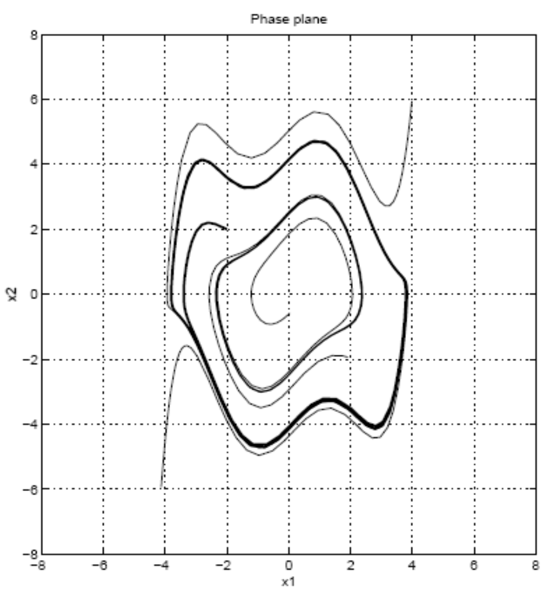
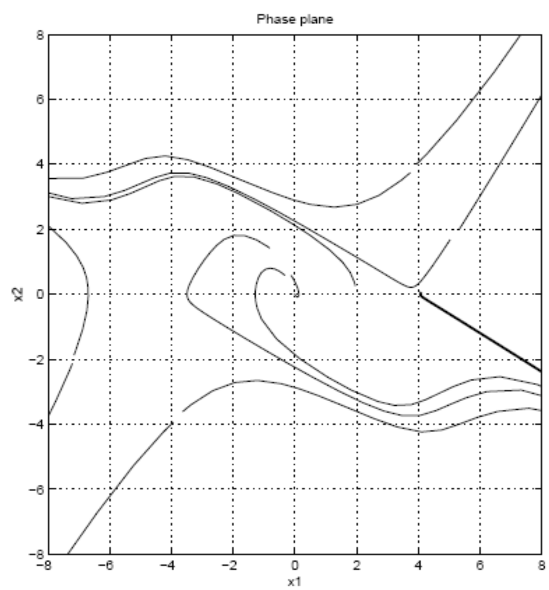
DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING
COLLEGE OF ENGINEERING
UNIVERSITY OF BAHRAIN

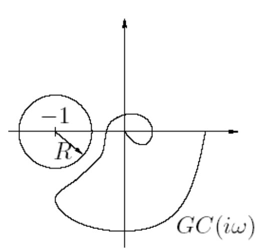
EENG 381: CONTROL SYSTEMS

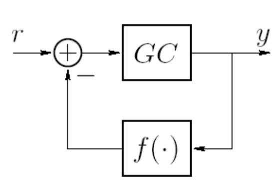
LABORATORIES SESSIONS MANUAL

Prof. Ebrahim Abdullah Mattar









NOTES :   Adopted with Permission From Author

EENG 381   Control Systems Laboratory Classes

The timetable for laboratory sessions is given separately. You are expected to attend all of these timetable sessions (*if, because of illness or some other good reason, you fail to attend a session then you must inform the appropriate laboratory supervisor immediately*).

Remember that experiments cannot be properly executed without prior study as the limited laboratory time must be devoted to experimental investigations.

Attendance records are kept so if you are late, please report to the academic supervisor to ensure that your presence is recorded. If you are absent from a class, you should contact the appropriate organizer at the earliest opportunity.

As with most University activities, it is YOUR RESPONSIBLIT to ensure that you receive maximum benefit from the facilities provided. You are MOST STRONGLY advised to study each experiment a few days on ADVANCE. This will involve reading additional materials such as lecture notes and course textbooks, deriving theoretical formulae quoted in the instructions, making preliminary calculations of expected results and considering appropriate experimental methods. Almost certainly you will encounter problems in understanding the background to an experiment, setting up equipment or interpretation of results.

- Remember that laboratory time is precious and must not be wasted because of insufficient preparation (time wasted in this way is also unfair to your partner: it will be regarded as a serious deficiency).

You are required to record all experimental work and design work in a personal A4 logbook with   HARD COVER.

WORK ON LOOSE-LEAF PAPERS WILL NOT BE ACCEPTED.

Your log work should contain records of trail design, mistakes, repeated work and comments which would not be expected to appear in a formal experimental report. It is essential to record everything you do and your reasons for doing it – the logbook should be thought of as a record of a conversation with yourself as the experiment proceeds or the design develops. As a result, you should have all the information you need in your log book to write a formal report on a experiment or design several months afterwards.

Your logbook should always contain significant entries. This is true even if you have spent the day typing your results. A record of the amount of work that you have done may prove invaluable for useful data.

At the end of each laboratory session you should write, in not more than half a page, a brief summary of your conclusions.

Report Writing

These notes are provided to assist in the preparation of the formal reports required.

Presentation:

A4 Page size.

Use a word processing system if possible, together with a printer that produces easily readable characters (sometimes a photocopy of the printed output is easier to read).

Any report that is difficult to understand, for any reason, will automatically be given a low grading.

All pages must have a ruled margin (at least 25mm) on the binding edge and be numbered. Only one side of the paper should be used.

All sections of text must be numbered serially in Arabic numerals.

All figures and graphs must have a title and be numbered serially in Arabic numerals.

All tables must have a title and be numbered serially in Roman numerals.

Report Structure:

Title page (front cover).
Summary (single page – about 50 words).
Contents (single page – should list content of report with appropriate text sections and page numbers).
Report (most reports start with an "Introduction" and finish with "Conclusions".
References (most student reports contain very references).
Appendices.
Acknowledgments (if appropriate).

Report Content:

The title of each report is announced at a suitable time, together with a brief specification of items to be included and a suggested maximum length.

The title should be directly applicable to the report produced. It is especially important that introductions and conclusions be concise and relate specifically to the main topics of the report. A common error with student reports is to begin detailed explanations immediately without any explanation of the overall system or justification for the approach taken.

Any item selected in the report specification for special consideration must be given appropriate emphasis in the report. Failure to include such items (e.g., "experimental evidence based on laboratory measurements") is a serious omission.

The report should exceed the maximum length without good reason as the marking will be partly based on conciseness. A report that appears to be too long will NOT normally achieve a high grade.

Reference should be sent out to the report body, and should be to reputable academic texts (e.g., IEEE publications).

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EENG 381: CONTROL SYSTEMS

COMPUTER LAB NO. 1
PRACTICAL: MAXIMUM OF (10) MARKS

COMPUTATIONS ON ANALOG TIME SIGNALS

Laboratory Objectives:

To learn some basics of analog and discrete signals computations and analysis.

Needed Equipment:

- Variable Capacitors, Resistors.
- Analog and digital Voltmeters (30-0-30).
- Hand Calculator.
- Storage Oscilloscope.
- Op-Amps and some Feedback Tools.

Introduction to the Experiment:

Analog and discrete-time signals are processed in accordance to certain applications on such signals. Op-Amps (known as Operational Amplifiers, as shown in Fig (1)) are considered as the main tools for computation continuous and discrete-time signals. The 741 operational amplifier (741 Op-Amp) is the basic kind for a wide range of commercial devices available on the market one a day. With standard op-amps, we can perform : signal scaling, integration, differnation, log calculations, and conversions. Op-amps have typically two inputs

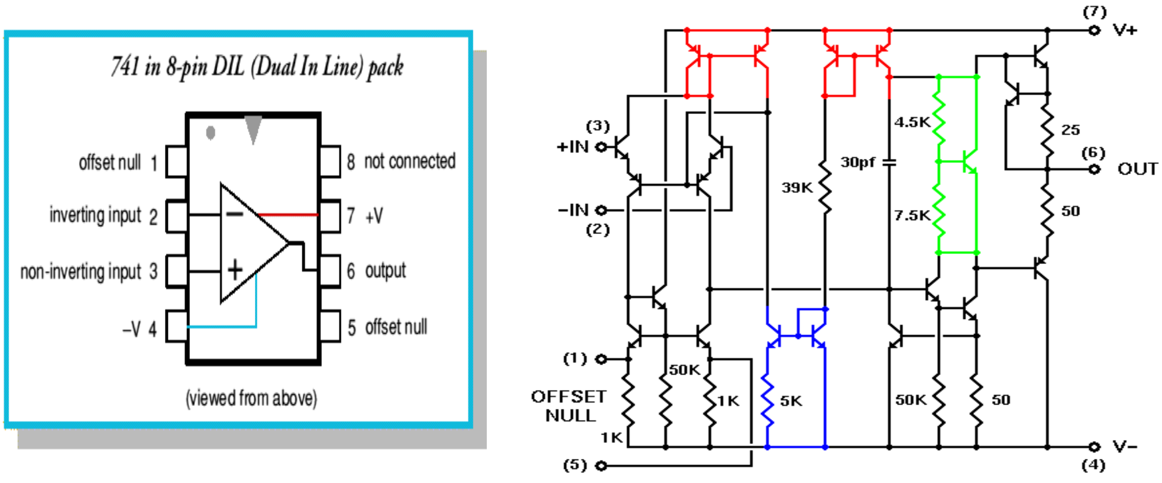

Fig (1) : (A) Op-Amp 741 Chip Layout. (B)The internal circuitry of the 741-op amp. (1)

NOTE : (1)

- (Prof. Connie Chang-Hasnain).

