Analog Instruments

An analog instrument is one in which the output or display is a continues function of time and bears a constant relation to input. Although digital instruments are increasing in number and applications, analog instruments still find extensive use in present day applications.

Classification of Analog Instruments There are a no. of was by which analog instruments are classified.

1. According to the quantity they measure. i.e. on the basis of measurand. e.g. instrument measuring voltage is classified as voltmeter, instrument measuring energy is classified as Energy meter, & so on.

2. According to the nature of current that can be measured by them. On this basis
   1) AC instruments
   2) DC Instruments
   3) AC/DC Instruments (Universal Instruments).

3. Analog instruments are also classified (a) Indicating (b) Recording (c) Integrating instruments.

(a) Indicating :- which directly indicate the magnitude of a quantity being measured. The make use of a pointer & dial for this purpose. Ordinary voltmeters, ammeters, wattmeters, etc - fall in this catagory.
Further divided into
(i) Electromechanical Instrument (ii) Electronic Instruments.

(b) Recording Instruments give a continous record of the quantity measured over a specified period of time. The variations of the quantity being measured are recorded by a pen attached to the moving system of the instrument; the moving system is operated by the quantity being measured, on a sheet of paper carried by a rotating drum.

e.g. * Recording voltmeter at a substation noting down voltage variations at substation during the day.

* Bio medical instruments recording various physiological parameters, like BP, heart rate, temp, of patients in ICU.

etc.

(c) Recording Instruments totalize events over a specified period of time. The summation which they give is the product of an electrical quantity and time.
e.g. Amper hour & watt hour meters are examples of this catagory.

(4) According to the method used for comparing the unknown quantity (measured) with the unit of measurement.
Two types

(a) Direct Measuring Instruments: These convert the energy of the measurand directly into energy that actuates the instrument and the value of unknown quantity is measured or recorded or displayed. e.g. Ammeters, voltmeters, wattmeters, etc.

(b) <u>Comparision Instruments</u>:
These measure the unknown quantity by comparision with a standard. e.g. DC & AC Bridges.

(5) According to the effect produced current or/and voltage and thus on the basis of which of the effect is used for its working. The various effects used are:

(i) Magnetic effect → (A), (V), (W), (E).
(ii) Heating effect → (A), (V), (W).
(iii) Electrostatic effect → (V).
(iv) Induction effect → AC, (A), (V), (W), (E).
(v) Hall effect → Flux meters, (A), & Poynting Vector watt meters.

<u>Home Small Assignment</u>

<u>Q</u>: Briefly study the principle of operation under lying the working of Instruments for the above five effects produced.

Electromechanical Indicating Instruments

Operating forces:-

Three forces are required for successful operation of an electromechanical indicating instrument.

① Deflecting Force

The deflecting or operating force is required to move the pointer from its zero position to any final steady position. The system producing such force is called deflection or moving system. The deflecting force can be produced by utilizing any of the ~~utilized~~ methods / effects. Thus the deflecting system of an instrument converts the electric current or potential into a mechanical force called deflecting force. The deflection system thus acts as a prime mover responsible for deflection of the pointer.

② Controlling Force

This force is required in an indicating instrument in order that the current produces deflection of the pointer proportional to its magnitude. The system producing a controlling force is called controlling system.

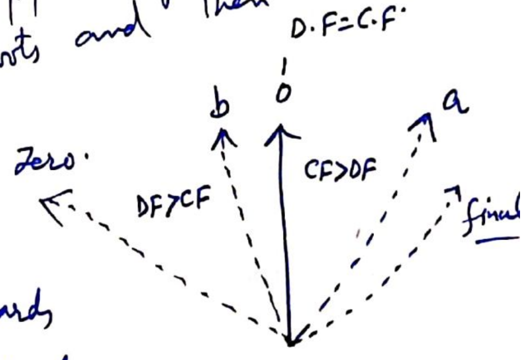
The Controlling System has two functions

(i) to produce a force equal and opposite to the deflecting force at final steady position of pointer to make the deflection of pointer definite for a particular magnitude of current.

