School of Engineering
The University of Jordan
Mechanical Engineering Department

System Dynamics and Control Laboratory (0904418)

Insert Your Course Name Here
(Course #)
Term Project/Home Work/Short or Full Lab Report …..

School of Engineering
The University of Jordan, Amman-Jordan

Project/Experiment/Report Title Goes here

by

FirstName Initial LastName (ID #)
FirstName Initial LastName (ID #)

Section #:

Month 9999

Abstract

An abstract consists of answering three basic questions:

1. What was done?
2. How it is was done? and
3. What were the basic findings and conclusions?

- ✓ Abstract should be written in passive voice.
- ✓ Abstract should not exceed 200 words.
- ✓ It should be written in three separate paragraphs.
- ✓ This section and all the coming sections should be written in Font 12, Times New Roman with regular style and single line spacing.
- ✓ This page should contain the abstract ONLY and numbered using the Roman Style (i.e. I, ii, iii …etc)
- ✓ It should be written in passive voice.

Nomenclature

The nomenclature defines the parameters, symbols and acronyms used in the report. Standardized symbols should be used whenever possible.

- The units should be added to the nomenclature.
- The parameters should be arranged alphabetically.
- This section should be written in separate page(s).

A	Area	[m2]
P	Pressure	[N/m2]
Re	Reynolds Number	[ND]

Subscript

f	Liquid
s	surface

Greek Symbols

μ	Dynamic viscosity	[N-s/m2]
α	Angle of attack	[deg]

Objective

The objective(s) should be written based on the instructor's explanation of the experiment.
DO NOT copy from laboratory manual.

Experimental Setup and Procedure

This section should contain the working principle of the setup used in the experiment.
It should contain a clear image of the setup with the main parts identified in suitable manner.
The figure's caption (name) should be written below it.

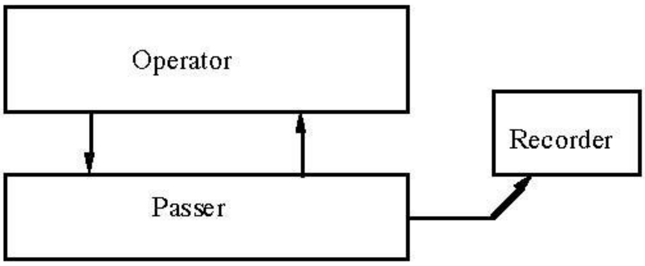


Figure (1): Some numbers from the result of the experiment on nothing

- ✓ Never start any paragraph with figure, table, graph …etc. You should allways write few introductry lines (e.g. This section discusses the setup used in conducting this experiment. The setup is shown below in Figure (1)).
- ✓ Define the major components of the setup.
- ✓ Explain briefly how it works.
- ✓ Finally, explain with your own words (DO NOT COPY FROM USER MANUAL) how you conducted the experiment.
- ✓ As of this page onwards, the page numbering should start using the 1-100 Arabic numbers.

Data Observation

The data observed are divide into two main items.

Given data

- o This includes the constants that were not changed in the experiment e.g atmspheric conditions, certain setup dimensions (if not changed) e,g diameter, length ….etc.
- o As for the material's properties e,g, density, viscosity, thermal conductivity …etc these should be mentioned with the reference wherefrom they were copied cited.

Observed data

- ✓ The data that were taken from the setup ONLY should be mentioned in the table.
- ✓ Table columns should be writen with units and without abbreviations.
- ✓ The table caption should be mentioned on top of the table.
- ✓ Do not add any calculated data in the table.

Table (1): The observed data

Trial #	Quantity 1 [unit]	Quantity 2 [unit]
1	4.0	4.9×10^{-2}
2	3.2	4.5×10^{-2}
3	2.8	4.4×10^{-2}

If the experiment consists of several parts, put the tables with each case defined before that.
For example :

Case (I) : Partially submerged torous
Inset the data observed table for this case below.

Case (II) : Totally submerged torous
Inset the data observed table for this case below.

Sample calculations

In this section you are required to provide with proper explanation (NOT only use equations and substitute numbers) the steps for your calculations.
You should state which data you are taking for sample calculations.
If the calculations involve theoretical and experimental values for comparison, you should calculate the percentage error in the experimental value.

Uncertainty analysis

This is extremely important part that tells the accuracy of the test procedure (NOT ONLY in the final value).
This can be extremely helpful if one wishes to find the main factor responsible for the error.
There are many methods suggested for this section :

1) Uncertainty propagation (you can use suitable software for that as you have been taught)
2) Limiting and relative limiting errors using equations.
3) Limiting and relative limiting errors using maximum/minimum method.

Finally a summery of the calculations should be added in separate table(s) with errors and uncertainity calculations.

Results and discussion

Present your results in a logical sequence, highlighting what is important and how the data you obtained have been analyzed to provide the results you discuss.

- You should discuss what you infer from the data.
- You need to adopt a critical approach.
- For example, discuss the relative confidence you have in different aspects of the measurements.
- Make sure that all diagrams, graphs etc. are properly labeled and have a caption.

- A *neat hand drawn diagram is preferable to a poorly made computer diagram*, or a poor resolution image copied from the web.

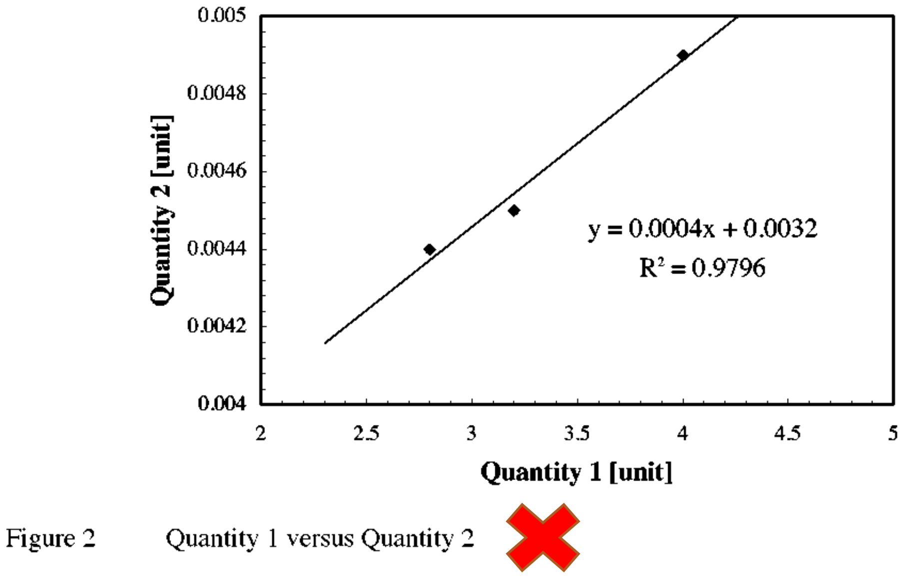


Figure (2) : Variation of Quantity (2) with Quantity (1)

- Graphs should be clear, informative, with proper legends and unit.
- If curve fiting is implemented, it should contain the fit model and its R2.
- Graph outline should be removed.

Conclusion

This is the section in which you need to put it all together. It differs from the abstract in that :

- It should be more informative, something that can easily be accomplished because you may devote more words to it. You should include a concise version of your discussion, highlighting what you found out, what problems you had, and what might be done in the future to remedy them.
- You should also indicate how the investigation could usefully be continued.

References

For this section, you should provide the source of information wherefrom you got the equations, fluid or materials properties.

Use this website : https://scholar.google.com/

- ✓ Textbooks, articles, company websites are trusted sources.
- ✓ Do not use the lab manual as a reference.
- ✓ List the references in same order as they appear in the text.
- ✓ For my students, I ask them to use the APA or Chicago style.

Book

Holman, J. P. (2012). Experimental methods for engineers. McGrawHill, New Yourk.

Journal article,
Sang, J., Yuan, Y., Yang, W., Zhu, J., Fu, L., Li, D., & Zhou, L. (2022). Exploring the underlying causes of optimizing thermal conductivity of copper/diamond composites by interface thickness. Journal of Alloys and Compounds, 891, 161777.

Web page,
http://www.gobbeldygook.co.uk. Viewed on 22/10/2020.

A word of caution on web based information. Journal articles and most books are peer reviewed. This means that other workers in the field have checked them for accuracy etc.. This is not true of web sites. Be careful in taking information from such sources and if at all possible verify the information by checking in books etc. You should also read the web information critically to see that it makes sense to you.
You are an engineer and should take pride in not being duped into making easy mistakes by faulty information.

College of Engineering & Technology
Mechanical Engineering Department
System Dynamics and Control Laboratory

MODULE: I, ANALOG COMPUTER

EXPERIMENT # 1
TITLE: FIRST ORDER SYSTEM

Prepared by: **Dr. Musa Abdalla**
First Established on: **September 2014**

MODULE I

FIRST ORDER SYSTEM RESPONSE

Lecture Part

1.1 Reading assignment
- Chapter one and two on dynamical system response

1.2 Definitions to learn
- The meaning of dynamical systems, system response, system order, transfer function, first order system characteristics, time constant, dead time or delay, block diagram representation, and Simulink simulation.

