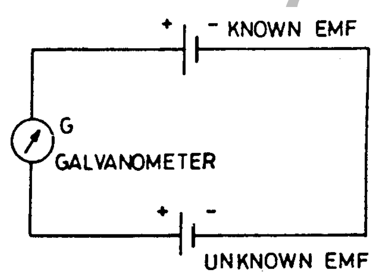
Electrical Measurements

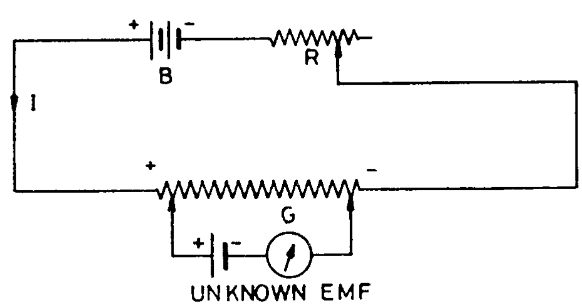
Potentiometers

The potentiometer is an instrument used for measurement of an unknown emf or potential difference by balancing it, wholly or partly by a known potential difference produced by the flow of a known current in a network of circuits of known characteristics. Potentiometers are extensively used in measurements where the precision required is higher than that can be obtained by ordinary deflection instruments or where it is important that no current be drawn from the source under test or where this current must be limited to a small value. Emfs are measured directly with a potentiometer in terms of the emf of a standard resistor, current can also be measured. From potentiometer measurements of voltage and current, power can be calculated and if time is also measured energy can be determined. The potentiometer is thus one of the most fundamental instruments of electrical measurements and is the means by which current, voltage, power and energy can be referred back to the basic electrical units.

The potentiometer works on the principle of opposing the unknown emf by a known emf with the negative terminals of the two emfs connected together and also the positive terminals connected together through a galvanometer as shown in figure.



Galvanometer gives no deflection if the two emfs are equal. For determination of unknown emfs by the method described above the known emf should be such that it can be varied to give a large number of known values, but this requirement cannot be met with the arrangement shown in figure. The alternative arrangement is to connect unknown emf in parallel with and in opposition to a voltage drop in the resistor as shown in figure.



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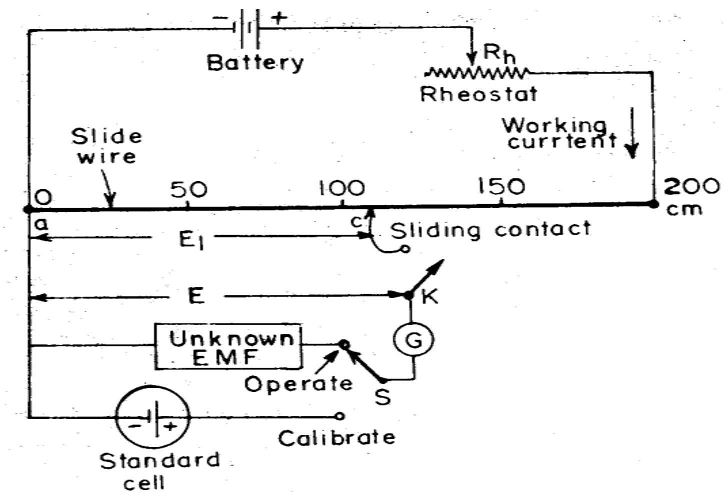
In this arrangement it is very simple to vary the current in the resistor and thus obtain with very fine adjustment any desired voltage. The foregoing voltage drop may be determined by calibrating the resistor with a standard cell.

Basic Potentiometer Circuit:



The principle of operation of all potentiometers is based on the circuit which shows the schematic diagram of the basic slide wire potentiometer.

With switch ‘S’ in the ‘operate’ position and the galvanometer key open the battery supplies the ‘*working current*’ through the rheostat R_h and the slide wire. The working current through the slide wire may be varied by changing the rheostat setting. The method of measuring the unknown voltage E, depends upon finding a position for the sliding contact such the galvanometer shows the zero deflection i.e. indicates null condition; when the galvanometer key K, is closed. Zero galvanometer deflection or a null condition means that the unknown voltage, E is equal to the voltage drop E_1 across portion ac of the slide wire. Thus determination of the value of unknown voltage now becomes a matter of evaluating the voltage drop E_1 along the portion ac of the slide wire.

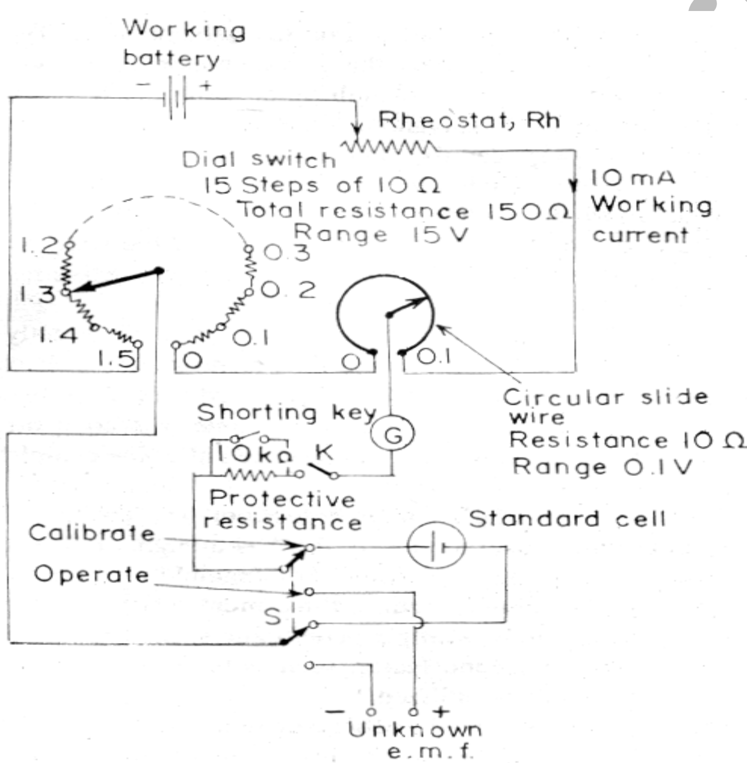
The slide wire has a uniform cross section and hence uniform resistance along its entire length. A calibrated scale in cm and fractions in cm is placed along the slide wire so that the sliding contact can be placed accurately at any desired position along the slide wire. Since the resistance of slide wire is known accurately the voltage along the slide wire can be controlled by adjusting the value of working current. The process of adjusting the working current so as to match the voltage drop across a portion of sliding wire against a standard reference source is known as *‘Standardisation’*.

