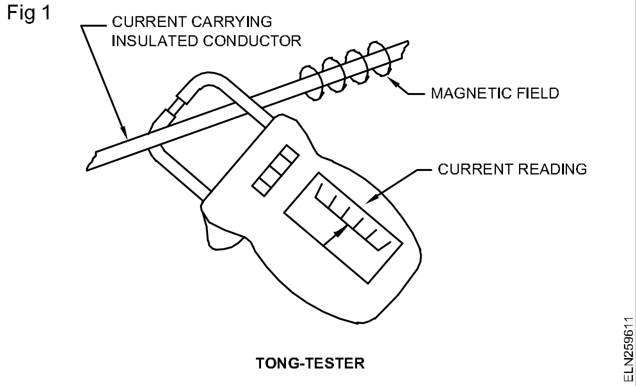
Tong - tester (clamp - on ammeter)

Objectives: At the end of this lesson you shall be able to
- **state the necessity of tong-testers**
- **state the construction and working of a tong-tester**
- **state the precautions to be observed while using a tong-tester.**

A tong-tester is an instrument devised for the measurement of A.C current, without interrupting the circuit. It is also called clip-on ammeter, or sometimes a clamp-on ammeter (Fig 1).

Fig 1



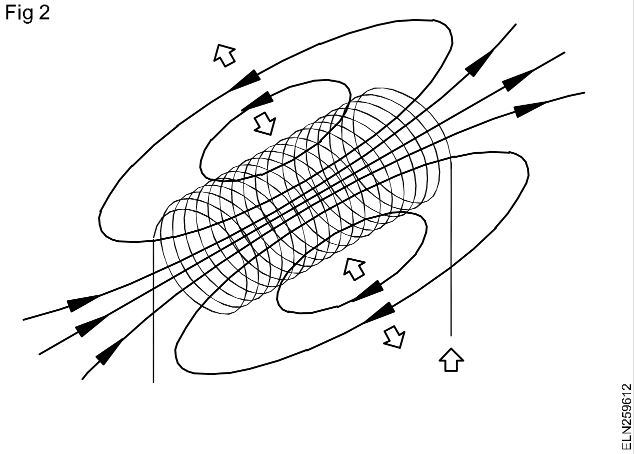
TONG-TESTER

Working principle

The instrument can function only when current passes through its deflecting system. It works under the mutual induction principle.

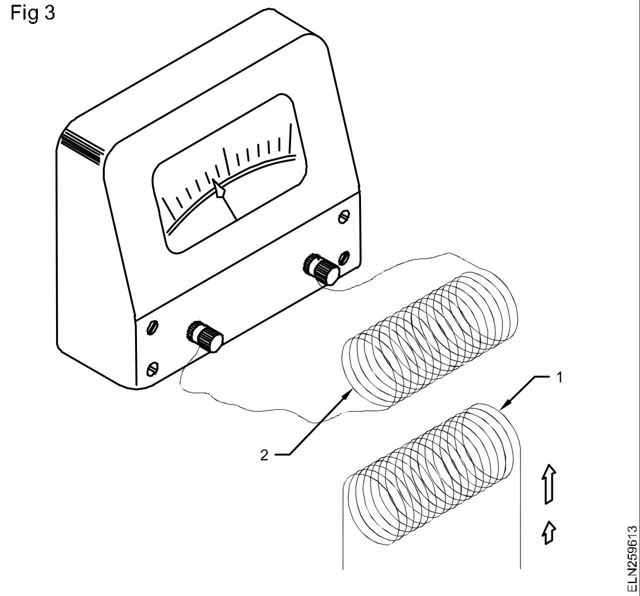
Electromagnetic induction: When a changing flux is linked with the coil, an emf is induced in the coil. The current in a coil so produced changes as that of the changing magnetic flux. If an alternating current is flowing through the coil, the magnetic flux produced is also alternative i.e. changing continuously.(Fig 2)

Fig 2



Placing another coil (2) in the changing flux of coil (1), an emf will be induced. (Fig 3)

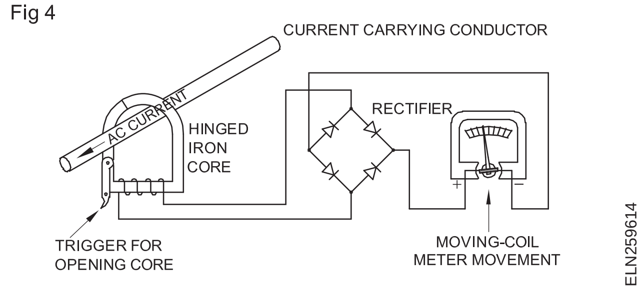
Fig 3



This induced emf will send the current, causing deflection of the meter. Introduction of a magnetic core between the coils increases the induced emf. The coil (1) is called primary and the coil (2) is called secondary.

Construction: Fig 4 shows a tong-tester (the clamp-on ammeter) circuit. The split-core meter consists of a secondary coil with the split-core and a rectifier type instrument connected to the secondary. The current to be measured in the conductor serves as the primary of one turn coil. It induces a current in the secondary winding and this current causes the meter to deflect.

Fig 4



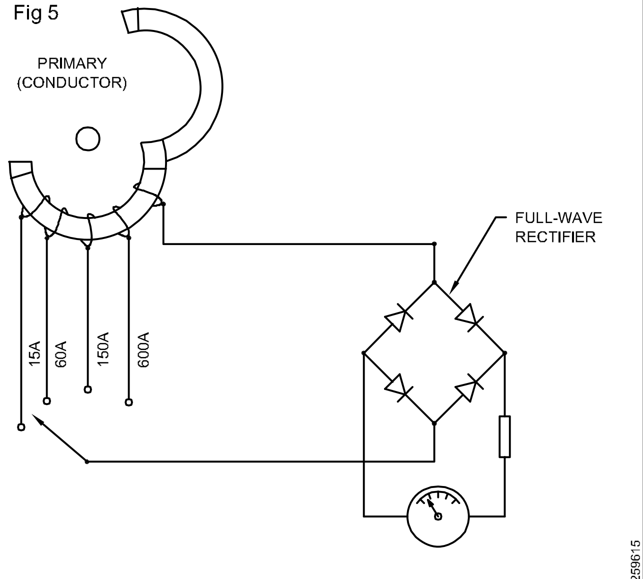
The core is so designed that there is only one break in the magnetic path. The hinge and the opening both fit tightly when the instrument closes around the conductor. The tight fit of the instrument ensures minimum variation in the response of the magnetic circuit.