A very typical commercial IC op amp circuit is the 741. This IC has been available for many years, and a number of variations have been developed to help minimize the errors inherent in its construction and operation. Nevertheless, the analysis we will perform here using the 741 will apply to any other IC op amp, if you take into account the actual parameters of the device you are actually using. Therefore, we will use the 741 as our example IC op amp. A problem with any op amp is a limited frequency response. The higher the gain of the complete circuit, the lower the working frequency response. This is one reason an overall gain of 20 is a practical limit. (Another reason is that the input and feedback resistors become too different from each other.) Also, the standard 741 has a *slew rate* of 0.5 v/µs. This means that the output voltage cannot change any faster than this. The newer generation of op amps, such as the 741S, have a slew rate more like 5 v/µs, and hence can operate over the entire audio range of frequencies without serious problems.

Laboratory Procedures:

(1) Gain Coefficient (Amplification and Attenuation) :
The scaling of the amplifier, and therefore the constant coefficient, is set by the input and feedback resistors. The gain of the circuit is given by ($-R_f/R_{in}$). Therefore, the gain of this particular circuit is (20k/10k = 2). We could equally well invert the incoming X signal before applying it to the circuit. Hence, construct the shown below circuits. It is an inverting amplifier (attenuator circuit). Apply a sin wave of (5 V_{pp} and 1 KHz frequency). Make the setting of R_1 and R_2 as a ratio of 3, 2, and 0.8. Record your results. Also apply a d.c Volt of variable value and watch your results.

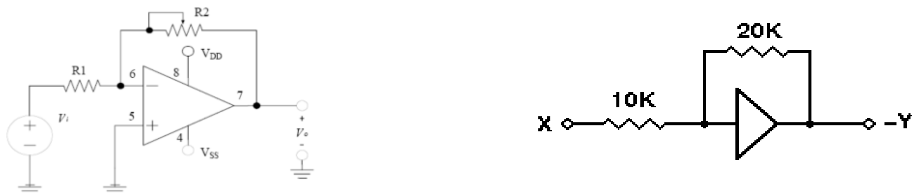

Fig. (2) : Inverting (Amplifier) or (Attenuator)

(2) Analog Addition, Subtraction and Logarithmic Circuit: The circuit shown in Fig (3-A) is designed to solve the equation (Z = 2X – Y). Input resistors are not set as the same value. Each input signal has its own separate coefficient. Since R_f is necessarily common to both inputs, the coefficients must be set by selecting different input resistors for the input signals, according to the desired coefficients. Each input signal uses its own input resistor, R_{in}, and its own separate value of R_f/R_{in} to determine its coefficient. There is no interaction between input signals or resistors. The circuit in Fig (3-B) combines features of the normal inverting amplifier and the non-inverting amplifier. Note that there are two resistors R_f as well as two R_{in} resistors. For correct circuit operation, it is important that the two pairs be matched. With the circuit shown, the equation for the output voltage is :

$$V_o = (R_f / R_{in})(V_2 - V_1)$$

Finally for LOG calculation of a signal, connect the circuit of Fig (3-C). Apply a variable signal (dc.) and watch the output. Apply different signals (like trinaglur wave, sequare wave), and record your results.

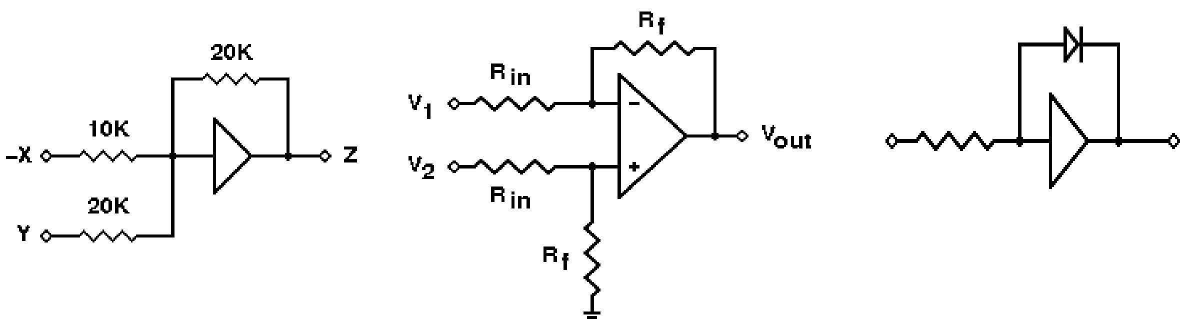

Fig. (3) : Addition, Subtraction of Two Signals, Log of a Signal.

(3) The Integrator and Differentiator

In Fig (4-A) is an integrator. If the input voltage is zero, no input current will flow. No feedback current can flow and the output voltage will remain constant. If the input is a non-zero value, equation for the output voltage becomes $V_{out} = -V_{in}/RC + K$, where R is the input resistance in ohms, C is the feedback capacitance in farads, and K is a fixed constant representing the accumulated voltage from the past. Still you can calculate the integration time contact.

Fig. (4) : (A) Integration : (B) : Differentiator of Signals

In Fig (3-B) we have a differnation circuit. Since the output voltage will reflect the input rate of change, this circuit will indeed do differentiation. The general equation for the output voltage is: $V_o = (-RC)\, dV_{in}/dt$ The (d/dt) notation indicates differentiation with respect to time. Apply a suitable signal (AC signal) like square and triangular wave, and observe the effect of that.

(4) Discrete –Time Signal Generation: (Analog to Digital Conversion), Continuous-Time Generation (Digital to Analog Conversion): Consider the need to generate discrete time values of analog signals. The result would be stored as a two-bit binary number. The first step in making this determination might be a set of three comparators, connected as shown to the right. As the analog voltage increases, the comparators will, one by one from the bottom up, change state from false to true. Of course, additional digital circuitry will be required to encode these signals into the corresponding digital number. Apply an analog signal (say 5V, hence look at the output of the converter). The circuit in Fig (5-B) is a basic digital-to-analog (D to A) converter. It assumes a 4-bit binary number in Binary-Coded Decimal (BCD) format, using +5 volts as a logic 1 and 0 volts as a logic 0. It will convert the applied BCD number to a matching (inverted) output voltage. The digits 1, 2, 4, and 8 refer to the relative weights assigned to each input. Thus, 1 is the Least Significant Bit (LSB) of the input binary number, and 8 is the Most Significant Bit (MSB). Apply the right digital signals and observe the effect of that at the output of Fig (4-B).

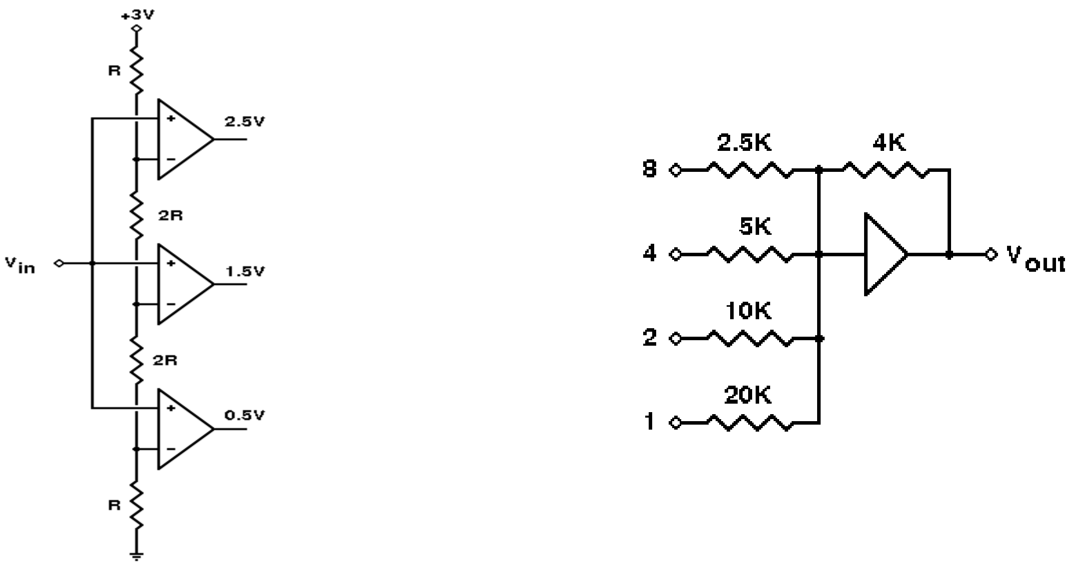

Fig. (5) : (A) : Signals Conversions : (B) : A/D and D/A converters.

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EENG 381: CONTROL SYSTEMS

COMPUTER LAB NO. 2
PRACTICAL: MAXIMUM OF (10) MARKS

CONVOLUTION THEORY

Laboratory Objectives:
To learn the Convolution theory, hence do real-time measurement and simulation.

Needed Equipment:
- Variable Capacitors, Resistors, and
- Analog and digital Voltmeters (–30 to + 30) scale.
- Hand Calculator.
- Storage Oscilloscope.

Introduction to the Experiment:
Convolution is regard as a time-scale approach to calculate an output of a dynamic system y(t) due to an external input x(t). Homogeneity, additivity, and shift invariance (as properties of LTI) may sound abstract but they are very useful terms. To characterize a shift-invariant linear system, we need to measure merely one issue: the way the system responds to a unit impulse. This response is called the impulse response function of the system. Once we've measured this function, we can hence, predict how a system will react to any other possible inputs.

