ATME COLLEGE OF ENGINEERING

13th KM Stone, Bannur Road, Mysore - 570 028

DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING

NOTES

Course:Control Systems

Course Code:BEE602

SEMESTER: VI

INSTITUTIONAL VISION AND MISSION

VISION:

- Development of academically excellent, culturally vibrant, socially responsible and globally competent human resources.

MISSION:

- To keep pace with advancements in knowledge and make the students competitive and capable at the global level.
- To create an environment for the students to acquire the right physical, intellectual, emotional and moral foundations and shine as torchbearers of tomorrow's society.
- To strive to attain ever-higher benchmarks of educational excellence.

Department Vision and Mission

Vision:

To create Electrical and Electronics Engineers who excel to be technically competant and fulfill the cultural and social aspirations of the society.

Mission:

- To provide knowledge to students that builds a strong foundation in the basic principles of electrical engineering, problem solving abilities, analytical skills, soft skills and communication skills for their overall development.
- To offer outcome based technical education.
- To encourage faculty in training & development and to offer consultancy through research & industry interaction.

Program Educational Objectives (PEOs)

PEO1: To produce competent and ethical Electrical and Electronics Engineers who will exhibit the necessary technical and managerial skills to perform their duties in society.

PEO2: To make graduates continuously acquire and enhance their technical and socio-economic skills

PEO3: To aspire graduates on R&D activities leading to offering solutions and excel in various career paths.

PEO4: To produce quality engineers who have the capability to work in teams and contribute to real time projects.

Program Outcomes (POs)

Engineering Graduates will be able to:

PO1: Engineering Knowledge: Apply the knowledge of mathematics, science, engineering fundamentals and an engineering specialization to the solution of complex engineering problems.

PO2: Problem Analysis: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.

PO3: Design / Development of solutions: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.

PO4: Conduct investigations of complex problems: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.

PO5: Modern tool usage: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.

PO6: The engineer and society: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.

PO7: Environment and sustainability: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.

PO8: Ethics: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.

PO9: Individual and team work: Function effectively as an individual and as a member or leader in diverse teams, and in multidisciplinary settings.

PO10: Communication: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

PO11: Project management and finance: Demonstrate knowledge and understanding of the engineering management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

PO12: Life-long learning: Recognize the need for and have the preparation and ability to engage in independent and lifelong learning in the broadest context of technological change.

Program Specific Outcomes (PSOs)

The students will develop an ability to produce the following engineering traits:

PSO1: Apply the concepts of Electrical and Electronics Engineering to evaluate the performance of powe system and also to control industrial drives by using power electronics.

PSO2: Demonstarte the concepts of process control for Industrial Automation, design models for environmental and social concerns and also exhibit continuous self-learning.

MODULE-1

1.1 A control system is an arrangement of physical components connected or related in such a manner as to command, direct, or regulate itself or another system, or is that means by which any quantity of interest in a system is maintained or altered in accordance with a desired manner.

Any control system consists of three essential components namely input, system and output. The input is the stimulus or excitation applied to a system from an external energy source. A system is the arrangement of physical components and output is the actual response obtained from the system. The control system may be one of the following type.

1) man made
2) natural and / or biological and
3) hybrid consisting of man made and natural or biological.

Examples:

1) An electric switch is man made control system, controlling flow of electricity.
   input : flipping the switch on/off
   system : electric switch
   output : flow or no flow of current
2) Pointing a finger at an object is a biological control system.
   input : direction of the object with respect to some direction
   system : consists of eyes, arm, hand, finger and brain of a man
   output : actual pointed direction with respect to same direction
3) Man driving an automobile is a hybrid system.
   input : direction or lane
   system : drivers hand, eyes, brain and vehicle
   output : heading of the automobile.

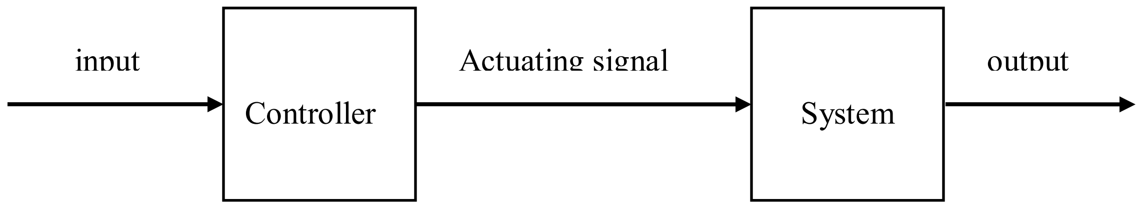
1.2 Classification of Control Systems

Control systems are classified into two general categories based upon the control action which is responsible to activate the system to produce the output viz.

1) Open loop control system in which the control action is independent of the out put.

2) Closed loop control system in which the control action is some how dependent upon the output and are generally called as feedback control systems.

Open Loop System is a system in which control action is independent of output. To each reference input there is a corresponding output which depends upon the system and its operating conditions. The accuracy of the system depends on the calibration of the system. In the presence of noise or disturbances open loop control will not perform satisfactorily.



EXAMPLE - 1 Rotational Generator

The input to rotational generator is the speed of the prime mover (e.g steam turbine) in r.p.m. Assuming the generator is on no load the output may be induced voltage at the output terminals.

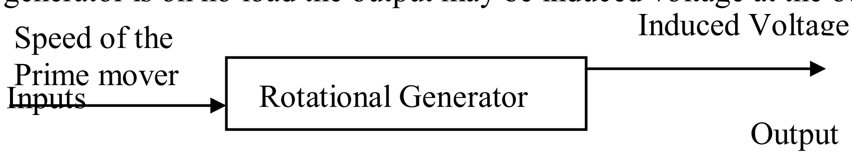


Fig 1-2 Rotational Generator

EXAMPLE – 2 Washing machine

Most (but not all) washing machines are operated in the following manner. After the clothes to be washed have been put into the machine, the soap or detergent, bleach and water are entered in proper amounts as specified by the manufacturer. The washing time is then set on a timer and the washer is energized. When the cycle is completed, the machine shuts itself off. In this example washing time forms input and cleanliness of the clothes is identified as output.

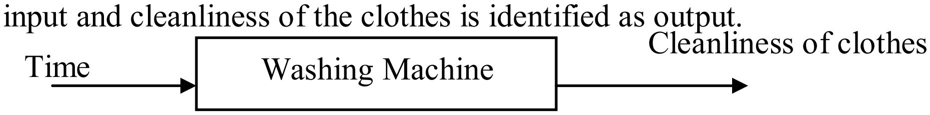


Fig 1-3 Washing Machine

EXAMPLE – 3 WATER TANK LEVEL CONTROL

To understand the concept further it is useful to consider an example let it be desired to maintain the actual water level 'c ' in the tank as close as possible to a desired level ' r '. The desired level will be called the system input, and the actual level the controlled variable or system output. Water flows from the tank via a valve V_o , and enters the tank from a supply via a control valve V_c. The control valve is adjustable manually.

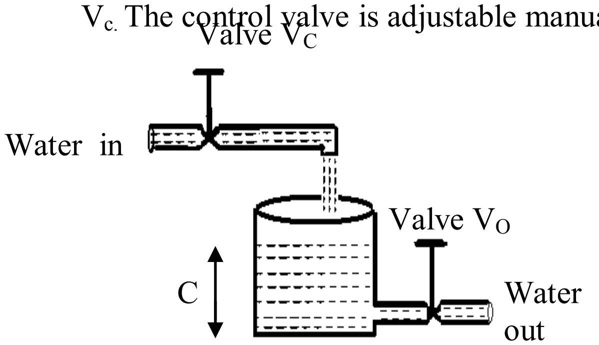


Fig –1.4 a) Water level control

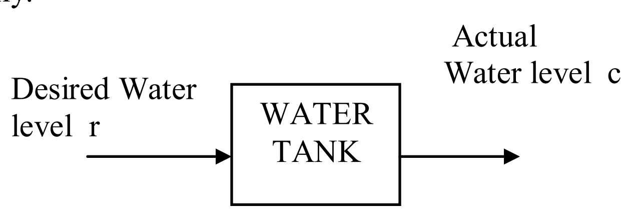


Fig 1-4 b) Open loop control

A closed loop control system is one in which the control action depends on the output. In closed loop control system the actuating error signal, which is the difference between the input signal and the feed back signal (out put signal or its function) is fed to the controller.

