ELECTROMECHANICAL INDICATING INSTRUMENTS

DIRECT CURRENT (')C) METERS

In 1881 Jacques d'Arsonval developed and patented the moving-coil galvanometer. The same basic construction is widely used in meter movements today.

The basic moving-coil system, generally referred to as the permanent magnet moving-coil (PMMC) or d'Arsonval meter movement is as shown below.

Between the north-south pole pieces of a horseshoe-shaped permanent magnet is a cylindrical soft iron core about which a coil of fine wire is wound. The coil is wound on a very tight metal frame and mounted in a jewel setting so that it can rotate freely in the magnetic field. When current flows in the coil, the developed electromagnetic torque causes the coil to rotate. This torque is counterbalanced by the mechanical torque of a spring attached to the movable coil. The balance of torques, and therefore the angular position of the movable coil, is indicated by a pointer against a fixed reference, the scale.

Steady-state Deflection

The equation for the developed torque, derived from the basic law for electromagnetic torque, is

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Thus torque is directly proportional to the flux density, current and the coil constants (area and turns). Since both flux density and coil area are fixed parameters for a given instrument, the developed torque is a direct indication of the current in the coil. **It should** be emphasized that the **PMMC meter** is a current responding device.

A typical PMMC instrument, with a 3'/2" case, a 1 mA range, and full-scale deflection of 100 degrees arc, would have the following characteristics:

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Dynamic Behaviour

To date the galvanometer has been considered as a simple indicating instrument in which the deflection of the pointer is directly proportional to the magnitude of the current applied in the coil. This steady-state response provides a reliable reading of direct current. In some applications however, the dynamic behaviour of the galvanometer (such as speed of response, damping, overshoot) can be important.

The motion of a moving coil in a magnetic field is characterized by three quantities.

(a) The moment of inertia (J) of the moving coil about its axis of rotation.

(1,) The opposing torque (S) developed by the coil suspension.

(c) The damping constant (D).

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Solution of the differential equation that relates these three factors yields several possibilities, which describe the dynamic behaviour of the coil in terms of its deflection angle 0.

r'~~;('r?~T~; '~Y~~?amiip~u case: ~i-ne cobia returns slowly to its rest position, after disturbance, without overshoot or oscillation. The pointer seems to approach the steady-state in a sluggish manner. This case is of minor importance and we would normally prefer to operate under the condition of curve II or curve III.

Curve H: Underdamped case: The motion of the coil is subject to damped sinusoidal oscillation. The rate of decay of these oscillations is determined by D, J and S.

Curve ifi: Critically damped case: The pointer returns promptly to its steady-state **position, without oscillation.**

Ideally, galvanometer responses would be critically damped, however, in practice most galvanometers are slightly underdamped, causing the pointer to overshoot a little before coming to rest.

Temperature Compensation

The PMMC movement is not inherently insensitive to temperature, but it may be temperature-compensated by use of series and shunt resistors of copper and manganin. Both the magnetic fieldstrength and spring tension decrease with an increase in temperature. The coil resistance increases with an increase in temperature. These changes tend to made the pointer read low for a given current with respect to magnetic fieldstrength and coil resistance. The spring changes, conversely, tends to cause the pointer to read high with an increase in temperature. The effects are not identical, however, hence the uncompensated meter tends to read low by approximately 0.2 per cent per ^{0}C rise in temperature.

Compensation may be accomplished by using swamping resistors in series with the coil. The swamping resistor is made of manganin (which has a temperature coefficient of practically zero). The total resistance of coil and swamping resistor increases slightly with a rise in temperature, but only just enough to counteract the change of springs and magnet, so that the overall temperature effect is zero.

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A more complete cancellation of temperature offset may be obtained with the arrangement shown below.

Here the total circuit resistance increases slightly with a rise in temperature, owing to the presence of the copper coil shunt resistor. For a fixed applied voltage, therefore, the total current decreases slightly with a rise in temperature. The resistance of the copper shunt increases more than the series combination of coil and manganin resistor; hence a larger fraction of the total current passes through the coil circuit. By correct proportioning of the copper and manganin parts complete cancellation of temperature effect may be accomplished.

NI~ One disadvantage of the use of swamping resistors is a reduction in the full-scale sensitivity of the movement, because a higher applied voltage is necessary to sustain the fullscale current.