The manner we use an impulse response function is rather illustrated in (Fig. 1). We envision of the input stimulus, (a sinusoid in this case), as if it were the sum of a collection of impulses. Since we recognize the responses we would get if each impulse was presented separately (i.e., scaled and shifted copies of the impulse response), hence, simply add together all of the (scaled and shifted) impulse responses to predict how the system will respond to the complete stimulus. To accomplish that in a mathematical notation, our target is to show that the response (e.g., membrane potential fluctuation) of a shift-invariant linear system (e.g., passive neural membrane) is written as a sum of scaled and shifted copies of the system's impulse response function.

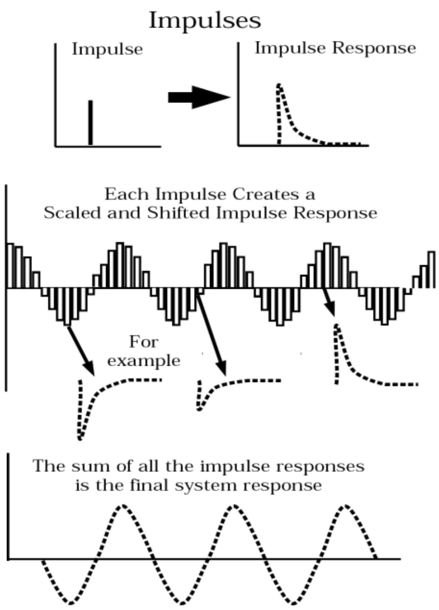
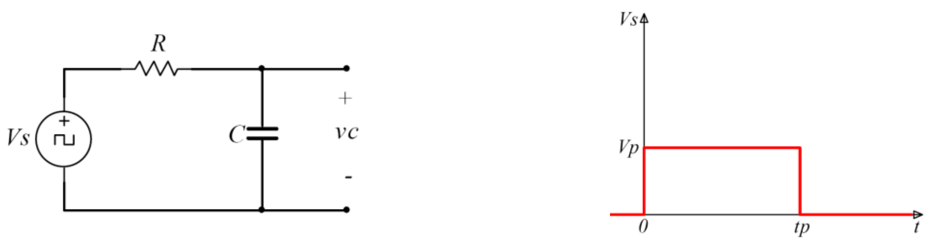


Fig (1): Convolution theory Summation of Impulses

$$y(t) = \int_{-\infty}^{\infty} x(s)\, h(t-s)\, ds.$$

$$f_1[k] * f_2[k] = \sum_{m=-\infty}^{m=\infty} f_1[m] f_2[k-m], \qquad -\infty < k < \infty$$



(a) (b)

Fig (2): RC circuit and assumed input signal x(t).

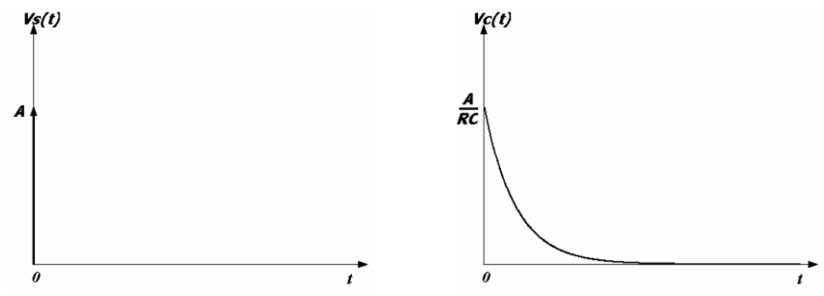


Fig (3) :   Impulse response of an RC circuit.

Experiment Steps :

1) Connect the RC circuit shown in Fig (2-a). Choose reasonable values for R and C accordingly.
2) Apply and impulse input of strength (A). If you try to constrain the area of the impulse to a constant $A=V_{ptp}$, then as the pulse becomes narrower, the amplitude V_p increases, resulting in an impulse of strength (A). The response of an impulse of strength (A) is then given by :

$$vc = \frac{A}{RC} e^{\frac{-t}{RC}}$$

3) Using the storage oscilloscope, try to identify the measured signal of the impulse response (shape and time scale).
4) You should get a response identical to the one shown in Fig (3). For various values of R and C, the shape changes.
5) Now apply the signal defined and shown in Fig (2-b). This is a step signal with a delay. Tp to be decided by you as a designer of the problem.
6) Record your results using the storage oscilloscope accordingly. You should get a result similar to the one shown in Fig (4).

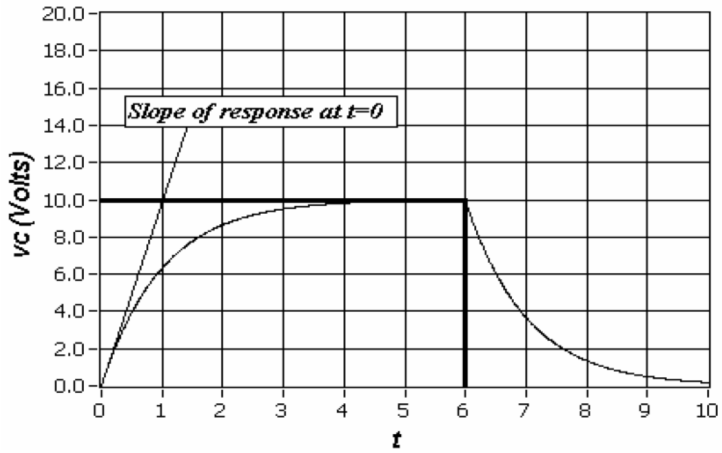


Fig (4) :   Real-time response of an RC circuit due to the step signal shown in Fig (2-B)

7) Verify your results via the convolution approach. Use x(t) as: (show the steps of the computation),

$$x(t) = u(t) - u(t-2) \quad \text{and} \quad h(t) = e^{-t}\, u(t)$$

8) Verify your results via MATLAB. Hence, write a piece of code to do the compute the convolution for the shown RC circuit.

9) Use the ready-written Matlab (function) or Command as : y =conv(x, h). Show that the real-time measurement is just similar to the MATLAB simulation.
10) Finally, run the code list shown below. Do think that it does the convolution? Compare it to the ready-made function of cov in step (9). Show your results.
11) Can you make the discrete-time convolution version the continuous-time? Which command you will use? Verify that via a simulation!!

```
% CONVOLUTION by code

fig_size = [232 84 774 624];
        t = 0:0.01:10;        % this is the time vector for simulation
        nt = length(t);
        dt = t(2);
                h = 2*t.*exp(-t) + exp(-2*t);                    % this is an example of an impulse response
        function (try yours)
                x = 1 - exp(-1.5*t);                             % this is an example input signal,  use the shifted
                step function

                % plotting of the impulse and input signals
                figure(1),clf,plot(t,x,t,h),grid,xlabel('Time (s)'),ylabel('Amplitude'),...
                title('Input x(t) and Impulse Response h(t)'),...
                text(2.5,0.95,'x(t)'),text(2.5,0.45,'h(t)'),set(gcf,' Position', fig_size)


                        figure(2),clf,plot(t,x,2.5-t,h),grid,xlabel('Time Tau (s)'),ylabel('Amplitude'),...
                        title('Input x(tau) and Impulse Response h(t-tau) plots, t = 2.5 s'),...
                        text(2.5,0.95,'x(tau)'),text(2.25,0.65,'h(t-tau)'),set(gcf,'Position',fig_size)


% Now computing the calculation of the product of  x(tau) & h(t-tau)  for t = 2.5 seconds only
%
                                tau = t(1:251);
                                  tmtau = 2.5 - tau;
                                    hx = (1 - exp(-1.5*tau)) .* ( 2*tmtau.*exp(-tmtau) + exp(-2*tmtau) - exp(-3*tmtau)
                                );
%
                figure(3),clf,plot(t(1:251),hx),grid,xlabel('Time Tau (s)'),ylabel('Amplitude'),...
                title('Product of the Input x(tau) and Impulse Response h(t-tau), t = 2.5 s'),...
                text(0.75,0.25,  'Value of y(t)  at  t = 2.5 s equals the area under this curve'),...
                set(gcf,'Position',fig_size)



%  Still you can get similar results using the Transfer function con concepts …

        [numh,denh] = residue([0;2;1;-1;],[-1;-1;-2;-3],0); % calculation of transfer function
           [numx,denx] = residue([1; -1],[0; -1.5],0); % calculation of input transform
              [numy,deny] = series(numx,denx,numh,denh); % calculation of output transform
%
```

```
[resy,poly,ky] = residue(numy,deny); % partial fraction expansion for output
%
y1 = lsim(numh,denh,x,t); % calculation of output using "lsim"
    figure(4),clf,plot(t,y1,t,x,t,h,t(251),y1(251),'r*'),grid,xlabel('Time (s)'),ylabel('Amplitude'),...
     title('Input x(t),Impulse Response h(t), and Output y(t)'),...
    text(2.5,0.9,'x(t)'),text(3.5,0.3,'h(t)'),text(3.5,1.6,'y(t)'),...
    text(2.7,y1(251),sprintf('y(t=2.5) = %g',y1(251))),set(gcf,'Position',fig_size)

y2 = conv(x,h) * dt; % calculation of output using "conv"
y2 = y2(1:nt);
y3 = 0;

figure(5),clf,plot(t,y1,'g-',t,y2,'r-.'),grid,xlabel('Time (s)'),ylabel('Amplitude'),...
title('Output y(t) from LSIM and from CONV'),set(gcf,'Position',fig_size)
```

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EENG 381: CONTROL SYSTEMS

COMPUTER LAB NO. 4
PRACTICAL: MAXIMUM OF (10) MARKS

INTRODUCTION AND VISUALIZATION OF CONTROL SYSTEM

Objectives

- The main objective of this experiment is to introduce a typical position and speed (feedback) control system to students.
- To visualize a complete control system and appreciate its components and elements, which will have a direct effect in the student understanding for the entire course.

