STUDY MATERIAL

ELECTRICAL TECHNOLOGY

(819)

CLASS – XII

(2018-19)

UNIT-1

A.C CIRCUITS

WHAT IS AN ALTERNATING VOLTAGE?

Faraday's law of induction provides a basis for converting mechanical energy into electrical energy. The basic idea is to move a coil of wire relative to a magnetic field. This motion will generate a current in the wire. Such a device is called a *generator* and a conceptual drawing of this device is shown in figure 1.

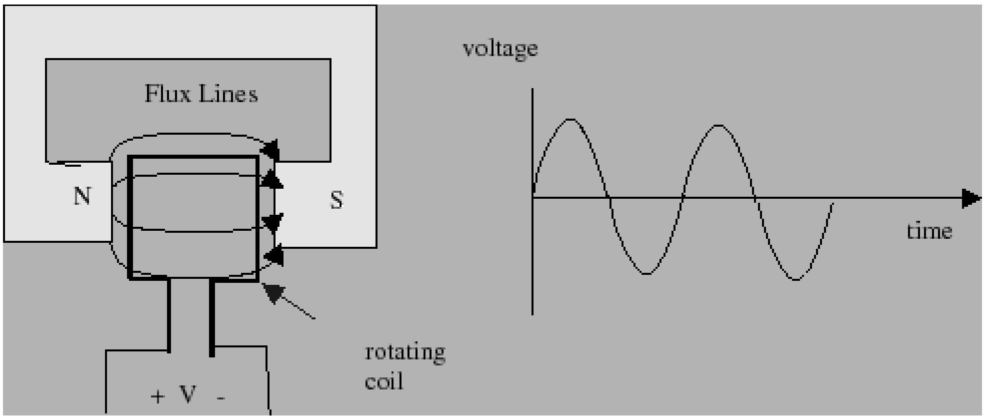


Figure 1: A generator and the voltage it generates

To make things simple, the coil is usually made to rotate within the field. As the coil rotates, it cuts through the flux lines, generating a voltage across the coil's terminals. When the face of the coil is parallel to the field, it cuts rapidly through the flux lines. But when the coil has turned 90 degrees and is perpendicular to the field lines, then the motion of the coil is tangential to the field and no voltage is produced. As the coil turns past this point, it cuts through the field in the opposite direction, generating a negative voltage. The end result of this chain of events is that the voltage produced by the generator varies as the cosine of the angle as shown below. This sinusoidal waveform is referred to as an *alternating* current or AC.

The equation for a waveform of this type is:

$$v(t) = A\cos(\omega t + \phi) \tag{1}$$

where A is the *amplitude*, ω is the *frequency*, and ϕ is the *phase* . Since $v(t)$ is a time-varying voltage signal, A has units of volts. The frequency has units of radians per second. Phase is measured in radians. We often measure frequency in a related unit of *cycles per second*. A cycle corresponds to 2π radians.

The sinusoidal waveform in equation 1 is a **periodic** waveform. A signal v is periodic if and only if there exists $T > 0$ such that $v(t) = v(t+T)$ for all t. To see if a sinusoidal waveform is periodic we therefore need to find T such that

$$A\cos(\omega t + \phi) = A\cos(\omega(t+T) + \phi) \tag{2}$$

In particular, we know that the cosine function repeats every 2π radians so we need to find T such that

$$A\cos(\omega(t+T) + \phi) = A\cos(\omega t + 2\pi + \phi) \tag{3}$$

Clearly this occurs if $\omega T = 2\pi$ or rather

$$T = \frac{2\pi}{\omega} \tag{4}$$

is the **fundamental period** of this sinusoidal function.

