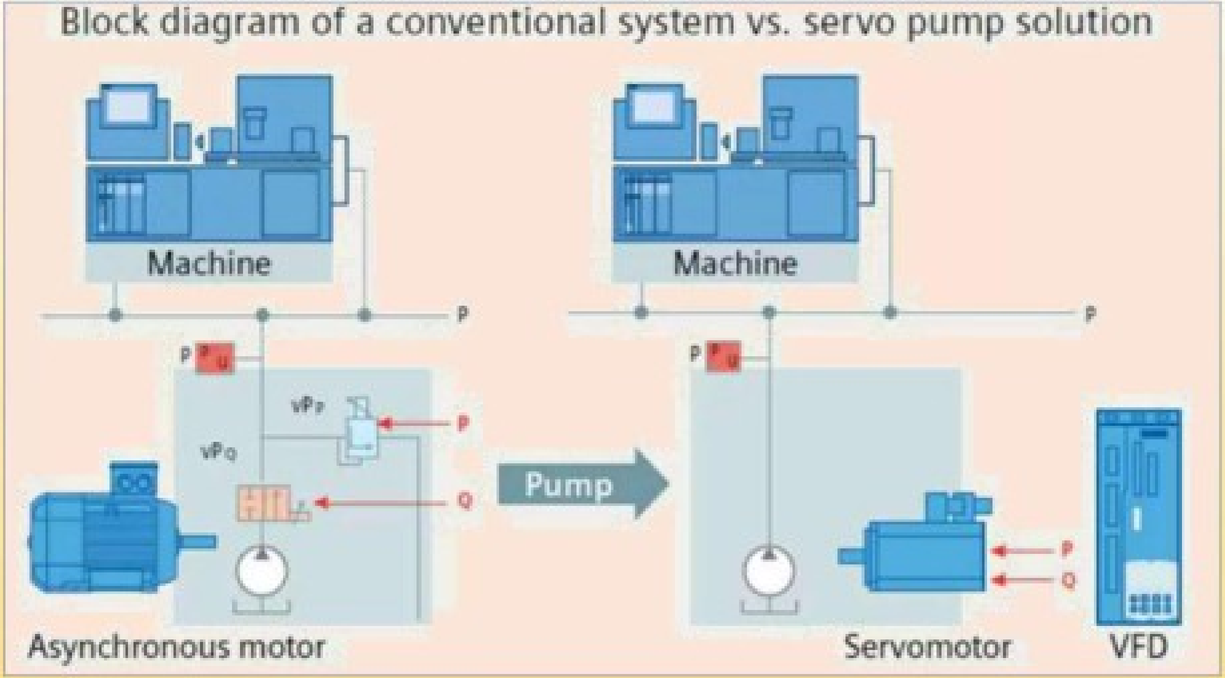
HYDRAULIC SERVO SYSTEMS

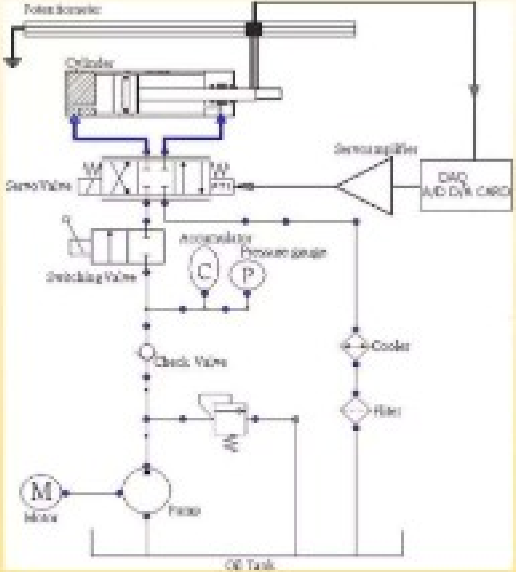


- Owing to increased computer power and ongoing developments, hydraulic servo systems have increased.
- Understanding the internal construction and the operational principle of servo hydraulic valves.
- Understanding the mathematical model of a simple hydraulic system uses a hydraulic servo valve.
- Controlling a hydraulic flow and pressure using a hydraulic servo valve.