To measure current with a clamp-on meter, open the jaws of the instrument and place them around the conductor in which you want to measure the current. Once the jaws are in place, allow them to close securely. Then, read the indicator position on the scale.

When the core is clamped around a current-carrying conductor, the alternating magnetic field induced in the core, produces a current in the secondary winding.

This current causes a deflection on the scale of the meter movement. The current range can be changed by means of a `range switch', which changes the taps on the transformer secondary (Fig 5).

Fig 5



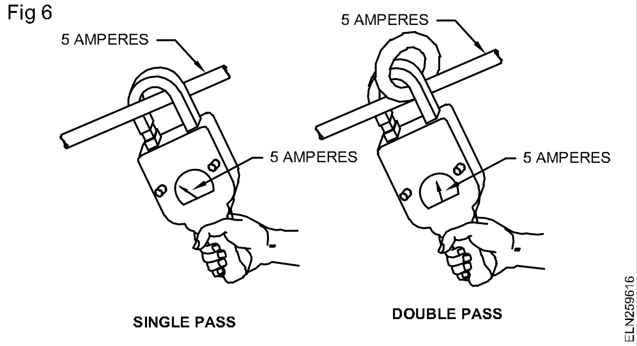
TAPPED-SECONDARY CIRCUIT

Safety: The secondary winding of the current transformer should always be either shunted or connected to the ammeter; otherwise, dangerous potential differences may occur across the open secondary.

Before taking any measurement, make sure the indication is at zero on the scale. If it is not, reset by the zero-adjustment screw. It is usually located near the bottom of the meter.

Looping the conductor more than once through the core is another means of changing the range. If the current is far below the meter's maximum range, we can loop the conductor through the core two or more times (Fig 6).

Fig 6



Application

1 For measuring the incoming current in the main panel board.

2 Primary current of AC welding generators.

3 Secondary current of AC welding generators.

4 Newly rewinded AC motor phase current and line current.

5 Starting current of all AC machines.

6 Load current of all AC machines and cables.

7 For measuring the unbalanced or balanced loads.

8 For finding the faults in AC, 3-phase induction motors.

Precaution

1 Set the ampere range from higher to low if the measuring value is not known.

2 The ampere-range switch should not be changed when the clamp is closed.

3 Before taking any measurement make sure the indication is at zero on the scale.

4 Do not clamp on a bare conductor for current measurement.

5 Seating of the core should be perfect.

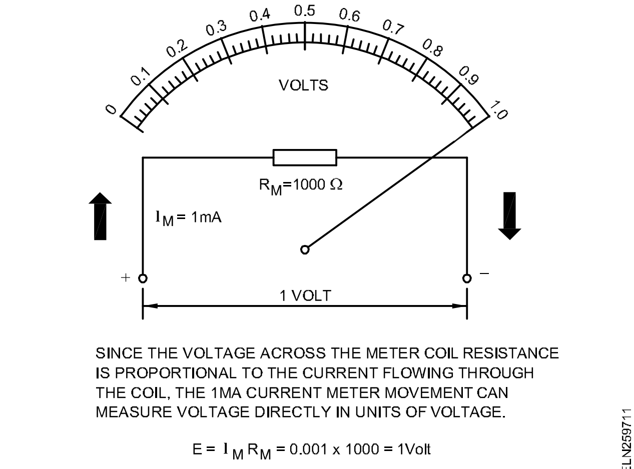
Extension of range of MC voltmeters - loading effect - voltage drop effect

Objectives: At the end of this lesson you shall be able to
- **state the function of the additional series resistance in a voltmeter**
- **calculate the value of the total resistance of the meter with respect to voltage and full scale deflection of current**
- **determine the resistance of a multiplier.**

Meter movement: A basic current meter movement by itself can be used to measure voltage. You know that every meter coil has a fixed resistance, and, therefore, when current flows through the coil, a voltage drop will be developed across this resistance. According to Ohm's Law, the voltage drop (E) will be proportional to the current flowing through the coil of resistance R (E = IR).

For example, in Fig 1 you have a 0-1 milliampere meter movement with a coil resistance of 1000 ohms. When 1 milliampere is flowing through the meter coil and is causing f.s.d. the voltage developed across the coil resistance will be:

Fig 1



$E = I_M R_M = 0.001 \times 1000 = 1$ volt.

If only half that current (0.5 milliampere) was flowing through the coil, then the voltage across the coil would be:

$E = I_M R_M = 0.0005 \times 1000 = 0.5$ volt.

It can be seen that the voltage developed across the coil is proportional to the current flowing through the coil. Also, the current that flows through the coil is proportional to the voltage applied to the coil. Therefore, by calibrating the meter scale in units of voltage instead of in units of current, the voltage in various parts of a circuit can be measured.

Although a current meter movement inherently can measure voltage, its usefulness is limited because the current that the meter coil can handle, as well as its coil resistance, are very low. For example, the maximum voltage you could measure with the 1 milliampere meter movement in the above example is 1 volt. In actual practice, voltage measurements higher than 1 volt will be required.

Multiplier resistors: Since a basic current meter movement can only measure very small voltages, The voltage range of a meter movement can be extended by adding a resistor, in series. The value of this resistor must be such that, when added to the meter coil resistance, the total resistance limits the current to the full-scale current rating of the meter for any applied voltage.