Standardisation:

The slide wire of the figure has a total length of 200cm and a resistance of 200Ω. The emf of the standard cell is 1.0186V. Switch ‘S’ is thrown to ‘*calibrate*’ position and the sliding contact is placed at 101.86cm mark on the slide wire scale. The rheostat R_h is now adjusted so as to vary the working current. The adjustment is carried on till the galvanometer shown no deflection when key ‘K’ is pressed. Under these conditions the voltage drop along the 101.86cm portion of the slide wire is equal to standard cell voltage of 1.0186V. Since the 101.86cm portion of the slide wire has a resistance of 101.86Ω, the working current in fact has been adjusted to a value $\frac{1.0186}{101.86} \times 1000 = 10mA$

The voltage at any point along the slide wire is proportional to the length of the slide wire. This voltage is obtained by converting the calibrated length into the corresponding voltage, simply by placing the decimal point in the proper position e.g. 153.6cm = 1.536V. If the potentiometer has been calibrated once, its working current is never changed.

Laboratory type (Crompton’s) Potentiometer:



The slide wire type of potentiometer is not a practical form of construction. The long slide wire is awkward and even for the length shown cannot be read to a very great degree of precision. Modern laboratory type potentiometers use calibrated dial resistors and a small circular wire of one or more turns thereby reducing the size of the instruments. The circuit of a simple laboratory type potentiometer as shown in above figure. There is one dial switch with fifteen steps each having a precision resistor. There is also a single turn circular slide wire. For the case shown the resistance of slide wire is 10Ω and the dial resistors have a value of 10Ω each. Thus the dial has a total resistance of 150Ω and in addition the slide wire has a resistance of 10Ω. The working current of the potentiometer is 10mA and therefore each step of dial switch

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corresponds to 0.1V. The slide wire is provided with 200 slide divisions and since the total resistance of slide wire corresponds to a voltage drop of 0.1V, each division of slide wire corresponds to 0.1/200 = 0.0005V. It is quite comfortable to interpolate readings up to 1/5 of a scale division and therefore with this potentiometer it is possible to estimate the readings up to 0.0001V.

This potentiometer is provided with a double throw switch which allows the connection of either the standard cell or the unknown emf to be applied to the working circuit A key and a protective resistance (usually about 10KΩ) is used in the galvanometer circuit. In order to operate the galvanometer at its maximum sensitivity provision is made to short the protective resistance when near the balance conditions.

The following steps are used when making measurements with the potentiometer:

1. The combination of dial resistors and the slide wire is set to the standard cell voltage. Supposing the value of emf of standard cell is 1.0186V, the dial resistor is put at 1.0V and the slide wire is put at 0.0186 setting.
2. The switch S is thrown to the calibrate position and the galvanometer key is tapped while the rheostat is adjusted for zero deflection on the galvanometer. The protective resistance is kept in the circuit in the initial stages so as protect the galvanometer from being getting damaged.
3. As the balance or null point is approached to protective resistance is shorted so as to increase the sensitivity of the galvanometer. Final adjustments are made for zero deflection with the help of rheostat. This completes the standardisation process for the potentiometer.
4. After completion of standardisation, the switch 'S' is thrown to operate position thereby connecting the unknown emf into the potentiometer circuit. With the protective resistance in the circuit the potentiometer is balanced by means of the main dial and the slide wire.
5. As the balance is approached the protective resistance is shorted and final adjustments are made to obtain true balance.
6. The value of unknown emf is read off directly from the settings of the dial adjust slide wire.
7. The standardisation of the potentiometer is checked again by returning the switch S to the calibrate position. The dial settings are kept exactly the same as in the original standardisation process. If the new reading does not agree with the old one, a second measurement of unknown emf must be made. The standardisation should be again checked after the completion of measurement. This potentiometer is a form of 'Crompton's Potentiometer'.

Multi-Range Potentiometer:

The single range potentiometer is frequently constructed to cover a range of 1.6V through; of course, it can be designed for any desired voltage within reasonable and practical limits. For example a Crompton's potentiometer is designed to measure voltages up to 1.9V by simply adding three more resistance steps to the main dial.

The circuit of a single potentiometer may be modified in a simple way to add a second range, which is usually by a second factor, such as 0.1 or 0.001; in order that the direct reading features of the original circuit may still be utilized.