- Servo hydraulics may be expressed as 'closed loop electro- hydraulic control".
- Operating in closed loop control means that operation is constantly monitored by means of measurement and deviations from required operation are automatically corrected.
- Servo valves were originally designed to be used in the aviation industry (or precise control of a variety of aircraft by means of small electrical input signals.
- Electrical or electronic control was changed to electro-hydraulic open loop and closed loop control due to high flight speeds and hence high applications.

Basic structure of hydraulic servo-system

- Control elements (valves, sensors, etc.),
- Actuating elements (cylinder and/or motors),
- Other elements (pipelines, measuring devices, etc.).



The basic concept of hydraulic system

- The pump converts the available (mechanical) power from the prime mover (electrical or diesel motor) to hydraulic power at the actuator.

- Valves are used to control the direction of pump flow, the level of power produced, and the amount of fluid and pressure to the actuator.

- The medium, which is a liquid, provides direct power transmission, a lubrication of the hydraulic system components, a valves sealing, and a hydraulic system cooling.

- Connectors, which link the various system components, direct the power of the fluid under pressure, and return fluid-flow to tank (reservoir).

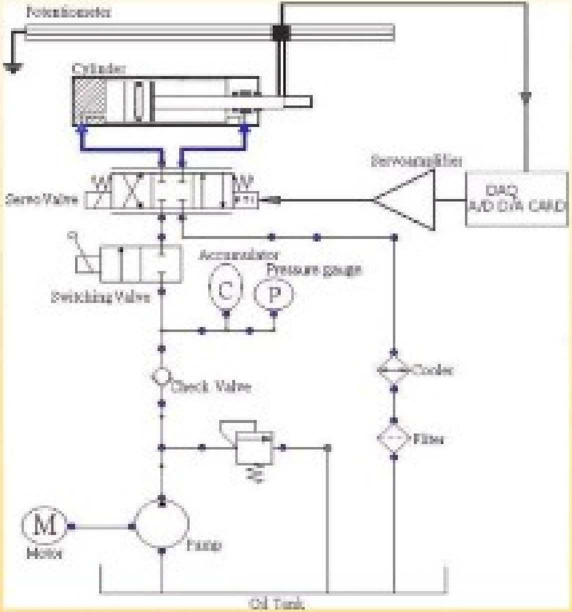
The basic concept of hydraulic system

The reasons for choosing a servo valves are their ability to control a mechanical parameters such as:

- Displacement or angle of rotation
- velocity or rotary speed
- force or torque

hydraulic parameters

- flow
- Pressure.



Components of closed loop electro-hydraulic control

- Closed loop control
- Electronics
- Hydraulics and
- Measurement technology. [1]

Characteristics and operations of Servo Valves

Servo valves can be broadly classified either as single-stage, two-stage or three-stage.
Single-stage servo valves consist of a torque motor or a linear force motor directly attached for positioning of the spool. Because torque or force motors have limited power capability, this in turn limits the hydraulic power capacity of single-stage servo valves.

In some applications the single-stage concept may also lead to stability problems.

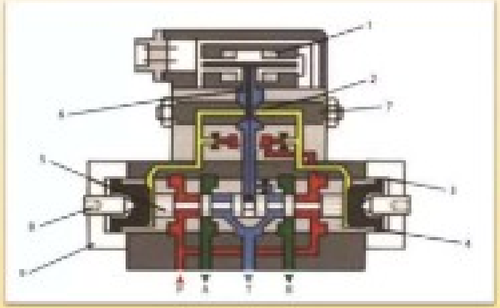
This is the case if the flow forces acting on the spool are close to the force produced by the electro-magnetic motor. Flow forces are proportional to the flow and the square root of the valve pressure drop, which gives a limitation in hydraulic power

The valve illustrated in the figure is a valve, which employs just one linear force motor (Proportional magnet) to move the spool either side of the central position. The electrical signal from a position transducer is then used for closed loop control of the spool position