1.3 Guiding questions to be answered
- What is a first order system?
- Draw a block diagram of a first order differential equation.
- Identify the main components in the block diagram and map them to the experiment electronic modules.
- How can one implement a step input excitation in laboratory?
- How can one analyze the system's response in the laboratory?
- How one may measure the system's time constant?
- Given the first order system response, can you find the system's transfer function?

1.4 Example to work out
- Refer to text book and lecture notes.

Laboratory Part

1.5 Pre-lab Session (must submit before the experiment)
- This session is intended to achieve the following (through informal student interaction):
    1. Ascertain that the students have reasonable level of general understanding of the concepts being addressed theoretically.
    2. Familiarity with the equipment to be used, the experimental procedure and the data to be acquired.
- The pre-lab presentation consists primarily on understanding the terminologies of section 1.2, answering the guiding questions of section 1.3, and understanding the overall objective and the experimental procedure. The pre-lab presentation will be due the day of conducting the experiment.
- The final experimental report will be due within a week after conducting the experiment.

1.6 Experimental part
- Experiment # 1: First Order System Response using the Analog Computer Rig

1.7 Homework/Assignment problems
- TBA.

EXPERIMENT # 1: FIRST ORDER SYSTEM

Apparatus: Quansor Analog Plant Simulator

The Quanser Analog Plant Simulator will be used to demonstrate dynamical systems response. The system consists of a series of electronic circuits that simulate the behavior of linear dynamical systems concepts such as time constant, steady state gain, damping, resonance and PID control. Using the system, students can learn the principles of:

- Circuit design
- System identification
- First- and second-order lag compensation and
- PID control

This is a completely integrated system for analog computer system design. The PID controller design rig is complimented with Analog Computer system modules. This basic module consists of: gain amplifiers, summing junctions, differentiation units, integration units, lags, and PID controller hardware.

The Analog Plant Simulator consists of a set of independent electronic circuits that can be interconnected. A series of potentiometers allow you to adjust the parameters of each block within a certain range. The system is supplied with 11 blocks:

- three first order lags, two second-order lags,
- one PID controller,
- two gains,
- two differential amplifiers,
- one summer,

RCA jacks are used throughout to allow for easy interconnections of inputs and outputs of each block. Each block has two identical RCA jacks for outputs. One output can be connected to another block, while the other one can be used for monitoring or feeding a different block.

Objectives

- The main flaw in teaching control theory is the gap between the theory and the implementation. Students tend to describe the control theory as a mathematical class, mainly due to lack of implementation and imagination from their part and illustration from the instructor's part.
- The control lab experiments are design to map the theory onto the implementation and realization, starting with first order system response and working up until a complete Proportional, Integra, Derivative controller (PID) is fully designed.
- Students should identify all the components learned in class and trace them back into laboratory modules. That includes all the testing signals, systems, controllers, performance measures and the output devices.
- Finally, Simulink from Mathworks is used to compliment this course as a computer design platform. The simulation should be used to verify and validate the findings in the lab.

Problem Formulation and Investigation

1. Simulate a first order system (ODE) response of the form

   $$a\frac{dy(t)}{dt}+by(t)=r(t)\,,\quad \text{use} \quad 3\frac{dy(t)}{dt}+2y(t)=r(t) \qquad \text{.........………….} \ (1)$$

   where y(t) is the first order system response, *a and b* are constant physical parameters that dedicates the system's time constant, and r(t) is an external excitation (system input).
2. Identify the needed Analog Computer module parts that are needed to implement the above differential equation Eq(1) (*Hint: draw a simulating block diagram for the ODE*)
3. Use the proper input/output devices to analyze the first order system.
4. Carry out complete first order system analysis based on the generated system output.
5. Understand the mapping between the block diagram components and the Analog Computer modules and the used testing signals and the output devices that are used to capture the system dynamics.

Procedure

1. The students should use the Analog Computer modules to implement the first order system response give by the first order differential equation (ODE).
2. First draw a block diagram of the first order differential equation as discussed in class, and identify the needed Analog Computer module parts accordingly.
3. Study the experiment Analog Computer modules in depth, and with the Laboratory Engineer discuss each component functionality (if needed). Also, notice the mapping between the physical components and the corresponding block diagram components.
4. First use a step input excitation generate an output and later use the input/output information to find the system's time constant (system identification). Discuss about the system steady state error.
5. Secondly, use a ramp input as a system excitation and generate the corresponding output.
6. Think how can you devise a procedure for testing the dynamical system linearity (***hint:*** *use superposition*).
7. Finally, devise a procedure to implement an impulse response and/or an Initial Condition system response.

Expected Deliverables

- Data: from a data acquisition device.
- Plots: system output vs. time for the different excitations.
- Analog Computer Modules: pictures and some discussions.
- Block Diagram: dynamical system block diagrams and the corresponding system implementation on the Analog Computer modules.
- Discussions and conclusions: should include
  1. Sufficient reference to actual test results,
  2. Error analysis,
  3. Opinions backed with evidence,
  4. Suggestions to improve the experiment,
  5. Sufficient deductions based on test results,
  6. References properly stated.

College of Engineering & Technology
Mechanical Engineering Department
System Dynamics and Control Laboratory

MODULE: II, SERVO SYSTEMS

EXPERIMENT # 2
TITLE: DC MOTOR SERVO SYSTEM, POSITION USING P-CONTROLLER

***Prepared by*:** **Dr. Musa Abdalla**
First Established on: **September 29, 2014**

MODULE II
SERVO SYSTEMS

Lecture Part

1.1 Reading assignment
- Chapter one and two on dynamical system response

1.2 Definitions to learn
- The meaning of dynamical systems, system response, system order, transfer function, second order system characteristics, time constants, rising time, percent overshoot, steady state error, proportional control, position servo systems, block diagram representation, and Simulink simulation.

1.3 Guiding questions to be answered
- What is a second order system?
- What are the differences between closed and open loop systems?
- What is meant by Servo systems?
- How can one control a position of a DC motor? What will happen if one excited a DC motor with a step input?
- Draw a closed loop system for a DC motor with a proportional controller (P-controller), $u(t)=K_pe(t)$
- How does the P-controller achieves position controller for a DC system?

1.4 Example to work out
- Refer to text book and lecture notes.

Laboratory Part

1.5 Pre-lab session
- This session is intended to achieve the following (through informal student interaction):
  1. Ascertain that the students have reasonable level of general understanding of the concepts being addressed theoretically.
  2. Familiarity with the equipment to be used, the experimental procedure and the data to be acquired.
- The pre-lab presentation consists primarily on understanding the terminologies of section 1.2, answering the guiding questions of section 1.3, and understanding the overall objective and the experimental procedure. The pre-lab presentation will be due the day of conducting the experiment.
- The final experimental report will be due within a week after conducting the experiment.

1.6 Experimental part
- Experiment # 2: DC Motor Servo System, using P-controller.

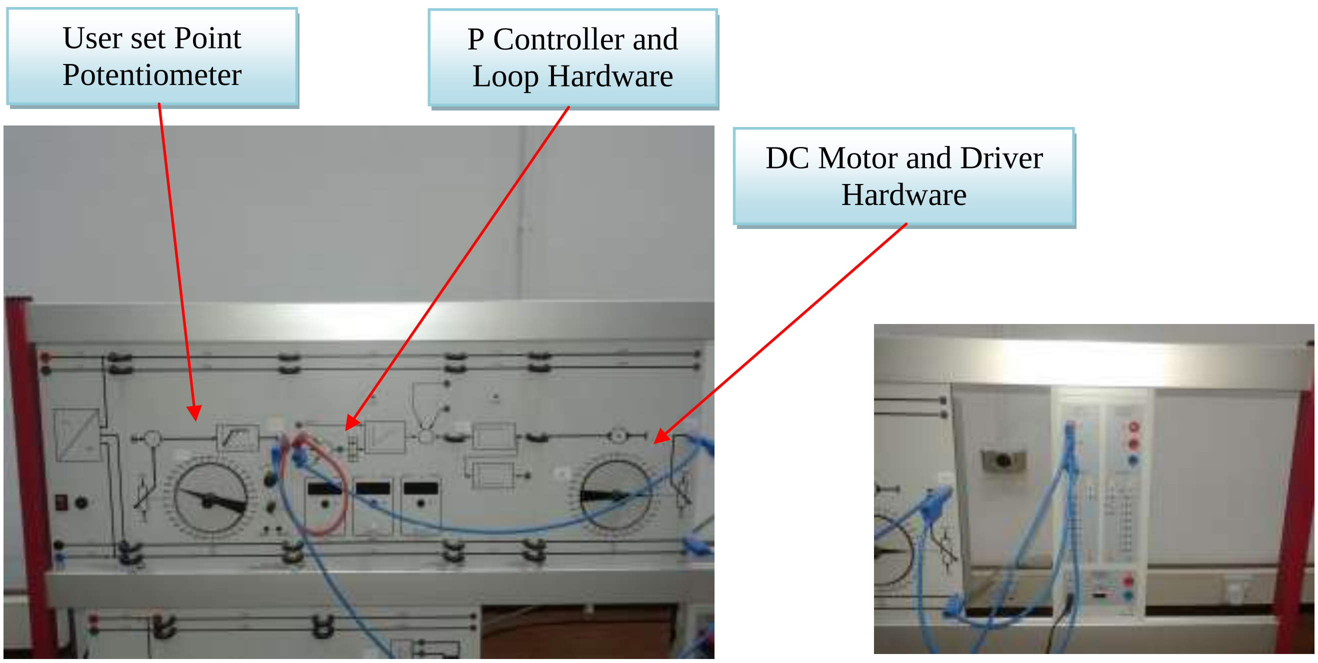
1.7 Homework/Assignment problems
- TBA.

