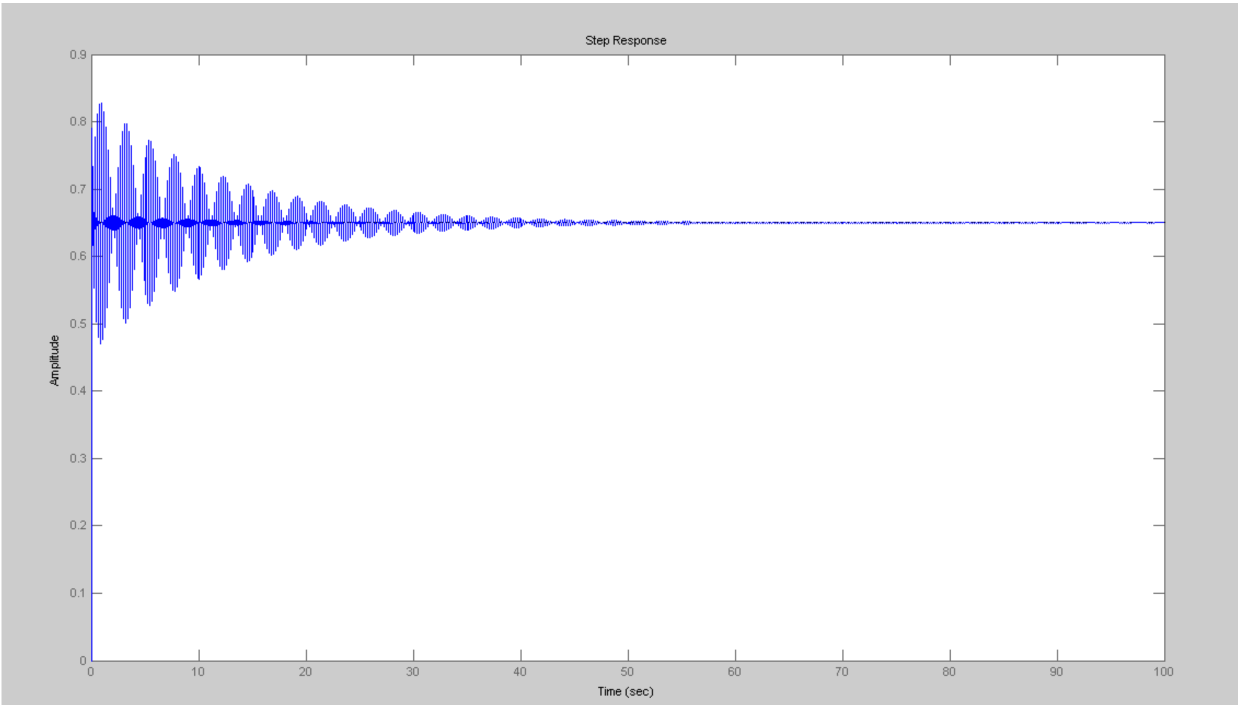


Figure: Unit step function
Comment: Our unit step function show oscillation at the beginning and then starts damping with 35% steady state error. So we can say the system is not stable.