(ii) to bring the moving system back to zero when the deflecting force is removed. In the absence of controlling force the pointer will not come to back to zero when the current is removed. Controlling force is usually provided by springs.

③ Damping Force

The deflecting and controlling force are produced by elements that have inertia and, therefore, the moving system will not come to rest immediately when deflection force is opposed by controlling force. The moving system over shoots and then undershoots



Let O = equilibrium position

When pointer moves from zero towards O, it gains inertia & swings ahead of it to a. Beyond O, at any position controlling force (CF) is greater than Deflecting force (DF), thus CF brings it back towards O. While moving from a to O, it gains a little inertia & goes to b. below O towards left D.F > C.F, thus pointer is shifted back towards O. These oscillations over & below O take place and after some time pointer settles at O.

If we do not provide extra forces to settle down these oscillations, we may have to wait for some time till oscillations settle down. Thus time taken in readings will be larger. Therefore damping forces are necessary so that moving system comes to its equilibrium position rapidly and smoothly without any oscillations.

Constructional Details of an Electromechanical Indicating Instrument

We have now three systems, producing three forces, deflecting force/moving force (Moving system), controlling force (Controlling system) & Damping force (Damping system). These three systems together comprise of the constructional details of an electromechanical indicating instrument.

(1) Moving System

The moving system has two requirements.

(i) moving parts should be lighter.

(ii) frictional forces should be minimum.

These requirements should be fulfilled in order that power required by the instrument for its operation is small. The power requirement is proportional to weight of moving parts and frictional forces. The moving system can be made lighter by using aluminium as far as possible. The frictional forces are reduced by using a spindle mounted between jewel bearings and by carefully balancing the system.

Moving System Supports

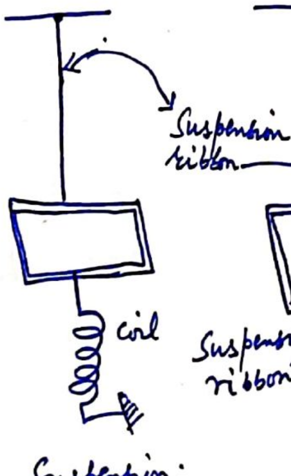
Considering the fact that the magnitude of deflecting and controlling forces are of very small magnitude and frictional forces have to be minimised, the instrument needs a proper support to its moving parts so that power requirement is minimised which will reduce interference by the instrument on the system where it is introduced for purpose of measurement.

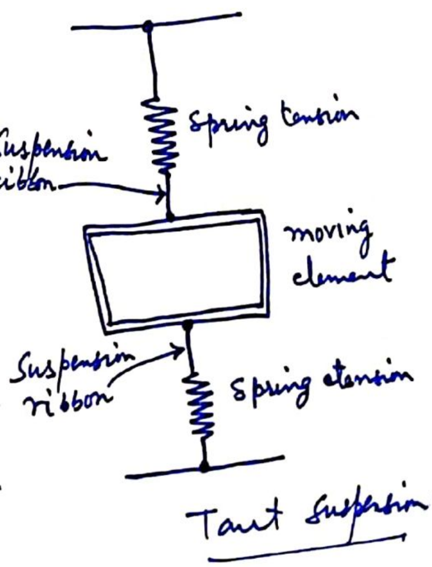
Three types of supports

(1) Suspension (2) Taut Suspension (3) Pivot & Jewel Bearing

(1) Suspension

It consists of a fine ribbon shaped metal filament for the upper suspension and coil of fine wire for the lower part. The ribbon is made of spring material like berrylium copper or phosphor bronze. The coiling of lower part is done in order to give negligible restraint on the moving system. This type of suspension requires careful levelling of the instrument, so that instrument hangs in correct vertical position.