EXPERIMENT # 2: DC MOTOR SERVO POSITION via P-CONTROLLER

Apparatus: DC Motor Servo System with Analog Computer

This is a completely integrated system for DC servo motor controller design. The PID controller design rig is complimented with Analog Computer system modules. These basic modules mainly consist of: gain amplifiers, summing junctions, differentiation units, integration units, testing signal generation units, in addition to the DC Servo hardware.

The DC Servo Experiment Module consists four main parts. The parts maybe integrated and connected to form the complete DC Servo motor, which includes the motor and drive hardware, controller, and the computer USB interface module. These Modules are shown clearly in the following pictures.



Motor and Controller Hardware USB Computer Interface

The DC Servo Module consists of the following main components

- DC Motor and Driver Hardware unit: this basically what are we trying to drive to a user desired position. It represents an actuator in a mechanical machine such as one axis in a CNC or router machine. The motor is connected to an indicator to aid the students in taking the motor's shaft angular displacement. A 360 degrees protractor is drawn around a circle to accomplish that.

- User Set Point Potentiometer: This is a variable resistor with a knob (potentiometer) that is used to enable the user to input a motor's desired angular displacement, which is internally changed into a corresponding voltage. Again, a 360 degrees protractor is drawn around a circle to aid the students or the user to accurately specify their desired angular shaft input.

- P-Controller block and Loop Hardware: A Proportional controller with variable gain (K_p maybe varied from zero to one hundred) is to be used to place the motor's shaft at a desired location. The rest of the closed loop hardware consists of a position sensor (a potentiometer) for the feedback and a summing junction between the feedback signal and the desired set point input.

- Data Output Module: This a USB computer interface module that is used to transfer system output data to the computer. The computer has a software that detects the data transfer module and streams all the data through the USB port, which is later depicted on the screen as the system's response graph.

Introduction

Engineers sometimes need to actuate a remote control element such as a Globe Valve in some industrial plants. Typically these are called Motor Operated Valves (MOV), which in reality are completely integrated feedback systems with communication abilities and built in smartness.

Servos create the same output conditions 'y(t)' for remote control purposes which create the same conditions at location B (states, positions, speeds, or torque) as those prevailing or specified at location A. If transmission, is to be as accurate as possible, the status at location B should be
"feed back", "compared" with the status at location A, and "adjusted" correspondingly (see Control loop block diagram).

Circuits without status indication are termed "open control loops". Looking at the results of the adjustment.(e.g. electric windings of car windows) this is an example of "control with non-independent feedback." This task is always performed by servomotors with powers ranging from approx. 20W to 20 kW.

Fields of application [2]

- Aerospace technology -
- Shipping -
- Road and rail traffic -
- Industrial and manufacturing processes-
- Wherever positions (x, y, z), speeds or angles need to be changed.

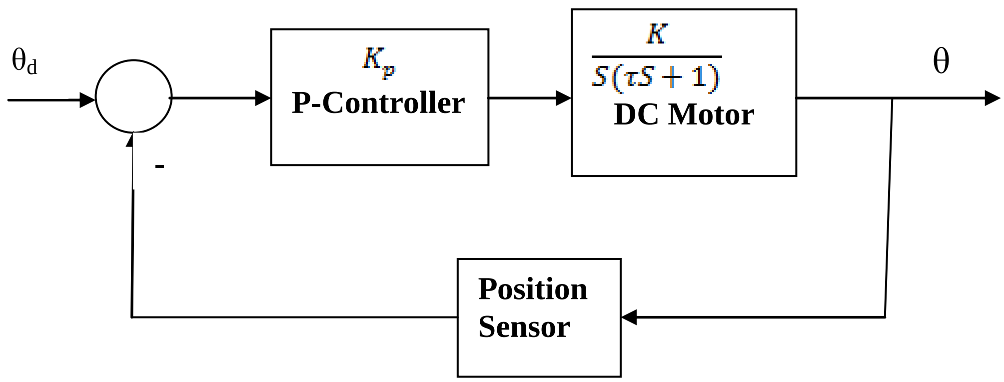
Servos [2]

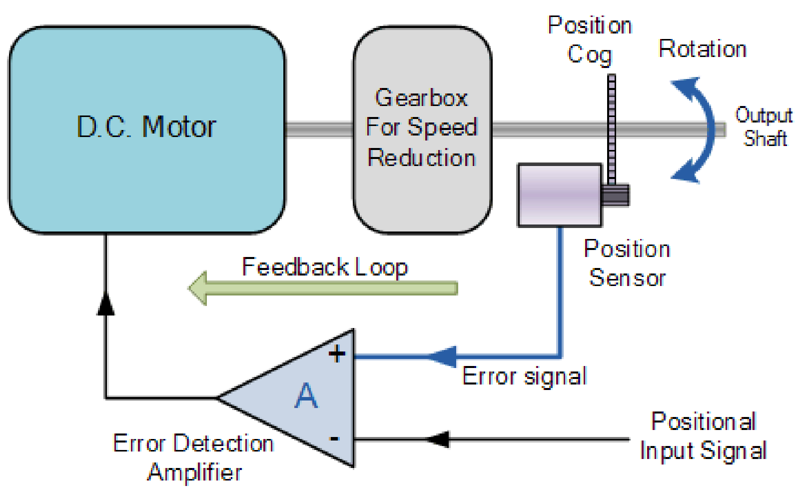
- Operate control flaps and remote-control steering gear for position control
- Operate analog control valves for speed regulation
- Operate several parabolic antennae at different locations
- Often fitted on CNC (Computer Numerical Control) machines for realizing' automated manufacturing processes with far greater accuracy
- Applied in NC technology for flexible manufacturing
- Applied in optics: automatic screen adjustment, range finding
- Function as control loops in vehicles: automatic throttle (cruise control) headlight range adjustment
- …..etc.

"Electrical DC Motors are continuous actuators that convert electrical energy into mechanical energy. The DC motor achieves this by producing a continuous angular rotation that can be used to rotate pumps, fans, compressors, wheels, etc. As well as conventional rotary DC motors, linear motors are also available which are capable of producing a continuous liner movement.

There are basically three types of conventional electrical motor available: AC type Motors, DC type Motors and Stepper Motors." [1]. For complete treatment of the subject please consult reference [1].

Servos are simply controlled systems that implement feedback strategies to regulate: position speed, torque or a combination of these physical parameters. In this experiment the student is confronted with controlling the angular position or displacement of DC motor. The control scheme that be used is a direct Proportional Controller (P-control). This simple controller could be easily implemented as shown in the block diagram.





"DC Servo motors are used in closed loop type applications were the position of the output motor shaft is fed back to the motor control circuit. Typical positional "Feedback" devices include Resolvers, Encoders and Potentiometers as used in radio control models such as airplanes and boats etc.

A servo motor generally includes a built-in gearbox for speed reduction and is capable of delivering high torques directly. The output shaft of a servo motor does not rotate freely as do the shafts of DC motors because of the gearbox and feedback devices attached" [1].

Please note that servo motors could have different types of actuations, such as: DC Motor, AC Motor, Pneumatic Cylinder, and Hydraulic Cylinder. However, for this experiment only DC motors will be used to demonstrate the working principles of a Servo-DC Motor.

The Servo Systems I - DC-Servo apparatus provides more in-depth information about D.C. servos. Here a slave potentiometer is treated as well as the requirements for a rapid and accurate control operation. A DC-servo with tacho-generator is also investigated, as is the influence of Kp and tacho feedback in terms of accuracy and correction time [2].

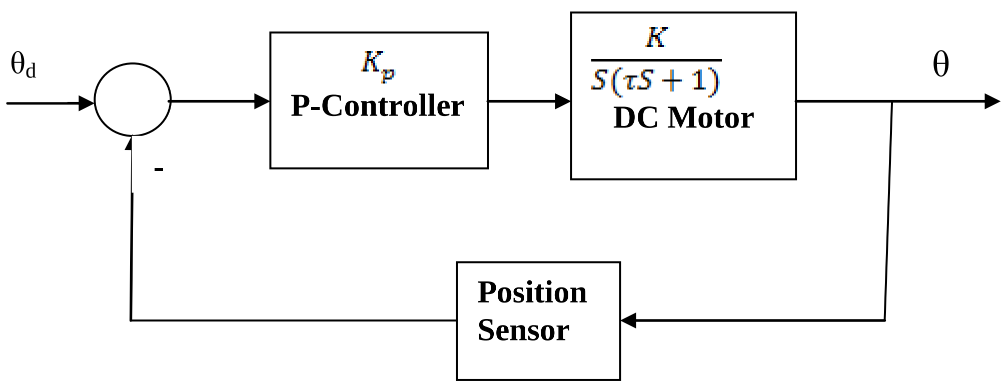
Objectives

Use the DC Servo experiment modules in order to:

1. First investigate the open loop DC motor response. This maybe accomplished by applying a direct input voltage. Continuous rotation of the DC motor should be observed. No control or regulation of the motor position is noticed.
2. Next, build the above negative feedback (closed loop) system, which incorporates a P-controller. Some form of position control should be noticed. In order to verify the position control an external disturbance should be used.
3. Investigate the steady state error for the position and correlate with the controllers gain Kp values. Also, study the motor's rise time with Kp changing.
4. Find the systems response and relate to second order system response.
5. Check system's stability and relate it to system's type
6. Try to find the transfer function for the position sensor by taking different readings.