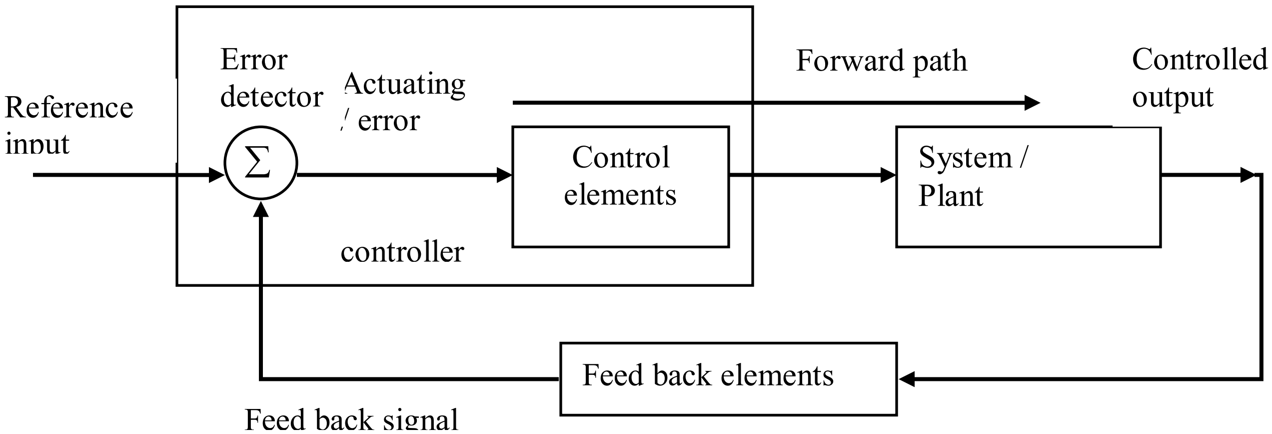


Fig –1.5: Closed loop control system

EXAMPLE – 1 – THERMAL SYSTEM

To illustrate the concept of closed loop control system, consider the thermal system shown in fig-6 Here human being acts as a controller. He wants to maintain the temperature of the hot water at a given value r^o C. the thermometer installed in the hot water outlet measures the actual temperature C^0 C. This temperature is the output of the system. If the operator watches the thermometer and finds that the temperature is higher than the desired value, then he reduce the amount of steam supply in order to lower the temperature. It is quite possible that that if the temperature becomes lower than the desired value it becomes necessary to increase the amount of steam supply. This control action is based on closed loop operation which involves human being, hand muscle, eyes, thermometer such a system may be called manual feed back system.

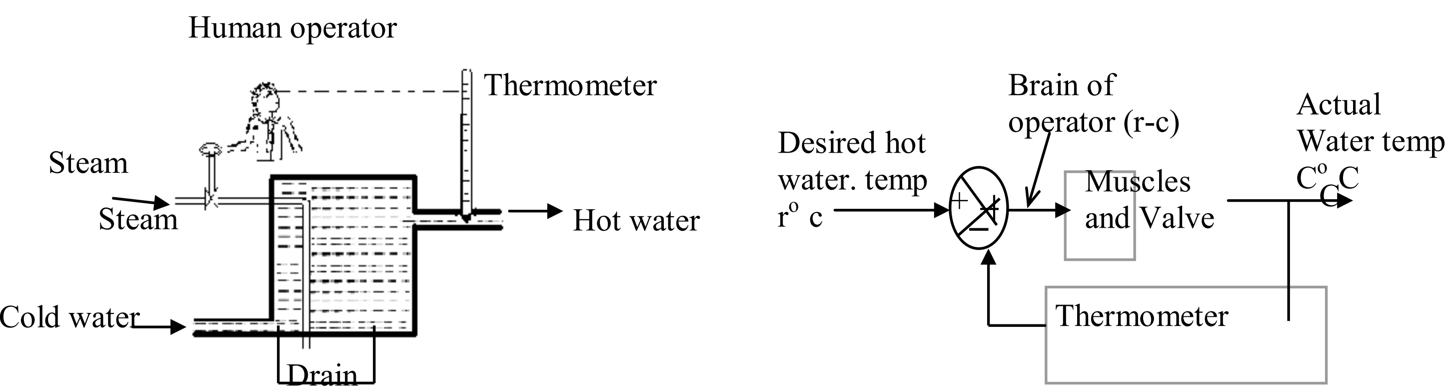


Fig 1-6 a) Manual feedback thermal system b) Block diagram

EXAMPLE –2 HOME HEATING SYSTEM

The thermostatic temperature control in hour homes and public buildings is a familiar example. An electronic thermostat or temperature sensor is placed in a central location usually on inside wall about 5 feet from the floor. A person selects and adjusts the desired room temperature (r) say 25^0 C and adjusts the temperature setting on the thermostat. A bimetallic coil in the thermostat is affected by the actual room temperature (c). If the room temperature is lower than the desired temperature the coil strip alters the shape and causes a mercury switch to operate a relay, which in turn activates the furnace fire when the temperature in the furnace air duct system reaches reference level ' r ' a blower fan is activated by another relay to force the warm air throughout the building. When the room temperature ' C ' reaches the desired temperature ' r ' the shape of the coil strip in the thermostat alters so that Mercury switch opens. This deactivates the relay and in turn turns off furnace fire, which in turn the blower.

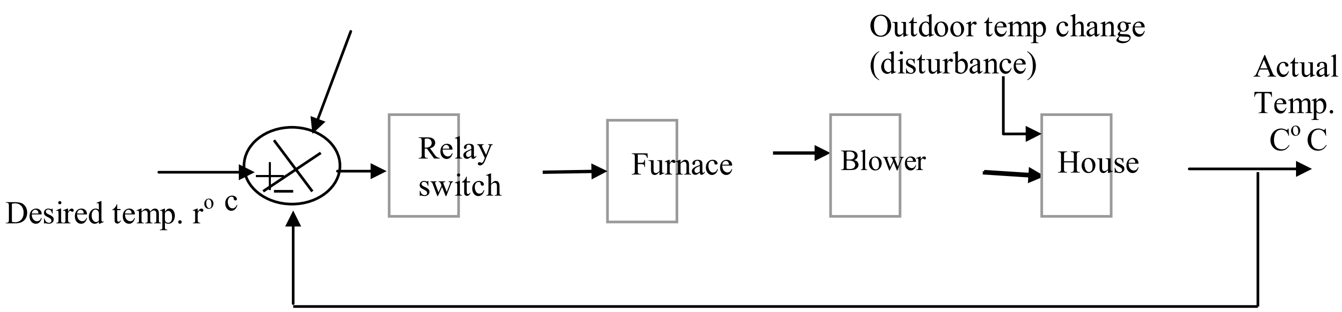


Fig 1-7 Block diagram of Home Heating system.

A change in out door temperature is a disturbance to the home heating system. If the out side temperature falls, the room temperature will likewise tend to decrease.

CLOSED- LOOP VERSUS OPEN LOOP CONTROL SYSTEMS

An advantage of the closed loop control system is the fact that the use of feedback makes the system response relatively insensitive to external disturbances and internal variations in systems parameters. It is thus possible to use relatively inaccurate and inexpensive components to obtain the accurate control of the given plant, whereas doing so is impossible in the open-loop case.

From the point of view of stability, the open loop control system is easier to build because system stability is not a major problem. On the other hand, stability is a major problem in the closed loop control system, which may tend to overcorrect errors that can cause oscillations of constant or changing amplitude.

It should be emphasized that for systems in which the inputs are known ahead of time and in which there are no disturbances it is advisable to use open-loop control. closed loop control systems have advantages only when unpredictable disturbances it is advisable to use open-loop control. Closed loop control systems have advantages only when unpredictable disturbances and / or unpredictable variations in system components used in a closed –loop control system is more than that for a corresponding open – loop control system. Thus the closed loop control system is generally higher in cost.

1.3 Definitions:

Systems: A system is a combination of components that act together and perform a certain objective. The system may be physical, biological, economical, etc.

Control system: It is an arrangement of physical components connected or related in a manner to command, direct or regulate itself or another system.

Open loop: An open loop system control system is one in which the control action is independent of the output.

Closed loop: A closed loop control system is one in which the control action is somehow dependent on the output.

Plants: A plant is equipment the purpose of which is to perform a particular operation. Any physical object to be controlled is called a plant.