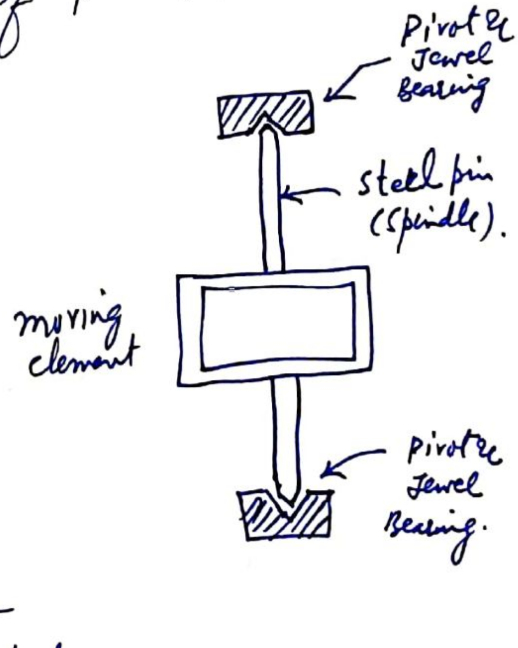


Not recommended for field use but suited for Lab applications.

② Taut Suspension It has a flat ribbon suspension both above and below the moving element, with suspension kept under tension by spring arrangement. The advantage is that exact levelling is not required if the moving element is properly balanced.

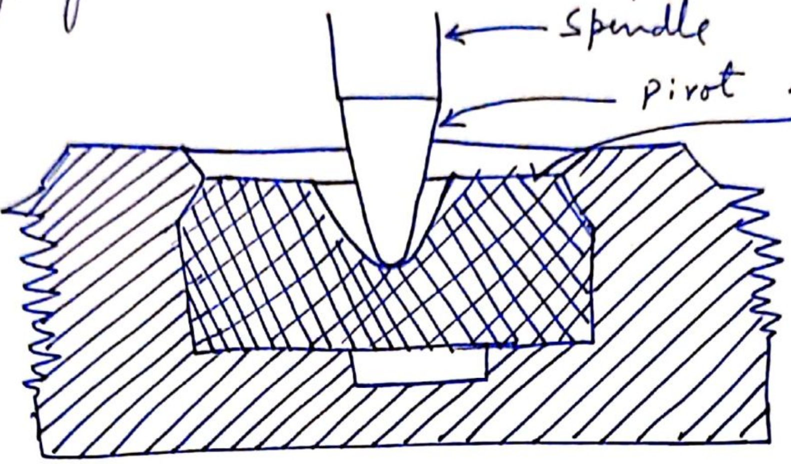
Suspensions & taut suspensions are used in instruments of galvanometer class which require a low friction and high sensitivity mechanism. Ribbon suspensions in addition to supporting the moving element, exert a controlling torque when twisted, thereby avoids use of pivots, jewels and control springs.

③ Pivot & Jewel Bearings



The moving system is mounted on a spindle made of hardened steel. The two ends of the spindle are made ~~cone~~ conical and then polished to form pivots. These ends fit conical holes in Jewels located in fixed parts of instruments, which are preferable made of Sapphire.

The combination of steel and sapphire gives lowest friction. On pivot + jewel bearing is shown below in a magnified manner :—



It has been found that the frictional torque, for jewel bearings is proportional to area of contact between the pivot and jewel. Thus the contact area between pivot and jewel should be small. The pivot is ground to a cone and its tip is rounded to a hemispherical surface of small area. The jewel is also ground to a cone of some what larger area. The jewel fits in the cone. The contact area should not be too small, otherwise the stress may exceed the crushing strength of the material of pivot.

NO instrument levelling is required, thus Can be used in instruments for field application. The instrument need not to be kept vertically upwards.

* Used in most of indicating instruments.