Procedure

1. Complete the wiring diagram as shown in the block diagram



2. With the Equipment is off power adjust the setpoint value to α = 0°(360°), and the output voltage to U = 0.0 V with the "zero" adjustor.

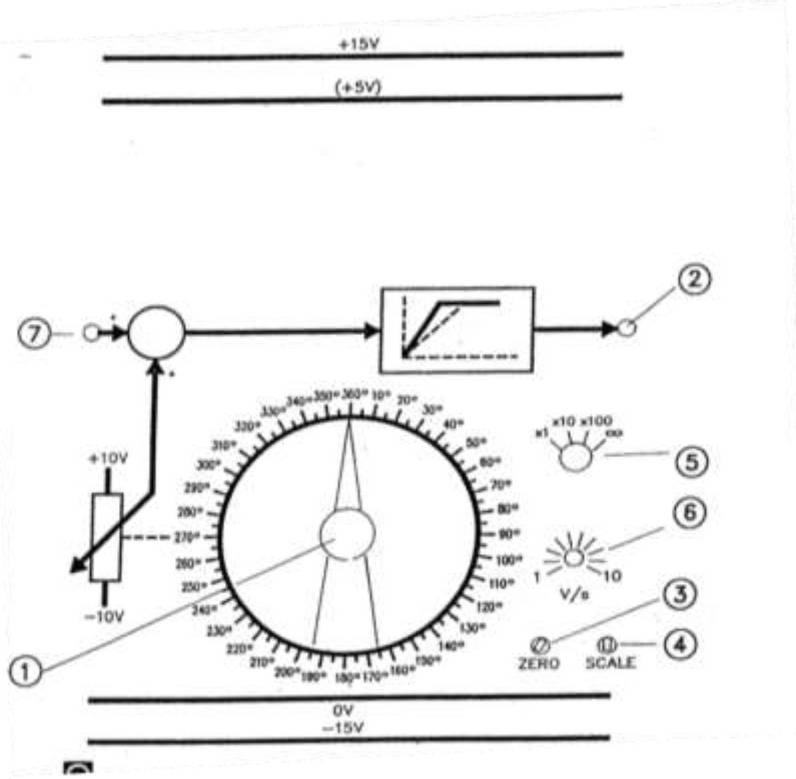
The set point module consists of a potentiometer (1) with an angular scale. The potentiometer is fed by a Stabilizer (+10 V) at one terminal while the other terminal is connected to an inverter which Generates (-10) V. The output (2) is buffered by an operational amplifier.

At the mechanical zero setting (360°), the electrical zero-point of Ua (2) can be corrected with the "Zero" adjustor (3). At 90° (or 270'), the "Scale" (4) Ua = +5.0 V (resp. -5.0 V) can be set with the adjustor. The fact that the potentiometer has two terminals which are connected to +10 V and -10 V Results in a dead angle (approx. 170°to 190°), within which the output voltage is

Ua = 0; when this range is exceeded, the output voltage• springs from one extreme value (e.g. +10 V) to the other (-10 V). **This range should be avoided during control processes.**

For certain control processes, it is important to make sure that the setpoint adjustment does not exceed certain rates of rise. For this reason, the output (2) is preceded by a "setpoint integrator" which makes it possible to adjust the rate of rise within ranges defined By x1 V/s up to x100 VIs (5); fine adjustments (1-10) can be made by means of the V/s adjustor (6). On the ∞ setting, the setpoint integrator is not operational.

The input summing has a non-inverting input(7), to which disturbance variables or variables subordinate to the setpoint value can be feed forwarded. They combine with the setpoint value with v=1.

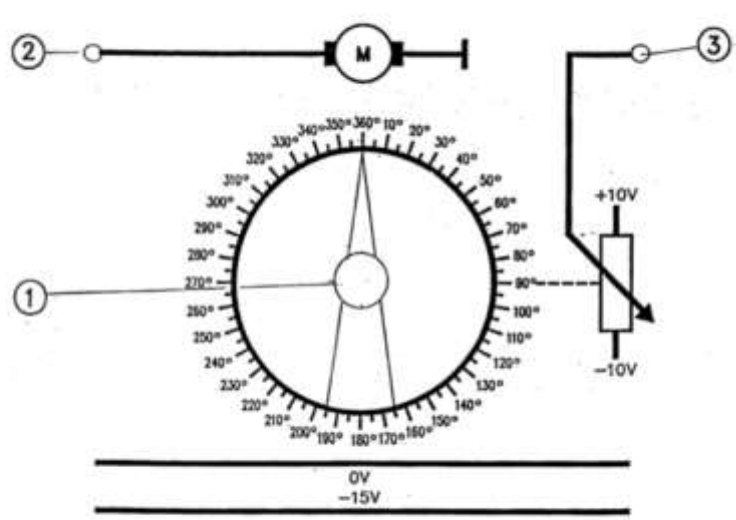


3. **Adjust the setpoint value to a = 90•, and U = 5.0 V with the "scale" adjustor.**
4. **Determine the starting and standstill voltages of the servo: Connect the output of the setpoint potentiometer directly to the input of the DC-servo (PID-controller inputs and outputs are disconnected).**

5. **Change the proportional controller knob with K_p=1, K_i=0 and K_p=0 (off). Monitor how the DC Motor responds for the selected setpoint input in the previous step.**

The DC Motor module hardware consists of a geared potentiometer (1) driven by a DC permanent-magnet motor. The driving voltage is applied to the input (2).

The DC motor draws a driving current (approx.. 15-20 rnA) from the power amplifier, which has a low internal impedance and little influence on the characteristics of the controlled system. The potentiometer terminals are connected to stabilized + and -10 V sources. The potentiometer wiper (output (3)) is buffered by an operational amplifier (v = 1).



6. **Adjust the proportional controller gain values and record the them in the following Table.**

Kp(scale div)	10	25	40	50	60	80	100
Steady state value							
Steady State Error							

Monitor the change in response due to changing the amount of gain. Take screen shots for all the previous values and find the steady state error

7. Develop a procedure to find the feedback sensor transfer function.

Expected Deliverables:

- Data: from a data acquisition device.
- Plots: system output vs. time for different excitations.
- DC Servo Modules: pictures and some discussions.
- Block Diagram: dynamical system block diagrams and the corresponding system implementation on the DC Servo modules.
- Discussions and conclusions: should include
    1. Sufficient reference to actual test results,
    2. Error analysis,
    3. Opinions backed with evidence,
    4. Suggestions to improve the experiment,
    5. Sufficient deductions based on test results,
    6. References properly stated.

Safety Features and Issues

1. Do not start the DC Motor unit before the instructor's or the Laboratory Engineer approval. All circuit wires must be fully investigated for correctness.
2. The primary safety features on all Electronic based units is implemented through Fuses. However, the emergency stop button or power switched removes all power from the unit in case of emergency.
3. Do not attempt to remove/install the wires when the unit is turned on.
4. Electrical and mechanical hazards need to be aware of when working in the control laboratory

Report Due Date: *One week from the experiment date*

*Notes:*____

References

[1] Electronics Tutorials Website, Tutorials Team, http://www.electronics-tutorials.ws/io/io_7.html

[2] The fundamentals of Servo Technology, Otto Korn, LD DIDACTIC, Publication T8.4.1

***Prepared by*:** **Dr. Musa Abdalla**
First Established on: **Fall 2014**

College of Engineering & Technology
Mechanical Engineering Department
System Dynamics and Control Laboratory

MODULE: II, SERVO SYSTEMS

EXPERIMENT # 4
TITLE: DC MOTOR SERVO SYSTEM, POSITION USING PID-CONTROLLER

Prepared by:

Results

1. Adjust the proportional controller's gain values and record them in the following Table.

Kp (scale div)	10	25	40	50	60	80	100	Remarks
Steady state value								
Steady State Error								
Percentage Overshoot								
Settling Time								

2. **Adjust the integral controller's gain values and record them in the following table**

Kp (scale div)	10	25	40	50	60	80	100	Remarks
Ki (scale div)								
Steady State Error								
Percentage Overshoot e								
Settling Time								

3. **Setting the integral gain (PD controller) to zero and adjusting Kd gain record and analyze**

Kp (scale div)	10	25	40	50	60	80	100	Remarks
Kd (scale div)								
Steady State Error								
Percentage Overshoot e								
Settling Time								

4. **Using the full PID Controller with trial and error try to get your best response.**

Kp (scale div)								Remarks
Ki (scale div)								
Kd (scale div)								
Steady State Error								
Percentage Overshoot e								
Settling Time								

Discussion

I. Find the transfer function for the PD controller loop and show why Kd minimizes the DC motor overshoot for the regulation of the position case.