Processes: Processes is a natural or artificial or voluntary operation that consists of a series of controlled actions, directed towards a result.

Input: The input is the excitation applied to a control system from an external energy **source.** The inputs are also known as actuating signals.

Output: The output is the response obtained from a control system or known as controlled variable.

Block diagram: A block diagram is a short hand, pictorial representation of cause and effect relationship between the input and the output of a physical system. It characterizes the functional relationship amongst the components of a control system.

Control elements: These are also called controller which are the components required to generate the appropriate control signal applied to the plant.

Plant: Plant is the control system body process or machine of which a particular quantity or condition is to be controlled.

Feedback control: feedback control is an operation in which the difference between the output of the system and the reference input by comparing these using the difference as a means of control.

Feedback elements: These are the components required to establish the functional relationship between primary feedback signal and the controlled output.

Actuating signal: also called the error or control action. It is the algebraic sum consisting of reference input and primary feedback.

Manipulated variable: it that quantity or condition which the control elements apply to the controlled system.

Feedback signal: it is a signal which is function of controlled output

Disturbance: It is an undesired input signal which affects the output.

Forward path: It is a transmission path from the actuating signal to controlled output

Feedback path: The feed back path is the transmission path from the controlled output to the primary feedback signal.

Servomechanism: Servomechanism is a feedback control system in which output is some mechanical position, velocity or acceleration.

Regulator: Regulator is a feedback system in which the input is constant for long time.

Transducer: Transducer is a device which converts one energy form into other

Tachometer: Tachometer is a device whose output is directly proportional to time rate of change of input.

Synchros: Synchros is an AC machine used for transmission of angular position synchro motor-receiver, synchro generator- transmitter.

Block diagram: A block diagram is a short hand, pictorial representation of cause and effect relationship between the input and the output of a physical system. It characterizes the functional relationship amongst the components of a control system.
Summing point: It represents an operation of addition and / or subtraction.
Negative feedback: Summing point is a subtractor.
Positive feedback: Summing point is an adder.
Stimulus: It is an externally introduced input signal affecting the controlled output.
Take off point: In order to employ the same signal or variable as an input to more than block or summing point, take off point is used. This permits the signal to proceed unaltered along several different paths to several destinations.
Time response: It is the output of a system as a function of time following the application of a prescribed input under specified operating conditions.

1.4 DIFFERENTIAL EQUATIONS OF PHYSICAL SYSTEMS

The term mechanical translation is used to describe motion with a single degree of freedom or motion in a straight line. The basis for all translational motion analysis is Newton‘s second law of motion which states that the Net force F acting on a body is related to its mass M and acceleration ‗a‘ by the equation $\Sigma F = Ma$

‗Ma‘ is called reactive force and it acts in a direction opposite to that of acceleration. The summation of the forces must of course be algebraic and thus considerable care must be taken in writing the equation so that proper signs prefix the forces.

The three basic elements used in linear mechanical translational systems are (i) Masses (ii) springs iii) dashpot or viscous friction units. The graphical and symbolic notations for all three are shown in fig 1-8

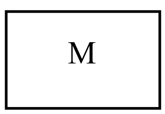


Fig 1-8 a) Mass

Fig 1-8 b) Spring

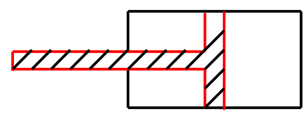
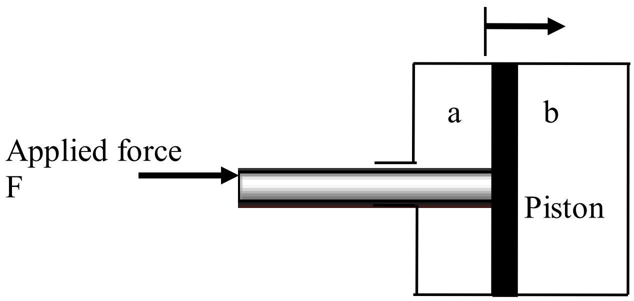


Fig 1-8 c) Dashpot

The spring provides a restoring a force when a force F is applied to deform a coiled spring a reaction force is produced, which to bring it back to its freelength. As long as deformation is small, the spring behaves as a linear element. The reaction force is equal to the product of the stiffness k and the amount of deformation.

Whenever there is motion or tendency of motion between two elements, frictional forces exist. The frictional forces encountered in physical systems are usually of nonlinear nature. The characteristics of the frictional forces between two contacting surfaces often depend on the composition of the surfaces. The pressure between surfaces, their relative velocity and others. The friction encountered in physical systems may be of many types

(coulomb friction, static friction, viscous friction) but in control problems viscous friction, predominates. Viscous friction represents a retarding force i.e. it acts in a direction opposite to the velocity and it is linear relationship between applied force and velocity. The mathematical expression of viscous friction F=BV where B is viscous frictional co-efficient. It should be realized that friction is not always undesirable in physical systems. Sometimes it may be necessary to introduce friction intentionally to improve dynamic response of the system. Friction may be introduced intentionally in a system by use of dashpot as shown in fig 1-9. In automobiles shock absorber is nothing but dashpot.



The basic operation of a dashpot, in which the housing is filled with oil. If a force f is applied to the shaft, the piston presses against oil increasing the pressure on side ‗b‘ and decreasing pressure side ‗a‘ As a result the oil flows from side ‗b‘ to side ‗a‘ through the wall clearance. The friction coefficient B depends on the dimensions and the type of oil used.

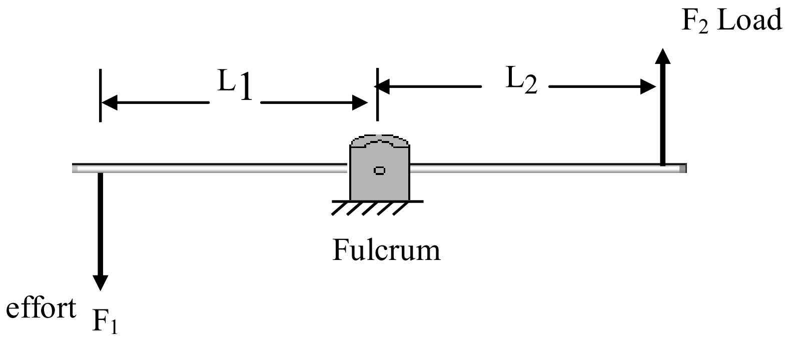
Outline of the procedure

For writing differential equations

1. Assume that the system originally is in equilibrium in this way the often-troublesome effect of gravity is eliminated.
2. Assume then that the system is given some arbitrary displacement if no distributing force is present.
3. Draw a freebody diagram of the forces exerted on each mass in the system. There should be a separate diagram for each mass.
4. Apply Newton‘s law of motion to each diagram using the convention that any force acting in the direction of the assumed displacement is positive is positive.
5. Rearrange the equation in suitable form to solve by any convenient mathematical means.

Lever

Lever is a device which consists of rigid bar which tends to rotate about a fixed point called ‗fulcrum‘ the two arms are called ―effort arm" and ―Load arm" respectively. The lever bears analogy with transformer



It is also called ‗mechanical transformer'

Equating the moments of the force

$F_1 L_1 = F_2 L_2$

$$F_2 = \frac{F_1 L_1}{L_2}$$

1.5 Rotational mechanical system

The rotational motion of a body may be defined as motion about a fixed axis. The variables generally used to describe the motion of rotation are torque, angular displacement θ, angular velocity (ω) and angular acceleration(α)

The three basic rotational mechanical components are 1) Moment of inertia J

2) Torsional spring 3) Viscous friction.

Moment of inertia J is considered as an indication of the property of an element, which stores the kinetic energy of rotational motion. The moment of inertia of a given element depends on geometric composition about the axis of rotation and its density. When a body is rotating a reactive torque is produced which is equal to the product of its moment of inertia (J) and angular acceleration and is given by $T = J\alpha = J \frac{d^2\theta}{dt^2}$

A well known example of a torsional spring is a shaft which gets twisted when a torque is applied to it. $T_s = K\theta$, θ is angle of twist and K is torsional stiffness.

There is viscous friction whenever a body rotates in viscous contact with another body. This torque acts in opposite direction so that angular velocity is ω given by

$T = f\omega = f \frac{d^2\theta}{dt^2}$ Where ω = relative angular velocity between two bodies.