For example, suppose one wanted to use the 1-milliampere, 1000-ohms meter movement to measure voltages up to 10 volts. From Ohm's Law, it can be seen that, if the movement is connected across a 10-volt source, 10 milliamperes would flow through the movement and would probably ruin the meter (I = E/R = 10/1000 = 10 milliamperes).

But the meter current can be limited to 1 milliampere if a multiplier resistor (R_{MULT}) is added in series with the meter resistance (R_M). Since a maximum of only 1 milliampere can flow through the meter, the total resistance of the multiplier resistor and the meter ($R_{TOT} = R_{MULT} + R_M$) must limit the meter current to one milliampere. By Ohm's Law, the total resistance is

$$R_{TOT} = E_{MAX}/I_M = 10 \text{ volts}/0.001 \text{ ampere} = 10{,}000 \text{ ohms.}$$

But this is the total resistance needed. Therefore, the multiplier resistance is

$$R_{MULT} = R_{TOT} - R_M = 10000 - 1000 = 9000 \text{ ohms.}$$

The basic 1-milliampere, 1000-ohms meter movement can now measure 0-10 volts, because 10 volts must be applied to cause a full-scale deflection. However, the meter scale must now be re-calibrated from 0-10 volts, or, if the previous scale is used all the reading should be multiplied by 10 (Fig 2).

Multiplying factor (M.F)

$$MF = \frac{\text{Proposed voltmeter range (V)}}{\text{Voltage drop across MC at FSD}} = \frac{V}{v}$$

Calculating the multiplier resistance using M F

$R_{MULT} = (MF - 1)\ R_M$

where

R_{MULT} = Multiplier resistance

M F = Multiplying factor

R_M = Meter resistance

A 1 mA meter has a coil resistance of 1000 ohms. What value of multiplier resistor is needed to measure 100V?

$$MF = \frac{V}{v}$$

$$v = I_M \times R_M$$

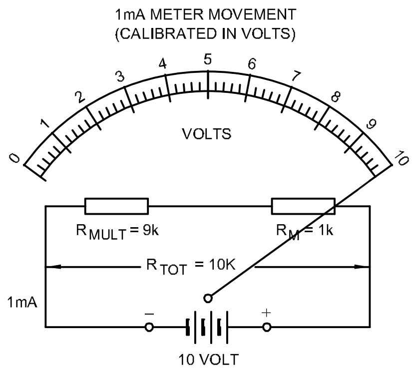
$$= 1 \times 10^{-3} \times 1000 = 1V$$

$$MF = \frac{V}{v} = \frac{100}{1} = 100$$

$$R_{MULT} = (MF - 1)R_M = (100 - 1)1000$$

$$= 99{,}000 \text{ ohms.}$$

Fig 2

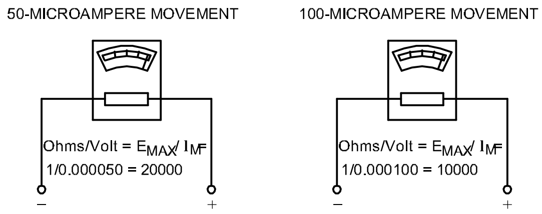


BY CONNECTING A MULTIPLIER RESISTOR IN SERIES WITH THE METER RESISTANCE, THE RANGE OF A BASIC METER MOVEMENT CAN BE EXTENDED TO MEASURE VOLTAGES HIGHER THAN THE $I_M\ R_M$ VOLTAGE DROP ACROSS THE METER COIL.

ELN259712

Sensitivity of voltmeter: An important characteristic of any voltmeter is its impedance or ohms per volt (ohms/volt) rating. Ohms/volt rating is the voltmeter sensitivity. The ohms/volt rating is defined as the resistance required ($R_M + R_{MULT}$) for full scale deflection. For example, the 1mA 1000 ohms meter movement indicates 1 volt at full scale deflection. Therefore its `ohm/volt' rating is 1000/1 or 1000 ohms/volt (Fig 3) ohms/volt = E_{MAX}/I_M.

Fig 3



THE VOLTMETER ON THE LEFT IS MORE SENSITIVE THAN THE ONE ON THE RIGHT BECAUSE IT OFFERS MORE RESISTANCE TO OBTAIN A DEFLECTION OF 1 VOLT; OR, TO PUT IT ANOTHER WAY, IT REQUIRES LESS CURRENT FROM THE CIRCUIT IT IS MEASURING FOR FULL-SCALE DEFLECTION.

ELN259713

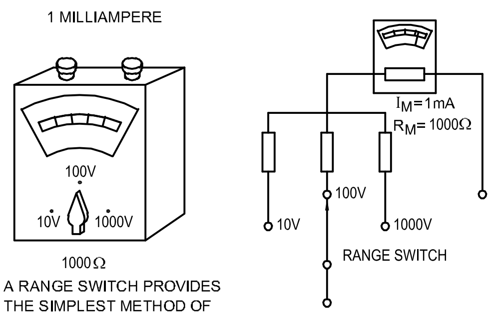
Multi-range voltmeters: In many types of equipment, one encounters voltages from a few tenths of a volt up to hundreds, and even thousands, of volts. To use single-range meters in these cases will be impractical, and costly. Instead, multi-range voltmeters that can measure several ranges of voltage, can be used.

A multi-range voltmeter contains several multiplier resistors that can be connected in series with the meter movement. A range switch is used to connect the proper resistor, or resistors, for the desired range (Fig 4). Also, in some cases, separate terminals for each range are mounted on the meter case (Fig 5).

The resistance of the multiplier should not change with temperature. Therefore, the material used for multipliers should have very low temperature coefficient of resistance. The temperature co-efficient of resistance of Manganin and Constantan are 0.000015 and 0.00001 respectively. Therefore, Manganin and Constantan are used for multipliers.