II. Fill in the effect of increasing the PID controller terms on the system response

Controller Term	Rising Time	Percentage Overshoot	Settling Time	Steady State Error	Remarks
K_p					
K_i					
K_d					

III. Under what conditions the usage of a PI controller will totally eliminate the steady state error?

Conclusions

College of Engineering & Technology
Mechanical Engineering Department
System Dynamics and Control Laboratory

MODULE IV: STABILITY APPLICATIONS

EXPERIMENT # 5
TITLE: ELEVATOR SYSTEM, MODELING, STABILITY AND SEQUENCE CONTROL

***Prepared by*: Dr. Musa Abdalla**
***First Established on:* Nov 8, 2015**

MODULE IV
ELEVATOR SYSTEMS

Lecture Part

1.1 Reading assignment
- Chapter four on second order dynamical system response and Sequence controllers design and applications.

1.2 Definitions to learn
- The modeling, stability and performance of second order systems: modeling of an elevator system, stability, performance of the elevator system, and sequence control.

1.3 Guiding questions to be answered
- What are the main parts of an elevator system?
- What is meant by sequence control?
- What are the equations of the modeled elevator system?
- What is the stability of an elevator system?
- What are the performance measures of second order system when subjected to a step?
- How the elevator system is is accelerated and decelerated?
- What is the flow chart of the sequence control scheme utilized in a simple elevator model?

1.4 Example to work out
- Refer to text book and lecture notes.

Laboratory Part

1.5 Pre-lab session
- This session is intended to achieve the following (through informal student interaction):
    1. Ascertain that the students have reasonable level of general understanding of the concepts being addressed theoretically.
    2. Familiarity with the equipment to be used, the experimental procedure and the data to be acquired.
- The pre-lab presentation consists primarily on understanding the terminologies of section 1.2, answering the guiding questions of section 1.3, and understanding the overall objective and the experimental procedure. The pre-lab presentation will be due the day of conducting the experiment.
- The final experimental report will be due within a week after conducting the experiment.

1.6 Experimental part
- Experiment # 5: Elevator system: modeling and sequence control.

1.7 Homework/Assignment problems
- TBA.

EXPERIMENT # 5: ELEVATOR SYSTEM MODELING, ANALYSIS AND CONTROL

Apparatus: Two Levels Prototype Elevator System

Elevator systems are widely used to facilitate humans comfort. There are many types of elevator systems such as Geared, Gearless, Electrical, and Hydraulics…etc. The Elevator prototype in Jordan University Control Laboratory is a two level model, which is a true scaled down model from an actual elevator. The elevator prototype may also be used to demonstrate troubleshooting and malfunctions of typical faults.

Figure 1.0 depicts a picture of the Elevator prototype with all its accessories. The elevator system works on three phase electrical power so extreme caution needs to be observed by technicians when handling the elevator internals.

The elevator prototype will be used to demonstrate sequence control, stability, performance and modeling. The students need to study the system carefully and observe all the designed components and their functions. Also, the students need to ponder on the control strategy that is used concentrating on the speed and acceleration profiles.

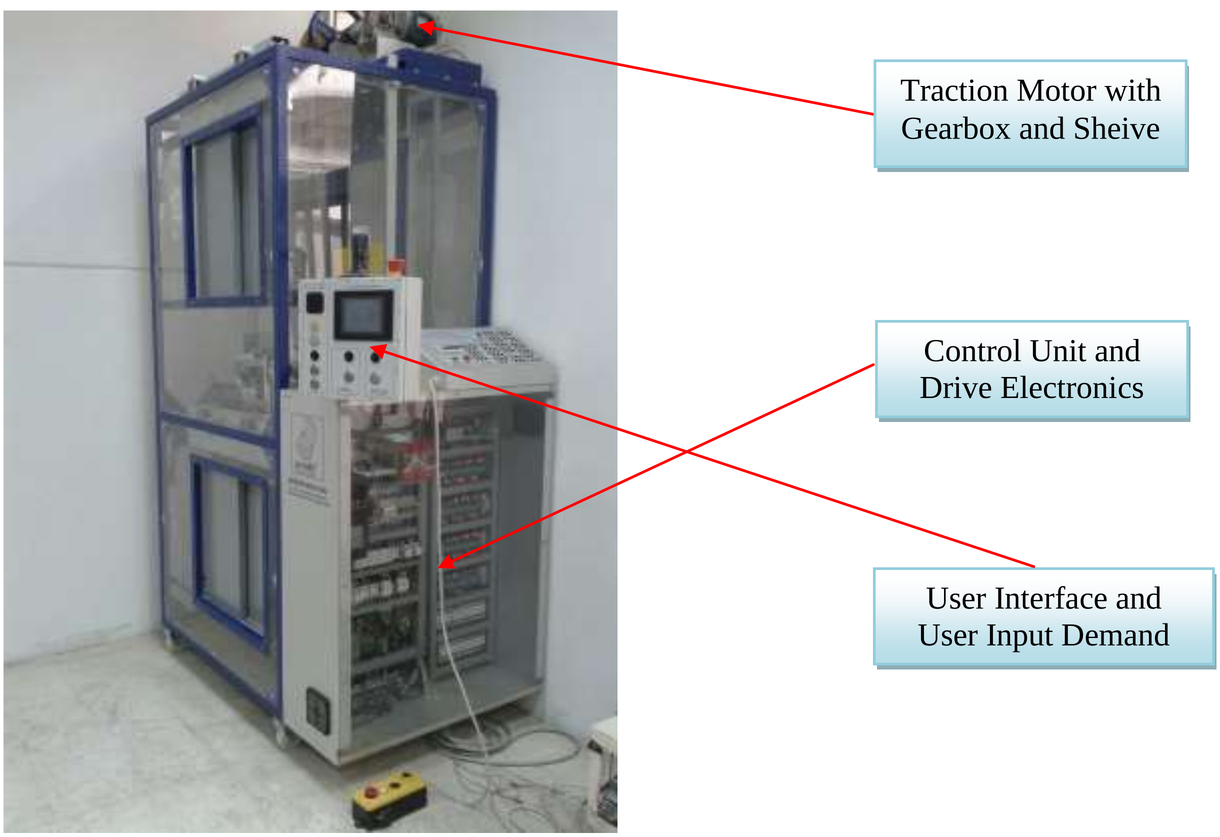


Figure 1.0: Elevator prototype

Figure 2.0 illustrates the detailed components of a Mitsubishi Elevator system. The students should study these components and may get further information from the Mitsubishi site. The components function analysis is a good exercise that helps to strengthen students' skills in Mechanical Design.

In this experiment, students should analyze the sequence control strategies that might be used in Elevator Systems. The Elevator Prototype should provide a good running demonstration of an actual scaled down model. Students are advised to run and verify different operational tests. Also,

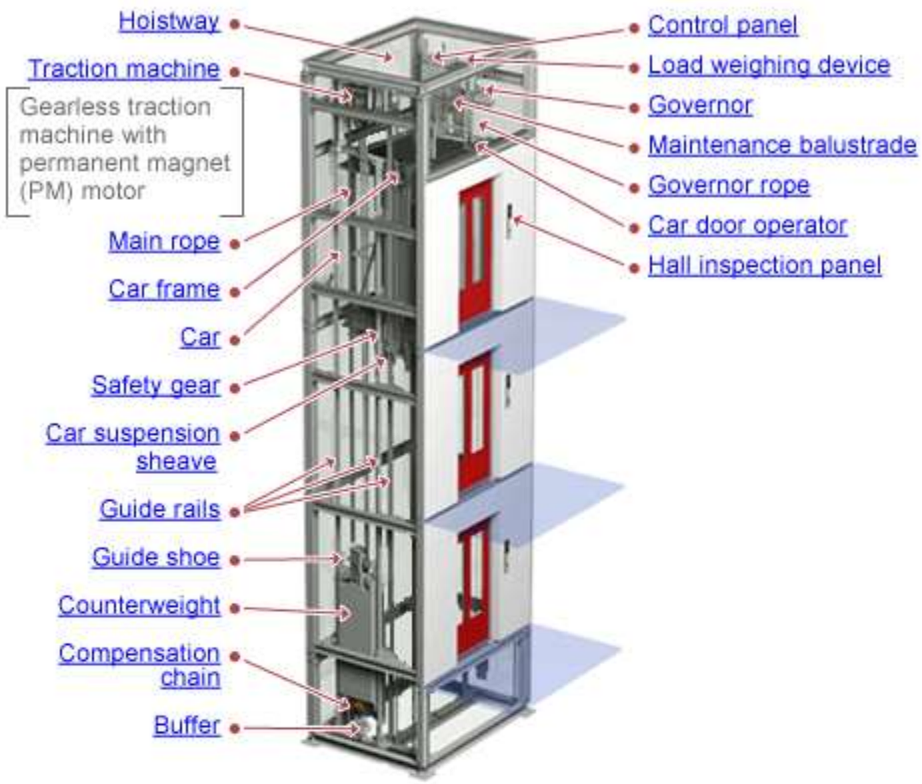


Figure 2.0: Mitsubishi Elevator System

Finally, students need to pay special attention for the various used sensors and limit switches equipped on the system. The operational flow chart for the Elevator System should be generated by the students to guarantee the understanding of the used control strategy.