Theory and Background

Automatic control systems are essential to our daily life and use. Feedback and closed loop systems are designed to achieve some behaviors. Good examples of these are, closing and opening of automatic doors, closing and opening of servo values, speed control motors and lifts. Hence, the main objective of this experiment is to explore different aspects of closed loop systems. Two examples are taken here, the speed control and position control.

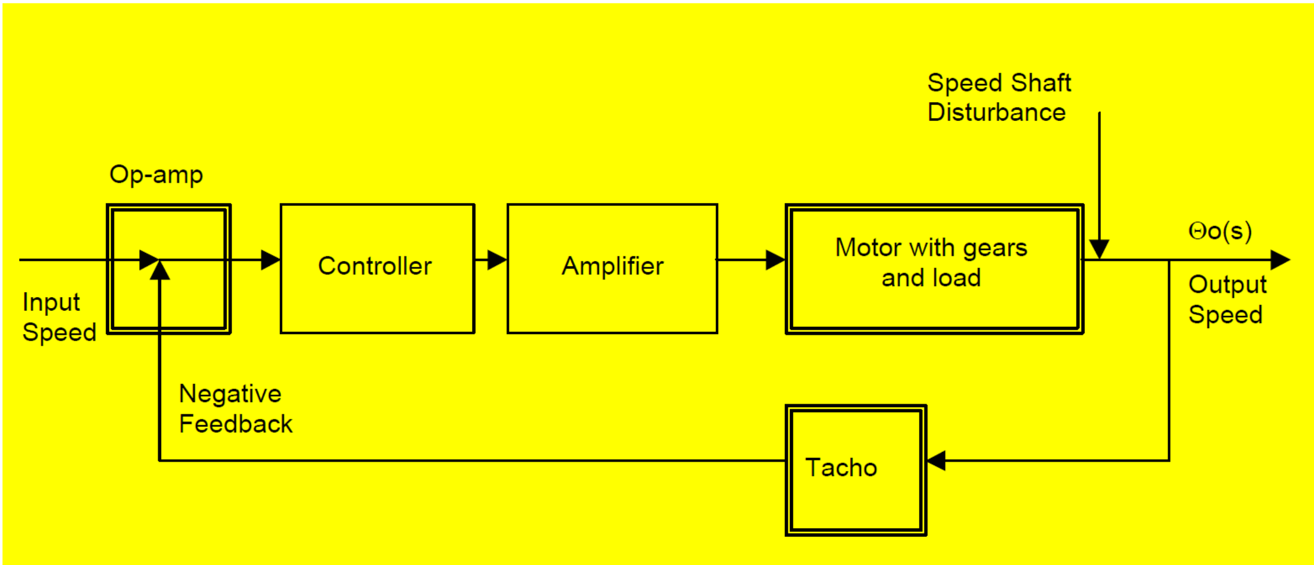
Equipment

- Operational Amplifier Unit 150A, Attenuation Unit 150B, Pre-Amp. Unit 150C, Servo Amplifier 150D, Power Supply 150E, Motor Unit 150F, Voltmeter (30-0-30), Load Unit 150L, Input and Output Potentiometers, Hand Calculator.
- Storage Oscilloscope.

Procedure

(a) Time response of a Closed Loop Position Control System:

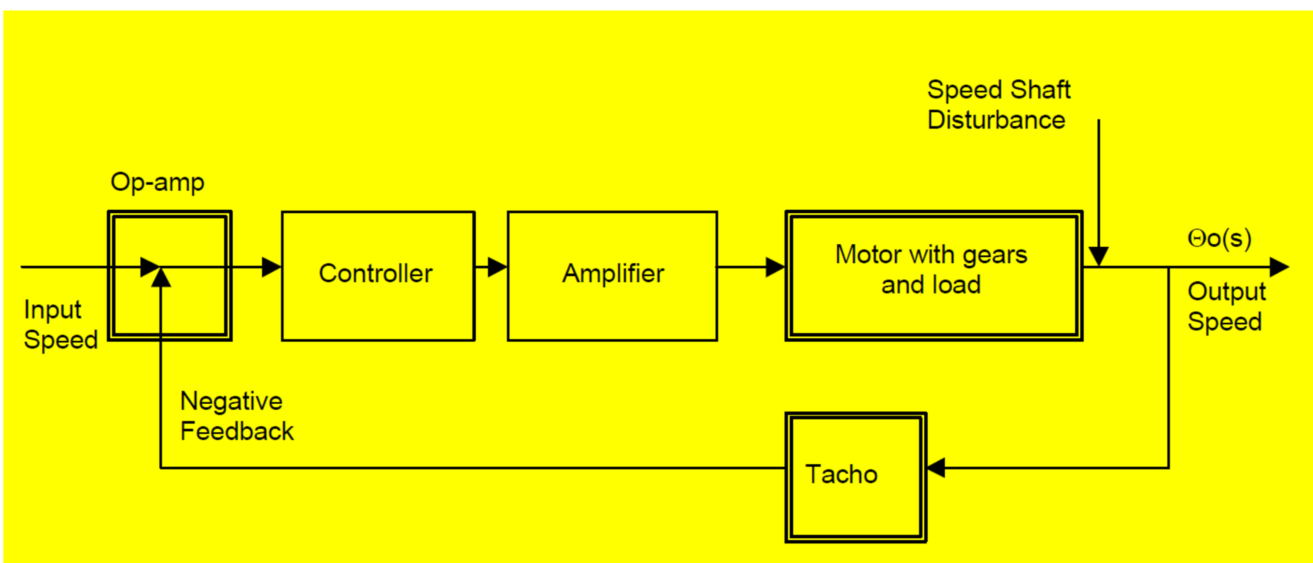
- Connect the position control system as given in Fig(1), (using Feedback Tools in the control lab).
- Connect the storage oscilloscope which is triggered by the same output (connected across the pot).
- Try to adjust the system gain (amplifier pot.), and observe the effect of this on the system position of the Dial.
- What conclusion you draw from the system behavior, have a look at the sensor used to measure motor shaft position.
- Can you visualize the main components of a closed loop system. If yes, draw them as block system. Comment on the used controller (closed loop with motor) : it is stable or not ?



Fig(1) : Position Control System

(b) Time response of a Closed Loop Speed Control System:

- Connect the speed control system as given in Fig (2), (using Feedback Tools).
- Connect the storage oscilloscope which is triggered by the same output (connected across the tacho).
- Try to adjust the system gain (amplifier pot.), and observe the effect of this on the system speed of the shaft.
- What conclusion you draw from the system behavior, have a look at the sensor used to measure motor shaft speed.
- Can you visualize the main components of a closed loop system. If yes, draw them as block system.



Fig(2) : Speed Control Systems

Discussion and Conclusion :

1. From the two constructed control systems, draw the associated blocks of the system.
2. What do you think is happening once the system gain is increasing ? Explain more.
3. What is the difference between speed control and position control.
4. What main conclusions you can draw from the two systems?

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EENG 381: CONTROL SYSTEMS

COMPUTER LAB NO. 5
PRACTICAL: MAXIMUM OF (10) MARKS

MATLAB AND SIMULINK FOR CONTROL ENGINEERING

Objectives

- The main objective of this experiment is to introduce the powerful Matlab and Simulink environments to the student.
- To achieve a few simulations of dynamic systems and compare them with some theoretical handwork.

Theory and Background

Matlab has been introduced early as excellent computing software that can help a control engineer to achieve a particular control system design. In this respect, and since then, Matlab has been the core software for a large number of developing routines that are concentrated towards control analysis and design. At this moment, Matlab and Simulink have been employed in so many analysis and design issues: such as Linear control theory, Robust control, Model Predictive Control, LMI theory, Intelligent Modeling and Control, Nonlinear Control, Fuzzy Control, and QFT control synthesis. Hence, this experiment has been designed to explore some typical Matlab applications for a control engineer.

Equipment:

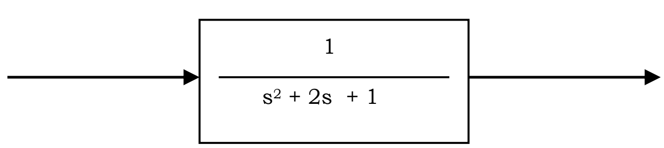
- Laptop or Desktop Personal Computer.
- Hand Calculator.
- Printer.

Procedure

(a) Time response:
- Start Matlab on your PC and make sure you have created your own working sub-directory.
- In the Matlab environment, make sure the *control toolbox* has been installed, type help control.
- Go to the sub-directory and create an m-file and call it *test1.m*.
- (Do not forget to save your file every time you run m-file)
- Type in test1.m clear and the following transfer function :

```
>> N=[1];
>> D=[ 1  2  1];
```

here you are creating a second order system of the following TF :



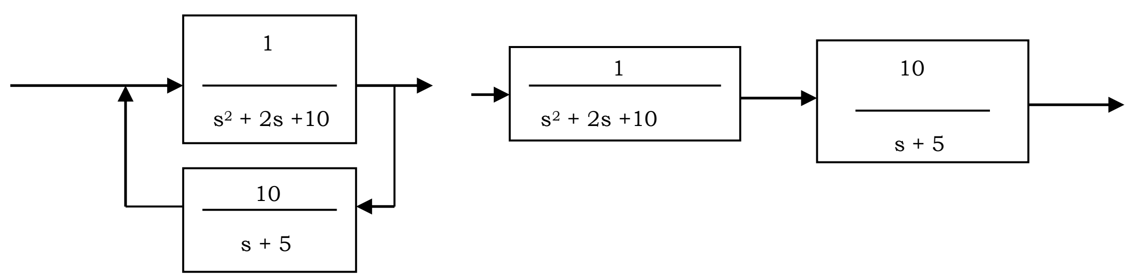
Type **step(N,D)** and observe the result.   How the system is responding.