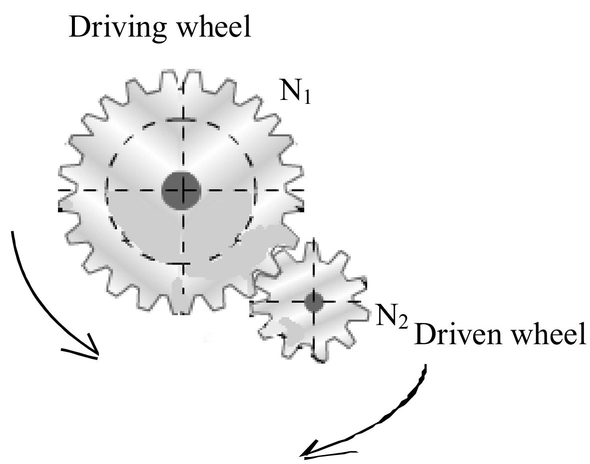
f = co efficient of viscous friction.

Newton's II law of motion states

$$\Sigma T = J \frac{d2\theta}{dt^2}.$$

Gear wheel

In almost every control system which involves rotational motion gears are necessary. It is often necessary to match the motor to the load it is driving. A motor which usually runs at high speed and low torque output may be required to drive a load at low speed and high torque.



1.6 Analogous Systems
Consider the mechanical system shown in fig A and the electrical system shown in fig B

The differential equation for mechanical system is

$$M + \frac{d^2x}{dt^2} + B\frac{dx}{dt} + KX = f(t) \quad \text{----------} \; 1$$

The differential equation for electrical system is

$$L + \frac{d^2q}{dt^2} \quad R \quad \frac{d^2q}{dt^2} \quad \frac{q}{c} \quad \text{----------} \; 2$$

Comparing equations (1) and (2) we see that for the two systems the differential equations are of identical form such systems are called ―analogous systems and the terms which occupy the corresponding positions in differential equations are analogous quantities"

The analogy is here is called force voltage analogy
Table for conversion for force voltage analogy

Mechanical System		**Electrical System**
Force (torque)	→	Voltage
Mass (Moment of inertia)	→	Inductance

Viscous friction coefficient → Resistance

Spring constant → Capacitance

Displacement → Charge

Velocity → Current.

Force – Current Analogy

Another useful analogy between electrical systems and mechanical systems is based on force – current analogy. Consider electrical and mechanical systems shown in fig.

For mechanical system the differential equation is given by

$$M + \frac{d^2x}{dt^2} \quad B \quad \frac{dx}{dt} \quad .X = f(t) \quad \text{----------} \ 1$$

For electrical system

$$C \frac{d^2x}{dt^2} + \frac{1}{R} + \frac{d\Phi}{dt^2} + \frac{\Phi}{L} = I(t)$$

Comparing equations (1) and (2) we find that the two systems are analogous systems. The analogy here is called force – current analogy. The analogous quantities are listed.

Table of conversion for force – current analogy

Mechanical System → Electrical System

Force(torque) → Current

Mass(Moment of inertia) → Capacitance

Viscous friction coefficient → Conductance

Spring constant → Inductance

Displacement (angular) → Flux

Velocity (angular) → Voltage

Illustration 1: For a two DOF spring mass damper system obtain the mathematical model where F is the input x_1 and x_2 are responses.

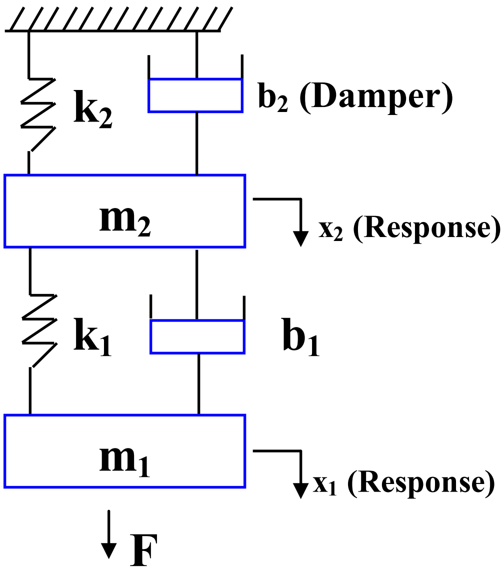


Figure 1.10 (a)

Draw the free body diagram for mass m_1 and m_2 separately as shown in figure 1.10 (b)

Apply NSL for both the masses separately and get equations as given in (a) and (b)

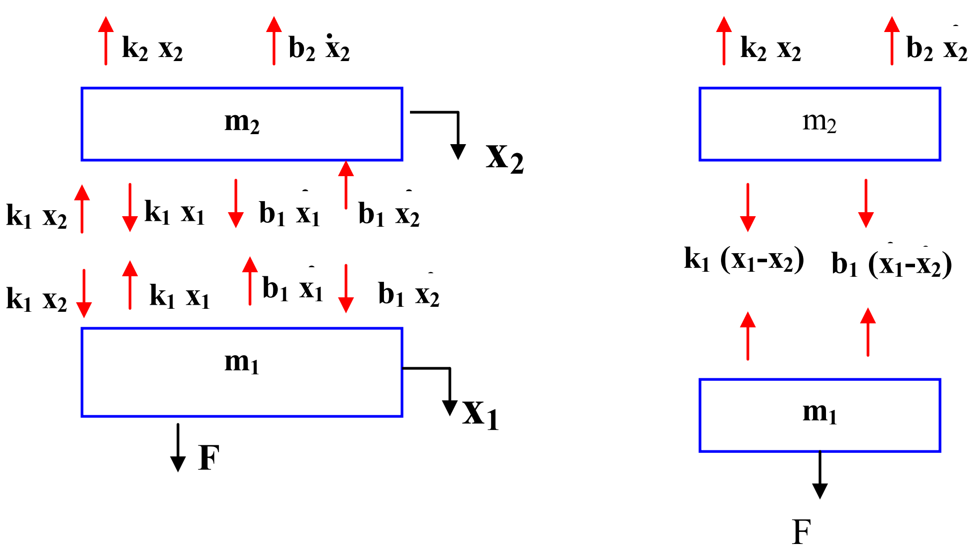


Figure 1.10 (b)

From NSL $\quad \sum F = ma$

For mass m_1

$$m_1 x_1 = F - b_1 (x_1 - x_2) - k_1 (x_1 - x_2) \qquad \text{--- (a)}$$

For mass m_2

$$m_2 \ddot{x}_2 = b_1 (\dot{x}_2 - \dot{x}_1) + k_1 (x_2 - x_1) - b_2 \dot{x}_2 - k_2 x_2 \qquad \text{--- (b)}$$

Illustration 2: For the system shown in figure 2.16 (a) obtain the mathematical model if x_1 and x_2 are initial displacements.

Let an initial displacement x_1 be given to mass m_1 and x_2 to mass m_2.

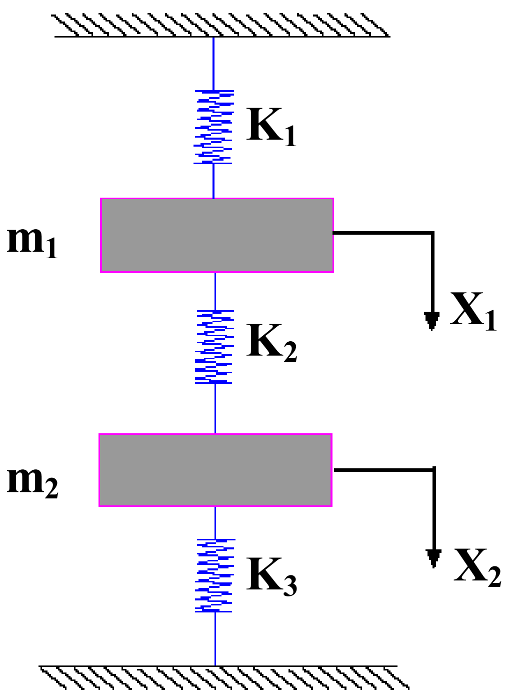


Figure 1.11 (a)