Introduction

Elevators are encountered on daily basis by people. However, their structure and operation is hardly questioned by their riders. In this experiment the students will model and analyze the operation of a down scaled actual Elevator System.

Fields of application

- Apartments lifts
- Towers lifts
- Industrial wenches
- …etc

Elevator Modeling

There are many types of Elevator Systems, but in this part only a gearless single wrap elevator is used for the deriving the Mathematical model. Figure 3.0 represents a simple modeling of an Elevator's cables, Car and Counter Weight. The cables are modeled by a spring-damper system due to their flexibility and friction, respectively.

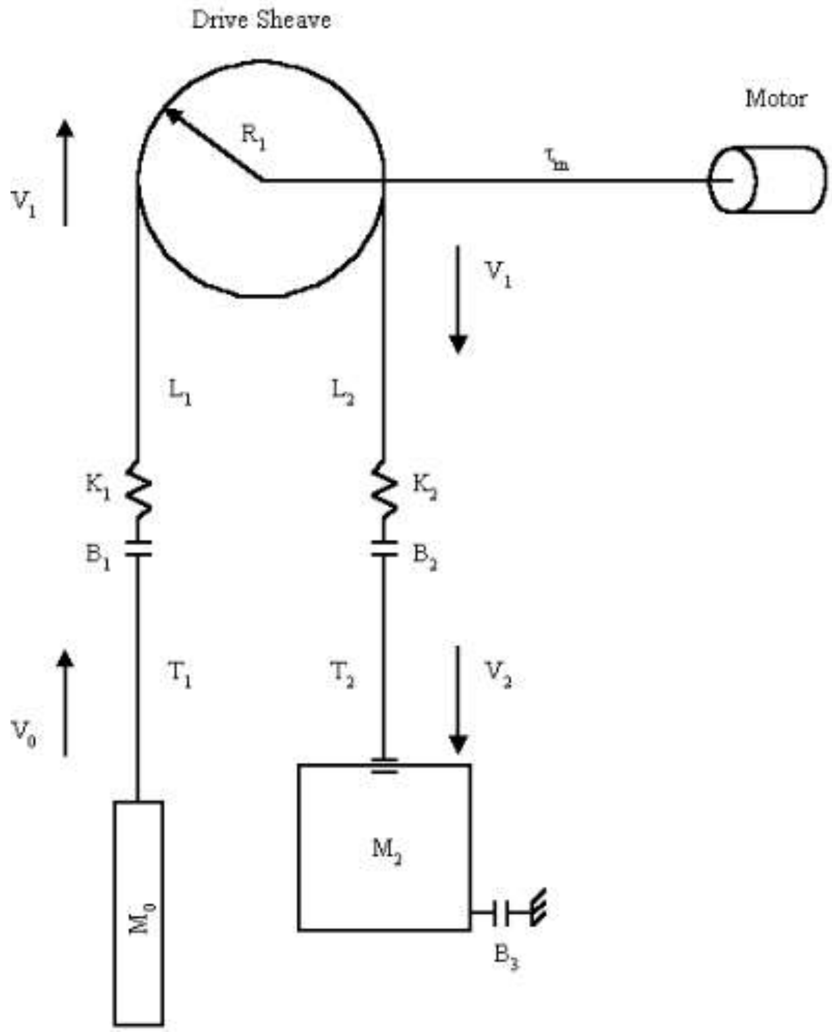


Figure 3.0: Elevator's simplified model

The students are requested to use free body diagrams and Newton's basic laws in motion to come up with the Mathematical model (set of ODEs). Once the model is generated, a Simulink model need to be build and tested to verify position, speed, acceleration and jerk profiles.

Objectives

Use the Elevator experiment module in order to:

1. Study the second order system response in position servo-systems,
2. Investigate the different types of sensor used in elevators,
3. Check system's stability and relate it to system's type,
4. Derive a mathematical model of the elevator system, and
5. Create a flow chart of the sequence control strategy that is used in elevators.

Procedure

1. **Perform pre-operational check to make sure that th*ere are* no obstacles that hinder the car or the counter weight, then select normal operation selector modes in the testing handheld pad and the fixed selector (the yellow and black boxes),**

2. Turn on the Elevator's main power socket,

3. Turn on the Elevator's main switches, the elevator should show power on (Red button illuminates),

4. Push the start button (Green button should illuminate and Red one will go off),

5. Wait for the CPU unit to boot and monitor the screen for warning or faults messages

6. One the Elevator is ready one may experiment with the level buttons and the obstacle sensors,

7. Run the Elevator few times and observe the mechanical mechanisms and the electrical sensors and controls.

8. **Develop a flow chart of the sequence control based on the Elevator's operation. Pay special attention to the sensors locations and the limit switches.**

Expected Deliverables

- Elevator mathematical model and simulation
- Plots: system output, velocity, acceleration and jerk.
- Elevator System: pictures and some discussions.
- Block Diagram: dynamical system block.
- Discussions and conclusions: should include
    1. Curves discussions,
    2. Error analysis,
    3. Opinions backed with evidence,
    4. Suggestions to improve the experiment,
    5. Sufficient deductions based on test results,
    6. One page survey of used elevator standards that pertains to human comfort on acceleration of elevators, and
    7. References properly stated.

Safety Features and Issues

1. DO NOT start the Elevator prototype before the instructor's or the Laboratory Engineer approval. All circuit wires must be fully investigated for correctness. Please note that the unit is powered from a three phase electric source, hence extra caution needs to be observed,
2. The primary safety features on all Electronic based units is implemented through Fuses and Trips. However, the emergency stop button or power switched removes all power from the unit in case of emergency,
3. Do not attempt to remove/install the wires when the unit is turned on, and
4. Electrical and mechanical hazards need to be aware of when working in the control laboratory

Report Due Date: *One week from the experiment date*

Notes:

References

[1] Elevator vendor's technical manual
[2] http://www.gaudisite.nl/ElevatorPhysicalModelSlides.pdf

Prepared by: **Dr. Musa Abdalla**
First Established on: **Fall 2014**

College of Engineering & Technology
Mechanical Engineering Department
System Dynamics and Control Laboratory

MODULE V: APPLICATIONS

EXPERIMENT # 8
TITLE: HEAT EXCHANGER CONTROL

Prepared by: **Dr. Musa Abdalla**
First Established on: **May 1, 2021**

MODULE VIII
INDUSTRIAL APPLICATIONS: HEAT EXCHANGER

Lecture Part

1.1 Reading assignment
- Review in your heat transfer text book the corresponding chapters on Heat Exchangers technology, operation and types.

1.2 Definitions to learn
- The modeling, Performance and control of Heat Exchangers.

1.3 Guiding questions to be answered
- What are the main parts of heat exchangers?
- What is meant by PID control?
- What are the equations of the modeled Heat Exchanger system?
- What is the stability of a Heat Exchanger system?
- What are the performance measures of Heat Exchanger system when subjected to a step?
- How the Heat Exchanger system is typically controlled?
- What is the proper control strategy for Heat Exchanger system that is adopted by the industry?

1.4 Example to work out
- Refer to text book and lecture notes.

Laboratory Part

1.5 Pre-lab session
- This session is intended to achieve the following (through informal student interaction):
  1. Ascertain that the students have reasonable level of general understanding of the concepts being addressed theoretically.
  2. Familiarity with the equipment to be used, the experimental procedure and the data to be acquired.
- The pre-lab presentation consists primarily on understanding the terminologies of section 1.2, answering the guiding questions of section 1.3, and understanding the overall objective and the experimental procedure. The pre-lab presentation will be due the day of conducting the experiment.
- The final experimental report will be due within a week after conducting the experiment.

1.6 Experimental part
- Experiment # 8: Heat Exchanger system control.

1.7 Homework/Assignment problems
- TBA.

EXPERIMENT # 8: PID CONTROL OF PLATE HEAT EXCHANGER SYSTEM

Apparatus: Gunt Heat Exchanger System

Heat Exchanger systems are widely used in the industry to facilitate heating or cooling of process fluids. There are many types of Heat Exchanger systems such as plate, shell and tube, double pipe, …etc. This experiment is used to illustrate the operation and control of Heat Exchanger systems.

Figure 1.0 depicts a picture of the Gunt Heat Exchanger system with all its accessories. A plate Heat Exchanger system is used to transfer thermal energy to a secondary fluid, the primary hot fluid is heated using an electric heater. A Proportional, Integral and Derivative (PID) controller is used to regulate the temperature of the secondary fluid to a desired user setpoint.