Compare your results with your handwork of step response for the same system.

- Type in the m-file grid and see the result on the graph. This will create a grid in the figure(1).
- Type in the m-file xlabel(' Time in second'), ylabel(' Amplitude in rad '). Type hold to hold fig.
- Type now impulse(N,D) which gives the impulse response.
- Compute by hand the system time response parameters for that system and compare them with Matlab results.
- Multiple 1/s in the TF and type step(n,d) for the new TF, this is response to a unit ramp.

(b) System interconnections :

- There are four main function to interconnect blocks in Matlab, append, parallel, series, feedback, star, connect.
- Show how can you connect two TF of the followings: (Use help command for each function).



(c) Frequency response:

- Create a new m file, call it test2.m.   Type the same TF as in part(a). Type bode(n,d), this is the frequency response.
- Type now nyquist(n,d), this should give the nyquist of your system. You can add to it the grid and titles.
- Type now nichols(n,d), which will generate the nichols chart for your system. This we shall study in the course later.
- Type margin(n,d), which will compute the gain and phase margins, a stability measure. If you want to see the poles and zeros for your system, type pzmap(n,d), through which you can make a map between the poles and time response.

(d) Simulink

- Finally start simulink environment by typing simulink in matlab.   With the aid of the instructor, learn how to create your own system in simulink, how to make negative and positive feedback, and how to see the results. Repeat part(a) and part(b) once again.

Discussion and Conclusion:

1. From the two simulated control systems, what are the potentials that matlab can add to the analysis and control of any control system ?   Why do you think they are essentials.
2. If are asked to simulate any dynamic system, what programming language you will chose and why.
3. Write a small program to simulate the dynamic system in part (a).
4. Comment on the calculations of the poles and zero by hand.

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EENG 381: CONTROL SYSTEMS

COMPUTER LAB NO. 6
PRACTICAL: MAXIMUM OF (10) MARKS

OPERATIONAL AMPLIFIERS AS SUMMING POINTS AND CONTROLLERS AND THEIR SIMULINK MODELS

Objectives

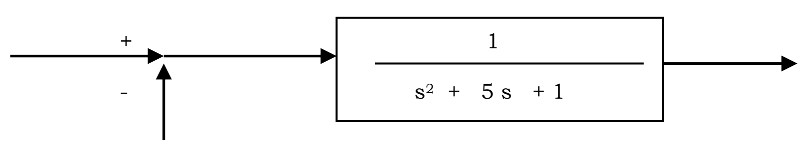
- The main objective of this experiment is to introduce and show how the *Operational Amplifier* can be used to sum two analogue voltages for control purposes.
- To achieve few simulations of a summing points and integrating op-amps using *simulink models*.

Theory and Background

Summing points and take-off points are two important points that constitute a typical feedback control system. In this sense, most analog control system use operational amplifiers to achieve the summing operations, i.e. yo=A(xi-xf). Hence it is required to select the value of the feedback gain A. In this experiment we shall deal with the structure of a typical summing points and their simulink model in Matlab.

Equipment

- Laptop or Desktop Personal Computer, Hand Calculator, Printer.
- Operational Amplifier Unit 150A, Attenuation Unit 150B, Power Supply 150E, Voltmeter (30-0-30).



Procedure

(a) Summing Effect of an Operational Amplifier :

- Set the feedback selector switch to the 100 kΩ resistor, for the circuit shown in Fig (1).
- Connect the voltmeter between common and the slider of each pot and adjust for zero reading.
- Connect the voltmeter between common and the output V_o and adjust the zero control to give a zero reading.
- Keep pot1 at 0V, pot2 at +2V between its slider and common, using the voltmeter as indicator. Measure V_o and enter the values in Table (1). Apply voltages to V_2 keeping V_1 at zero. Apply to V_1 and keep V_2 at 0V.
- Finally vary V_1 and V_2 and record in Table (1).
- Do an integrator and diff. Controllers using the suitable op-amps.

$V_{cal} = -(R_2/R_1) \times (V_1+V_2)$

No.	K_1 gain	V_1	V_2	V_o (measured)	V_{cal}	error	V_1	V_2	K_2 gain	Diff measure	cal		Error
1													
2													
3													
4													
5													
6													
7													
8													
9													
10													

Table (1)

(b) Summing Effect of an Operational Amplifier via a Simulink Model :

- Start Simulink in your PC.
- Create a new simulink – file, show how can you simulate a summing point by selecting the suitable simulink components. Show the result of your model by looking at the output graph. For the same voltages you have been using in part (a), repeat the same using the constructed simulink models.
- Are you able to appreciate the effect of a summing point and how it can be used as a simple controller?
- Try now to construct a much-complicated controller (integrator) and (diffre.) via simulink. Test it for any suitable signals. Verify it mathematically. Use the hints given in Fig (2).

Fig (1)

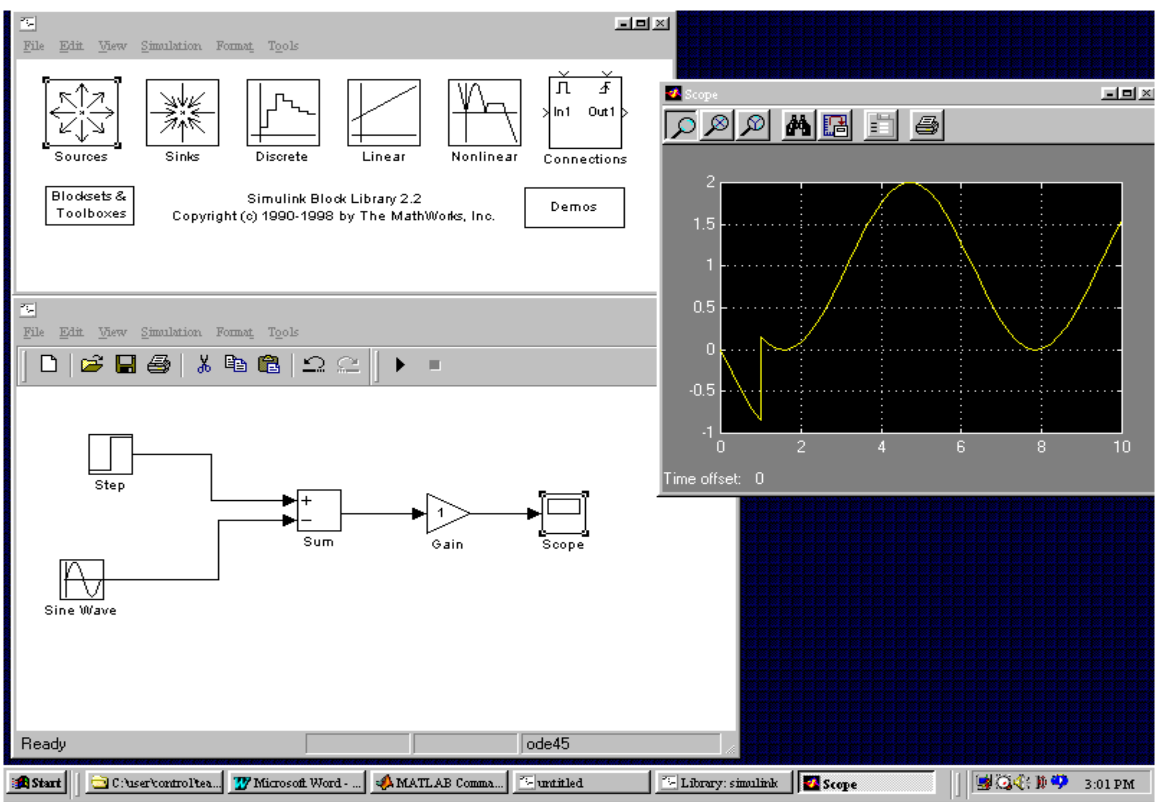


Fig (2)

Discussion and Conclusion :

1. Why a summing point so essential in a closed loop control system? Explain the physical meaning of it?
2. How can you implement a summing point via electronic circuit (not op-amps)? Draw the circuit.
3. Write the appropriate mathematical model of the circuit in [2] and show how it works.
4. Explain what will happen once the system is in positive feedback mode.

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EENG 381: CONTROL SYSTEMS

COMPUTER LAB NO. 7
PRACTICAL: MAXIMUM OF (10) MARKS

ROUTH-HURWITZ STABILITY FOR A POSITION CONTROL SYSTEM

Objectives

- The main objective of this experiment is to investigate the practical stability of a closed loop position control system.
- To compute the most suitable controller gain k_c using the Routh-Hurwitz stability criterion method.
- To simulate this process in Matlab for poles and zero location, in addition to Simulink for dynamic system simulation.
- To practically obverse how poles would affect the system behavior.

Theory and Background

The stability of a typical dynamic control system is essential to any control engineer. In this respect, there are a number of approaches through which an engineer can decide on whether a typical control system stable or not. For instance, checking the polynomial of the characteristic equation is one approach for small systems, however, for higher order linear systems, Routh-Hurwitz approach has been used extensively in this sense. R-H stability is achieved via the construction of a typical table through which the polynomial coefficients are inserted and manipulated in a certain manner to find out the absolute stability of the system.