② Controlling System

Two types of control systems are used

(i) Gravity control (ii) Spring control

(i) Gravity control

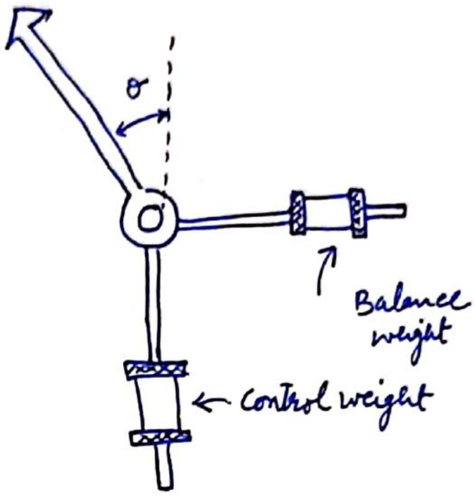


Fig (a).

In this type of control a small weight is placed on an arm attached to the moving system. The position of this weight is adjustable. This weight produces a controlling torque due to gravity.

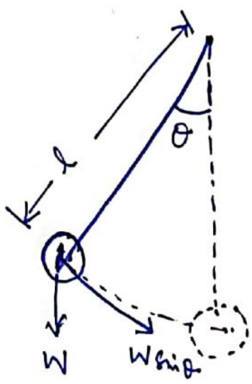


Fig (b).

Fig a shows the pointer at zero position. In this case control torque is zero. When the system is deflected by an angle θ as shown in fig (b). The weight acts at a distance l from centre, and the component of weight trying to restore the pointer back to zero position is $W \sin\theta$

∴ Controlling torque $= W \sin\theta \times l$
$= Wl \sin\theta$

$T_c = K_g \sin\theta$ where $K_g = Wl$ = Constant.

Thus controlling torque is proportional to sine of the angle of deflection of moving system.

The instrument needs to held in vertical position.

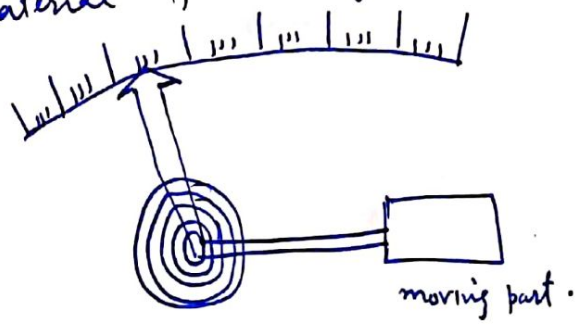
For this reason, gravity control is not suited for indicating instruments

(ii) <u>Spring Control</u> :-

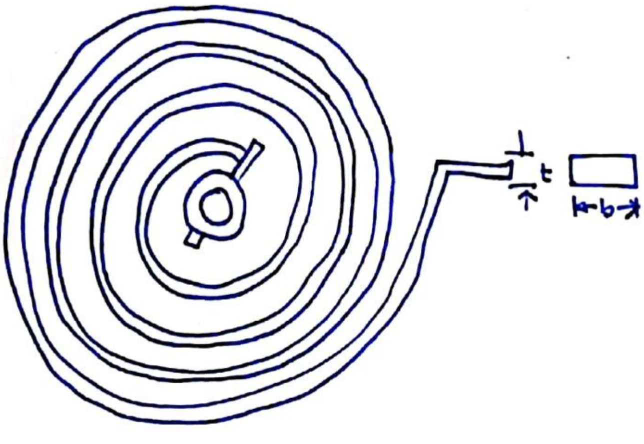
A hair spring is attached to the moving system and exerts a controlling a torque when the moving system deflects. The essential requirements for instrument spring are :-

(i) They should be non-magnetic
(ii) They should be mechanical fatigue proof.
(iii) Where springs are used to lead current into moving system, they should have a small resistance, sufficient cross-sectional area to carry current without temperature rise. They should also have a low resistance temp. coefficient.