- 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. 40

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

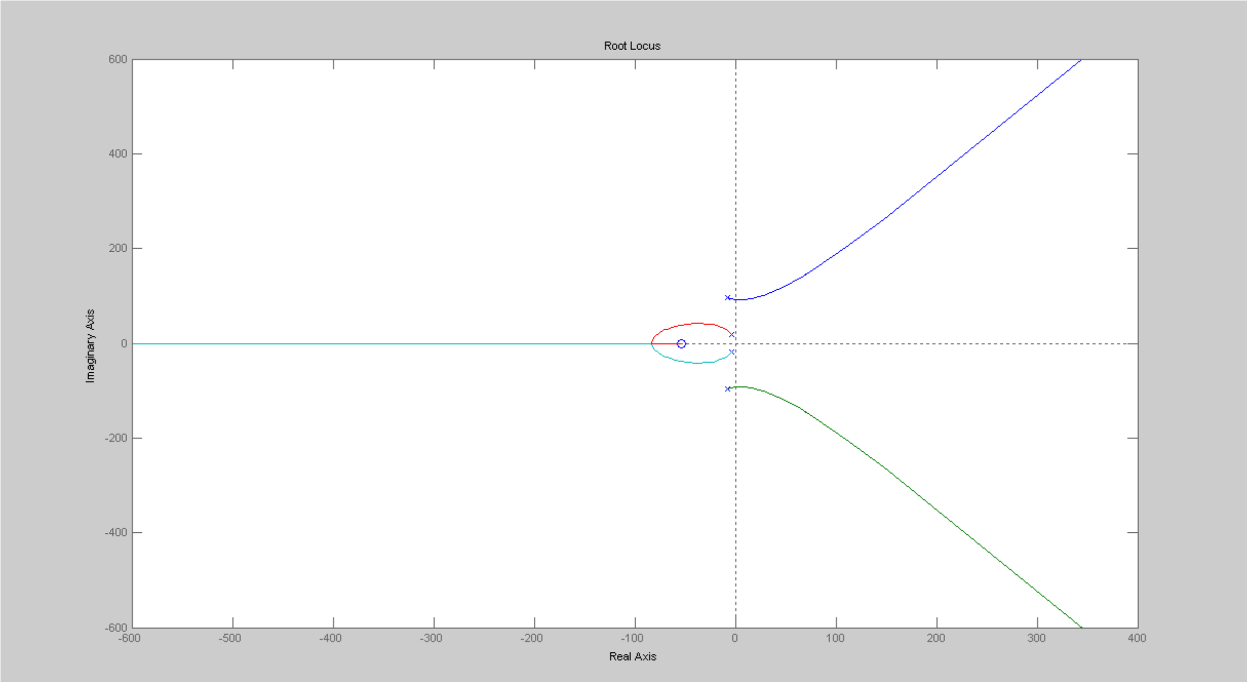


Figure: Root Locus of the system.

We get four poles and one zero, One pole is going to zero, 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 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.