The *size* of a sine wave can be measured in a variety of ways. We may, for instance, use the waveform's amplitude (A) to specify the waveform's size. Another measure of "size" is the signal's **root mean square** or **rms**strength

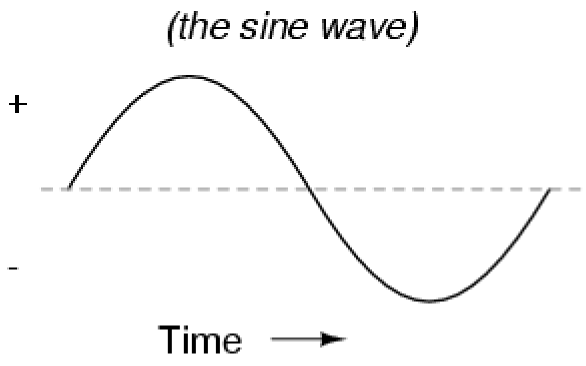
$$\text{RMS} = \left[\int_0^{\omega/2\pi} (A\cos(\omega t + \phi))^2 \, dt \right]^{1/2} \quad (5)$$

Since generators naturally produce sine waves, these waveforms play an important role in electrical engineering. It also turns out that sine waves also provide an efficient way of transporting electrical energy over a long distance. This is part of the reason why AC voltages are used in international power grids and, of course, this is why your wall socket provides a 120 volts (rms) AC voltage at 60 Hz.

In contrast to AC voltages, batteries provide a *direct current* or DC voltage. DC voltages are constant over time. In order to obtain DC voltages from an AC wall socket we're going to have to find some way of **regulating** the AC power source.

AC WAVEFORMS

When an alternator produces AC voltage, the voltage switches polarity over time, but does so in a very particular manner. When graphed over time, the "wave" traced by this voltage of alternating polarity from an alternator takes on a distinct shape, known as a *sine wave*: Figure below



Graph of AC voltage over time (the sine wave).

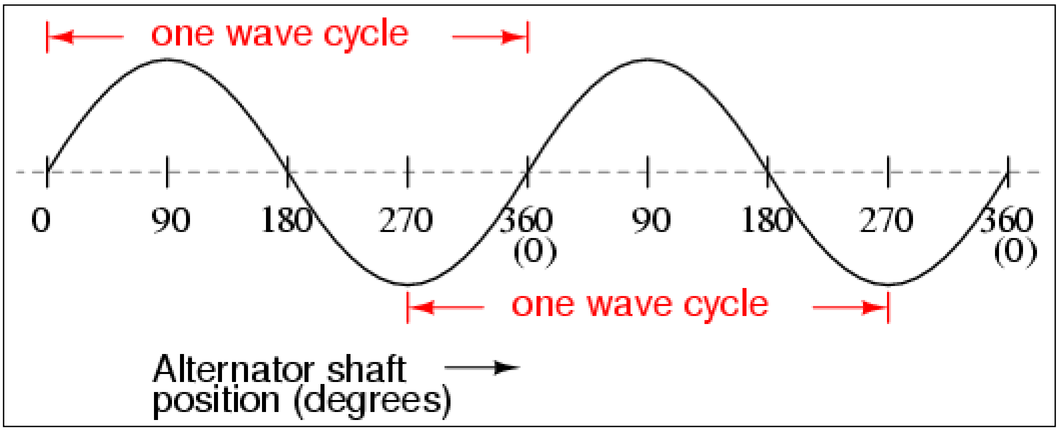
In the voltage plot from an electromechanical alternator, the change from one polarity to the other is a smooth one, the voltage level changing most rapidly at the zero ("crossover") point and most slowly at its peak. If we were to graph the trigonometric function of "sine" over a horizontal range of 0 to 360 degrees, we would find the exact same pattern as in Table below.

Trigonometric "sine" function.

Angle (o)	**sin(angle)**	**wave**	**Angle (o)**	**sin(angle)**	**wave**
0	0.0000	zero	180	0.0000	zero
15	0.2588	+	195	-0.2588	-
30	0.5000	+	210	-0.5000	-
45	0.7071	+	225	-0.7071	-
60	0.8660	+	240	-0.8660	-
75	0.9659	+	255	-0.9659	-
90	1.0000	+peak	270	-1.0000	-peak
105	0.9659	+	285	-0.9659	-
120	0.8660	+	300	-0.8660	-
135	0.7071	+	315	-0.7071	-
150	0.5000	+	330	-0.5000	-
165	0.2588	+	345	-0.2588	-
180	0.0000	zero	360	0.0000	zero

The reason why an electromechanical alternator outputs sine-wave AC is due to the physics of its operation. The voltage produced by the stationary coils by the motion of the rotating magnet is proportional to the rate at which the magnetic flux is changing perpendicular to the coils (Faraday's Law of Electromagnetic Induction). That rate is greatest when the magnet poles are closest to the coils, and least when the magnet poles are furthest away from the coils. Mathematically, the rate of magnetic flux change due to a rotating magnet follows that of a sine function, so the voltage produced by the coils follows that same function.