Fig 4

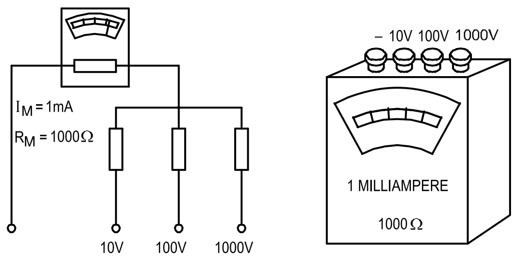
THE RANGE OF THIS 1mA, 1000 METER MOVEMENT, WHICH CAN MEASURE ONLY 0-1 VOLT, HAS BEEN EXTENDED TO MEASURE 0-10, 0-100, AND 0-1000 VOLTS BY USING MULTIPLIER RESISTORS FOR EACH RANGE.



A RANGE SWITCH PROVIDES THE SIMPLEST METHOD OF SETTING THE METER TO THE DESIRED RANGE.

ELN259714

Fig 5



SOME METERS HAVE SEPARATE TERMINALS FOR SETTING THE METER TO THE DESIRED RANGE.

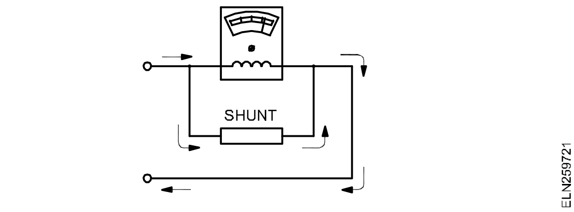
ELN259715

Extension of range of MC ammeters

Objectives: At the end of this lesson you shall be able to
- **define shunt used in ammeter**
- **calculate a shunt resistance to extend the range of an ammeter**
- **name the material used for shunt**
- **apply the use of terminals in standard shunts.**

Shunts: Moving coils of basic meters by themselves cannot carry large currents, since they are made of fine wire. To measure a current greater than that which the moving coil can carry, a low resistance, called a SHUNT, is connected across the instrument terminals (Fig 1).

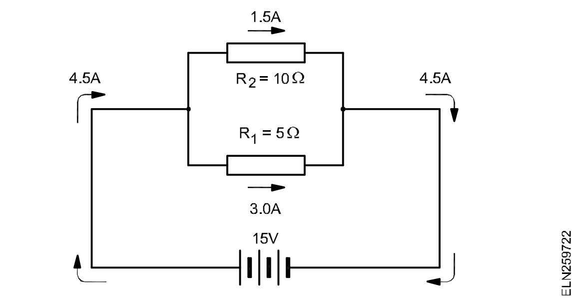
Fig 1



The shunt, therefore, makes it possible to measure currents much greater than that could be measured by the basic meter alone.

The current through each resistor is inversely proportional to its resistance; that is, if one resistor has twice the resistance of another, the current flowing through the larger resistor will be half the current through the smaller one. (Fig 2)

Fig 2



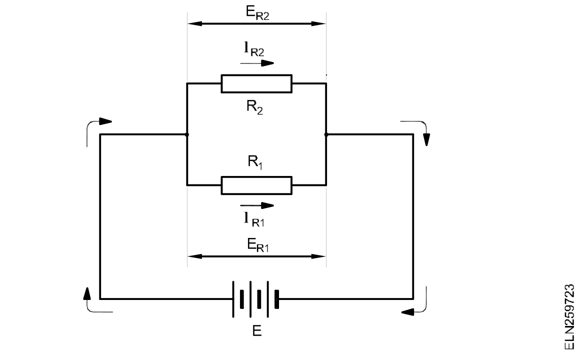
Current flow divides between two resistors parallel in a ratio inversly proportional to their resistance.

Resistor R_2 is twice as large as resistor R_1. Therefore, the current through R_2 will be one-half the current through R_1.

Every meter coil has definite DC resistance. When a shunt is connected in parallel with the coil, the current will divide between the coil and the shunt, just as it does between any two resistors in parallel. By using a shunt of proper resistance, the current through the meter coil will be limited to the value that it can safely handle, and the remainder of the current will flow through the shunt.

Voltage drops in parallel circuits: Examine the parallel circuit shown in Fig 3. It can be seen that the voltage across both resistors is the same. As already explained Ohm's Law states that the voltage across a resistor equals the current through the resistor times the value of the resistor.

Fig 3



Since the same voltage appears across R_1 and R_2 then $E_{R1} = E_{R2}$. From this we derive $I_{R1}R_1 = I_{R2}R_2$. This equation can be used to calculate the shunt needed for a particular current measurement.

Therefore, the voltage across R_1 is $E_{R1} = I_1R_1$ and the voltage across R_2 is

$$E_{R2} = I_2R_2.$$

However, since the same voltage is across both R1 & R2 then

$$E_{R1} = E_{R2}, \text{ therefore,}$$

$$I_{R1}R_1 = I_{R2}R_2.$$

This simple equation, with very slight modifications, can be used to calculate the value of a shunt for a current meter for any application.

The shunt equation: A meter and shunt combination is identical to the parallel circuit shown in Fig 4. Instead of labelling the top resistor R_2, it can be labeled R_M, which represents the resistance of the moving coil. Resistor R_1 can be labelled R_{SH} to represent the resistance of the shunt. I_{R1} and I_{R2} then become I_{SH} and I_M to indicate the current flow through the shunt and through the meter. This means that the equation $I_{R1}R_1 = I_{R2}R_2$ can now be written as $I_{SH}R_{SH} = I_MR_M$.

Therefore, if three of these values are known, the fourth can be calculated. Since the shunt resistance R_{SH} is always the unknown quantity, the basic equation

$$I_{SH}R_{SH} = I_M R_M \text{ becomes } R_{SH} = \frac{I_M R_M}{I_{SH}}$$

From this equation, shunts can be calculated to extend the range of a current meter to any value,

where R_{SH} = shunt resistance

I_M = meter current

R_M = resistance of moving coil instrument

I_{SH} = current flow through shunt.