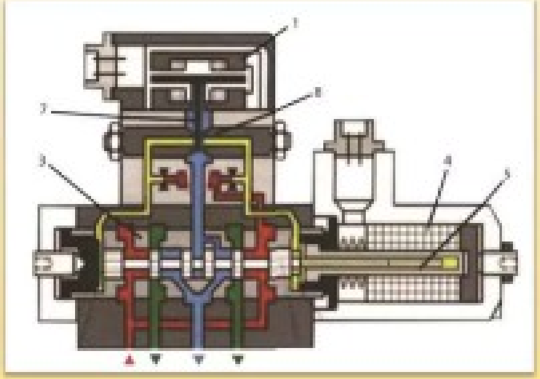
One of the most common types of servo valve is the two stages one. Either a flapper nozzle pilot stage or a jet pipe stage can be used in conjunction with an electric torque motor to control the main spool in the valve as illustrated in Figure.

2 stage directional servo valve as shown in Figure 2.17 basically consist of:

- the 1st stage
- mechanical feedback (3) as a link between 1st and 2nd stages, and
- The 2nd stage with interchangeable control sleeve (4) and control spool (5) which is coupled to mechanical feedback (3).



Control spool (5) is linked almost backlash-free to the torque motor (1) of the 1st stage by the mechanical feedback (3).The type of feedback used in this case depends on the torque balance at the torque motor (1) and feedback spring (3).This means, when a change in electrical input signal creates unequal torques, flapper plate (6) is first moved from the mid position between the control orifices. As a result, a pressure difference is produced which acts on both ends of the control spool Due to the pressure difference, the position of the control spool (5) changes As a result of this change, the feedback spring (3) bends until the flapper plate is pulled back to the center position to such an extent that the main spool stops moving and the torques are the same again. The spool stroke and hence flow, which are proportional to the input signal have therefore been reestablished. The two socket screws (8) (located left and right in the valve covers (9) may be used to move the position of the control sleeve (4) control land with respect to the control spool (5), in order to adjust the hydraulic null point. [1]



These 2-stage directional servo valves basically consist of:

- The 1st stage
- the 2nd stage with interchangeable control sleeve (3) and
- An inductive positional transducer (4) with its core (5) secured to the control spool (6).

The control spool (6) is coupled to the inductive positional transducer (4) by means of suitable electronics. A change in the position of the main spool (6). As well as a change in the command signal produce a differential voltage at the output when the core (5) is displaced within the coil of the positional transducer. The difference between command and feedback signals is measured by suitable electronic components and fed as a closed loop error to the first stage of the valve. This signal moves the flapper plate (7) from the mid-position between the two control orifices (8). As a result, a pressure difference is produced between the two control chambers (9) and (10). The control spool (6) with the attached core (5) of the inductive positional transducer (4) is shifted until the command signal is the same as the actual signal. When this is the case, the flapper plate returns to the center position. In closed loop control, control chambers (9) and (10) are pressure-balanced and the control spool is held in this controlled position. Due to the position of the control spool (6) with respect to the control sleeve (3) a control opening is produced to control flow; this is proportional to the command signal, in the same way that the spool stroke and flow are proportional to this signal. The valve frequency response is optimized by means of the electrical gain in the electronic control [1]

the 3-stage directional servo valves basically consist of the 1st stage control and the 2nd stage in the form of a flow amplifier stage in the 3rd stage for open loop flow control of the main oil flow and an inductive positional transducer whose core is secured to the control spool of the 3rd stage as illustrated in Figure

Electro-Hydraulic Servo System Construction

In this chapter the mathematical model of the project is discussed, where the position tracking performance of an electro-hydraulic servo (EHS) system using proportional-integral-derivative (PID), description of flow control valve, and how the valves responding to change in electrical input, and the effects of coils in torque motor, and represent servo valve spool dynamics through wider frequency range. The relationship between valve control flow and actuator champers pressure, also describe the piston motion and the total frictional force depend on piston velocity.