If we were to follow the changing voltage produced by a coil in an alternator from any point on the sine wave graph to that point when the wave shape begins to repeat itself, we would have marked exactly one *cycle* of that wave. This is most easily shown by spanning the distance between identical peaks, but may be measured between any corresponding points on the graph. The degree marks on the horizontal axis of the graph represent the domain of the trigonometric sine function, and also the angular position of our simple two-pole alternator shaft as it rotates: Figure below



Alternator voltage as function of shaft position (time).

Since the horizontal axis of this graph can mark the passage of time as well as shaft position in degrees, the dimension marked for one cycle is often measured in a unit of time, most often seconds or fractions of a second. When expressed as a measurement, this is often called the *period* of a wave. The period of a wave in degrees is *always* 360, but the amount of time one period occupies depends on the rate voltage oscillates back and forth.

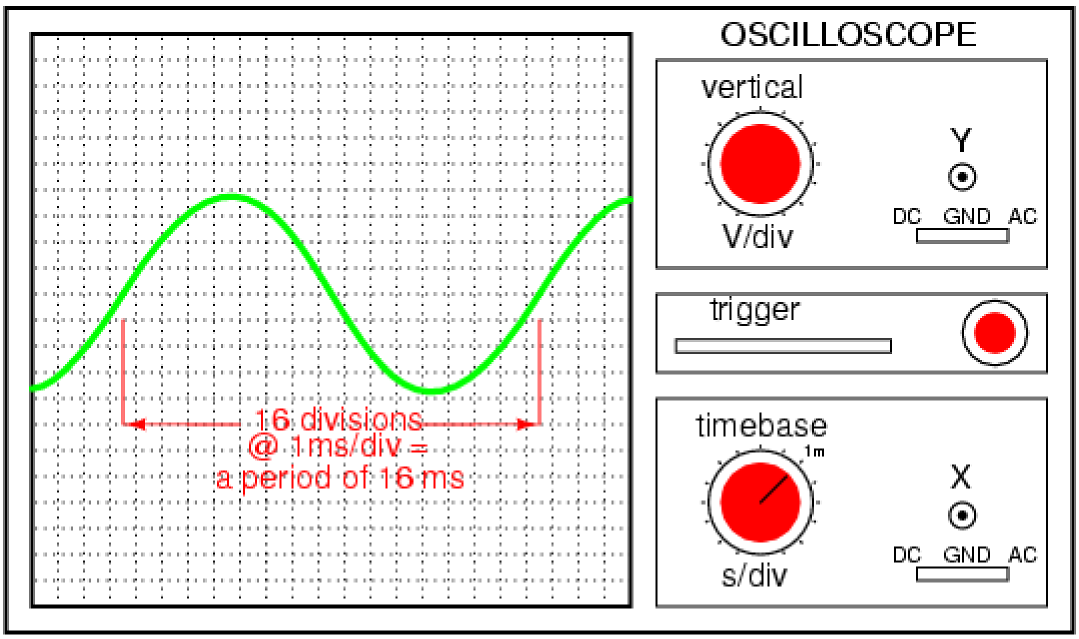
A more popular measure for describing the alternating rate of an AC voltage or current wave than *period* is the rate of that back-and-forth oscillation. This is called *frequency*. The modern unit for frequency is the Hertz (abbreviated Hz), which represents the number of wave cycles completed during one second of time. In the United States of America, the standard power-line frequency is 60 Hz, meaning that the AC voltage oscillates at a rate of 60 complete back-and-forth cycles every second. In Europe, where the power system frequency is 50 Hz, the AC voltage only completes 50 cycles every second. A radio station transmitter broadcasting at a frequency of 100 MHz generates an AC voltage oscillating at a rate of 100 *million* cycles every second.