The value of current through the shunt(I_{SH}) is simply the difference between the total current you want to measure, and the actual full-scale deflection of the meter.

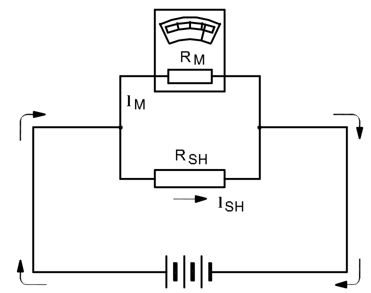
$I_{SH} = I - I_M$ where I = total current.

The meter and shunt act like R_1 and R_2 in parallel.

So, $R_{SH} = \frac{I_M R_M}{I_{SH}}$

Calculating shunt resistance: Assume that the range of a one milliampere meter movement is to be extended to 10 milliamperes, and the moving coil has a resistance of 27 ohms. Extending the range of the meter to 10 milliamperes means that 10 milliamperes will be flowing in the overall circuit when the pointer is deflected full scale. (Fig 5)

Fig 4



THE METER AND SHUNT ACT LIKE R_1 AND R_2 IN PARALLEL. SO, $R_{SH} = \frac{I_M R_M}{I_{SH}}$

I_M = 1 mA (0.001 A)

I = Current to be measured = 10mA

R_M = 27 Ohms

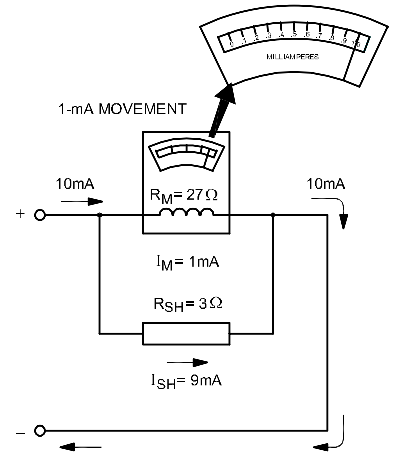
$I_{SH} = I - I_M$ = 10 mA – 1 mA

= 9 mA (0.009 A)

$$R_{SH} = \frac{I_M R_M}{I_{SH}} = \frac{0.001 \times 27}{0.009} = 3 \text{ ohms.}$$

Shunt material: The resistance of shunt should not vary due to the temperature. The shunt is usually made of Manganin which has negligible temperature coefficient of resistance. A high current shunt of a switch board instrument is shown in Fig 6.

Fig 5

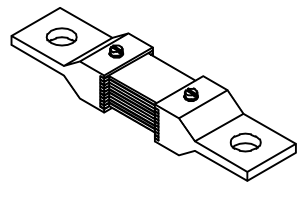


THE RANGE OF THIS 1-MILLIAMPERE METER MOVEMENT WAS EXTENDED TO 10 MILLIAMPERES BY USING THE SHUNT EQUATION $R_{SH} = \frac{I_M R_M}{I_{SH}}$

Multi-range ampere meters: In only some applications, it is practical to use an ampere meter having only one range; for example, only 0-1 ampere or 0-100 milliamperes, 0-10 ampere, and so on.

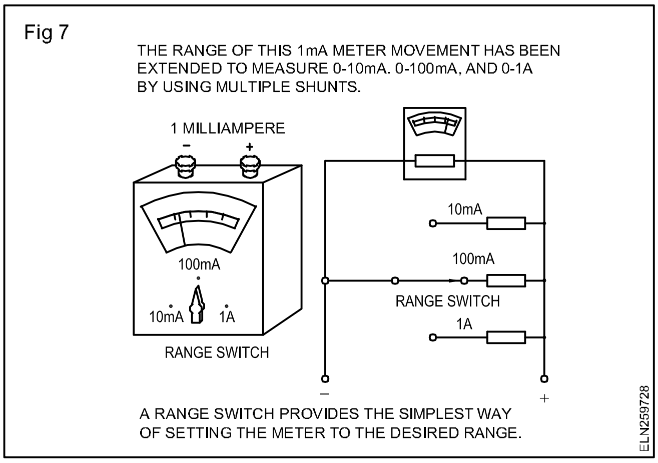
In many places, particularly when trouble shooting, it would be impractical to use a number of separate ampere meters to measure all of the currents encountered in a piece of equipment. In these cases, a multi-range ampere meter is used. (Fig 7)

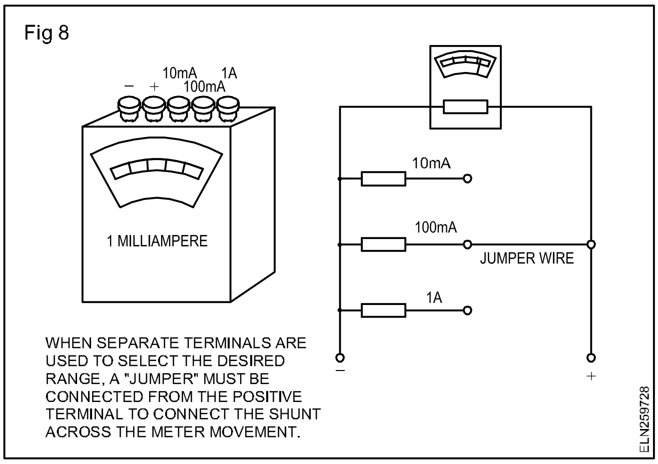
Fig 6



HIGH CURRENT SHUNT FOR A SWITCHBOARD INSTRUMENT

A multi-range ampere meter is one containing a basic meter movement and several shunts that can be connected across the meter movement. A range switch is usually used to select the particular shunt for the desired current range. (Fig 7) Sometimes, however, separate terminals for each range are mounted on the meter case. (Fig 8).