Comparison between proportional valve and servo valve

The basic decision is whether to use servo valves or proportional valves. The main difference between them is how the spool is shifted. Proportional valves use an electric coil and magnet, like the voice coil of typical audio speaker, to directly move the spool. Servo valves use small torque motor to control hydraulic pressure, which in turn moves the spool (pilot-actuated).

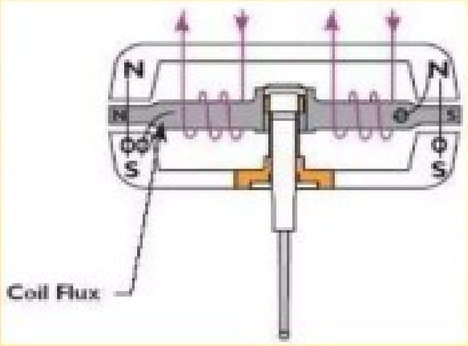
The response of these two valve types differs because of the force available to shift the spool. Servo valves generally respond faster than proportional valves

Modeling the EHS System

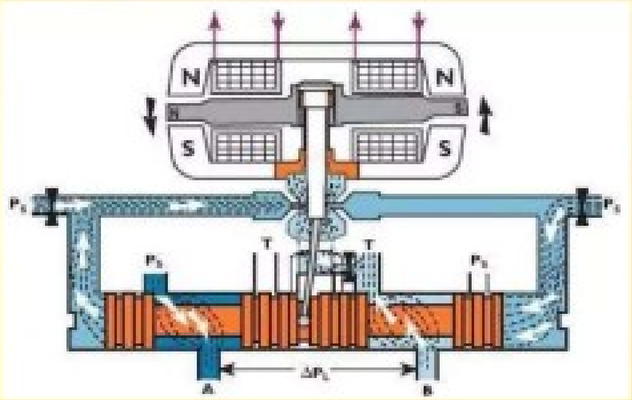
Dynamics equation of EHS system consists of servo valve and hydraulic actuator as illustrated in Figure (3.5).The hydraulic actuator motion is controlled by modulating the hydraulic oil flow from the cylinder chambers using a servo valve. The mass is attached with a spring and a damper that generates the counter force against the actuator.

Flow Control Servo Valve

The two stages nozzle-flapper servo-valve consists of three main parts, an electrical torque motor, a hydraulic amplifier and valve spool assembly.



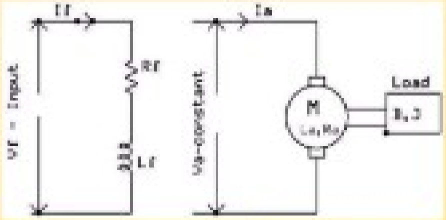
The motor consists of an armature mounted on a thin-walled sleeve pivot and suspended in the air gap of a magnetic field produced by a pair of permanent magnets. When current is made to flow in the two armature coils, the armature ends become polarized and are attracted to one magnet pole piece and repelled by the other. This sets up a torque on the flapper assembly, which rotates about the fixture sleeve and changes the flow balance through a pair of opposing nozzles, shown in Figure (3.2). The resulting change in throttle flow alters the differential pressure between the two ends of the spool, which begins to move inside the valve sleeve.



Lateral movement of the spool forces the ball end of a feedback spring to one side and sets up a restoring torque on the armature/flapper assembly. When the feedback torque on the flapper spring becomes equal to the magnetic forces on the armature the system reaches an equilibrium state, with the armature and flapper centered and the spool stationary but deflected to one side. The offset position of the spool opens flow paths between the pressure and tank ports (and T), and the two control ports (A and B) in the figure (3.2), allowing oil to flow to and from the actuator

Torque Motor

In the electronic design, the electrical characteristics of the servo-valve torque motor may be modeled as a series L-R circuit. The transfer function of a series L-R circuit is:

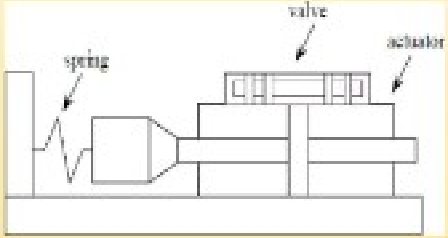


$$\frac{I(S)}{V(S)} = \frac{1}{SL_f + R_f}$$

Values of inductance and resistance for series and parallel winding configurations of the motor are published in the manufacturer's data sheet. The lateral force on the valve spool is proportional to torque motor current, but oil flow rate at the control ports also depends upon the pressure drop across the load.