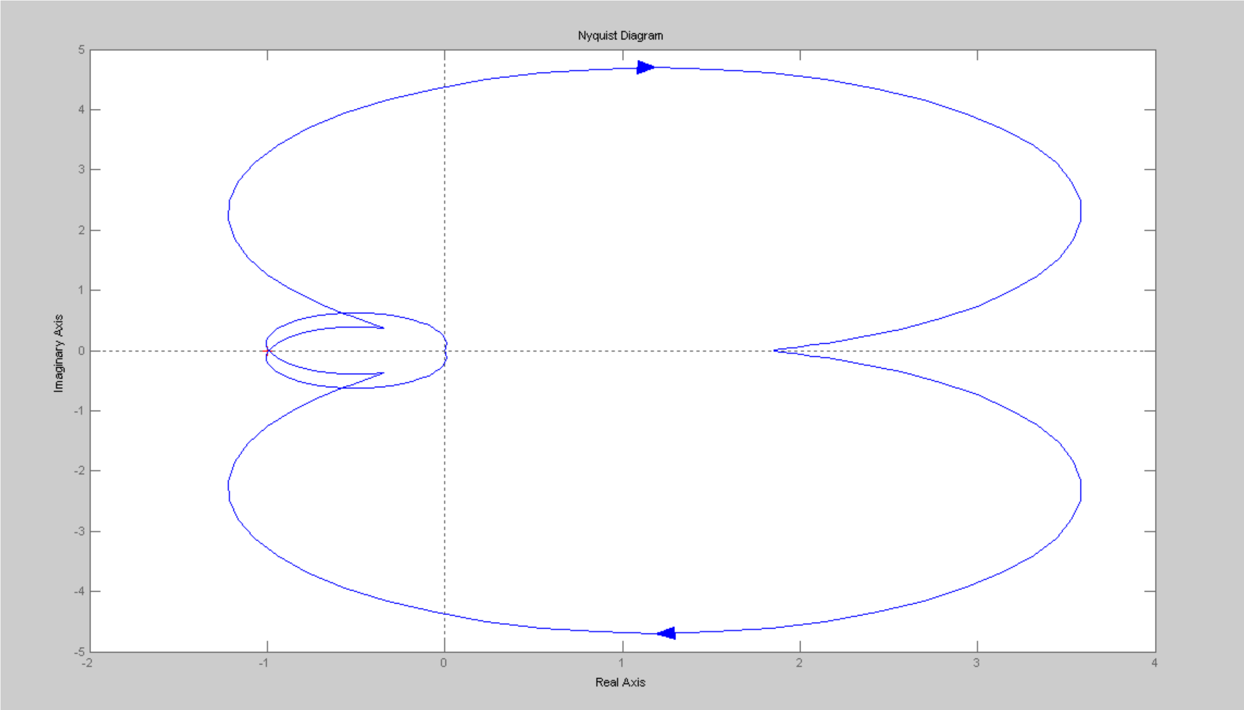
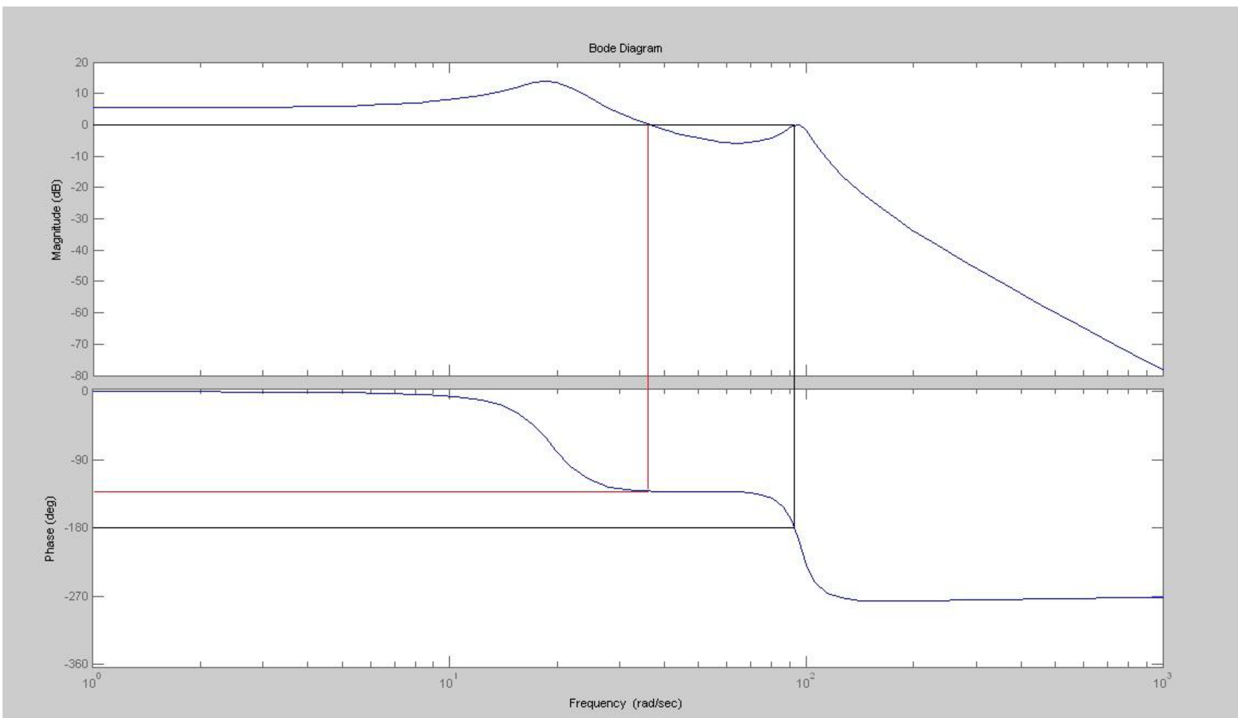


Figure: Nyquist plot of active pantograph control system

The curve start from zero and goes to infinity an 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)



Bode Diagram
Magnitude (dB)
Phase (deg)
Frequency (rad/sec)
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-180
-270
-360
10^0
10^1
10^2
10^3

Figure: bode plot of the active pantograph control system.
In here our gain margin is zero and our phase margin is
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.