Prior to the canonization of the Hertz unit, frequency was simply expressed as “cycles per second.” Older meters and electronic equipment often bore frequency units of “CPS” (Cycles Per Second) instead of Hz. Many people believe the change from self-explanatory units like CPS to Hertz constitutes a step backward in clarity. A similar change occurred when the unit of “Celsius” replaced that of “Centigrade” for metric temperature measurement. The name Centigrade was based on a 100-count (“Centi-”) scale (“-grade”) representing the melting and boiling points of H_2O, respectively. The name Celsius, on the other hand, gives no hint as to the unit's origin or meaning.

Period and frequency are mathematical reciprocals of one another. That is to say, if a wave has a period of 10 seconds, its frequency will be 0.1 Hz, or 1/10 of a cycle per second:

$$\text{Frequency in Hertz} = \frac{1}{\text{Period in seconds}}$$

An instrument called an *oscilloscope*, Figure below, is used to display a changing voltage over time on a graphical screen. You may be familiar with the appearance of an *ECG* or *EKG* (electrocardiograph) machine, used by physicians to graph the oscillations of a patient's heart over time. The ECG is a special-purpose oscilloscope expressly designed for medical use. General-purpose oscilloscopes have the ability to display voltage from virtually any voltage source, plotted as a graph with time as the independent variable. The relationship between period and frequency is very useful to know when displaying an AC voltage or current waveform on an oscilloscope screen. By measuring the period of the wave on the horizontal axis of the oscilloscope screen and reciprocating that time value (in seconds), you can determine the frequency in Hertz.



$$\text{Frequency} = \frac{1}{\text{period}} = \frac{1}{16\text{ ms}} = 62.5\text{ Hz}$$

Time period of sinewave is shown on oscilloscope.

Voltage and current are by no means the only physical variables subject to variation over time. Much more common to our everyday experience is *sound*, which is nothing more than the alternating compression and decompression (pressure waves) of air molecules, interpreted by our ears as a physical sensation. Because alternating current is a wave phenomenon, it shares many of the properties of other wave phenomena, like sound. For this reason, sound (especially structured music) provides an excellent analogy for relating AC concepts.

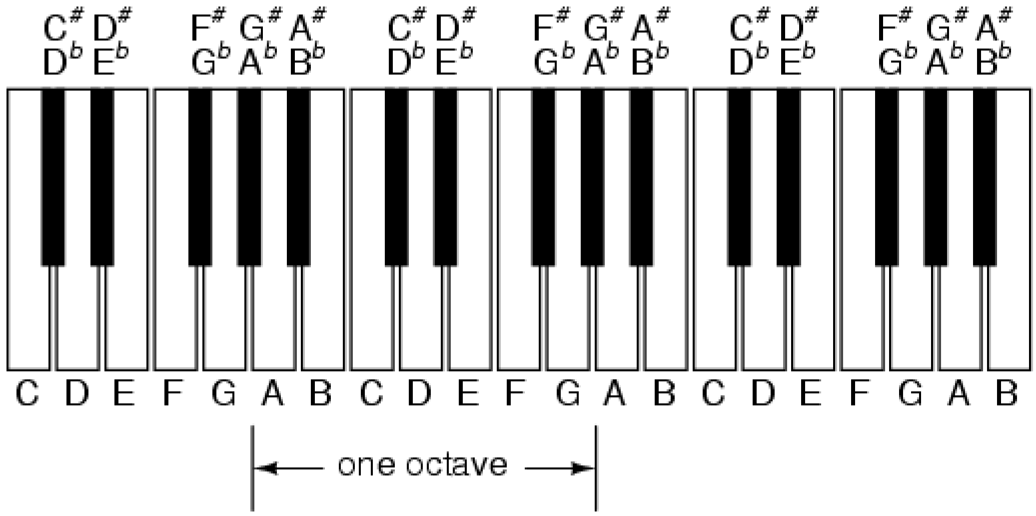
In musical terms, frequency is equivalent to *pitch*. Low-pitch notes such as those produced by a tuba or bassoon consist of air molecule vibrations that are relatively slow (low frequency). High-pitch notes such as those produced by a flute or whistle consist of the same type of vibrations in the air, only vibrating at a much faster rate (higher frequency). Figure below is a table showing the actual frequencies for a range of common musical notes.