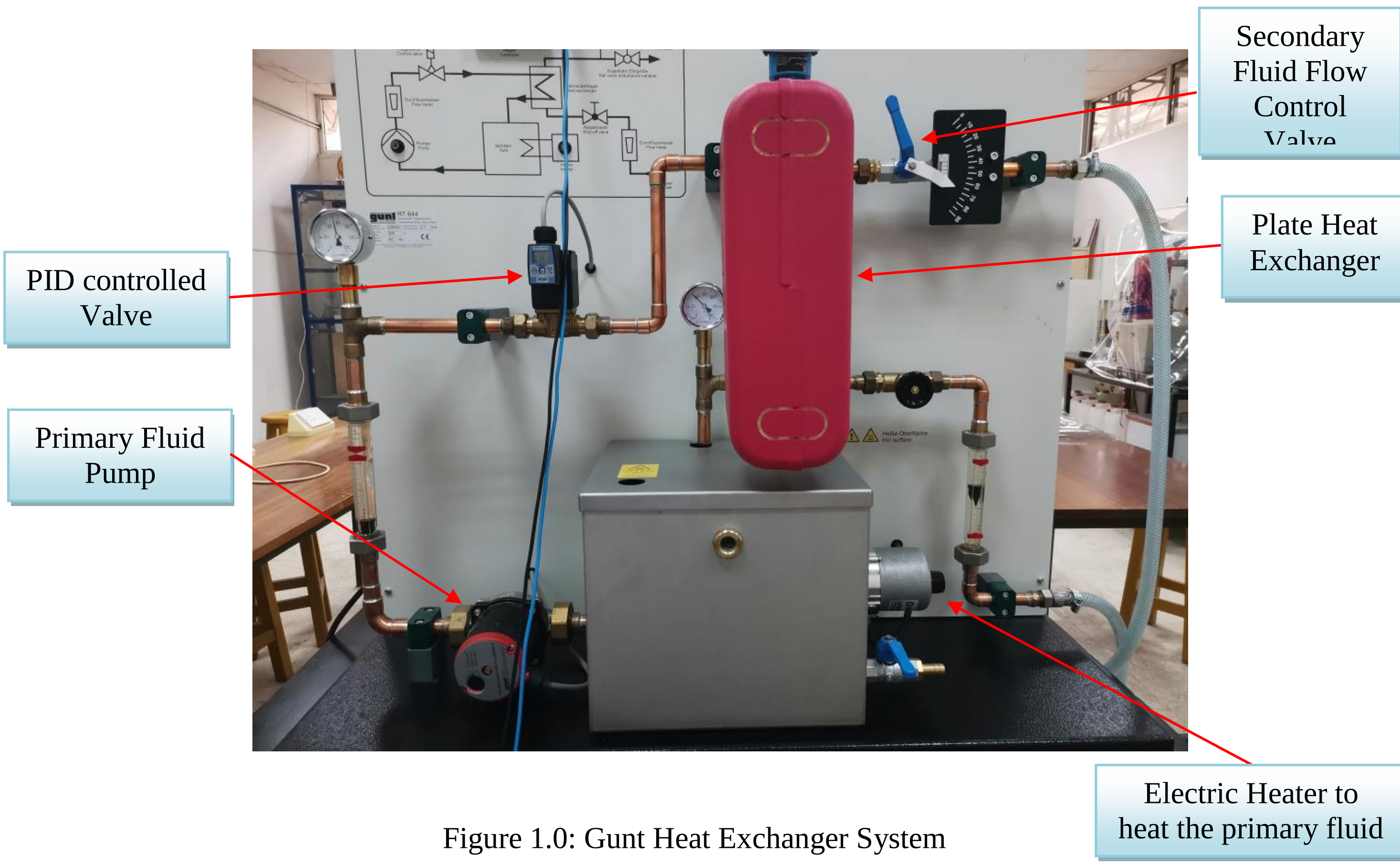


Figure 1.0: Gunt Heat Exchanger System

Figure 2.0 depicts the secondary fluid (i.e. process fluid) main tank and circulating pump. This surge tank is used instead of a tap water because the control laboratory is not equipped with a water supply system.

Figure 2.0: Heat Exchanger secondary fluid main tank

Figure 3.0 illustrates the Piping and Instrument Diagram (P&ID) of the Heat Exchanger System. The students should study these schematics and may get further information from the Gunt site. The components function analysis is a good exercise that helps to strengthen students' skills in Mechanical Design.

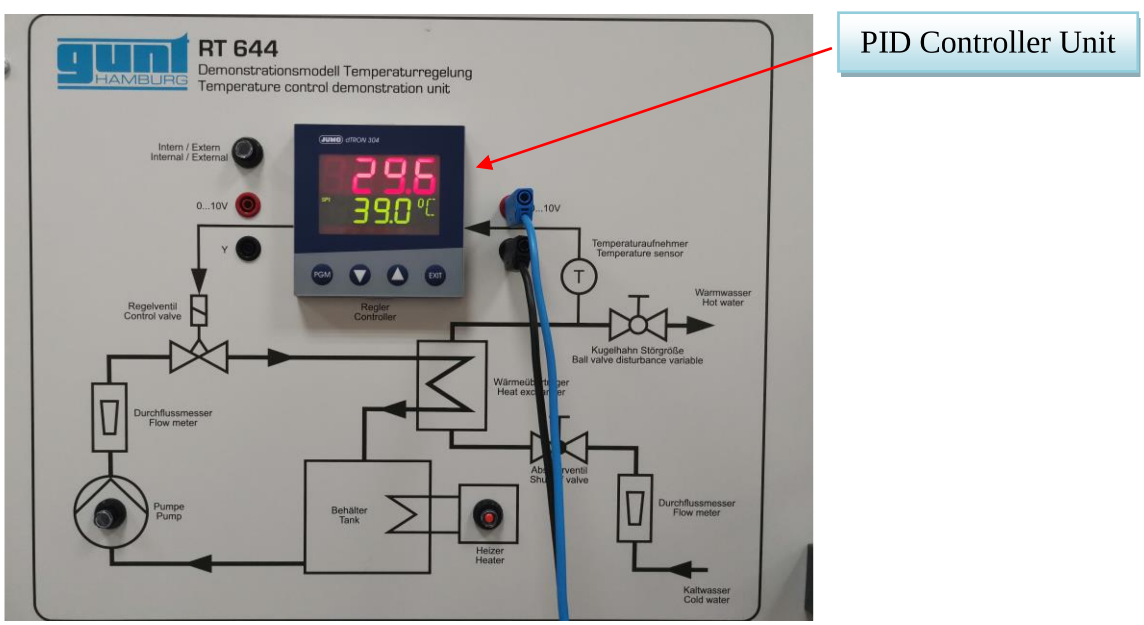


Figure 3.0: P&ID schematics for the Heat Exchanger system

In this experiment, students should analyze the control strategy that might be used in Heat Exchanger system. This Gunt plate Heat Exchanger prototype should provide a good running demonstration of an actual scaled down model. Students are advised to run and verify different operational tests.

Finally, students need to pay special attention for the various used sensors, valves and controllers equipped on the system. The operational flow chart for the Heat Exchanger system should be generated by the students to guarantee the understanding of the used control strategy.

Objectives

Use the Heat Exchanger Application module in order to:

1. Study the first order system response of the Heat Exchanger systems,
2. Investigate the different types of sensor used in Heat Exchangers,
3. Check system's stability and relate it to system's type,
4. Derive a mathematical model of the Heat Exchanger system, and
5. Create a flow chart of the sequence control strategy that is used in Heat Exchangers.

Procedure

1. **Students should come up with the operational procedure.**

Expected Deliverables

- Heat Exchanger mathematical model and simulation
- Plots: system output temperature.
- Heat Exchanger System: drawings using MS Visio and some discussions.
- Block Diagram of the closed loop system.
- Discussions and conclusions: should include
    1. Curves discussions,
    2. Error analysis,
    3. Opinions backed with evidence,
    4. Suggestions to improve the experiment,
    5. Sufficient deductions based on test results,
    6. One-page survey of used Heat Exchanger, and
    7. References properly stated.

Safety Features and Issues

1. DO NOT start the Heat Exchanger prototype before the instructor's or the Laboratory Engineer approval. All circuit wires must be fully investigated for correctness. Please note that the unit is powered from a single phase 220V electric source, hence extra caution needs to be observed,
2. The primary safety features on all Electronic based units is implemented through Fuses and Trips. However, the emergency stop button or power switched removes all power from the unit in case of emergency,
3. Do not attempt to remove/install the wires when the unit is turned on, and
4. Electrical and mechanical hazards need to be aware of when working in the control laboratory

Report Due Date: *One week from the experiment date*

Notes:

References

[1] Gunt technical manual
[2] Private notes

Prepared by: **Dr. Musa Abdalla**
First Established on: **Spring 2021**

College of Engineering & Technology
Mechanical Engineering Department
System Dynamics and Control Laboratory

MODULE VI: SYSTEM IDENTIFICATIONS

EXPERIMENT # 6
TITLE: MASS-SPRING-DAMPER SYSTEM IDENTIFICATION – TIME RESPONSE

Prepared by: **Dr. Musa Abdalla**
First Established on: **Nov 8, 2015**

MODULE IV
SYSTEM IDENTIFICATION

Lecture Part

1.1 Reading assignment

- Chapter four on second order dynamical system response and Vibration course notes.

1.2 Definitions to learn

- The modeling, second order system response, underdamped systems behavior, system identification, systems parameters: mass, damping and stiffness.

1.3 Guiding questions to be answered

- How is the underdamped system response?
- What is meant by damped oscillations?
- What are the equation of the standard second order system?
- What type of poles the mass-spring-damper system should possess?
- What is meant by log decrement?
- What is the performance index method?
- What other identification strategies are out there in the frequency domain?

1.4 Example to work out

- Refer to text book and lecture notes.