Calibration of MI Ammeter and Voltmeter

Objectives: At the end of this lesson you shall be able to
- **define the term 'calibration' and standards accuracy precision,resolution and sensitivity**
- **explain the calibration of voltmeter and ammeter**
- **state precaution to be observed during using ammeter and voltmeter.**

In many industrial operations, measurement instruments must be trusted to provide the accuracy stipulated by the original design to assure a satisfactory product. This confidence is provided by a periodic testing and adjustment of the instrument to verify the required performance. This type of maintenance is called calibration.

Standards

Before calibration can begin, you must have the accurately known values of the measured quantities against which to compare the measurements made by the instrument being calibrated. Thus, for an instrument that is supposed to measure current of 1 milli ampere, you must have, for comparison, a source of current that is known to within at least that range or better. Only then you can say whether the instrument performs satisfactorily.

A very accurately known quantity used for calibration of instruments is known as a standard.

Calibration standards	
Quantity	**Standard**
Voltage	Standard cell, high precision source
Current	Voltage standard and standard resistance standard milli volt source, gas filled/ mercury filled thermometers.
Pressure	Dead weight tester, Standard Hg monometer, sub standard pres sure gauges, pneumatic calibrator

Accuracy

Accuracy is defined as the ability of a device to respond to a true value of a measured variable under reference conditions. Accuracy is usually expressed as a percent uncertainty with reference to some part of measurement.

Precision

The term precision refers to the ability of the measuring instrument to agree with itself repeatedly.

Resolution

The resolution of a measurement system refers to the minimum detectable change in the measured variable.

Sensitivity

Sensitivity can be defined as the ratio of a change in output to the change in input causes it.

CALIBRATING DC AND AC METERS (AMMETER & VOLTMETER)

Both DC and AC meters are calibrated in essentially the same way. To calibrate a DC meter, a very accurate DC current source is connected to the meter. The output of the current source must be variable, and some means must be available to monitor the output current of the source. Many sources have built-in meter for this purpose.

The output of the current source is varied in very small steps, and at each step the scale of the meter being calibrated is marked to correspond to the reading on the monitoring device. This procedure is continued until the entire scale of the meter is calibrated.

Same procedure is used to calibrate an AC meter, except that a 50/60 cps sine wave is used mostly. Also, you know that an a-c meter reads the average value of a sine wave, but it is desirable for the meter to indicate rms values. Therefore the rms equivalent are calculated and marked on the scale.

Thermocouple meters are calibrated on the basis of a sine wave. But the calibration is made at the frequency at which the meter will be used. At the extremely high frequencies at which it is used, a phenomenon known as skin effect occurs.

At these frequencies, the current in a wire travels at the surface of the wire, the higher the frequency, the closer the current moves to the surface of the wire. This effect increases the resistance of the thermocouple heater wire because the diameter of the wire becomes, in effect, smaller.

Thus the resistance of the heater wire varies with frequency. Since the resistance of the heater wire varies with frequency, thermocouple meters must be calibrated at specific frequencies.

METER ACCURACY

METER	TYPICAL ACCURACY
Moving coil	0.1 to 2%
Moving iron	5%
Rectifier type moving coil	5%
Thermocouple	1 to 3%

Precautions to be observed when using an ammeter in measurement work

1 Never connect an ammeter across a source of EMF. Because of its low resistance it would draw damaging high currents and damage the delicate movement. Always connect an ammeter in series with a load capable of limiting the current.

2 Observe the correct polarity. Reverse polarity causes the meter to deflect against the mechanical stop and this may damage the pointer.

3 When using a multi range meter, first use the highest current range, then decrease the current range until substantial deflection is obtained. To increase the accuracy of the observation, use the range that will give a reading as near to full scale as possible.

The following general precautions should be observed when using a Voltmeter

1 Observe the correct polarity. Wrong polarity causes the meter to deflect against the mechanical stop and this may damage the pointer.

2 Place the voltmeter across the circuit or component whose voltage is to be measured.

3 When using a multi range voltmeter, always use the highest voltage range and then decrease the range until a good up scale reading is obtained.

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

Loading effect of voltmeter and voltage drop effect of ammeter in circuits

Objectives: At the end of the lesson you shall be able to
- **define the term 'multiplier'**
- **analyse the effect of sensitivity/resistance across the terminals of a voltmeter,while measuring resistance by the voltage drop method (loading effect of the voltmeter)**
- **solve simple problems pertaining to the loading effect of voltmeter**
- **analyse the effect of voltage drop across the ammeter in the resistance measurement.**

Multipiler

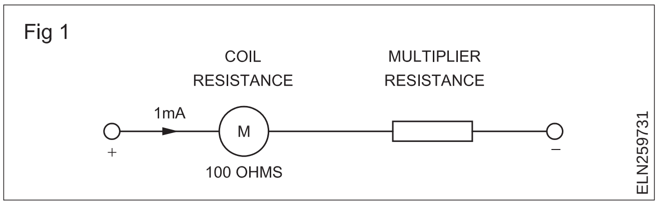
In the case of P.M.M.C. instruments, we have seen that the moving coil consists of fine gauge copper wire. This copper wire can carry very low current in the order of milli or micro amperes only.

The acceptable current which enables the instrument to read full scale is called full scale deflection current or F.S.D. current. When such a P.M.M.C. instrument is to be converted as a voltmeter, the moving coil has to be connected with a high resistance in series so that the current could be restricted within the F.S.D. current value. This series resistance is called **multiplier** resistance.

Example: A P.M.M.C. instrument with an internal resistance (coil resistance) of 100 ohms has full scale deflection current of 1mA. This instrument has to be converted as a voltmeter to measure 10V.

Calculate the value of the multiplier resistance.

Referring to Fig 1, for 10V range, the safe current which could be allowed through the coil will be = 1mA.