Equipment

- Operational Amplifier Unit 150A, Attenuation Unit 150B, Pre-Amp. Unit 150C, Servo Amplifier 150D, Power Supply 150E, Motor Unit 150F, Voltmeter (30-0-30), Load Unit 150L, Input and Output Potentiometers, Hand Calculator.
- Storage Oscilloscope. Desktop computer with Matlab-Simulink

System Parameters : You have to drive the corresponding TF given that :

J_m=11.3X10- 7kgm^2, B_m=1X10-6 Nm/rad, k_l =3.5 V/1000 rpm,
k_b =3.5 V/1000 rpm, R_a =20 Ohm, L_a =0.6 mH.

Procedure

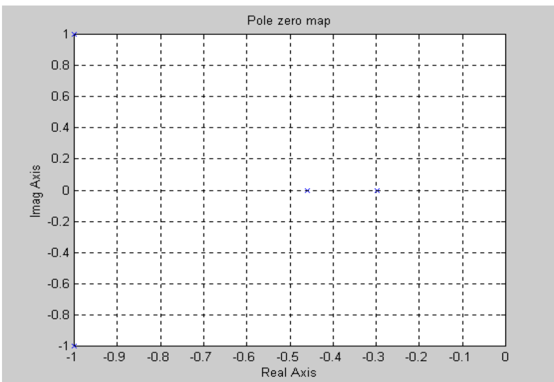
(a) Time response of a Closed Loop Position Control System:

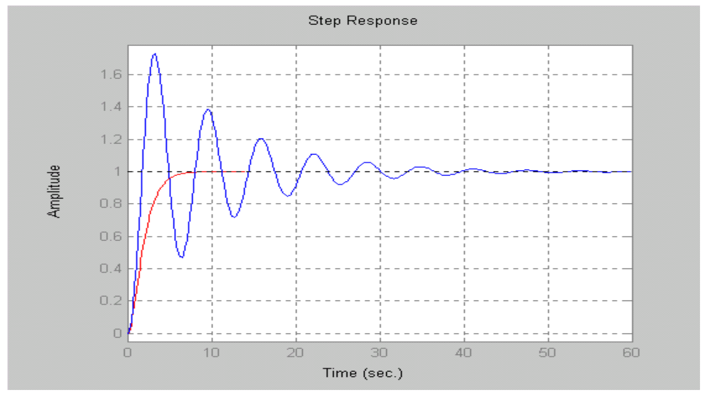
- Connect the position control system as given in Fig (1), (using Feedback Tools in the control lab).
- Connect the storage oscilloscope which is triggered by the same output (connected across the pot).
- Try to adjust the system gain (amplifier pot.), and observe the effect of this on the system position of the Dial.

(b) TF of the system :

- Get the block diagram of the system in front of you. You have to drive the corresponding TF given that J_m=11.3X10-7kgm^2, B_m=1X10-6 Nm/rad, k_I =3.5 V/1000 rpm, k_b =3.5 V/1000 rpm, R_a =20 Ohm, L_a =0.6 mH.

- Find the suitable value of k_c that would make your system most suitable in behavior over the time domain.
- Use matlab to obverse the location of the closed loop poles.
- Confirm your results by **hand** calculations.
- Set the value of k_c to be suitable. Run the system. Get the output using a storage oscilloscope. Finally simulate this in simulink and compare the two results.
- Start to change some of the system parameters, see how the location of the poles-zero change and the associated time response.





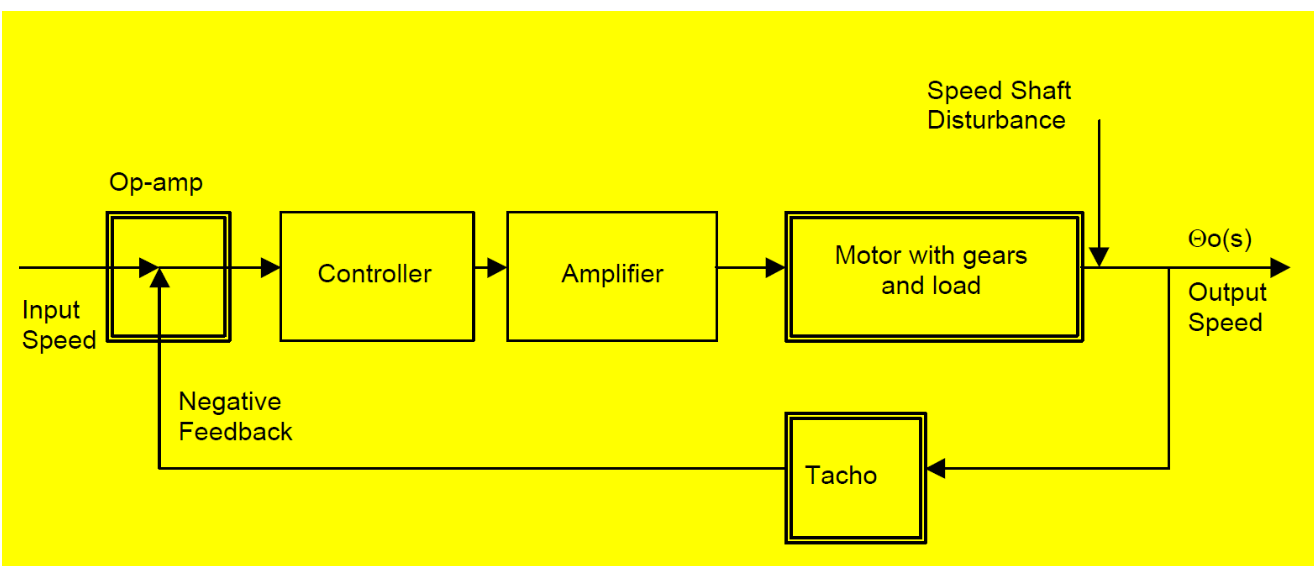


Fig (1) : Position Control System

Discussion and Conclusion :

1 What is the relation between the time response and the location of the poles and zeros over the s-plane?
2 From the closed loop position control system, drive this relation mathematically.
3 For the closed loop position control system, compare the real time response and the simulated one for different values of poles and zeros (as a function of k). Elaborate in your comments.
4 What are the main issues you can draw from this experiment in terms of real time response and s-plane poles locations.

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EENG 381: CONTROL SYSTEMS

COMPUTER LAB NO. 8
PRACTICAL: MAXIMUM OF (10) MARKS

ROOT LOCUS USING MATLAB AND POSITION CONTROL SYSTEM

Objective

- The objective of this experiment is to investigate practical use of the root locus analysis tool for a position control system.
- To simulate this process in Matlab for poles and zero location, in addition to Simulink for dynamic system simulation.

Equipment

- Operational Amplifier Unit 150A, Attenuation Unit 150B, Pre-Amp. Unit 150C, Servo Amplifier 150D, Power Supply 150E, Motor Unit 150F, Voltmeter (30-0-30), Load Unit 150L, Input and Output Potentiometers, Hand Calculator.
- Storage Oscilloscope. Desktop computer with Matlab-Simulink.

Theory and Background

Control system engineers have utilized a number of techniques to analyze and design a controller for a typical closed loop control system. One of the most employed approaches is the Root Locus. In particular, Root Locus shows graphically the location of a closed loop poles through the knowledge of the open loop poles and zeros. In addition to this, it shows also the location of the closed loop poles as a loop gain k varies from zero up to infinity. Once the desired response is known, hence it will be then easy task to find from the Root Locus the associated gain to achieve such response.

Procedure

(a) Root Locus Analysis:

- Construct the root locus for the following dynamic control system, for $0 \le k \le \infty$:

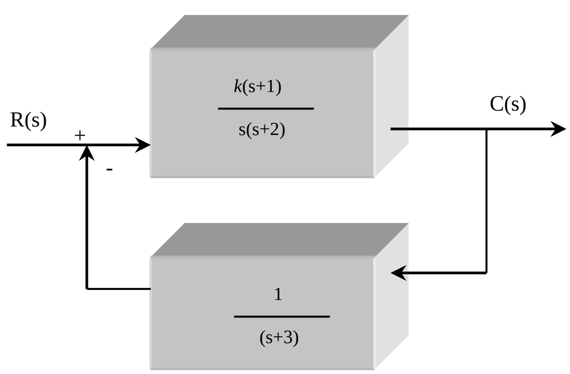


Fig (1)

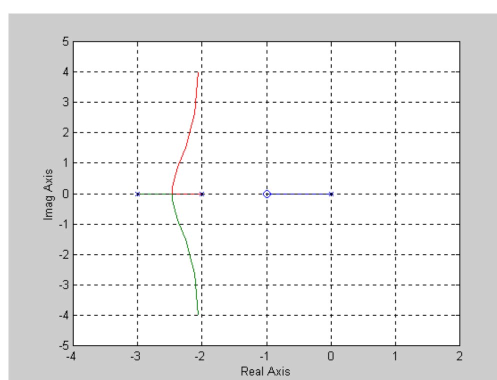


Fig (2)

(a) *Root locus for a third order system :*

- Using matlab, verify your result via typing :

```
» n=[1 1]; d=[1 5 6 0];
» rlocus(n,d);
» grid;
```

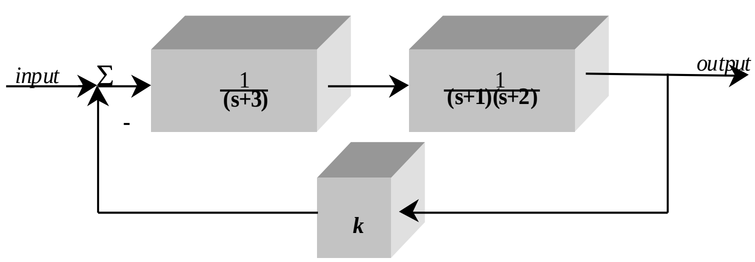
Then try only » [r,k]=rlocus(n,d)

- Observe the results. What information you can get from screen data ? Hence try >> plot(r,'x') .
- We want to find the value of *k* corresponding to a pair of complex roots. Use rlocfind function to do this, after the a root locus plot has been obtained with the rlocus function. This will print (*select a point in the graphic window*). After you select by the pointer, the corresponding value of pole and associated gain *k* will be displaced. Use >> rlocfind(n,d). Hence select a pole of (-2.0509 + 4.3228I) from the graph window.