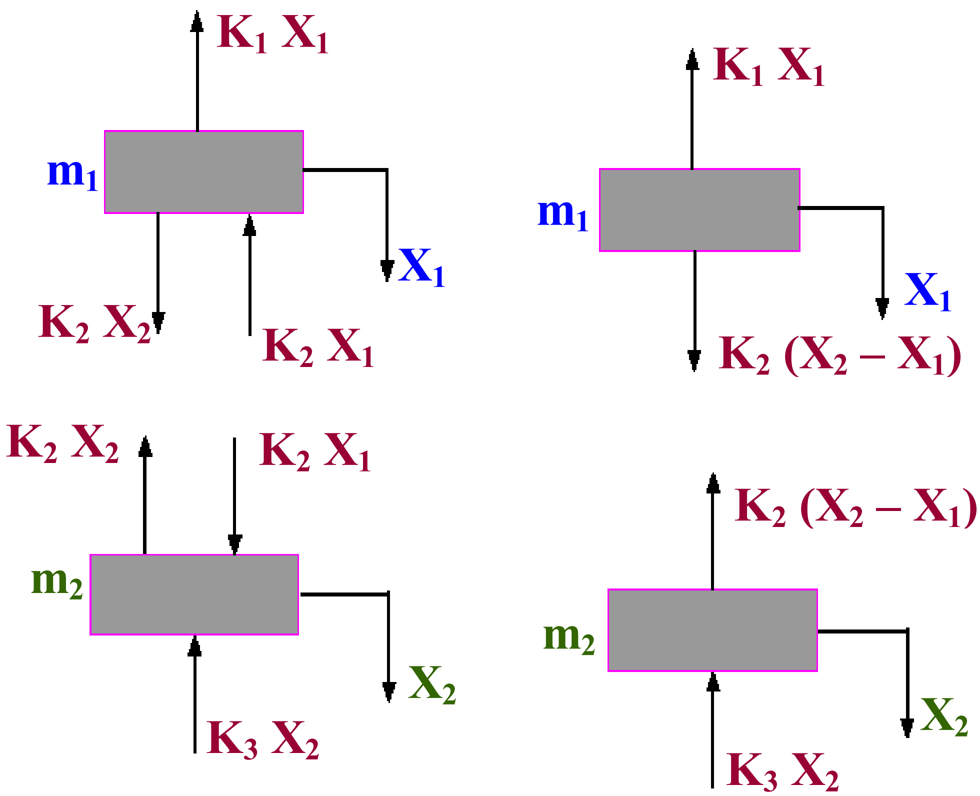


Figure 2.16 (b)

Based on Newton‘s second law of motion: $\sum F = ma$

For mass m_1

$m_1\ddot{x}_1 = - K_1x_1 + K_2\,(x_2-x_1)$

$m_1\ddot{x}_1 + K_1x_1 - K_2\,x_2 + K_2x_1 = 0$

$m_1\ddot{x}_1 + x_1\,(K_1 + K_2) = K_2x_2$ ----- (1)

For mass m_2

$m_2\ddot{x}_2 = - K_3x_2 - K_2\,(x_2 - x_1)$

$m_2\ddot{x}_2 + K_3\,x_2 + K_2\,x_2 - K_2\,x_1$

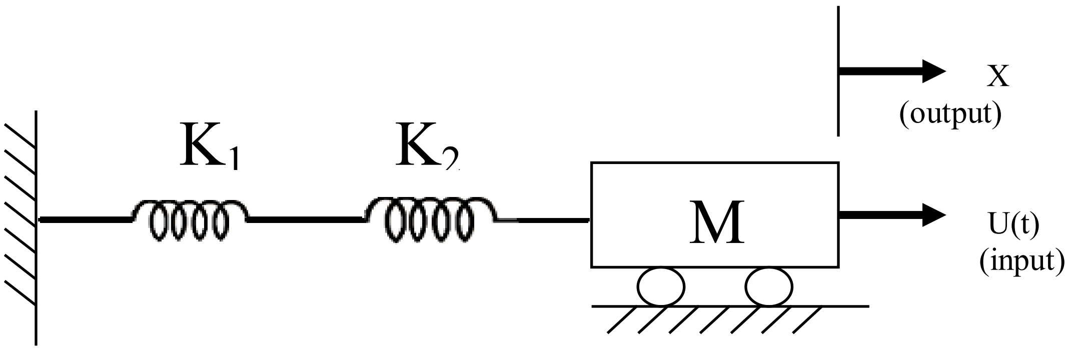
$m_2\,\ddot{x}_2 + x_2\,(K_2 + K_3) = K_2x_1$ ----- (2)

Mathematical models are:

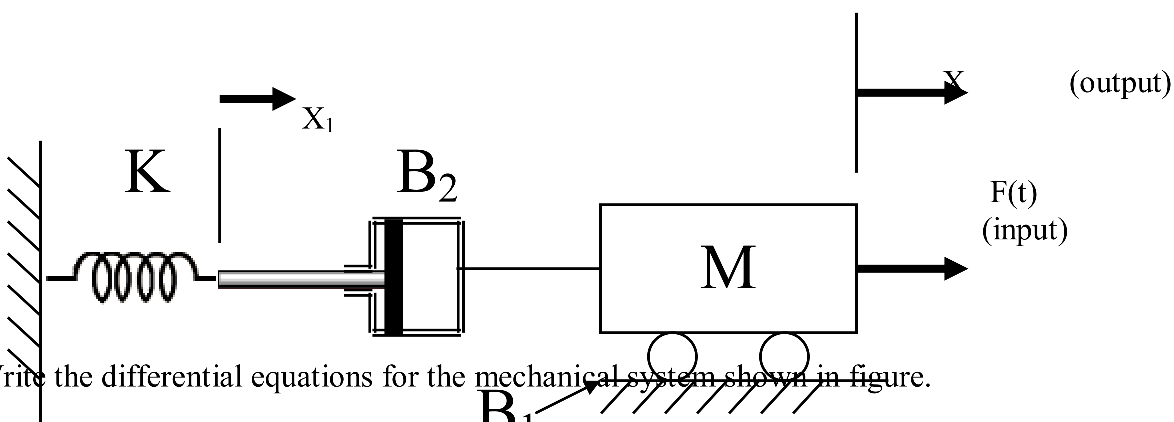
$m_1\ddot{x}_1 + x_1 (K_1 + K_2) = K_2x_2$ ----- (1)

$m_2\ddot{x}_2 + x_2 (K_2 + K_3) = K_2x_1$ ----- (2)

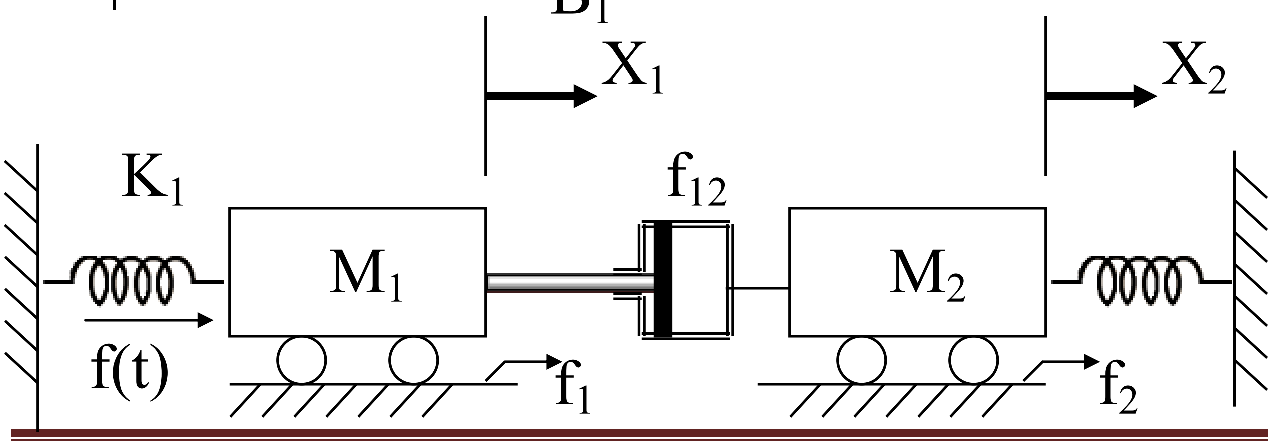
1.Write the differential equation relating to motion X of the mass M to the force input u(t)