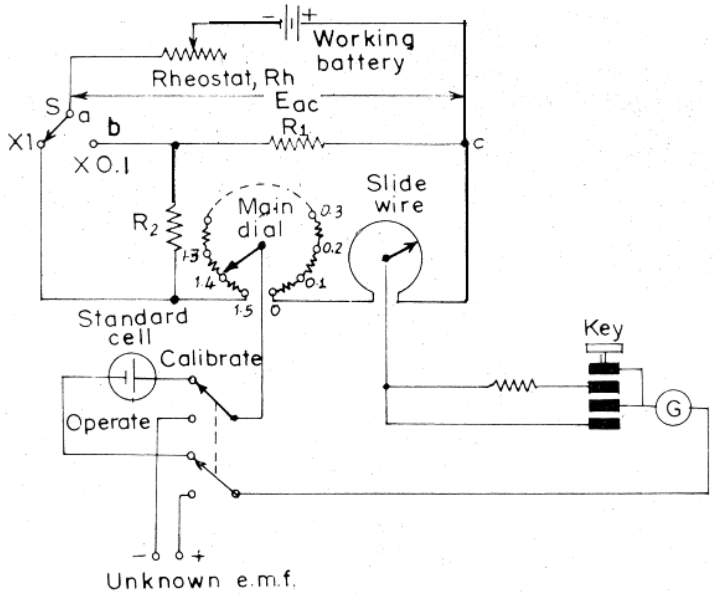


Fig.5. Duo-range potentiometer

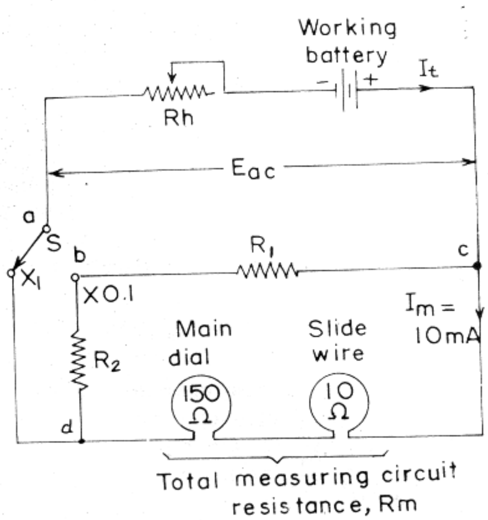


Fig.6. Simplified diagram

In the above figure shows the schematic diagram of a due range (two range) potentiometer. The two ranges are obtained by using two resistors R_1 and R_2 and a range selecting switch S. The operation of due range potentiometer of figure 5 may be more easily understood and analyzed by redrawing in its simplified form by omitting the galvanometer and calibration (standardizing) circuit. The simplified diagram is shown in figure 6.

In figure 6 the total resistance of measuring of circuit, R_m consists of resistance of main dial in series with that of slide wire. The main dial has fifteen steps of 10Ω each and therefore it has a total resistance of 150Ω. The resistance of slide wire is 10Ω. The measuring circuit current I_m must be equal to 10mA in order to produce a voltage drop of 1.6V across the measuring circuit resistance R_m I.e. resistance of the main dial and the slide wire in series. The diagram figure 5 and 6 with the range switch S in ×1 position, represent an identical arrangement as shown in figure 4. When the range switch S is thrown to position ×0.1 the measuring current I_m must be reduced to $\frac{1}{10}$ of its original value i.e. 1mA in order to produce a voltage drop of 0.16V across the measuring circuit resistance R_m.

The design of circuit of a duo range potentiometer should be such that it is possible to change the measuring ranges without re adjusting the rheostat or changing the value of working voltage of the battery. This is essential so that once the instrument has been calibrated on ×1 range, calibration of the ×0.1 range is not necessary. The above requirement means that the voltage E_{ac} in figure 6 remains the same for both position of range switch S. The condition is satisfied only when the total battery current has the same value for each measuring range.

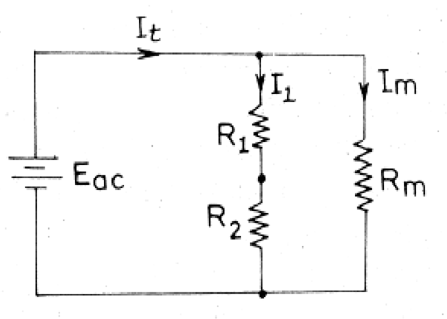


Fig.7. Circuit for X1 range

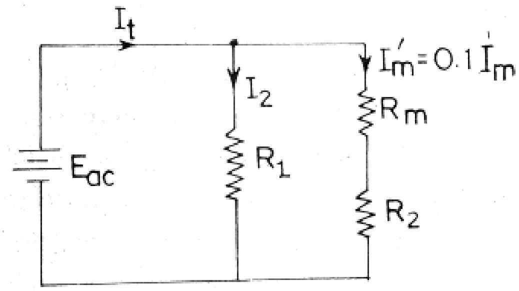


Fig.8. Circuit for X0.1 range

In order to analyses the operation of due range potentiometer figure 6 draw simple circuit diagram for the two ranges. Figure 7 shows the circuit for ×1 range and figure 8 shows the circuit for ×0.1 ranges.

On range ×1 the range resistors R_1 and R_2 in series are in parallel with total measuring resistance R_m. On the ×0.1 range, the range resistor R_1 is in parallel with the series of combination R_2 and R_m.

In order that the total current I_t drawn from the battery is the same, we must have

$$\frac{R_m(R_1+R_2)}{R_1+R_2+R_m} = \frac{R_1(R_m+R_2)}{R_1+R_2+R_m}$$

or, $R_2R_m = R_1R_2$

or, $R_1 = R_m$

This means that range resistance R_1 must equal the resistance of the measuring circuit in order that the total current drawn from the battery is the same for the both the ranges.

Now current through the measuring circuit on ×0.1 ranges should be $\frac{1}{10}$ of the current in the measuring circuit on ×1 range,

This means that $I_m' = 0.1I_m$

Now, $I_m = \frac{E_{ac}}{R_m}$

And $I_m' = \frac{E_{ac}}{R_m+R_2}$

or, $0.1I_m = \frac{E_{ac}}{R_m+R_2}$

$\therefore 0.1(R_m + R_2) = R_m$

$R_2 = 9R_m = 9R_1$

For the circuit of figure 6 where circuit resistance R_m = 160Ω. We have;

$R_1 = R_m = 160\Omega$ and $R_2 = 9R_m = 1440\Omega$.

With this arrangement the total current drawn from the battery is 11mA for each of the two ranges.

The above mentioned potentiometer measures voltage up to 1.6V as ×1 range and up to 0.16V on the ×0.1range. On the lower the dial readings are simply multiplied by the range factor of 0.1 to get the voltage being measured. If the slide wire has 100 scale divisions and each division can be interpole to one fifth of a division the resolutions of the potentiometer are;

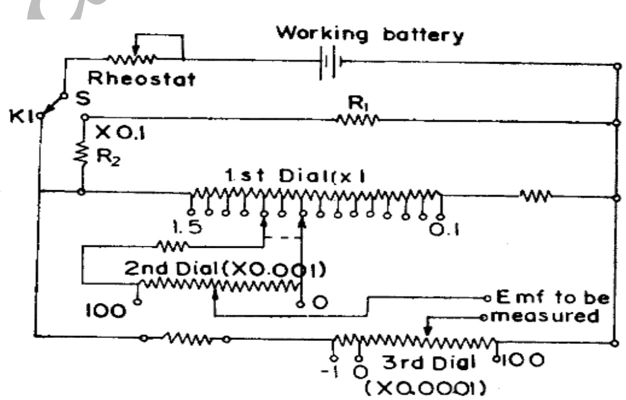
$\frac{1}{5} \times \frac{1}{100} \times 0.01$ V = 20μV, on the ×0.1 range.