Note	Musical designation	Frequency (in hertz)
A	A_1	220.00
A sharp (or B flat)	$A^{\#}$ or B^{b}	233.08
B	B_1	246.94
C (middle)	C	261.63
C sharp (or D flat)	$C^{\#}$ or D^{b}	277.18
D	D	293.66
D sharp (or E flat)	$D^{\#}$ or E^{b}	311.13
E	E	329.63
F	F	349.23
F sharp (or G flat)	$F^{\#}$ or G^{b}	369.99
G	G	392.00
G sharp (or A flat)	$G^{\#}$ or A^{b}	415.30
A	A	440.00
A sharp (or B flat)	$A^{\#}$ or B^{b}	466.16
B	B	493.88
C	C^1	523.25

The frequency in Hertz (Hz) is shown for various musical notes.

Astute observers will notice that all notes on the table bearing the same letter designation are related by a frequency ratio of 2:1. For example, the first frequency shown (designated with the letter "A") is 220 Hz. The next highest "A" note has a frequency of 440 Hz -- exactly twice as many sound wave cycles per second. The same 2:1 ratio holds true for the first A sharp (233.08 Hz) and the next A sharp (466.16 Hz), and for all note pairs found in the table.

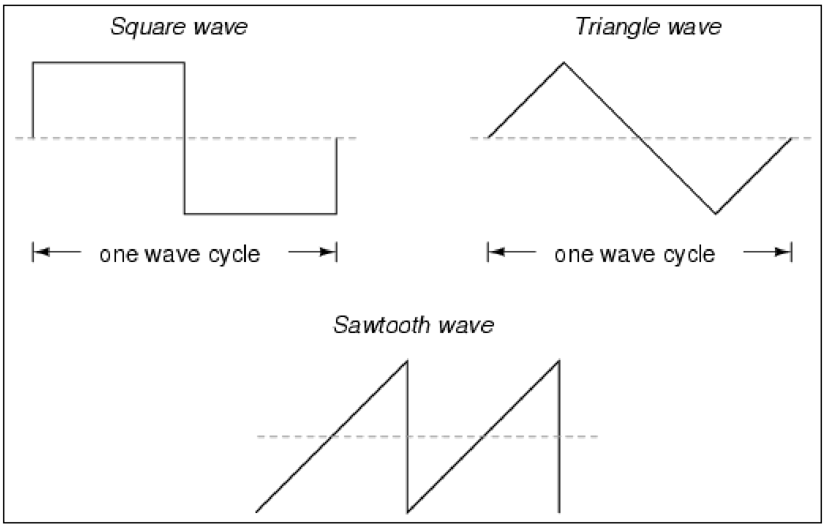
Audibly, two notes whose frequencies are exactly double each other sound remarkably similar. This similarity in sound is musically recognized, the shortest span on a musical scale separating such note pairs being called an *octave*. Following this rule, the next highest "A" note (one octave above 440 Hz) will be 880 Hz, the next lowest "A" (one octave below 220 Hz) will be 110 Hz. A view of a piano keyboard helps to put this scale into perspective: Figure below



An octave is shown on a musical keyboard.

As you can see, one octave is equal to *seven* white keys' worth of distance on a piano keyboard. The familiar musical mnemonic (doe-ray-mee-fah-so-lah-tee) -- yes, the same pattern immortalized in the whimsical Rodgers and Hammerstein song sung in The Sound of Music -- covers one octave from C to C.

While electromechanical alternators and many other physical phenomena naturally produce sine waves, this is not the only kind of alternating wave in existence. Other "waveforms" of AC are commonly produced within electronic circuitry. Here are but a few sample waveforms and their common designations in figure below



SOME COMMON WAVESHAPES (WAVEFORMS).

These waveforms are by no means the only kinds of waveforms in existence. They're simply a few that are common enough to have been given distinct names. Even in circuits that are supposed to manifest “pure” sine, square, triangle, or sawtooth voltage/current waveforms, the real-life result is often a distorted version of the intended waveshape. Some waveforms are so complex that they defy classification as a particular “type” (including waveforms associated with many kinds of musical instruments). Generally speaking, any waveshape bearing close resemblance to a perfect sine wave is termed*sinusoidal*, anything different being labeled as *non-sinusoidal*. Being that the waveform of an AC voltage or current is crucial to its impact in a circuit, we need to be aware of the fact that AC waves come in a variety of shapes.