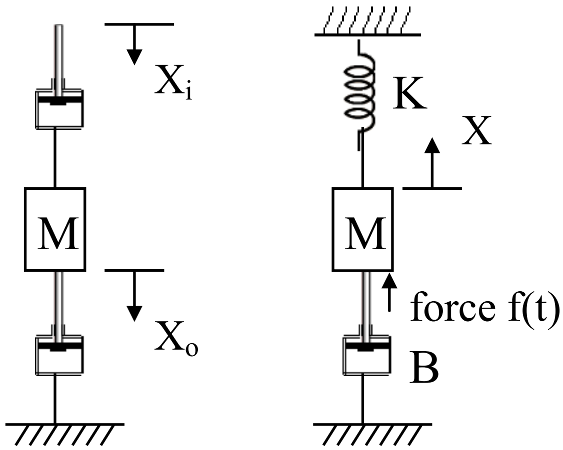
2. Write the force equation for the mechanical system shown in figure



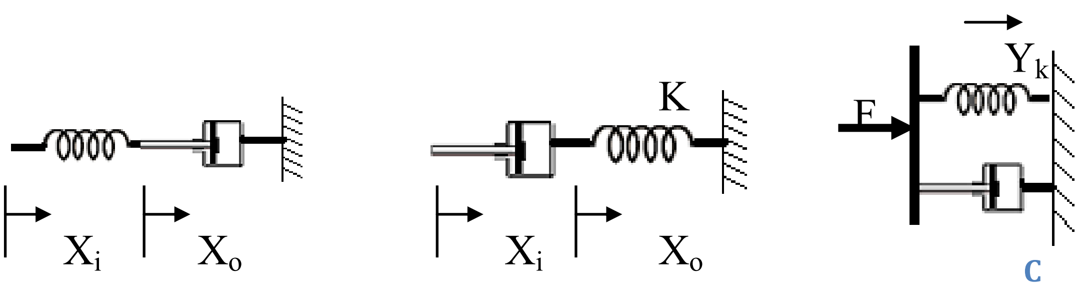
3. Write the differential equations for the mechanical system shown in figure.



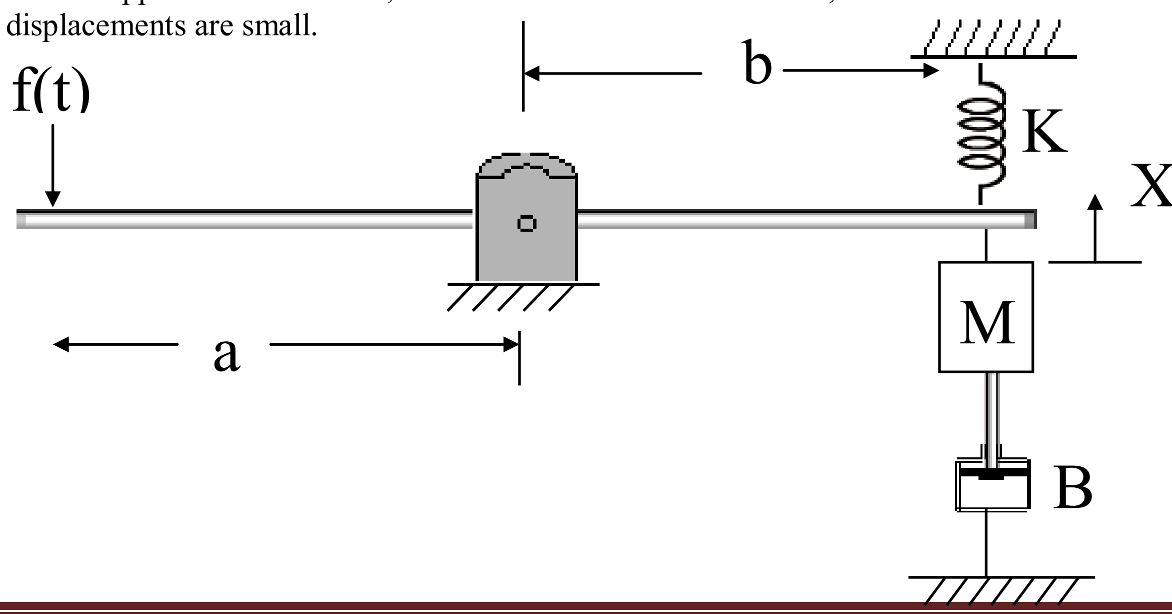
4. Write the modeling equations for the mechanical systems shown in figure.



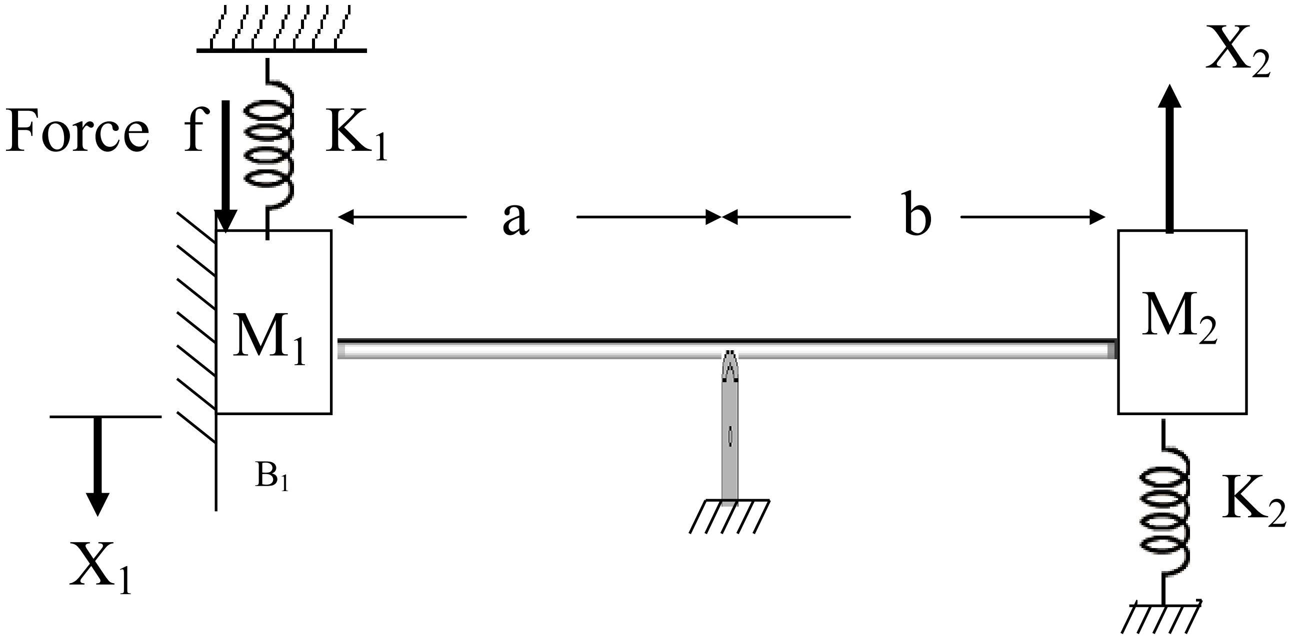
5. For the systems shown in figure write the differential equations and obtain the transfer functions indicated.



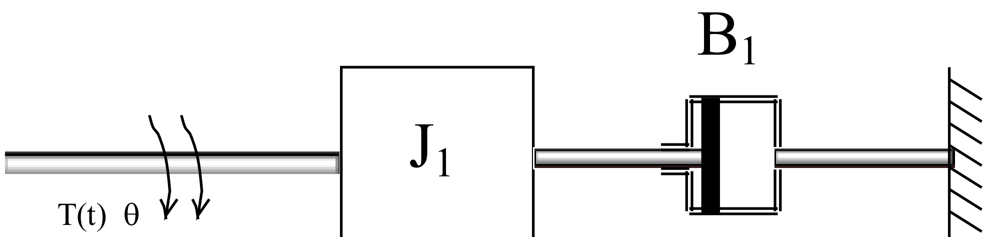
6. Write the differential equation describing the system. Assume the bar through which force is applied is not flexible, has no mass or moment of inertia, and all displacements are small.