The duo range potentiometer has two distinct advantages in having the low range for small voltages:

i. Precision of reading is increased by one decimal place.
ii. A greater part of reading is made on the dial resistors which have inherently a greater accuracy than the slide wire.

<u>Vernier Potentiometer:</u>

The limitations imposed on performance of ordinary potentiometers by slide wire are eliminated in a Vernier potentiometer. The instrument has two ranges: the normal range of 1.6V down to 10μV and a lower range of 0.16V down to 1μV.



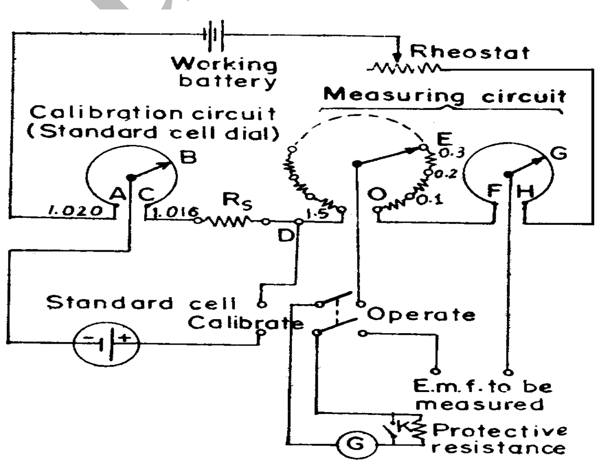
This potentiometer uses the Kelvin Varley arrangement shown in figure. However in this potentiometer there are three measuring dials. The first dial measures up to 1.5V (on the X1 range) in steps 0.1V; the middle dial has 102 studs and reads up to 0.1V in steps of 0.001V; the third dial also has 102 studs and reads from-0.0001V to 0.001V in steps of 0.00001V (i.e. 10μV). There is no slide wire. The resistances of the middle dial shunt two of the coils of first dial. The moving arm of middle dial carries two arms spaced two studs apart. In actual practice the resistance of second dial is greater than that between two studs in the main (first) dial, so that the voltage drop across the second dial is greater than 0.1V. If this is not done the voltage drop in switch contact resistances and leads would render the converge of middle dial to less than 0.1V. The third dial is obtained from a shunt circuit which permits a true zero and a small negative setting to be obtained.

The Vernier potentiometer reads to increment of 0.00001V (10μV) on range X1 and has readability of 1μV on X0.1 range. If a third range of X0.01 is provided, the readability becomes 0.1μV. This does not mean, unfortunately, that small voltages can be read with assurance to 0.1μV. Measurements are subject to stray thermal and contact emfs in the potentiometer, galvanometer and the measuring circuits. These emfs can be minimized only by special construction i.e. proper selection of metals for resistors, terminals and connecting leads and also by the use of thermal shields.

Standard cell dial:

All modern potentiometers incorporate a separate standard cell dial circuit.

This provides a means of standard cell balance resistance to suit the emf value of the particular standard cell used. Also a separate standard cell dial permits the operator to check the standard cell balance at any time during the course of measurement without disturbing the potentiometer setting. In the below figure shown a separate standard cell dial incorporated in a single range potentiometer.

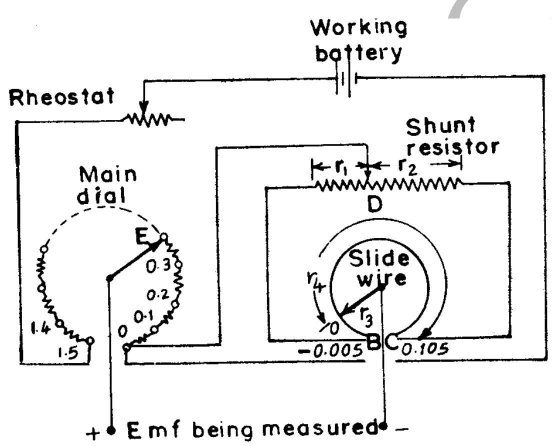


The potentiometer is provided with an independent standardizing circuit AD which can be set on any range of standard cell emf from 1.016V to 1.020V. A drop of 1.016V is provided by resistance R_s and the remaining drop of 0.004V is provided by the slide wire AC. Thus a considerable change in standard cell emf owing to temperature changes can be allowed for the operation of circuit. The slide wire of calibrating circuit is set to read the emf of the standard cell which is connected to the potentiometer. The selector switch S is put at the calibrate position and the rheostat is adjusted, so that there is no current flowing through the galvanometer. This fixes the working current to its proper value. The switch S is then thrown to the operate position and unknown emf is read by adjusting the measuring circuit dial and slide wire.

The standardizing circuit may be checked for constancy of working current any time during the measurements by simply throwing the switch S back to calibrate position. This process does not disturb the measuring circuit while convenience and speed of measurements is increased.

True Zero:

In the student type potentiometer it is impossible to obtain true zero because the two contacts cannot coincide absolutely. The drawback is eliminated in the simplified circuit.



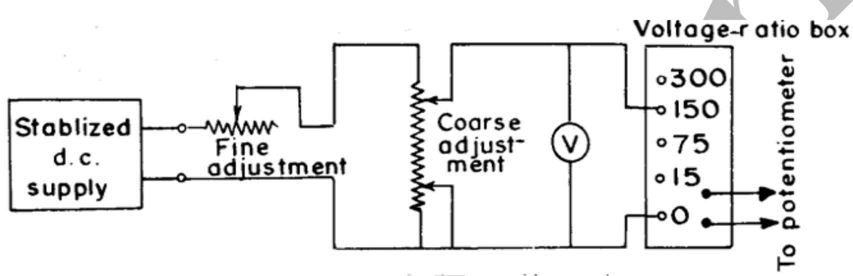
The slide wire BC is provided with a shunt resistor which is tapped at D. This tapping is made 0 on the main dial. When the contact is in a position such $\frac{r_1}{r_3} = \frac{r_2}{r_4}$ that zero. The slider can travel a little lower than zero position giving a small negative reading. The movement of slider above zero gives positive reading. The range of slide wire is usually from -0.005 to +0.105V.