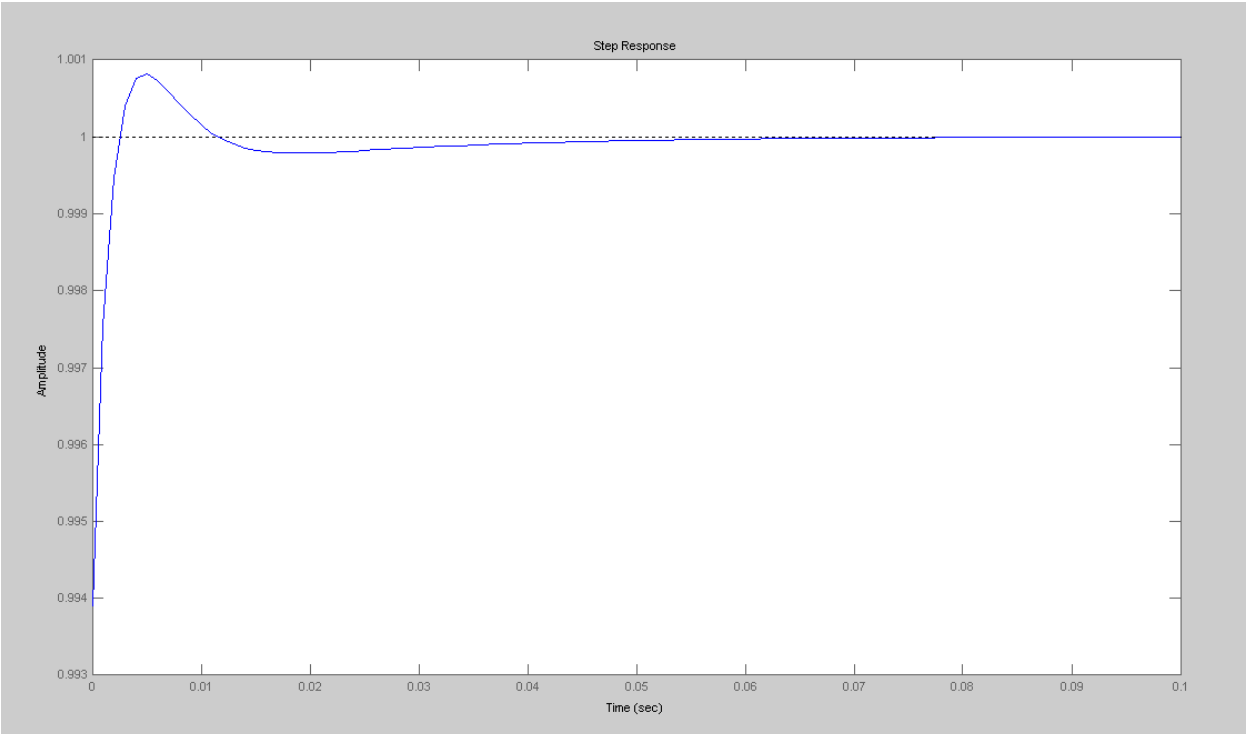


Figure: Unit step function of the pantograph active control system, with PID controller.

➢ 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 improve via unit step function.