- The closed loop poles locations are then found (do your hand calculation).
- What is dominant pole? Verify your results via a step input to the system in Fig (1). This is done via expansion of *CLTF* via :

```
» k =20.57;
» n =k*[1 4 3];
» d =[1 5 6+k k 0];
» [r,p,k] = residue(n,d);
```

- Find the value of and corresponding settling time.
- Finally verify this via the step command.



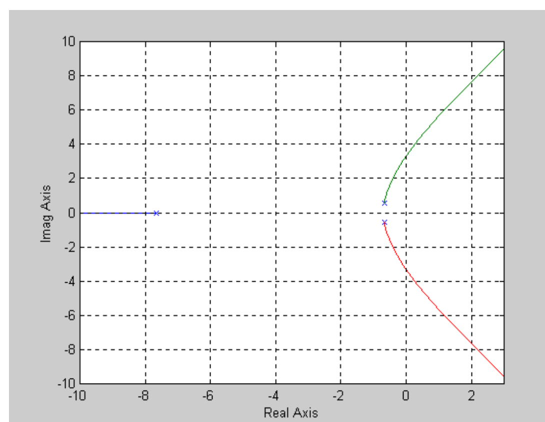


Fig (3)

(b) *Root locus for a third order system:*
Repeat part (a) for the system shown in Fig (3).

(c) TF and root locus for a position control system of the system, Fig (4) :
- Get the block diagram of the system in front of you. You have to drive the corresponding TF given that J_m=11.3X10-7kgm^2, B_m=1X10-6 Nm/rad, k_I =3.5 V/1000 rpm, k_b =3.5 V/1000 rpm, R_a =20 Ohm, L_a =0.6 mH.
- Repeat part (a) for the position control system.

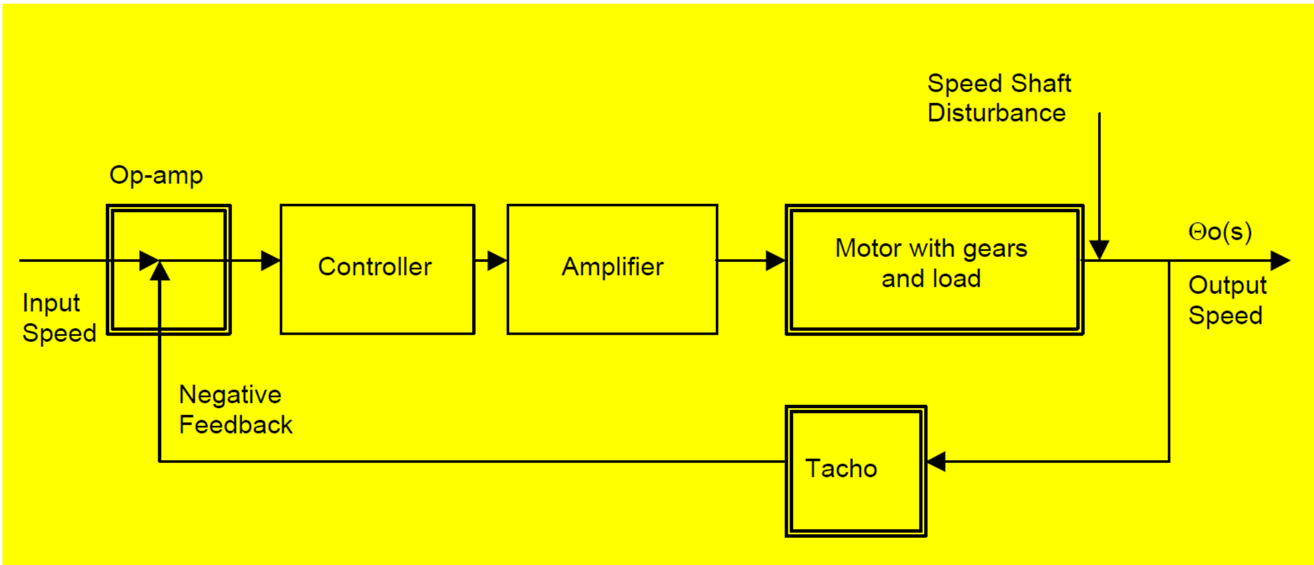


Fig (4) : Position Control System

Discussion and Conclusion:

1. Root Locus is considered a very powerful tool for stability analysis, what are the drawbacks of this technique?
2. Draw the root locus for the position control system and verify it through Matlab.
3. Compare the root locus for the position control by hand and via Matlab software.

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EENG 381: CONTROL SYSTEMS

COMPUTER LAB NO. 7
PRACTICAL: MAXIMUM OF (10) MARKS

FREQUENCY RESPONSE FOR POSITION CONTROL SYSTEM: BODE PLOT AND NYQUIST EXPERIMENT

Objectives
- The objective of this experiment is to investigate practical use of the frequency response analysis tool for a position control system.
- To simulate this process in Matlab for Bode and Nyquist Plots.

Theory and Background
Frequency response methods have been used to analyze closed loop dynamic systems, in addition to designing typical controllers. Magnitude and phase play important measures for quantifying the amount of energy a system have. Once the response of the system is known for over a large range of frequencies, this gives an insight about how to attach a typical controller at some frequencies to make the system act in the required manner. This experiment looks in details in how to obtain a typical frequency response of a system, experimentally and theoretically.

Equipment
- Operational Amplifier Unit 150A, Attenuation Unit 150B, Pre-Amp. Unit 150C, Servo Amplifier 150D, Power Supply 150E, Motor Unit 150F, Voltmeter (30-0-30), Load Unit 150L, Input and Output Potentiometers, Hand Calculator.
- Storage Oscilloscope. Desktop computer with Matlab-Simulink.
- Get the block diagram of the system in front of you. You have to drive the corresponding TF given that J_m=11.3X10-7kgm^2, B_m=1X10-6 Nm/rad, k_I =3.5 V/1000 rpm, k_b =3.5 V/1000 rpm, R_a =20 Ohm, L_a =0.6 mH.

Procedure
Bode Plot Frequency Response Analysis:
- Construct the open loop frequency response for the following dynamic control system, for $0 \le k \le \infty$, where initially k can be assumed to be unity.

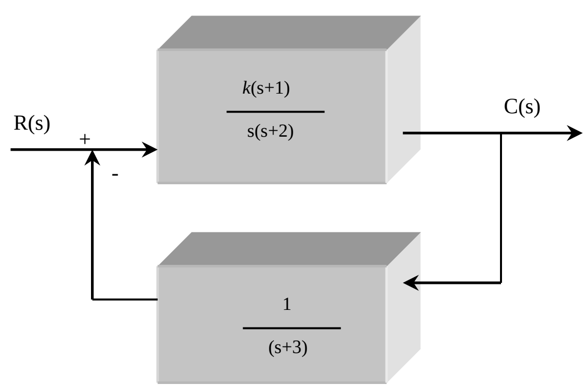

Fig (1)

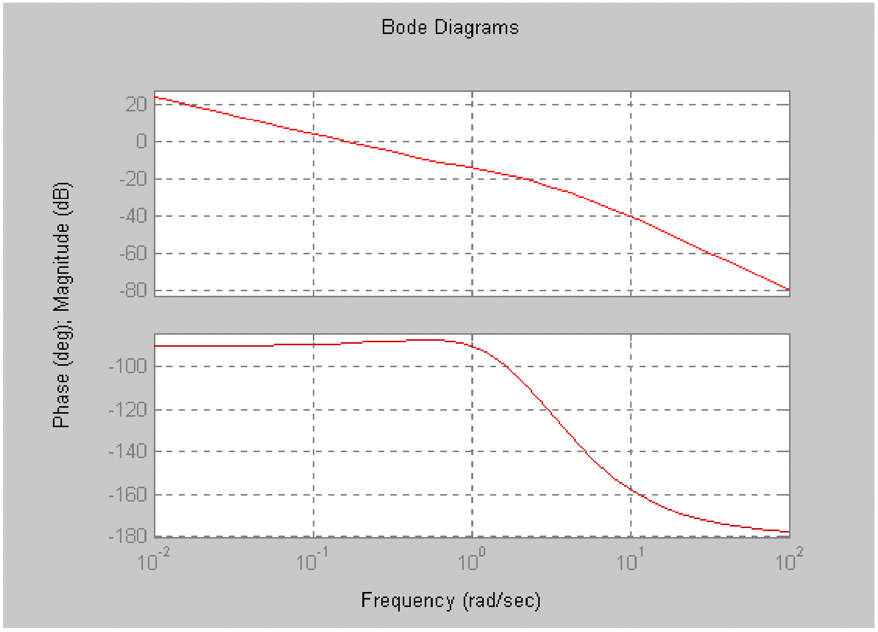

Fig (2)

- Using Matlab, verify your result via typing :
  » n=[1 1] ;
  » d =[1 5 6 0] ;
  » bode(n,d) ;
  » [Gm,Pm,Wcg,Wcp] = margin(MAG,PHASE, W) ;
- Observe the results.
- What information you can get from screen data of the system frequency response?
- From the graph, find the gain and phase margins, hence calculate the relative stability of the system.
- Use the proper Matlab command to find the associated gain and gain margins and compare them to your hand calculations. Using the TF of the closed loop position control system, repeat the same previous steps.
- Obtain the frequency response experimentally. Hence compare your results with the above Bode plot analysis.