REVIEW:

- AC produced by an electromechanical alternator follows the graphical shape of a sine wave.
- One *cycle* of a wave is one complete evolution of its shape until the point that it is ready to repeat itself.
- The *period* of a wave is the amount of time it takes to complete one cycle.
- *Frequency* is the number of complete cycles that a wave completes in a given amount of time. Usually measured in Hertz (Hz), 1 Hz being equal to one complete wave cycle per second.
- Frequency = 1/(period in seconds)

WHAT IS POWER FACTOR?

Power factor is the ratio between the KW (Kilo-Watts) and the KVA (Kilo-Volt Amperes) drawn by an electrical load where the KW is the actual load power and the KVA is the apparent load power. It is a measure of how effectively the current is being converted into useful work output and more particularly is a good indicator of the effect of the load current on the efficiency of the supply system.

All current flow will cause losses in the supply and distribution system. A load with a power factor of 1.0 result in the most efficient loading of the supply and a load with a power factor of 0.5 will result in much higher losses in the supply system.

A poor power factor can be the result of either a significant phase difference between the voltage and current at the load terminals, or it can be due to a high harmonic content or distorted/discontinuous current waveform.

Poor load current phase angle is generally the result of an inductive load such as an i nduction motor, power transformer, lighting ballasts, welder or induction furnace. A distorted current waveform can be the result of a rectifier, variable speed drive, switched mode power supply, discharge lighting or other electronic load.

A poor power factor due to an inductive load can be improved by the addition of power factor correction, but, a poor power factor due to a distorted current waveform requires an change in equipment design or expensive harmonic filters to gain an appreciable improvement.

Many inverters are quoted as having a power factor of better than 0.95 when in reality, the true power factor is between 0.5 and 0.75. The figure of 0.95 is based on the cosine of the angle between the voltage and current but does not take into account that the current waveform is discontinuous and therefore contributes to increased losses on the supply.

Power Factor Correction

Capacitive Power Factor correction is applied to circuits which include induction motors as a means of reducing the inductive component of the current and thereby reduce the losses in the supply. There should be no effect on the operation of the motor itself.

An induction motor draws current from the supply, that is made up of resistive components and inductive components.

The **resistive** components are:

1) Load current.
2) Loss current.

The **inductive** components are:

3) Leakage reactance.
4) Magnetizing current.

The current due to the leakage reactance is dependent on the total current drawn by the motor, but the magnetizing current is independent of the load on the motor.

The magnetizing current will typically be between 20% and 60% of the rated full load current of the motor. The magnetizing current is the current that establishes the flux in the iron and is very necessary if the motor is going to operate.

The magnetizing current does not actually contribute to the actual work output of the motor. It is the catalyst that allows the motor to work properly. The magnetizing current and the leakage reactance can be considered passenger components of current that will not affect the power drawn by the motor, but will contribute to the power dissipated in the supply and distribution system.

Take for example a motor with a current draw of 100 Amps and a power factor of 0.75 The resistive component of the current is 75 Amps and this is what the KWh meter measures. The higher current will result in an increase in the distribution losses of (100 x 100) /(75 x 75) = 1.777 or a 78% increase in the supply losses.

In the interest of reducing the losses in the distribution system, power factor correction is added to neutralize a portion of the magnetizing current of the motor.

Typically, the corrected power factor will be 0.92 - 0.95 Some power retailers offer incentives for operating with a power factor of better than 0.9, while others penalize consumers with a poor power factor. There are many ways that this is mete red, but the net result is that in order to reduce wasted energy in the distribution system, the consumer will be encouraged to apply power factor correction.

Power factor correction is achieved by the addition of capacitors in parallel with the connected motor circuits and can be applied at the starter, or applied at the switchboard or distribution panel. The resulting capacitive current is leading current and is used to cancel the lagging inductive current flowing from the supply.