Application of DC Potentiometer:

In addition to measurement of voltage, the potentiometer is the usual basis for calibration of all voltmeters, ammeters and wattmeter. The potentiometer may also be used for measurement of current, power and resistance. Since the potentiometer is a dc device, the instruments to be calibrated must be dc moving iron or electrodynamometer types.

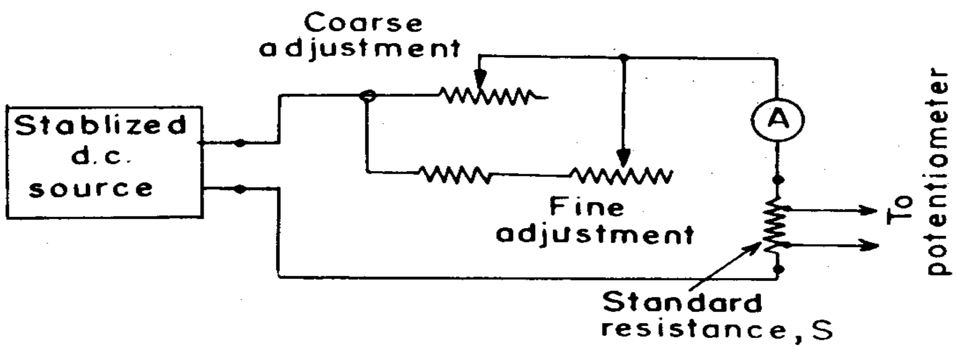
1) **Calibration of Voltmeter:**

The foremost requirement in this calibration process is that a suitable stable dc voltage supply is available since any changes in the supply voltage will cause a corresponding change in the voltmeter calibration.



In the above figure shows a potential divider network, consisting of two rheostats, one for coarse and other for fine control of calibrating voltage. These controls are connected to the supply source and with the help of these controls it is possible to adjust the voltage so that the pointer coincides exactly with a major division of the voltmeter. The voltage across the voltmeter is stepped down to a value suitable for application to a potentiometer with the help of a volt-ratio box. For accuracy of measurements, it is necessary to measure voltages near the maximum range of the potentiometer, as for as possible.
Thus if a potentiometer has a maximum range of 1.6V, to achieve high accuracy we will have to use to low voltage ranges for voltages less than 1.6V and use appropriate tapings on volt-ratio box for voltages higher than 1.6V.
The potentiometer measures the true value of voltage. If the potentiometer reading does not agree with the voltmeter readings, a negative or positive error is indicated. A calibration curve may be drawn with the help of the readings of voltmeter and potentiometer.

2) Calibration of Ammeter:



In the above figure shows the circuit for calibrating an ammeter. A standard resistance of suitable value and sufficient current carrying capacity is placed in series with the ammeter under calibration. The voltage across the standard resistor is measured with the help of potentiometer and the current through the standard resistance (and hence the ammeter) can be computed.

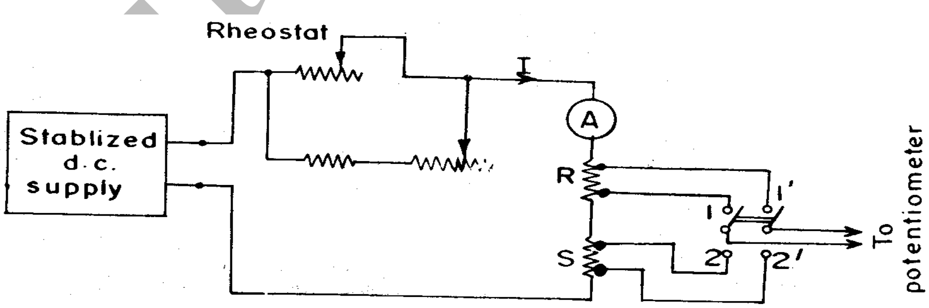
Current I = $\frac{V_s}{S}$

Where, V_s = Voltage across the standard resistor as indicated by the potentiometer.

And S = resistance of standard resistor.

Since the resistance of the standard resistor is accurately known and the voltage across the standard resistor is measured by a potentiometer this method of calibrating an ammeter is very accurate. A calibration curve indicating the errors at various scale readings of the ammeter may be plotted.

3) Measurement of Resistance:



The circuit of measurement of resistance with a potentiometer is shown in figure. The unknown resistance, R is connected in series with a standard resistor S. The current through the circuit is controlled with the help of a rheostat. A two pole double throw switch is used. This switch, when put in position 1, 1' connects the unknown resistance to the potentiometer is V_R.

$$\therefore V_R = IR$$

Now the switch is thrown to position 2, 2' this connects the standard resistor to the potentiometer. Suppose the reading of potentiometer is V_S.

$$V_S = IS$$

$$\therefore \quad R = \frac{V_R}{V_S}.S$$

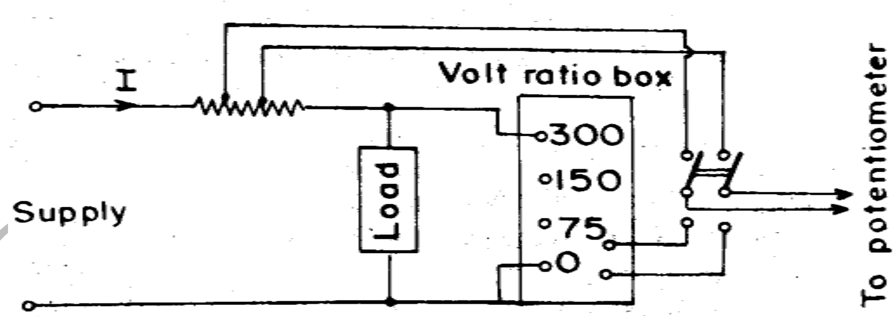
Since the value of standard resistance S is accurately known value of R can also be accurately known.

The accuracy of this method depends upon the assumption that there is no change in the value of current when the two different measurements are taken. Therefore a stable dc supply is absolutely necessary. The difficulty of ensuring this condition is the chief disadvantage of this method.