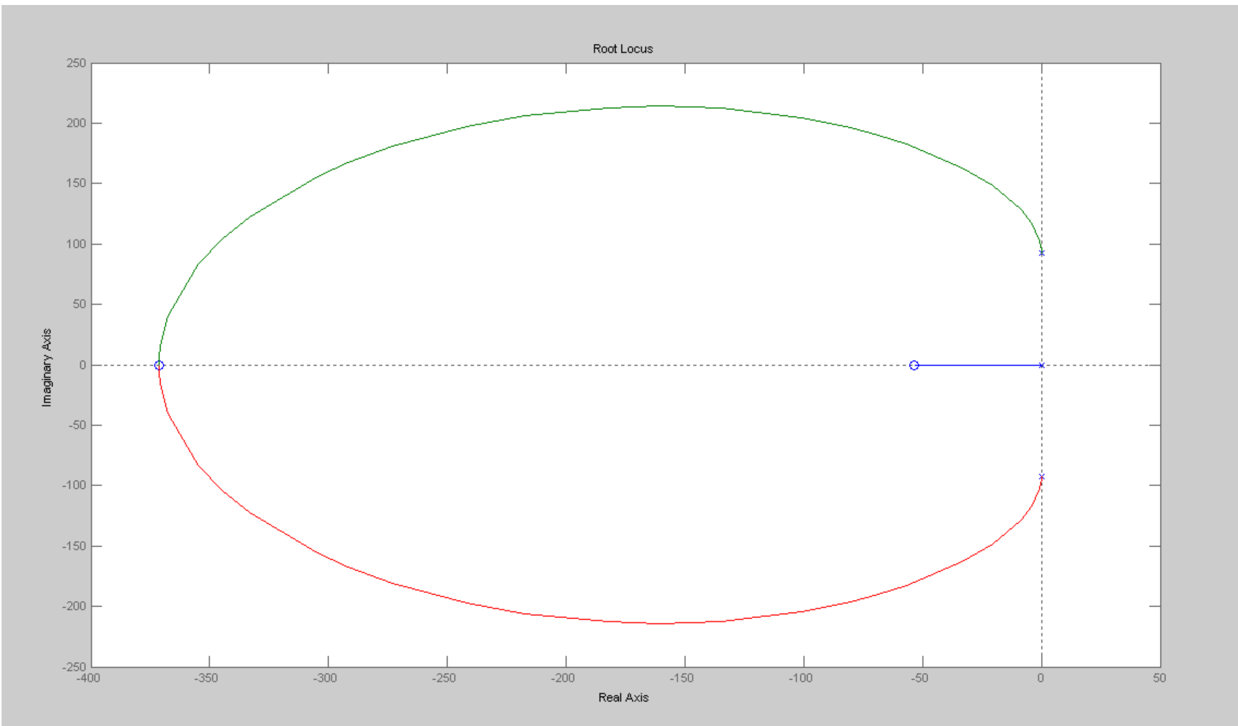


Figure: root locus of the active pantograph control system with PID controller

- 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 not stable with a gain margin (GM) of 95dB and phase margin (PM) of infinity.