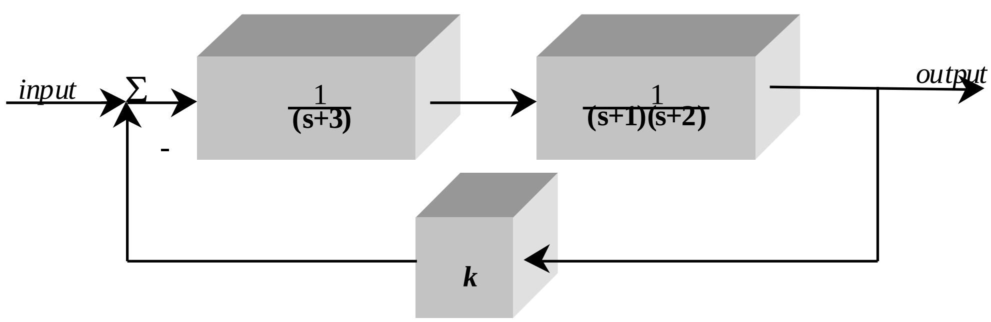

Fig (3) Closed loop system.

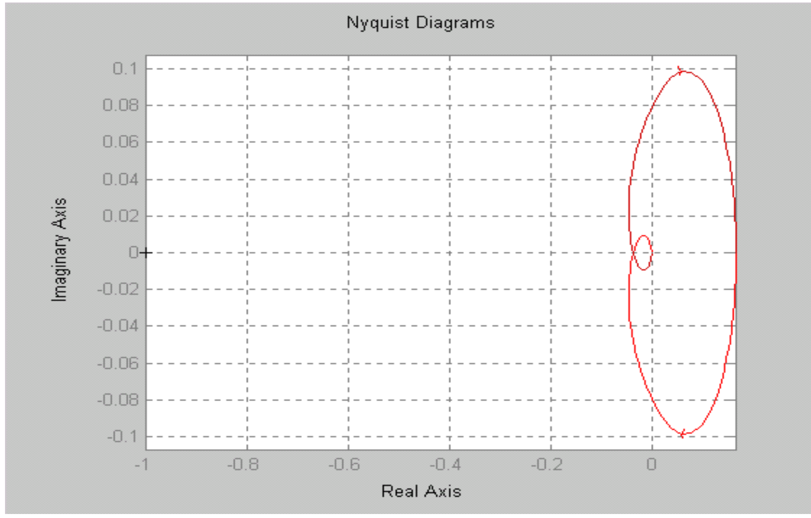

Fig (4) Associated Nyquist plot.

Nyquist Plot Analysis:

This part will make an analysis via the use of Nyquist analysis tool.

- Using Matlab, verify your result via typing :

```
» clear
» n=1;
» d=[1 3 11 6];
» nyquist(n,d)
» grid
```

- Observe the results.   What information you can get from screen data of the system frequency response?
- From the graph, find the gain and phase margins, hence calculate the relative stability of the system using the Nyqsit plot.
- Use the proper Matlab command to find the associated gain and gain margins and compare them to your hand calculations.
- Using the TF of the closed loop position control system, repeat the same previous steps.
- Obtain the frequency response experimentally.   Hence compare your results with the above Nyquist plot analysis.

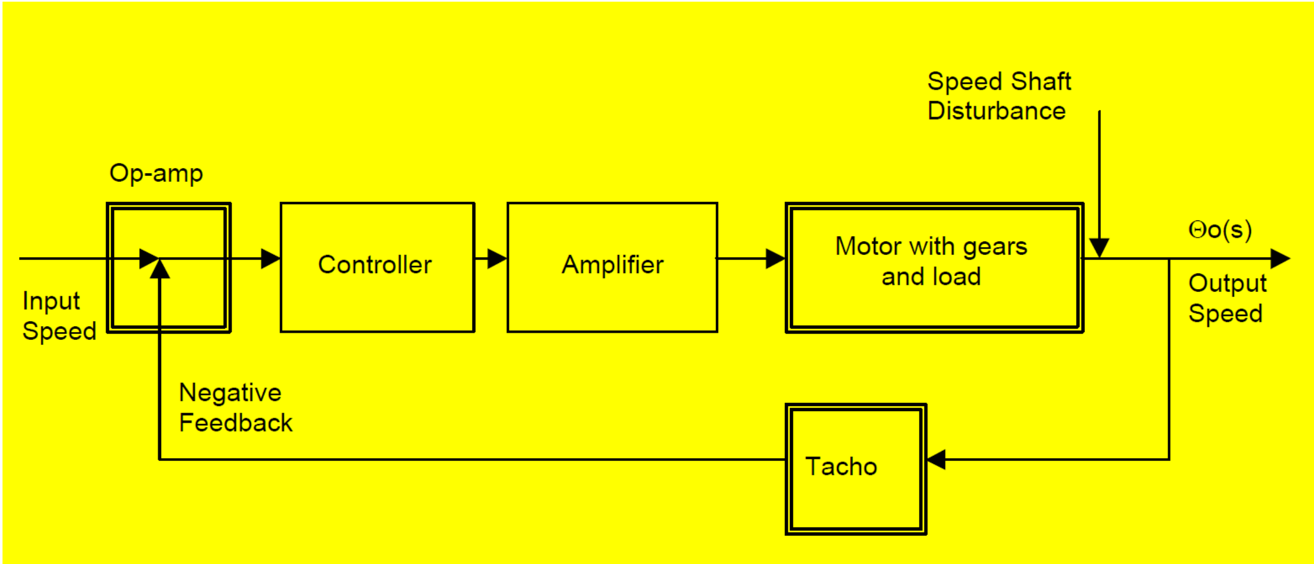

Fig (4) : Position Control System

Discussion and Conclusion :

1. What are the main parameters someone can extract from the frequency response of control system?
2. Explain the drawbacks of both the frequency response and Nyquist plot.?
3. For the position control system, once k=1, what will be the gain and phase margins ? Use the frequency response, Nyquist and Nichols chart to verify your results.

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EENG 381: CONTROL SYSTEMS

COMPUTER LAB NO. 9
PRACTICAL: MAXIMUM OF (10) MARKS

CONTROLLER SYNTHESIS

Objectives:

- The objective of this experiment is to design a lag or lead controller for a position control system with specific characteristics in time and frequency domains.
- To simulate the designed controller with the position system in Matlab and comparing them with real time measurements.

Theory and Background

Look at your lecture notes and assignment no. 4, before attempting this experiment.

Equipment :
- Operational Amplifier Unit 150A, Attenuation Unit 150B, Pre-Amp. Unit 150C, Servo Amplifier 150D, Power Supply 150E, Motor Unit 150F, Voltmeter (30-0-30), Load Unit 150L, Input and Output Potentiometers, Hand Calculator.
- Desktop computer with Matlab - Simulink, Capacitors, Resistors and Op-amps (741), Hardware Design kits.

Procedure

<u>(a) Analysis Stage :</u>
Given in the last lab the transfer function of the position Control System. It uses one drive motor and associated servo-amplifier to position the shaft in the required radian. For a unity controller, obtain for the following relations :

Sensitivity function.
Complementary sensitivity function.
Forward loop function.

The followings:
Bode approximation, hence verify it via Matlab.
Nyquist polar plot and verify it via Matlab.
Magnitude and phase plots and Nichols chart.
Gain and phase margin for each case.
Comment on the relative stability for each case.

(b) Controller Synthesis of the Dynamic Position Control system :

After you have made the analysis of the position control system (as in part a), now it is the time to design a hardware controller to meet certain control specifications. It is desired to design a controller to meet the following performance specifications :

- once the input is a ramp with slope (velocity) = 2π rad/s, the steady state error in position must be less than or equal to $\pi/10$ rad.
- Phase margin ϕ_{pm} of $45 \pm 5°$.
- Gain cross over frequency $\omega 1 \geq 1$ rad/s.

Design a suitable lead or lag controller and show all the design steps, hence make sure the system is performing well via Matlab simulation. A typical lead or lag controller is given by the following transfet function :

$c(s) = \frac{s+a}{s+b}$ a > b lead $c(s) = \frac{s+a}{s+b}$ ~~b~~ > a lag controller

After you have verified your results via simulations, build the hardware controller on a design board using the suitable resistors, capacitor, and op-amps circuits. Finally connect the position servo and the controller hardware you built. Show that the system is responding right to a ramp input with slope (velocity) = 2π rad/s. Compare your real time measurements with the Matlab simulation of the position control with the built controller.

Discussion and Conclusion :

1. Explain the physical meaning of the Sensitivity function, Complementary sensitivity function, Forward loop function.
2. For the lead-lag controllers design and implementation in part (b), what will be the major drawback of such controllers.
3. Will it be possible to achieve the same design specifications via a PID controller? Explain why?