As such the total resistance between the terminals of the 10V voltmeter should be

$$R_T = \frac{\text{Volts}}{\text{FSD current}} = \frac{10V}{\frac{1}{1000}} \text{ amps.}$$

$$= 10000 \text{ ohms.}$$

The value of the coil resistance = 100 ohms

The value of multiplier resistance

$$R_{Multiplier} = R_{Total} - R_{coil\ resistance}$$

$$= 10000 - 100 = 9900 \text{ ohms.}$$

From the above it is clear that the current through the P.M.M.C. instrument cannot be more than the FSD current, and, if the current in the meter exceeds the FSD current, the meter may burn out. The ratio between the set voltage range and the resistance of the voltmeter is called the sensitivity or ohms per volt rating of the voltmeter.

Therefore

$$\text{Sensitivity 'S'} = \frac{\text{Resistance between terminals of the voltmeter}}{\text{Range of voltmeter}}$$

In the above example we have sensitivity

$$= \frac{10000}{10} = 1000 \text{ ohms / volt.}$$

Note that the sensitivity S is essentially the reciprocal of the full scale deflection current of the basic meter movement.

$$S = \frac{1}{I_{FSD}} = \frac{1}{1mA} = \frac{1}{\frac{1}{1000}} \text{ ohms/volt}$$

$$= 1000 \text{ ohms/volt.}$$

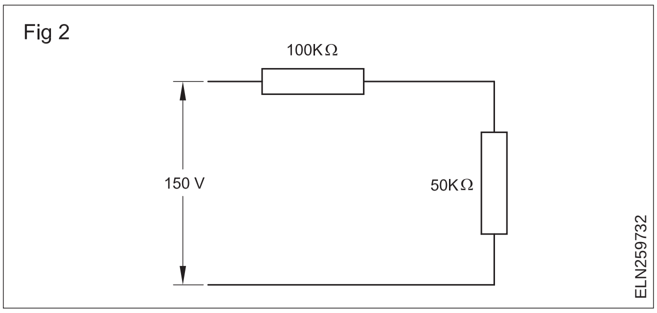
Let us study how the voltmeter sensitivity causes loading effect in the circuit by the voltmeter.

Loading effect of a voltmeter: The sensitivity of a voltmeter is an important factor when selecting a meter for a certain voltage measurement. A low sensitivity voltmeter may give an almost correct reading when measuring voltages in low-resistance circuits, but it is certain to produce very high errors in high resistance circuits. It is due to the fact that the voltmeter, when connected across a high resistance circuit, acts as a shunt for that portion of the circuit, and, thereby, reduces the equivalent resistance in that portion of the circuit.

As such, the meter will then give a lower indication of the voltage drop than what actually existed before the meter was connected. This effect is called the loading effect of a voltmeter and it is caused principally by the low sensitivity of the voltmeter.

The loading effect of a voltmeter could be explained through the following example.

Example: It is desired to measure the voltage across the 50-k ohm resistor in the circuit of Fig 2. Two voltmeters are available for this measurement, voltmeter 1 with a sensitivity of 1,000 ohms/V and voltmeter 2 with a sensitivity of 20,000 ohms/V. Both meters are used on their 50 V range.



Calculate (i) the reading of the meters (ii) the error in each reading, expressed as a percentage of the true value.

Solution

An inspection of the circuit indicates that the voltage across the 50-k ohm resistor

$$V_1 = \frac{50k \text{ ohm}}{150k \text{ ohm}} \times 150V = 50V$$

This is the true value of the voltage across the 50-k ohm resistor.

Voltmeter 1 (S=1,000 ohm/V)has a resistance of 50V x 1,000 ohm/V = 50-k ohm on its 50V range. Connecting the meter across the 50-k ohm resistor (Fig 3) causes the equivalent parallel resistance to be decreased to 25k Ohm, and the total circuit resistance to 125 kilo ohms (Fig 4).The potential difference across the combination of the meter and the 50-k ohms resistor is

$$V_1 = \frac{25k \text{ ohm}}{125k \text{ ohm}} \times 150V = 30V$$

Hence, the voltmeter indicates a voltage of 30V instead of the actual 50V.

Fig 3

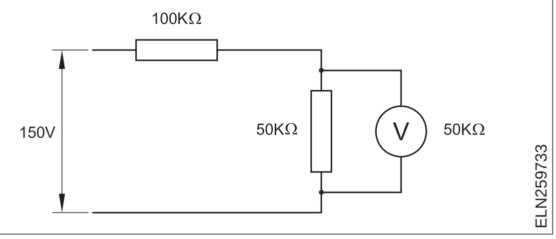
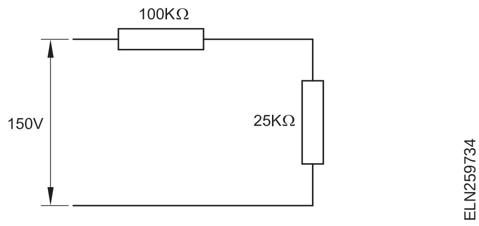
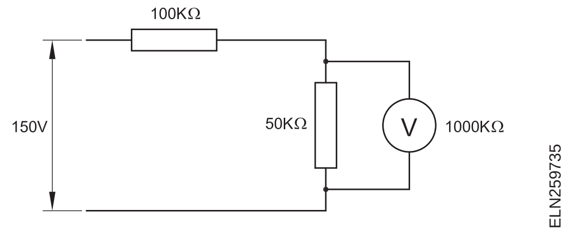


Fig 4



Voltmeter 2 (S=20k ohm/V) has a resistance of 50V x 20k ohm/V = one megohm on its 50V range. When this meter is connected (Fig 5) across the 50-k ohm. the equivalent parallel resistance equals 47.6k ohm.

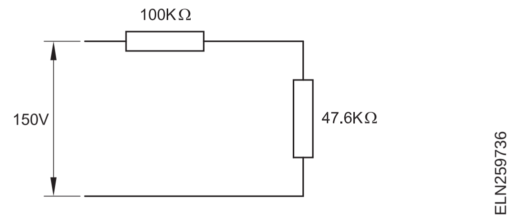
Fig 5



The total resistance of the circuit will be 147.6k ohm (Fig 6).