Valve Spool Dynamics

In order to represent servo valve dynamics through a wider frequency range, a second order transfer function is used as approximation of the valve dynamics. The relation between the servo valve spool position and the input voltage v can be written as:[5]



$$\frac{x_v}{v} = \frac{K_v}{s^2/\omega_v{}^2 + 2\xi_v S/\omega_v + 1} \quad (5)$$

Where k_v is the valve gain, ξ_v is the damping ratio of the servo valve and ω_v is the natural frequency of the servo valve.

1. **Cylinder Chamber Pressure**

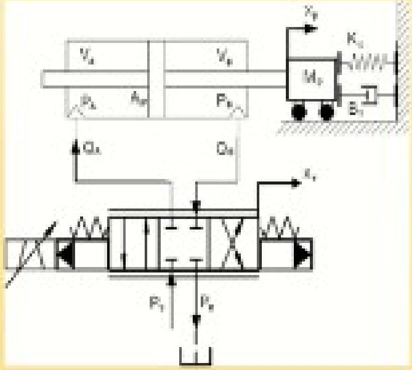
The servo valve control the flows Q in each chamber in the actuator can be models from the orifice equations relates the spool valve position x_v , pressure difference and servo valve gain K . For the ideal orifice equation

Hydraulic Power Supply

The behavior of the hydraulic power supply may be modeled in the same way as the chamber volumes by applying the flow continuity equation to the volume of trapped oil between the pump and servo valve. In this case, the input flow is held constant by the steady speed of the pump motor, and the volume does not change. The transformed equation is:

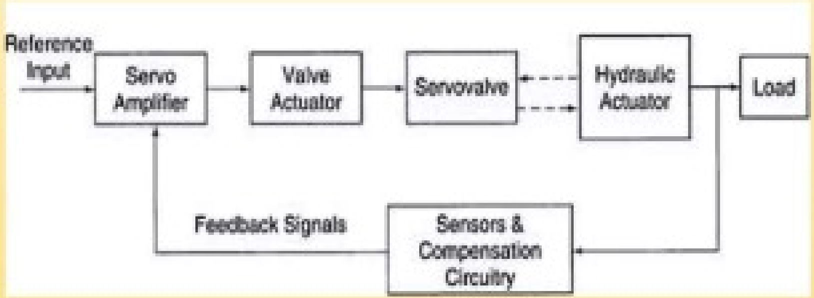
The servo valve control the flows Q in each chamber in the actuator can be models from the orifice equations relates the spool valve position x_v , pressure difference P_L and servo valve gain K . For the ideal orifice equation:[2]

$$Q = K x_v \sqrt{\Delta P_L} \tag{6}$$

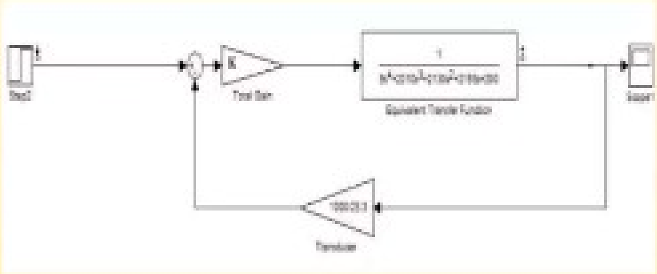


The systems model and response simulation

In this section the mathematical modeling of EHS system is discussed, where the system consists of electronic drive, hydraulic actuator, servo valve, and piston transducer. The mathematical model behavior of servo valve can be developed from the relationship between the displacement and the input voltage v.