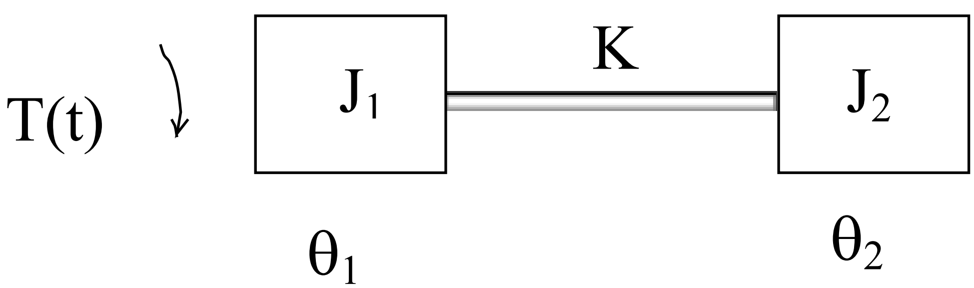
7. Write the equations of motion in terms of given mechanical quantities.



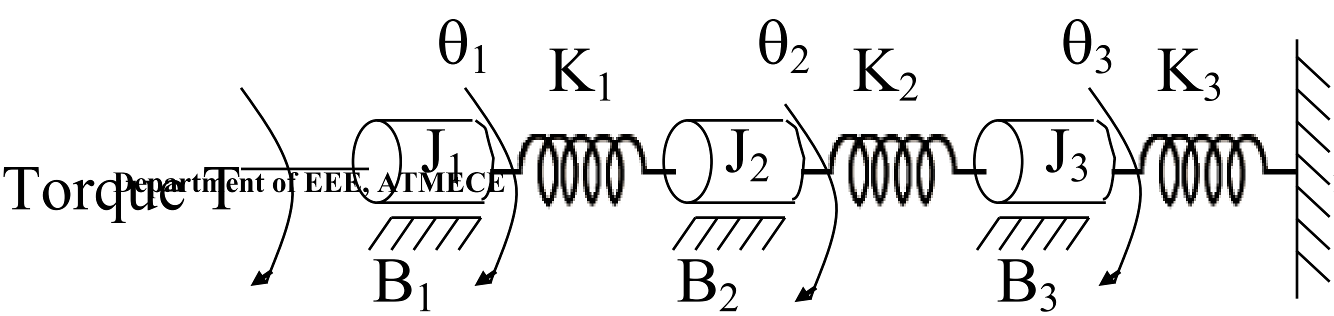
8. Write the force equations for the mechanical systems shown in figure.



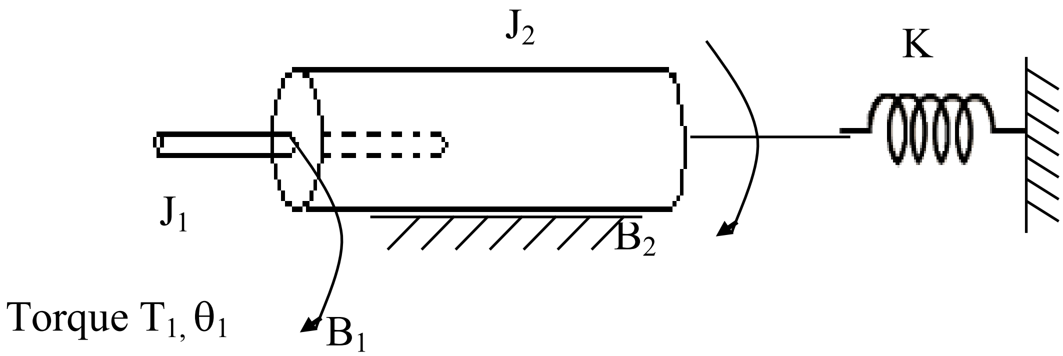
9. Write the force equation for the mechanical system shown in figure.



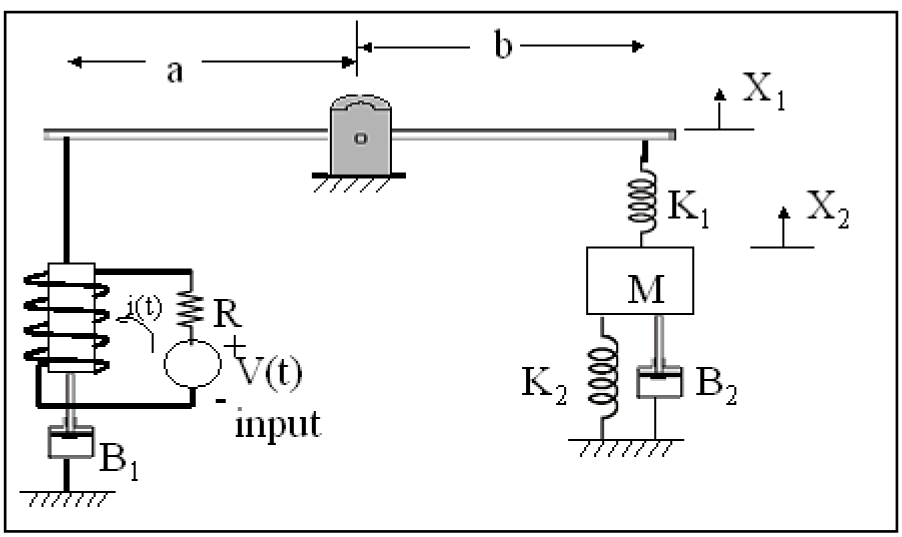
10. Write the force equation for the mechanical system shown in figure.



11. Torque T(t) is applied to a small cylinder with moment of inertia J_1 which rotates with in a larger cylinder with moment of inertia J_2. The two cylinders are coupled by viscous friction B1. The outer cylinder has viscous friction B_2 between it and the reference frame and is restrained by a torsion spring k. write the describing differential equations.



12. The polarized relay shown exerts a force $f(t) = K_{i.}\ i(t)$ upon the pivoted bar. Assume the relay coil has constant inductance L. The left end of the pivot bar is connected to the reference frame through a viscous damper B_1 to retard rapid motion of the bar. Assume the bar has negligible mass and moment of inertia and also that all displacements are small. Write the describing differential equations. Note that the relay coil is not free to move.



13. Figure shows a control scheme for controlling the azimuth angle of an armature controlled dc. Motion with dc generator used as an amplifier. Determine transfer function

$\frac{\theta_L(s)}{u(s)}$. The parameters of the plant are given below.

Motor torque constant = KT in N.M /amp
Motor back emf constant = K_B in V/ rad / Sec
Generator gain constant = K_G in v/ amp
Motor to load gear ratio = $\frac{N_2}{N_1}$

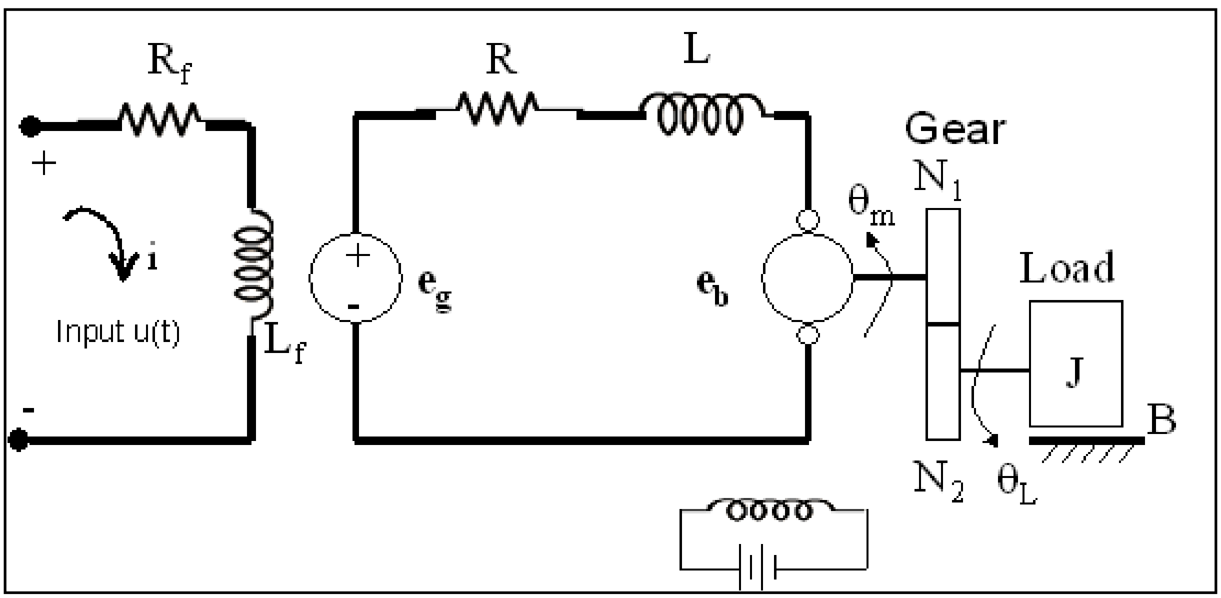
Resistance of the circuit = R in ohms.