This combination produces a voltage of

Fig 6



$$V_2 = \frac{47.6\text{k ohm}}{147.6\text{k ohm}} \times 150\text{V} = 48.36\text{V}$$

which is indicated on the voltmeter instead of the actual 50V.

The error in the reading of voltmeter 1.64V

$$\%\text{error} = \frac{\text{true voltage - apparent voltage}}{\text{true voltage}} \times 100$$

$$= \frac{50\text{V} - 30\text{V}}{50\text{V}} \times 100 = 40\%$$

The error in the reading of voltmeter 2 is

$$= \frac{50\text{V} - 48.36\text{V}}{50\text{V}} \times 100 = 3.28\%.$$

The calculation of the error in the example indicates that the meter with the higher sensitivity of ohms/volt rating gives the most reliable result. It is important to realize the factor of sensitivity, particularly when voltage measurements are made in high-resistance circuits. Hence the following points are required to be followed while using a voltmeter.

- When using a multi-range voltmeter, always use the highest voltage range, and then decrease the range until a good up-scale (above mid-scale) reading is obtained.
- Always be aware of the loading effect. This effect can be minimised by using a voltmeter of high sensitivity and highest range in voltmeter.
- Before reading the meter, try to select a range in the multi-scale instrument such that the reading obtained is above mid-scale. The precision of the measurement decreases if the indication is at the low end of the scale.

Effect of voltage drop across the ammeter in resistance measurement: The ammeter/voltmeter method of measuring resistance is very popular since the instrument required for this is usually available in the laboratory.

In this method, two types of connections of meters are possible (Figs 7a and b).

Fig 7a

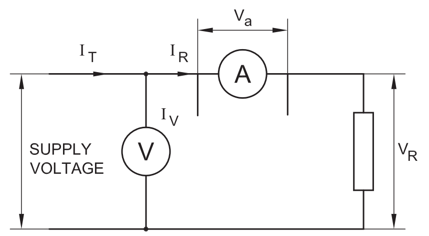
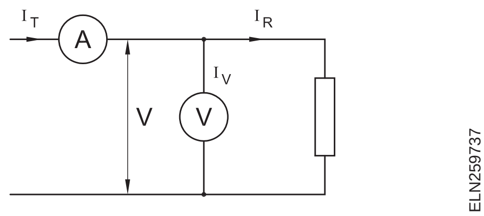


Fig 7b



In both the cases, if readings of the ammeter and voltmeter are taken, then the measured value of resistance is given by

$$R_m \frac{\text{Voltmeter reading}}{\text{Ammeter reading}} = \frac{V}{I}$$

The measured value of resistance R_m, would be equal to the true value R, provided the ammeter resistance is zero and the voltmeter resistance is infinite, to make the circuit condition undisturbed.

However, in practice this is not possible, and hence, both the methods give inaccurate results. But the error in measurement could be reduced under different values of resistance to be measured as explained below.

Circuit (Fig 7a): In this circuit, the ammeter measures the true value of the current through the resistor. But the voltmeter does not read the true voltage across the resistance. On the other hand, the voltmeter measures the voltage drop across the resistance and also the ammeter.

Let R_a be the resistance of the ammeter.

Then the voltage drop across the ammeter $V_a = IR_a$

$$R_{mt} = \frac{V}{I} = \frac{V_R + V_a}{I_R} = \frac{IR + IR_a}{I_R}$$

$$= R + R_a \text{ ....Eqn.(1)}$$

true value of resistance $R = R_{m1} - R_a$ ... Eqn.(2)

From equation 2, it is clear that the measured value of resistance is higher than the true value. It is also clear from the above equation, that the true value is equal to the measured value only if the ammeter resistance R_a is zero.

$$\text{Relavtive error } e_r = \frac{R_{m1} - R}{R}$$

$$e_r = \frac{R_{m1} - (R_{m1} - R_a)}{R}$$

$$= \frac{R_a}{R} \text{ ....Eqn.(3)}$$

Conclusion: From equation 3, it is clear that the error in measurement would be small if the value of resistance under measurement is large as compared to the internal resistance of the ammeter. Therefore, the circuit shown in Fig 7(a) is most suitable for measuring high resistance values only.

Circuit (Fig 7b): In this circuit the voltmeter measures the true value of the voltage across the resistance but the ammeter measures the sum of currents through the resistance and the voltmeter.

Let R_V be the resistance of the voltmeter. Then the current through the voltmeter

$$I_V = \frac{V}{R_V}$$

Measured value of the resistance

$$R_{m2} = \frac{V}{I} = \frac{V}{I_R + I_V}$$

$$R_{m2} = \frac{V}{\frac{V}{R} + \frac{V}{R_V}} \text{ .....Eqn.(4)}$$

By multiplying the denominator and numerator by $\frac{R}{V}$, Eqn.(4) becomes

$$R_{m2} = \frac{R}{1 + \frac{R}{R_V}} \text{ .....Eqn.(4)}$$

From equation 4, it is clear that the true value of resistance is equal to the measured value only if

- the resistance of the voltmeter R_V is infinite
- the resistance to be measured 'R' is very small when compared to the resistance of the voltmeter.

$$\text{Relative error } e_r = \frac{R_{m2} - R}{R}$$

By elimination process, we get

$$e_r = \frac{R_{m2} - R}{R} \text{ ...Eqn.(5)}$$

The value of R_{m2} is approximately equal to R.

$$\text{Therefore } e_r = \frac{-R}{R_V} \text{ .....Eqn.(6)}$$

Conclusion: From equation (6), it is clear that the error in measurement would be small if the value of resistance under measurement is very small as compared to the resistance of the voltmeter. Hence the circuit shown in Fig 7(b) should be used when measuring resistances of a lower value.