Laboratory Part

1.5 Pre-lab session

- This session is intended to achieve the following (through informal student interaction):
    1. Ascertain that the students have reasonable level of general understanding of the concepts being addressed theoretically.
    2. Familiarity with the equipment to be used, the experimental procedure and the data to be acquired.
- The pre-lab presentation consists primarily on understanding the terminologies of section 1.2, answering the guiding questions of section 1.3, and understanding the overall objective and the experimental procedure. The pre-lab presentation will be due the day of conducting the experiment.
- The final experimental report will be due within a week after conducting the experiment.

1.6 Experimental part

- Experiment # 6: System Identification: Mass-spring-Damper system parameter identification.

1.7 Homework/Assignment problems

- TBA.

.

EXPERIMENT # 6: SYSTEM IDENTIFICATION
MASS-SPRING-DAMPER PARAMETER ESTIMATION

Apparatus: Process Control Simulator

The process control rig will be used to simulate the behavior of a second order system. In this case, it represents a Mass-Spring-Damper system. The process rig is equipped with many diverse variable interconnections together with a range of non-linear functions. These blocks make the simulator sufficiently versatile to permit a detailed study of the dynamic responses of a wide variety of linear or non-linear processes. It also enables the students to apply different control strategies such as proportional, integral and derivative controls.

The process control simulator is a special-purpose analog simulator employing integrated circuit operational amplifiers laid out in such a manner to allow the principles of process control methods to be studied in the laboratory. Figure 1.0 illustrates the main components of the rig.

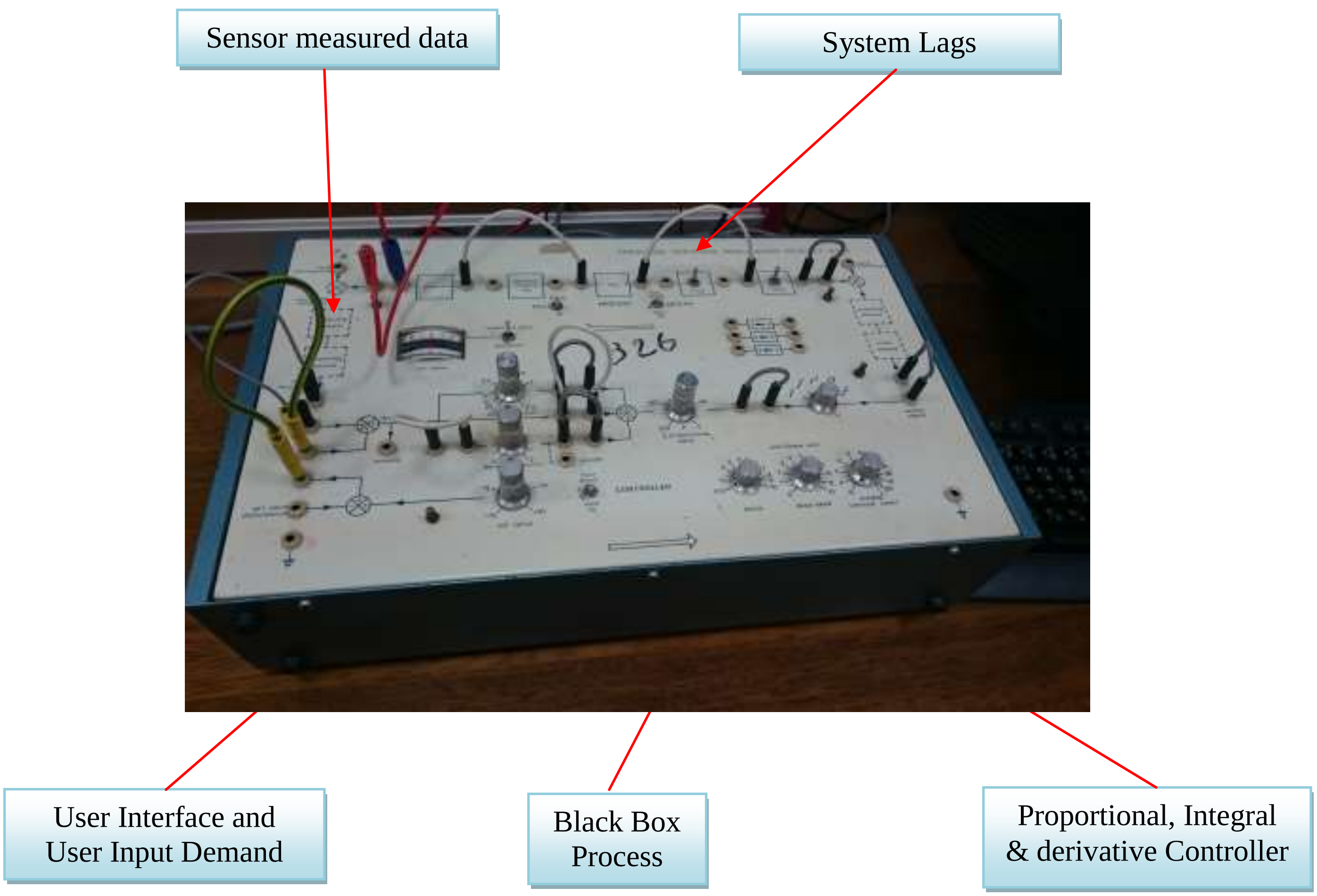


Figure 1.0: Process Control Simulator Rig

Introduction

System identification or reverse engineering is one of the most important engineering applications. Black boxes systems may be analyzed and inside information generated to make their understanding possible.

The field of system identification uses statistical methods to build mathematical models of dynamical systems from measured data. System identification also includes the optimal design of experiments for efficiently generating informative data for fitting such models as well as model reduction.

Fields of application

- Reverse engineering
- Parameter estimation
- Industrial controllers tuning
- …etc

Objectives

Use the System Identification module in order to:

1. Study the second order system response,
2. Estimate system's parameters,
3. Learn two system identification techniques applicable to 2^{nd} order systems,
4. Perform an example or reverse engineering, and
5. Perform error analysis to in.

Procedure

1. **Perform pre-operational check to make sure that everything in place,**
2. Connect the process control simulator PID controller with the process,
3. Connect the PC data acquisition system with desired points to measure, making sure that there is common ground between the two systems,
4. Turn on the process control simulator from the side switch,
5. Wait for the process transients to subside, then move the selector set point to a new desired set point.
6. The output measured parameter maybe seen on the PC screen,
7. Capture the dynamics and store on your flash for further analysis on Matlab or Excel, finally
8. **Repeat the test process for three different desired inputs.**

.

Expected Deliverables

- System Identification of the Mass-Spring-Damper system
- Plots: system output and simulation comparisons.
- Process control simulator: pictures and some discussions.
- Discussions and conclusions: should include
    1. Curves discussions,
    2. Error analysis,
    3. Opinions backed with evidence,
    4. Suggestions to improve the experiment,
    5. Sufficient deductions based on test results, and
    6. References properly stated.

System Identification Methods

There are many methods that may be used for system identification. However, log decrement and performance index methods will be used in this experiment. The log decrement was shown previously in your vibration course. I have provided information on these two techniques in the subsequent pages.

Figure 2.0 depicts a typical second order underdamped response (i.e. similar to the mass-spring-damper response). The response in the experiment is due to a step input, while the one shown in Figure 2.0 is due to an impulse. However, the same analysis still applies in both cases.

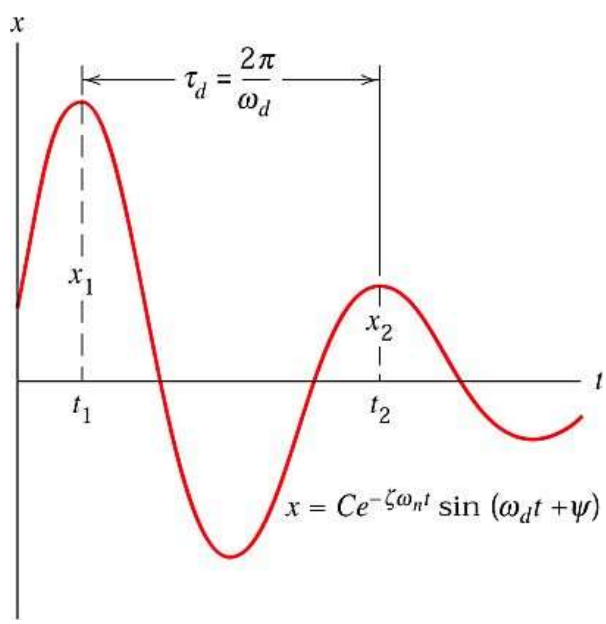


Figure 2.0: Log Decrement concept

.

Safety Features and Issues

1. Do not start the process control simulator before the instructor's or the Laboratory Engineer approval. All circuit wires must be fully investigated for correctness.,
2. The primary safety features on all Electronic based units is implemented through Fuses and Trips. However, the emergency stop button or power switched removes all power from the unit in case of emergency,
3. Do not attempt to remove/install the wires when the unit is turned on, and
4. Electrical and mechanical hazards need to be aware of when working in the control laboratory

Report Due Date: *One week from the experiment date*

*Notes:*____

____

____

____

____

____

____

____

____

____

____

____

____

____

____

____

____

____

____

____

____

____

____

____

____

.

.