The resistance of the standard resistor, S which must be accurately known, should be of the same order as the resistance, R, under measurement. The ammeter inserted in the circuit is merely for indicating whether the current flowing through the circuit is within the capacity of the resistors or not otherwise the exact value of current flowing need not be known. It is desirable that the current flowing through the circuit be so adjusted that the value of voltage drop across each resistor is of the order of 1 volt.

The potentiometer method of measurement of resistance is suitable for measurement of low resistances.

4) Measurement of Power:



The circuit for measurement of power with a potentiometer as shown in above figure. Two measurements are made, one across the standard resistance S connected in series with the load and the other across at output terminals of the volt-ratio box.

The current in the circuit can be computed from the voltage drop across the standard resistance and the voltage across the load can be computed from the potentiometer reading across the output terminals of volt-ratio box.

Let, V_S = reading of potentiometer when connected across S.

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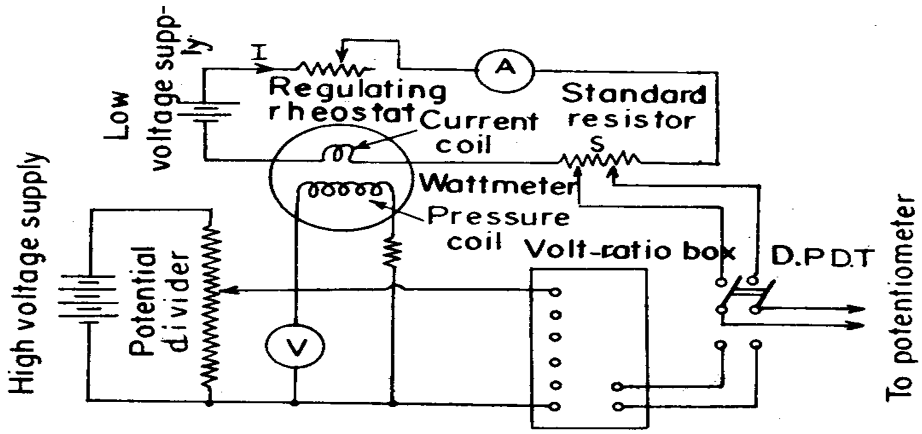
V_R = reading of potentiometer when connected across volt-ratio box.

∴ Current through the load, $I = \frac{V_S}{S}$, Voltage across load, $V = KV_R$, Where K is the multiplying factor of volt-ratio box.

∴ Power consumed, $P = VI = KV_R = \frac{V_S}{S}$.

5) Calibration of Wattmeter:



For calibration of a wattmeter a circuit similar to circuit measurement of power may be used. Such an arrangement however results in a considerable consumption of power especially when the wattmeter has a large rating. In order to save expenditure of power, the arrangement of figure is used. The current coil of wattmeter is supplied from a low voltage supply and a series rheostat is inserted to adjust the value of current.

The potential circuit is supplied from the supply. A volt-ratio box is used to step down the voltage for the potentiometer to read. This type of arrangement is known as '*Phantom loading*'. The voltage V and the current I are measured in turn with the potentiometer employing a double pole double throw (DPDT) switch. The true power is then VI and the wattmeter reading may be compared with this value.

Phantom Loading:

When the current rating of a meter under test is high a test with actual loading arrangements would involve a considerable waste of power. In order to avoid this 'Phantom' or 'Fictitious' loading is done.

Phantom loading consists of supplying the pressure circuit from a circuit of required normal voltage and the current circuit from a separate low voltage supply. It is possible to circulate the rated current through the current circuit with a low voltage supply as the impedance of this circuit is very low. With this arrangement the total power supplied for the test is that due to the small pressure coil current at normal voltage, plus that due to the current circuit current supplied at low voltage. The total power therefore, required for testing the meter with phantom loading is comparatively very small.

AC Potentiometers:

The dc potentiometer is an accurate and versatile instrument and thus it is obvious that the potentiometer principle be applied to measurement of alternating currents or voltages. The principle of alternating current potentiometer is the same as that of the direct current potentiometer. The most important difference between a dc and an ac potentiometer is that, whereas in a dc potentiometer only the magnitudes of the unknown emf and potential voltage drop have to be made equal to obtain balance, in the ac instrument both magnitude and phase of the two have to be same to obtain balance. Thus an ordinary dc potentiometer cannot be used for ac measurement and certain modifications have to be made and additional features incorporated in it so that it may be used for ac work.

There are some practical difficulties with ac potentiometers. These are:

1. A basic condition for balance in an ac potentiometer is the equality of voltages under comparison at all instants and it requires equality in phase as well as in magnitude of both the ac sources at every instant. Hence both the potentiometer circuit and the circuit under test should be supplied from a single ac source, with the two circuits isolated, where necessary, by using a transformer. Thus frequency and waveform of the current in the measuring circuit of the potentiometer remains always the same as that of the voltage under measurement.
2. In order to ensure a balance in the presence of higher harmonics, the null detector employed is ordinarily either a vibration galvanometer or a frequency selective detector but error in measurement cannot eliminated because this way null detector tuned to the fundamental frequency leaves out the higher harmonics. Therefore the null detector will give zero deflection for a balance at the fundamental frequency but not at the instantaneous values of the result waveform. As an alternative arrangement, if an average indicating detector is used, it may not give the same balance point as an rms indicating device. In the presence of harmonics it may be possible that a balance is never may be possible that a balance is never achieved by the detector and this way the accuracy of measurement will get affected very much in the presence of harmonics. So the source of ac supply should be free from harmonics.
3. The great difficulty associated with the ac potentiometers is the imperfect standardisation procedure which contributes to an error while in the case of dc potentiometers, standardisation is done directly with a standard cell, which is of the utmost precision, and the accuracy of measurement is very high but no such device is feasible with ac potentiometers for standardisation. Therefore ac potentiometers are standardized by measuring either the supply current with a direct reading ammeter of high precision or the applied voltage with a voltmeter. In any case, however, the accuracy of the indicating instrument employed.
4. The slide wire and resistance coils are required to be non-reactive to avoid error in readings.