Materials used for spring are, silicon bronze, hard rolled silver or copper, platinum silver, platinum silver and german silver. Phosphor bronze is most commonly used material for spring material.



Flat spiral springs are used in almost all indicating instruments. The inner end of the spring is attached to the spindle and the outer end carries a spigot which engages in a circular disc surrounding the jewel screw.



This disc carries an arm which is slotted and splayed out at the end. The purpose of slotted extension arm is to allow the spring to be coiled or uncoiled slightly, so that the pointer may be set at zero. The slotted arm is actuated by a set screw mounted at the front end of the instrument, and therefore, zero setting of the instrument can be done without removing the cover.

The controlling torque (T_c) developed by a flat spiral spring is given by:

$$T_C = \frac{Ebt^3}{12l} \cdot \theta \ (N\text{-}m).$$

where $E \rightarrow$ Youngs Modulus of spring material; N/m^2

b = width of spring (m)

t = thickness of spring (m)

l = length of spring (m)

θ = angular deflection (rad).

$E, b, t, l \longrightarrow$ Constant for a spring;

$$\boxed{T_C = K\theta}$$

where $K = \frac{Ebt^3}{12l}$. (N-m/rad)

K = spring constant or (control constant) or torsion constant or restoring constant.

units of (K = N-m/rad)

Comparison b/w Gravity Control and Spring Control

Advantages of Gravity control are

(i) It is cheap
(ii) The control is independent of temprature variations.
(iii) It does not deteriorate with time

But the instrument is to be kept in correct vertical position. That is why application is limited to Lab work.

Effect on Shape of Scale :-

Consider an instrument whose deflection torque is directly proportional to the current being measured.

$\therefore$ Deflecting Torque $T_d = K_d I$ where K_d = Constant.

(a) Spring controlled meter ; $T_C = K\theta$ θ = deflection. K = Spring constant;

At equilibrium ; $T_C = T_d$

$K\theta = K_d I$ $\therefore \theta = \frac{K_d}{K} \cdot I$

$$\boxed{\theta = K_2 I} \quad \text{where } K_2 = \frac{K_d}{K}$$

Thus deflection is proportional to current and thus scale is uniform.

(b) Gravity control ; $T_c = K_g \sin\theta$

At balance; $T_d = T_c$;

$K_d I = K_g \sin\theta$

$\therefore \sin\theta = \frac{K_d}{K_g} I = K_2' I$

$\sin\theta = K_2' I \Rightarrow \boxed{\theta = \sin^{-1}(K_2' I).}$

Since deflection is proportional to Sin inverse of $(K_2 I)$ the scale will be non-uniform in shape.

Thus to conclude, even if the operating principle was based on linear realation b/w T_d & I, but the spring control resulted in uniform scale (linear) whereas Gravity control has made the instrument scale shape non-uniform.

Example :- A Permanet magnetic moving coil instrument (PMMC) has a full scale deflection of 90° for a current of 2A. The deflection torque in a PMMC instrument is directly proportional to current in the moving coil. Find the value of current required for a deflection of 30° if the instrument is, (a) spring controlled (b) Gravity controlled.

Sol/:- $T_d \propto I$ (PMMC);

for $\theta = \theta_1 = 90°$; $I = I_1 = 2A$

(a) Spring control :- $\theta \propto I$ $\theta_2 = 30°$;

$$\frac{\theta_1}{\theta_2} = \frac{I_1}{I_2}$$

$$\frac{90}{30} = \frac{2}{I_2}$$

$\therefore$ $I_2 = \frac{2}{3} = 0.667\ A.$

(b) for spring control. $\sin\theta \propto I$

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{I_1}{I_2}$$

$$\frac{\sin 90}{\sin 30} = \frac{2}{I_2}$$

$I_2 \times 1 = 2 \times \sin 30$

$I_2 = 2 \times \frac{1}{2} = 1\ A$