In order to represent the actuator dynamics from the previous equation through a wider frequency range, a second order transfer function is obtained. The transfer function of actuator is the relation between the piston position and the input force can be written as

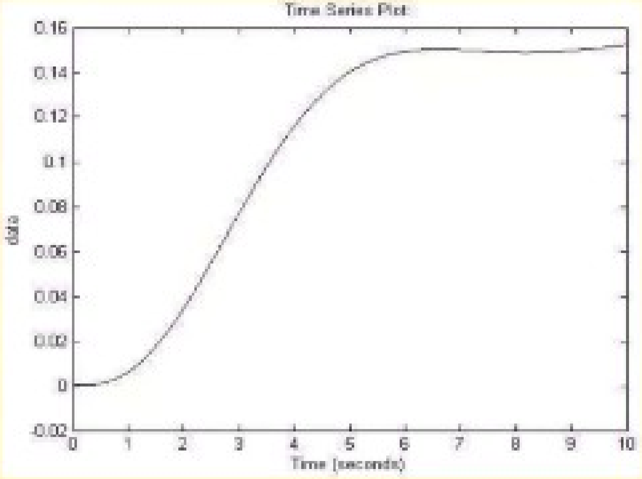


The transfer function of the feedback transducer signal is the relation between the piston displacement and the input voltage v that was found as a constant gain by comparison the ratio between the two parameters.

The equivalent open loop transfer function of the whole system without controller is:

System's response

The exact total gain of the forward transfer function can be found practically , Appling Routh-Huriwtz criterion will give the range of this gain for stability which is $0 < K < 50$, at a specific gain of K=10 the response of the uncontrolled system is shown in the figure (3.8) below :

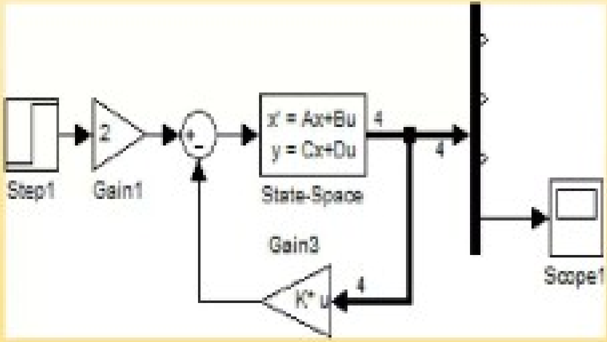


After knowing the exact value of the gain K , a PID controller is to be designed , after implementing this controller and due to system's variation a little tuning in the PID controller is required

System's response using state feedback controller

By using state feedback controller, the system will be stable as shown in the figure below:

The block diagram of the EHH system using state feedback controller is shown below:



Electro-Hydraulic Servo System Construction

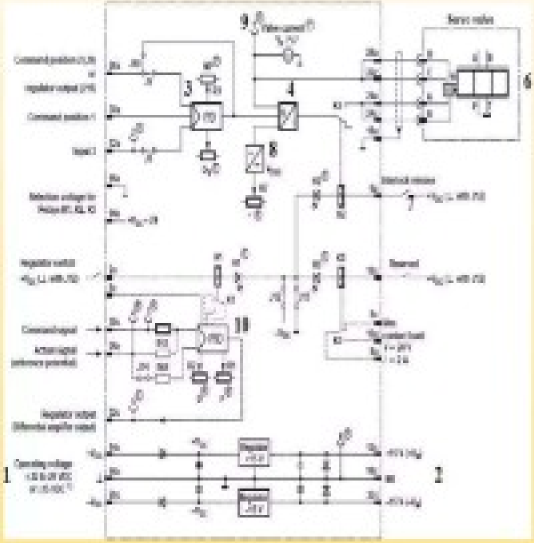
This chapter discusses the hydraulic model constructed based on the mathematical model explained in chapter three, beginning with the structure design of the servo hydraulic system, principles of system's operation, explaining the characteristics and relationships, plotting curves for flow, pressure and frequency response, and how to use the project in the laboratories' experiments by the students.