Standardizing of AC Potentiometer and use of Transfer Instruments:

The ac potentiometers are made direct reading type, i.e. the readings are read off directly from the dial settings. In order to do that the ac potentiometer must be standardized as is done in the case of dc instruments. The standardisation is done with the help of a standard dc source i.e. a standard cell or a zener source and a transfer instruments. The transfer instrument is usually an electrodynamometer milli-ammeter, so constructed that its response to alternating currents is the same as its dc response. Such an instrument can be calibrated on dc and then brought to the same setting ac alternatively a thermocouple type of instrument may be used as a transfer instrument.

Classification of AC Potentiometer:

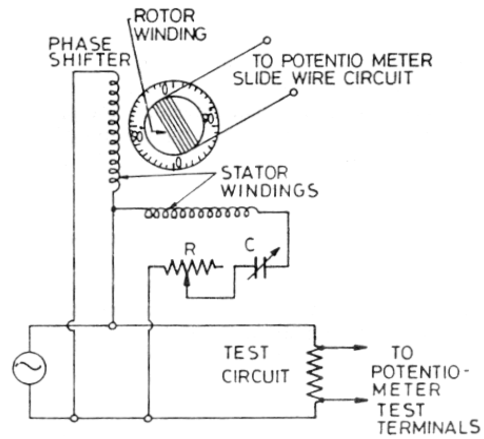
AC Potentiometers are usually classified according to the manner in which the instrument dials (or scales) present the value of unknown voltage. There are two general types of ac potentiometers.

i. Polar Potentiometers: In these instruments the unknown emf is measured in polar form i.e. in terms of its magnitude and relative phase. The magnitude is given by one scale and its phase angle with respect to some reference vector is given by the second scale. Provision is made for reading phase angles up to 360^0.

ii. Co-ordinate Potentiometers: In these instruments the unknown emf is measured in terms of its components along and perpendicular to a standard axis. The two components of the unknown emf are given directly by two different scales known as ‘in phase’ and ‘quadrature’ scales.

Drysdale AC Polar Potentiometer:

The first direct reading polar potentiometer was developed by Drysdale in 1908 and had been extensively used up to present time. It consists of a potentiometer of the ordinary dc type having its coils non-inductively wound and other auxiliary apparatus. A phase shifting transformer known as Drysdale phase shifter is used to feed the slide wire circuit so that the current of constant magnitude but variable phase can be obtained in the slide wire circuit. The phase shifter consists of a two phase starter and a single phase rotor, the position of which can be changed by hand and read from the scale provided for this purpose. A rotating field of constant magnitude is produced when currents flow in the stator winding and so an emf of constant magnitude is induced in the rotor, the phase of which can be changed relative to the stator supply voltage by rotating the rotor through any desired value. The phase displacement of the secondary (rotor) emf is indicated by the rotor position and is rotated from its zero position. The two phase supply for the stator is obtained from a single phase supply by employing a phase splitting device consisting of a capacitor and a resistance as shown in figure. The phase shifting transformer is supplied from the same source as the current or voltage to be measured.



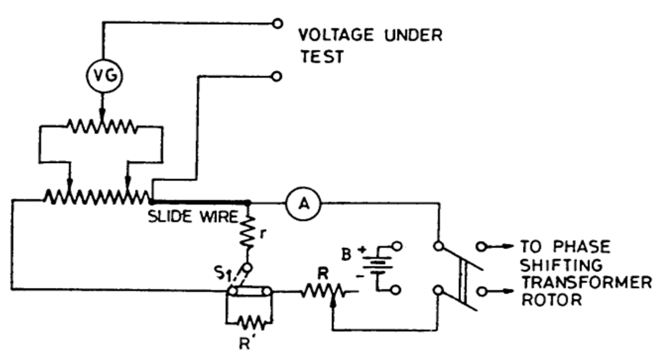
Connections of Drysdale Polar Potentiometer

A precision type electro-dynamometer ammeter is used for the standardisation of the instrument. The standardisation of the instrument is done as follows:

The slide wire circuit is switched to dc supply, the detector is taken out of circuit, the standard cell and D'Arsonval galvanometer is connected to the terminals marked as test terminals, the slide wire contact is set for the standard cell emf and the current control resistance R is adjusted until balance is obtained. The reading of the ammeter A then indicates the value of alternating current required in the ac measurements. The galvanometer and standard cell are then removed from the circuit and dc supply is replaced by that from the phase shifter and the rheostat R is re-adjusted unit the ammeter reads the same as before.

The ammeter A reads correctly on both dc and ac and since the coils of the slide wire circuit are non-inductively wound, the potentiometer remains direct reading when used with an ac supply.

Operation with Alternating Current:



Simplified Connection Diagram of Drysdale Tinsley AC Potentiometer

Drysdale Tinsley potentiometer is shown in figure. In the circuit V_G is a vibration galvanometer, R is a variable resistance for controlling the slide wire circuit current, r is a shunting resistance for changing the range of the potentiometer, R' is the resistance which comes into the slide wire circuit as soon as the shunt resistance r is put in the circuit by switch S_1 so that the resistance of the working portion of the potentiometer remains the same and A is a precision ammeter.

R is a rheostat for adjustment of the slide wire current. The phase shifting transformer, whose connections are shown in previous figure, is omitted for clearance.

The instrument is first standardized, as discussed earlier, and the potentiometer is made direct reading. Then the currents in the stator windings of the phase shifter are adjusted to exact quadrature by means of the variable resistor and capacitor, these being adjusted until the alternating current in the slide wire becomes constant for all positions of the rotor.

The unknown voltage is then impressed to the potentiometer test terminals. Balance is obtained by adjusting the position of slide wire contact and position of phase rotor till zero deflection is obtained in the vibration galvanometer. Now the magnitude and phase angle of unknown voltage with reference to an arbitrary reference vector are read from the slide wire and phase shifter scales respectively.