PMMC meter used as an ammeter a)C)

Since the coil winding is small and light, it can carry only a very small current. When a larger current is to be measured, it is necessary to bypass the major part of the current through a resistance, called a shunt, as shown below.

Since the shunt resistance is in parallel with the meter, the voltage drops across the shunt and movement must be the same, thus:

Example

Calculate the valve of the shunt resistance required to convert a 1-mA meter movement, with 100 () internal resistance, with a 0 to 10 mA ammeter.

The current range of the dc ammeter may be further extended by a number of shunts to produce a multirange ammeter.

Note switch S must be a make-before-break **type to prevent damage to the unprotected meter movement as the range is changed.**

The universal, or Ayrton shunt eliminates the possibility of having the meter in circuit without a shunt. This advantage is gained at the expense of an increase in the overall meter resistance.

The individual resistance valves of the shunt are calculated by starting with the most sensitive range and working towards the least sensitive.

On the most sensitive range

Where I is the full-scale current of the most sensitive range.

On the next range ~ + R~ are in parallel with Ra + ~

(Where current I is the maximum current for the range on which the ammeter is set) On the least sensitive range

Example Calculate the shunt resistances for the circuit shown below:-

Solution The total shunt resistance R~ is found from

The following precautions should be observed when using an ammeter in measurement work:

(i) Never connect an ammeter across a source emf. Because of its low resistance it would draw a damaging high current and destroy the delicate movement. Always connect an ammeter in series with a load capable of limiting the current.

(ii) **Observe the correct polarity. Reserve** polarity causes the meter to deflect against the mechanical stop and this may damage the pointer.

(iii) When using a multirange meter, first use **the highest current range;** then decrease the current range until substantial deflection is obtained. To increase accuracy of the observation, use the range that will give a reading as near to full-scale as possible.

PMMC Meter used as a volmeter (1)C)

Multiplier Resistance:- The basic PMMC meter movement can be converted to a dc volmeter by connecting a multiplier R_8 in series with the meter movement as shown below:-

The multiplier limits the current through the movement so as not to exceed the value of the full scale deflection current. A dc voltmeter measures the potential difference between two points in a dc circuit and is therefore connected across a source of emf or a circuit component. The meter terminals are generally marked ^{11}pos^{11} and "neg", since polarity must be observed.

The value of a multiplier is calculated from
where: ^{1}f8 = full scale deflection current of the movement
R, internal resistance of the movement
Ra = multiplier resistance
V = full-range voltage of the instrument

The addition of a number of multipliers, together with a range switch, provides the instrument with a workable number of voltage ranges.

A variation of the above circuit is shown below where the multipliers are connected in a series string and the range selector switches the appropriate amount of resistance in series with the movement.

This system has the advantage that all multipliers except the first have standard resistance valves can be obtained commercially in precision tolerances. The low-range multiplier, Ra, is the only special resistor that must be manufactured to meet the specific circuit requirement.

ExamDle

A PMMC movement with internal resistance, R~ = 100 ~, and the full-scale current, If, = 1 mA, is to be converted into a multirange dc voltmeter with voltage ranges of 0-10 V, 0-50 V, 0-250 V, 0-500 V. Use a series multiplier string.

Solution

For 10 V range (V_4) position of range switch), the total circuit resistance is

For the 50 V range

For the 250 V range

For the 0-500 V range

NOTE: only the low range multiplier, R4, is a non-standard valve.

Sensitivity:- Note from the previous example how a current of 1 mA is obtained for voltages of 10 V, 50 V, 250 V and 500 V across the meter terminals. For each voltage range, the quotient of the total circuit resistance **RT** and the range voltage is always 1,000 ()/V. This figure is often referred to as the sensitivity or the U per-volt **rating,** of the voltmeter. Note that the sensitivity, S, is essentially the reciprocal of the full-scale deflection current of the basic movement, or

The sensitivity S of the voltmeter may be used to advantage in the sensitivity method of calculating the resistance of the multiplier in a d.c. voltmeter

where S = sensitivity of the voltmeter, in ~IV
V = voltage range, as set by the range switch
= internal resistance of the movement
Ra = resistance of the multiplier

Repeating the previous example by the sensitivity method

Voltmeter Loading Effect: When using a voltmeter to measure the voltage across a circuit component, the voltmeter itself is parallel with the circuit components. Since the parallel combination of two resistors is less than either alone, the resistance seen by the source is less with the voltmeter connected than without; therefore the voltage is connected. The decrease in voltage may be negligible or it may be appreciable, depending on the sensitivity of the voltmeter being used. This **effect** is called voltmeter loading.