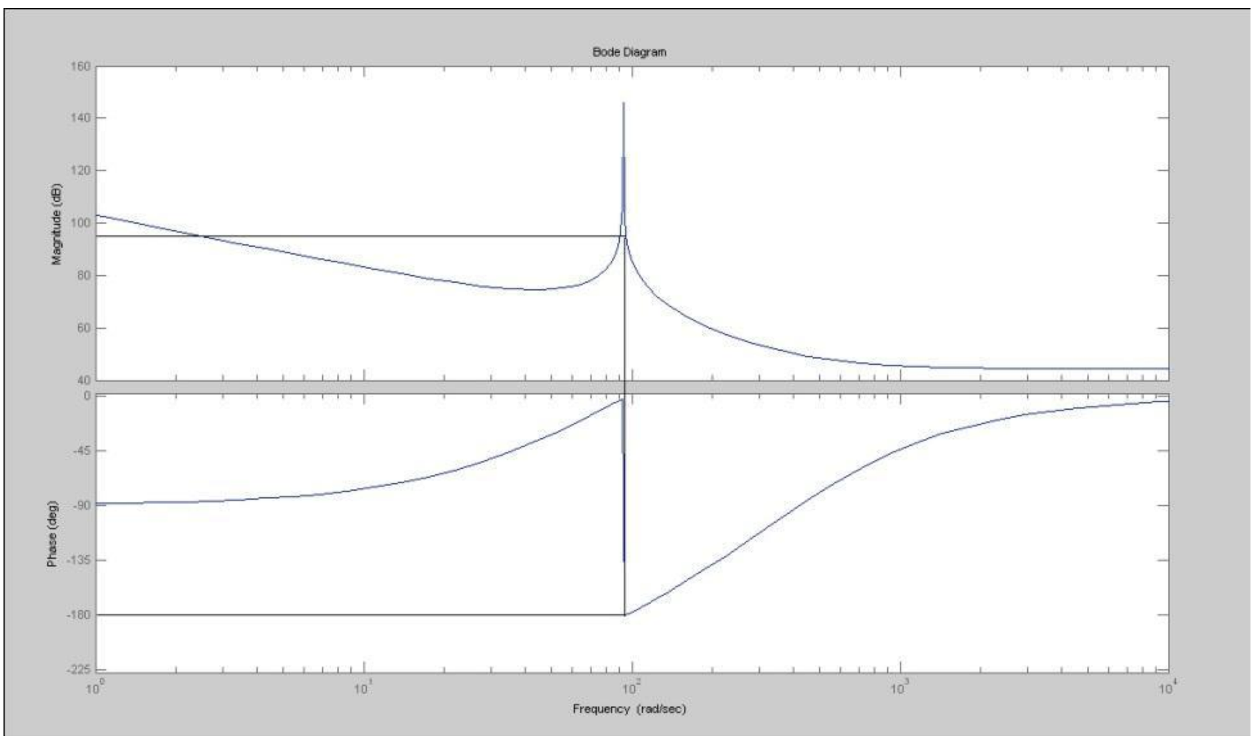


Figure: bode plot of the active pantograph control system with PID controller

- 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 does not touch -1 or hugs -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.

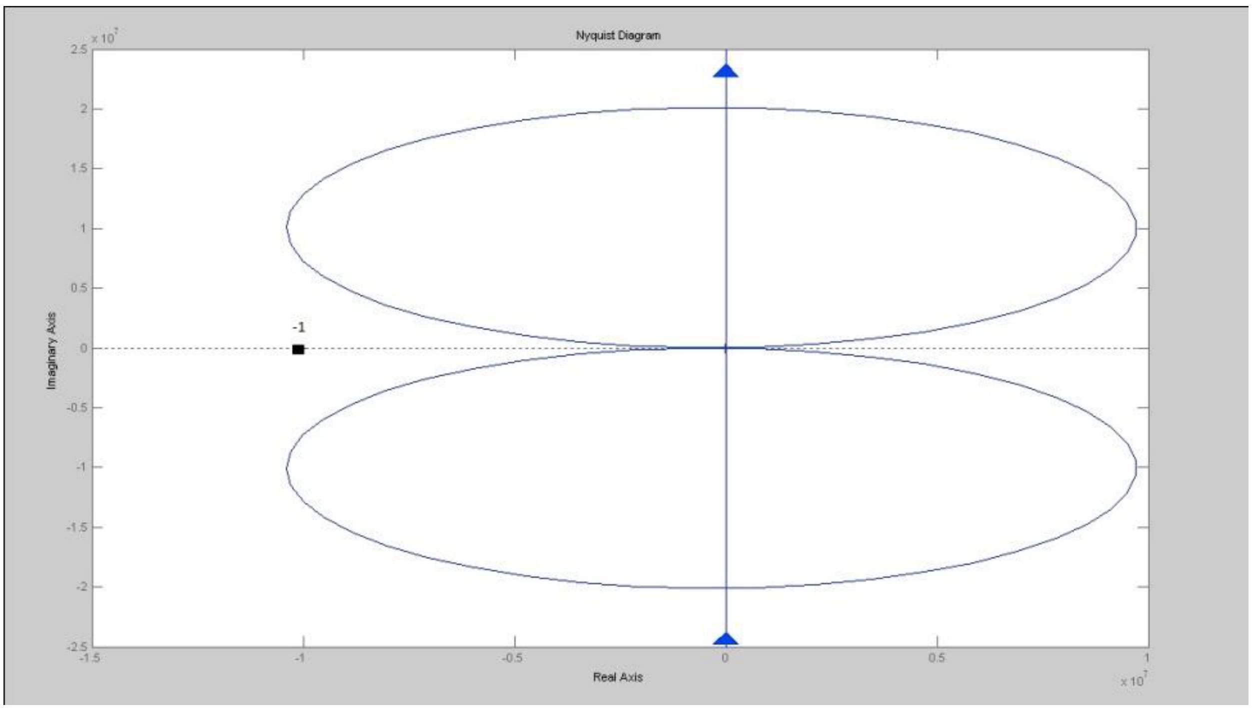


Figure: Nyquist diagram of the active pantograph control system with PID controller.

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.

REFERENCES:

[1] Control System engineering Sixth Edition by Norman S NISE
[2] Proportional-Integral-Derivative (PID) Controllers StanisławH. Żak School of Electrical and Computer Engineering