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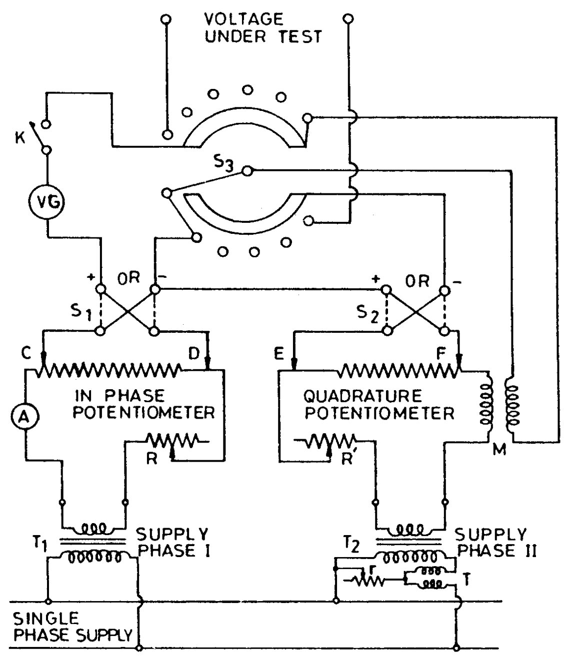
Gall Tinsley AC Potentiometer:

This instrument is of co-ordinate type and consists of two separate potentiometer circuits enclosed in a common case. One of these is 'in-phase' potentiometer and the other is 'quadrature' potentiometer. The slide wire circuits are supplied with two currents having a phase difference of 90^0. The value of unknown potential difference is obtained by balancing the voltage both on in-phase are quadrature phase slide wires simultaneously in order to balance in phase and quadrature components of unknown potential difference respectively on the in-phase and quadrature slide wires. If the measured values on in-phase and quadrature slide wires are V_1 and V_2 respectively then magnitude of unknown voltage, $= \sqrt{V_1^{\ 2} + \ V_2^{\ 2}}$, phase angle of the unknown voltage with respect to the current in phase portion of the potentiometer is given by $\boldsymbol{\theta}=\tan^{-1}\left(\frac{V_2}{V_1}\right)$



Gall-Tinsely AC Potentiometer Connection Diagram

The connection diagram for a simplified co-ordinate potentiometer is shown in figure. CD and EF are the respectively sliding contacts of the in-phase and quadrature potentiometers. R and R' are slide wires current controlling rheostats. The two potentiometer slide wires may either be supplied from a two phase alternator or by means of phase splitting device when single phase supply is used. T_1 and T_2 are two step down transformers having output voltage of 6 volts. These transformer and r is a variable resistance, which is used for obtaining 90^0 phase shift. VG is a galvanometer, K is a galvanometer key. A is a reflecting dynamometer ammeter which is used for maintaining the current in both the slide wires at a standard value of 50mA. S_1 and S_2 are two sign changing switches and are used for reversing the direction of unknown emf applied to the slide wires. S_3 is a selector switch and is used to apply the unknown voltage to the potentiometer.

There are four pairs of terminal for the application of such voltages, although the connection of only one pair connected to an unknown voltage V. The position of selector switch, shown in figure is called test position and it allows the current in the quadrature potentiometer slide wire to be compared with that in the in-phase potentiometer wire with the help of mutual inductance M.

Operation:

The dc supply is connected to the in-phase slide wire circuit, vibration galvanometer VG is replaced by a D'Arsonval galvanometer and a standard cell is connected to the testing terminals. Now the current in the in-phase slide wire is adjusted to the standard value of 50mA by varying the rheostat R. The dynamometer instrument which has torsion head, is turned to give zero deflection on direct current. This setting is left undistributed for ac calibration, the dc supply is replaced by ac supply and the current in the slide wire is adjusted by varying R to give zero deflection in dynamometer is replaced by ac vibration galvanometer.

The magnitude of current in the quadrature potentiometer must also be equal to that in the in-phase wire and the two currents should be exactly in quadrature.

The current in the in-phase potentiometer wire is adjusted to the standard value of 50mA, the switch S_2 is adjusted to 'test position' so that the emf induced in the secondary winding of mutual inductance M is impressed across the in-phase potentiometer wire through the vibration galvanometer. Since the induced emf in the secondary of mutual inductance M will be equal to $2\pi f M_i$ volts in magnitude and will lag 90^0 behind the current in the quadrature wire where f is supply frequency, I is current in amps flowing in the quadrature wire and M is mutual inductance in henry. So the value of emf calculated from the relation $e' = 2\pi f M_i$ for a current I = 50mA is set on in-phase potentiometer wire and R' and r are varied till exact balance point is obtained. At balance position of the current in the potentiometer wire will be equal to standard value 50mA in magnitude and exact in quadrature with in potentiometer wire. Any difference in polarity between the two circuits is corrected for by means of sign changing switched S_1 & S_2.

The unknown voltage is then applied to the potentiometer by means of switch S_3 and balancing is obtained on both of the potentiometer slide wires by alternate adjustment of the two slide wire settings. Difference in polarity is adjusted by means of switches S_1 and S_2. The reading of slide wires CD and EF gives the in-phase and quadrature components of the unknown voltage both in magnitude and polarity.

Advantages and limitations of AC Potentiometer:

The main advantage of the ac potentiometer lies in its versality. By employing shunts and volt-ratio boxes its use may be extended to cover current, voltage and resistance measurements over a wide range of values. Further, the fact that phase, as well as magnitude is measured leads to such applications as measurement of power, measurement of inductance and phase angle of the coil etc. The principle of ac potentiometer is also incorporated in certain special measurement circuits: a good example is the Arnold circuit for measurement of error in CTs.

Despite these advantages, ac potentiometers are not very widely used. They suffer from the following disadvantages:

1. Slight difference in reading of the reflecting dynamometer instrument either in dc or ac calibration introduces error in the alternating current to be set at standard value.
2. The normal value of mutual inductance M is affect due to mutual inductance between various parts of the instrument and so a slight difference is introduced in magnitude of the current of quadrature wire compared to that in the in-phase potentiometer wire.
3. In accuracy in the measured value of frequency will also result in the quadrature potentiometer wire current differ from that of in-phase potentiometer wire.
4. The potential gradient of the wires is affected due to the presence of inter capacitance and mutual inductance.
5. Since the standardization is done on the basis of rms value and balance is obtained depending upon the fundamental only so presence of harmonics in the wave form introduces operating troubles and the vibration galvanometer tuned to the fundamental may not show full null position at all.