1. Interface card (Analogue amplifier Type VT-SR2):

Servo amplifier cards convert an input signal to a proportional current to drive the servo valve torque motor. On industrial hydraulics systems several servo amplifiers feature an integrated PID (proportional, integrator, and derivative) control circuit, which allows tuning for optimum performance of position control, or constant velocity circuits. With the added ability to combine the PI, PD, or PID controls for any circuit, a wider range of electro-hydraulic motion control sequences can be engineered, for sophisticated applications in automotive, plastics, machine tool, heavy industry and other applications. Its Amplify with high open-loop gain (operational amplifiers) are frequently encountered in analog signal processing circuits, since the application of negative feedback enables numerous transfer functions to be implemented.

Analogue amplifier

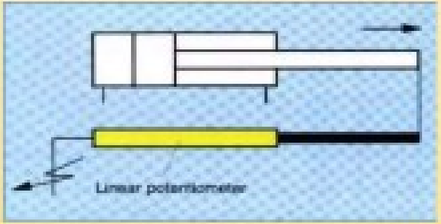
Connection manual of servo amplifier



The circuit for the servo amplifier is shown in Figure (4.3), where a smoothed DC voltage between ±22 V and ±28 V is necessary as the supply, and a stabilized voltage of+15 V is then produced from the supply voltage for the amplifier card, this voltage is used for the supply of external actuators such as potentiometers (tapping point at 12c (+15 V) and at 22c (-15 V) and the supply of internal operational amplifiers. Furthermore, two basic function groups should be considered:

Linear potentiometer:

A linear taper potentiometer has a resistive element of constant cross-section, resulting in a device where the resistance between the contact (wiper) and one end terminal is proportional to the distance between them. Linear taper describes the electrical characteristic of the device, not the geometry of the resistive element. Linear taper potentiometers are used when an approximately proportional relation is desired between shaft rotation and the division ratio of the potentiometer.



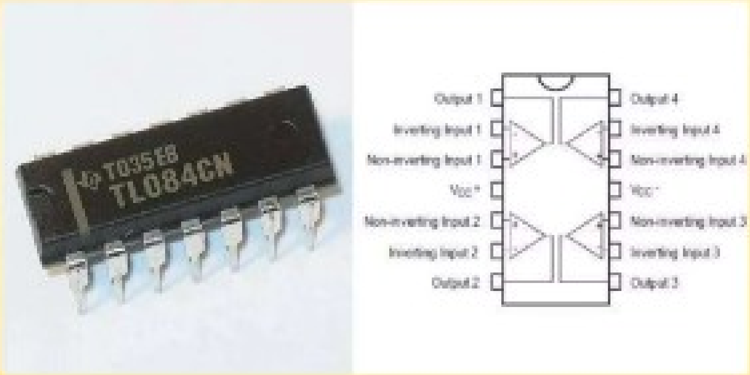
Precision rotary potentiometers

It is a component, a three-terminal resistor with a sliding contact that forms an adjustable voltage divider. If only two terminals are used, one end and the wiper, it acts as a variable resistor, so it's used to control the input voltage to this system

Operational amplifier

The operational amplifier family is designed to offer a wider selection than any previously developed operational amplifier family.

Each of these JFET-input operational amplifiers incorporates well-matched, high-voltage JFET and bipolar transistors in a monolithic integrated circuit. The devices feature high slew rates, low input bias and offset currents, and low offset voltage temperature coefficient. Offset adjustment and external compensation



Flow meter

It's an instrument for monitoring, measuring, or recording the rate of flow, pressure, or discharge of a fluid, as of a gaseous fuel.

Principles of system's operation

A command voltage is selected via the command voltage potentiometer.

The actual position of the piston is measured and fed back as a voltage by the feedback potentiometer.

The error is amplified by the amplifier and is thus able to energize the servo valve coil.

As the actual displacement changes, the actual voltage created by the feedback potentiometer also changes.

The actual voltage gradually approaches the command voltage, until they are finally both equal when the required position has been reached

When the required displacement has been reached, the error is zero and the servo valve closed.

The variables disrupting open loop control no longer or scarcely effect closed loop control.