ExamDle: Two different voltmeters are used to measure the voltage across resistor **RB** as shown below. The meters are as follows:Meter A: S = 1 kU/V, R~ = 0.2 kU, range = 10 V Meter B: S = 20 kU/V, R~ = 1.5 kU, range = 10 V.

Calculate:- (a) Voltage across **RB** without any meter connected
~) Voltage across **RH** when meter A is used
(c) Voltage across **RB** when meter B is used
(d) Error in voltmeter readings.

Solution:

Note that while the reading obtained with meter B is much closer to the correct value, the voltmeter has still introduced a 2% error. It is thus apparent that for measurement in electric circuits where high values of resistance are generally used that voltmeter sensitivity must be high.

ExamDle:- Find the voltage reading and percent error of each of the reading obtained with voltmeter on:

(a) its 3 V range
(1)) its 10 V range

(c) its 30 V range

The instrument has a 200 U/V sensitivity and is connected across **RB** in the diagram below.

Solution: Without the voltmeter loading

Note the 30 V range introduces the least error due to loading. However, the voltage measured causes only a 10% full-scale deflection, whereas in the 10 V range the applied voltage causes approximately one-third full-scale deflection with less than 2% error. The reading obtained on the 10 V range would be acceptable and less subject to gross error as discussed previously.

We can experimentally determine if the voltmeter is introducing appreciable error by changing to a higher range. If the voltmeter reading does not change, then the meter is not loading the circuit appreciable. If loading is observed, select the range with the greatest deflection and thus giving the more precise measurement.

The following general precautions should be observed when using a voltmeter:

(i) **Observe the correct polarity. Wrong polarity causes** the meter to deflect against the mechanical stop and this may damage the pointer.

(ii) Place the voltmeter across the circuit or component whose voltage is to be measured.

(iii) When using a multirange voltmeter, always use the highest voltage range and then decrease the range until a good "up-scale" reading is obtained.

(iv) **Always be aware of the loading effect. The effect** can be minimized by using as high a voltage range (and highest sensitivity) as possible. The precision of measurement decreases if the indication is at the low end of the scale.

Ammeter Loading Effect:-

A source of error in measurement (frequently overlooked) is the error caused by inserting an ammeter in circuit to obtain a current reading. All ammeters contain some internal resistance that may range from a low value for meters capable of measuring in the ampere range to an appreciable value of 1 kU or greater for microammeter. Inserting an ammeter in a circuit always increases the resistance of the circuit, and therefore, always reduces the current in the circuit. The error caused by the meter depends on the relationship between the value of resistance in the original circuit and the value of resistance in the ammeter.

As shown below, the expected current, I~, is the current without the ammeter in circuit. When the ammeter is included in circuit, the current will be reduced to ~ due to the added meter resistance, R~.

From Thevenin's theorem, where E and R_1 are the Thevenins equivalent parameters of the circuit to be measured.

Voltmeter-Ammeter method of measurlng resistance

If the voltage V across the resistor and the current I through the resistor are measured, the unknown resistance Ra can be calculated by Ohm's law:

This equation implies that the ammeter resistance is zero and the voltmeter resistance infinite, so that the conditions in the circuit are not disturbed.

In fig. (a) below the true current supplied to the load is measured by the ammeter, but the voltmeter measures the supply voltage rather than the actual load voltage. To find the true voltage across the load, the voltage drop across the ammeter must be subtracted form the voltage reading. If the voltmeter is placed directly across the resistor, as shown in fig. (1)), it measures the true load voltage, but the ammeter is in error by the amount of current drawn by the voltmeter.

In either situation, an error is introduced in the measurement of Ra The correct method of connecting the voltmeter depends on the value Ra and the resistance of the voltmeter and ammeter. In general, the ammeter resistance is low and voltmeter resistance is high.