Inductance of the circuit = L in Henry

Moment of inertia of motor = J

Viscous friction coefficient = B

Field resistance = R_f

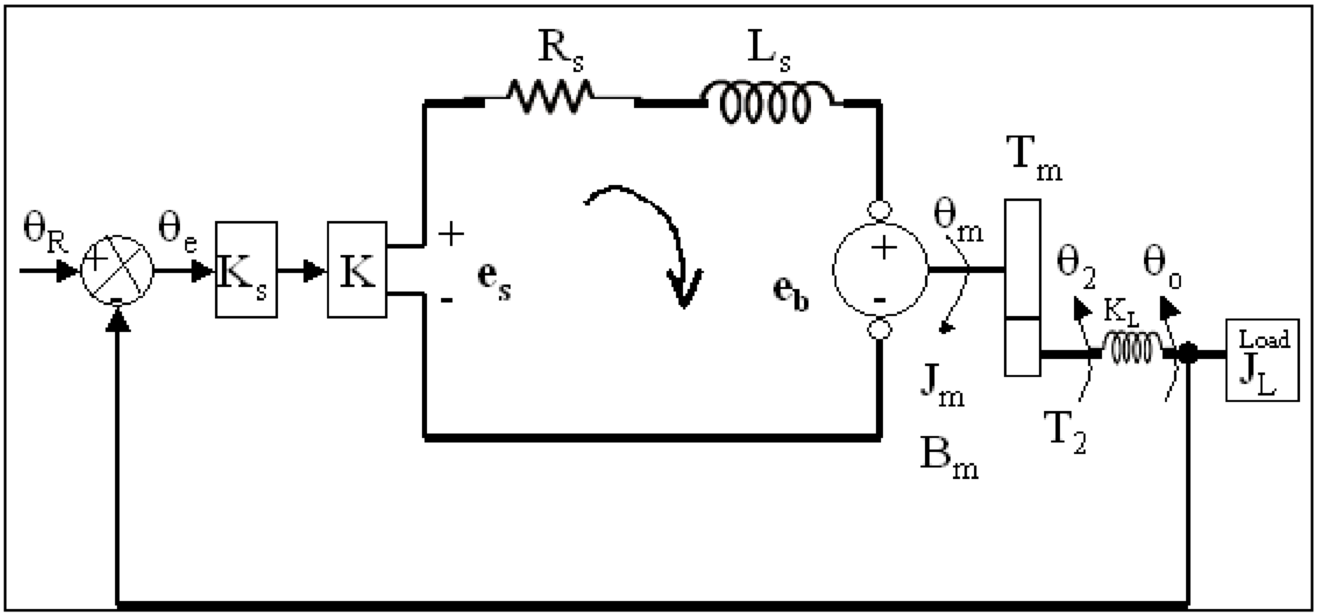


Field inductance = L_f

14. The schematic diagram of a dc motor control system is shown in figure where K_s is error detector gain in volt/rad, k is the amplifier gain, K_b back emf constant, K_t is torque

constant, n is the gear train ratio = $\frac{\theta_2}{\theta_1} = \frac{T_m}{T_2}$ B_m = motion friction constant

J_m = motor inertia, K_L = Torsional spring constant J_L = load inertia.



15. Obtain a transfer function C(s) /R(s) for the positional servomechanism shown in figure. Assume that the input to the system is the reference shaft position (R) and the system output is the output shaft position (C). Assume the following constants.

Gain of the potentiometer (error detector) K_1 in V/rad

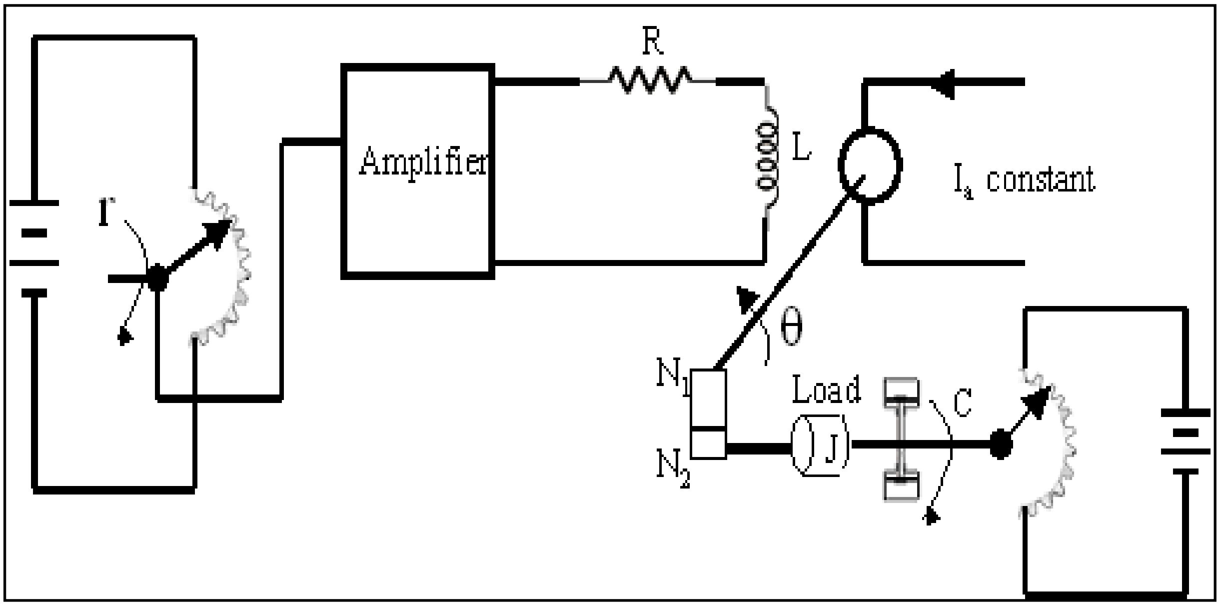
Amplifier gain ‗K_p‘ in V / V

Motor torque constant ‗K_T‘ in V/ rad

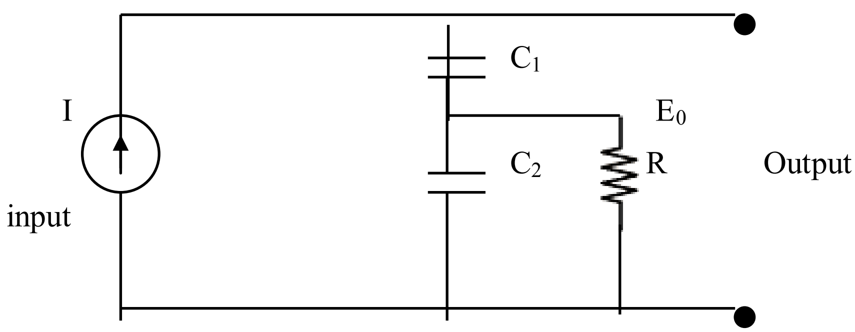
Gear ratio N_1 / N_2

Moment of inertia of load ‗J‘

Viscous friction coefficient ‗f‛



16. Find the transfer function $E_0(s) / I(s)$



Recommended Questions :

1. Name three applications of control systems.
2. Name three reasons for using feedback control systems and at least one reason for not using them.
3. Give three examples of open- loop systems.
4. Functionally, how do closed – loop systems differ from open loop systems.
5. State one condition under which the error signal of a feedback control system would not be the difference between the input and output.
6. Name two advantages of having a computer in the loop.
7. Name the three major design criteria for control systems.
8. Name the two parts of a system‘s response.
9. Physically, what happens to a system that is unstable?
10. Instability is attributable to what part of the total response.
11. What mathematical model permits easy interconnection of physical systems?
12. To what classification of systems can the transfer function be best applied?
13. What transformation turns the solution of differential equations into algebraic manipulations ?
14. Define the transfer function.
15. What assumption is made concerning initial conditions when dealing with transfer functions?
16. What do we call the mechanical equations written in order to evaluate the transfer function ?
17. Why do transfer functions for mechanical networks look identical to transfer functions for electrical networks?
18. What function do gears and levers perform.
19. What are the component parts of the mechanical constants of a motor‘s transfer function?