In fig. (a) the ammeter reads the true value of the load current (I,), and the voltmeter measures the supply voltage ~ If Ra is large compared to the internal resistance of the ammeter, the error introduced by neglecting the voltage drop across the ammeter is negligible and V~ is very close to the true load voltage V~. The **connection of fig. (a) is therefore the best circuit when measuring high-resistance values.**

In fig. (1)) the voltmeter reads the true valve of the load voltage (V~ and the ammeter reads the supply current ('t). If Ra is small compared to the internal resistance of the voltmeter, the current drawn by the voltmeter does not appreciably affect the total supply current and It is very close to the true valve of the load current IX This **connection is therefore the best cfrcuit when measuring the low-resistance valves.**

To measure an unknown Ra use the circuit below:

(i) Connect the voltmeter across Ra with the switch in position 1, and observe the ammeter reading.

(ii) Now switch the voltmeter to position 2. If the ammeter reading does not charge, restore the voltmeter to position 1. The systems indicate a low-resistance measurement. Record both I and V and calculate Ra.

(iii) If the ammeter reading decreases when the voltmeter is changed from position 1 to position 2, leave the voltmeter at position 2. The symptoms indicate a high-resistance measurement. Record both I and V and calculate Ra.

Series Type ohmmeter:

The series type ohmmeter consists essentially, of a PMMC meter connected in series with a resistance and a batter to a pair of terminals to which the unknown resistance is connected.

R_1 = current limiting resistor
R_2 = zero adjust resistor
E = internal battery
= internal resistance of
meter Ra = unknown resistor

When the unknown resistor Ra = 0 (terminals A and B shorted) maximum current flows in the circuit. Under this condition, shunt resistor R_2 is adjusted until the movement indicates full-scale current (If,). The full-scale current position of the pointer is marked "OU" on the scale. Similarly, when Ra = ~ (terminals A and B open), the current in the circuit drops to zero and the movement indicates zero and the movement indicates zero current, which is marked "00" on the scale. Intermediate markings may be placed on the scale by connecting different known values of Ra to the instrument. The accuracy of these scales marking depends on the repeating accuracy of the movement and the tolerance of the calibrating resistors.

The battery voltage will decrease gradually with time and age, so that full-scale current drops and the meter does not read "0" when A and B are shorted. The variable shunt resistor R_2 provides an adjustment to counteract the effect of battery voltage decay.

NOTE: Resistor R_2 can be placed in series with R_1 and adjusted for variations in E, but the calibration of the instrument is now affected to a much greater extent over the whole range of readings.

A convenient quantity to use in the design of a series-type ohmmeter is the value Ra which causes half-scale deflection of the meter. At this position, the resistance across terrninal A and B is defined as the halt-scale position resistance Ra. If introducing Rh reduces the meter current to 1/2 $^{1}{}_{f8}$, the unknown resistance must be equal to the total internal resistance of the ohmmeter. Therefore: -

The total resistance presented to the battery then equals 2Rh, the battery current needed to supply the half-scale deflection is

To produce full-scale deflection, the battery current must be doubled, and therefore

The shunt current through R_2 is

The voltage across the shunt (E,~ is equal to the voltage across the movement thus

Shunt-Type Ohmmeter

The shunt-type ohmmeter is particularly suited to the measurement of low-value resistors.
It is not commonly used in test instruments, **but it is found in laboratories** for special low-resistance applications.

When the unknown resistor Ra = 0 ***U*** (A and B shorted) the meter current is zero. If the unknown resistor Ra = 00 (A and B open), the current finds a path only through the meter and R_1 can be adjusted so that the pointer of the meter reads full scale. This ohmmeter therefore has the "zero" mark at the left-hand side of the scale (no current) and the "infinite" mark at the right-hand side of the scale (full-scale deflection current).

When Ra = 00 the full-scale current will be

where E = internal battery voltage R_1 = current limiting resistor
= internal resistance of the movement

For any value of Ra connected across the meter terminals, the meter current decreases and is

given by:At half-scale reading of the meter (I~ - 0.5 I~a) and the above equation reduces to

where Rb
= external resistance causing half-scale deflection. To determine the relative scale values for a given value of R_1, the half-scale reading may be found by equating equation (i) and (iii) and solving for **Rb.**

Thus the half-scale resistance is determined by limiting resistor R_1 and the internal resistance of the meter ~. The limiting resistance R_1, is in turn determined by the meter resistance, ~, and the full-scale deflection current, ~

Multlmeters:

In a multimeter, also known as a volt-ohm-milliameter ~OM), a function select switch is used to enable the same instrument to measure voltage, resistance or current, and a range switch selects the magnitude of the parameter being measured. These instruments basically consist of the separate circuits used to measure voltage, current and resistance, in one instrument.