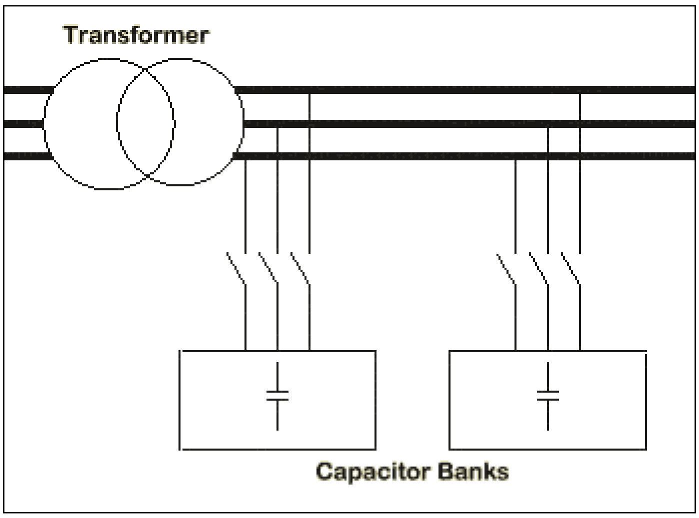
METHODS OF POWER FACTOR CORRECTION

Capacitors connected at each starter and controlled by each starter is known as *"Static Power Factor Correction"* while capacitors connected at a distribution board and controlled independently from the individual starters is known as *"Bulk Correction".*

BULK CORRECTION

The Power factor of the total current supplied to the distribution board is monitored by a controller which then switches capacitor banks In a fashion to maintain a power factor better than a preset limit. (Typically 0.95)

Ideally, the power factor should be as close to unity (Power factor of "1") as possible. There is no problem with bulk correction operating at unity.



STATIC CORRECTION

As a large proportion of the inductive or lagging current on the supply is due to the magnetizing current of induction motors, it is easy to correct each individual motor by connecting the correction capacitors to the motor starters.

With static correction, it is important that the capacitive current is less than the inductive magnetizing current of the induction motor.

In many installations employing static power factor correction, the correction capacitors are connected directly in parallel with the motor windings. When the motor is off-line, the capacitors are also off-line. When the motor is connected to the supply, the capacitors are also connected providing correction at all times that the motor is connected to the supply. This removes the requirement for any expensive power factor monitoring and control equipment.

In this situation, the capacitors remain connected to the motor terminals as the motor slows down. An induction motor, while connected to the supply, is driven by a rotating magnetic field in the stator which induces current into the rotor.

When the motor is disconnected from the supply, there is for a period of time, a magnetic field associated with the rotor. As the motor decelerates, it generates voltage out its terminals at a frequency which is related to it's speed.

The capacitors connected across the motor terminals, form a resonant circuit with the motor inductance.

If the motor is critically corrected, (corrected to a power factor of 1.0) the inductive reactance equals the capacitive reactance at the line frequency and therefore the resonant frequency is equal to the line frequency.

If the motor is over corrected, the resonant frequency will be below the line frequency.

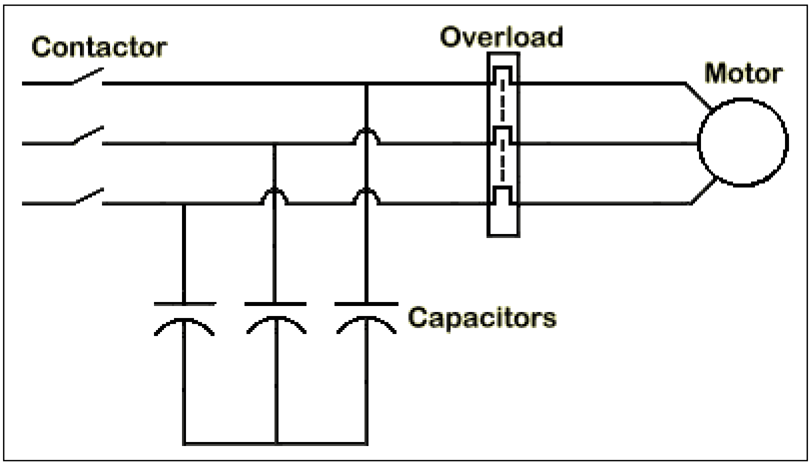
If the frequency of the voltage generated by the decelerating motor passes throu gh the resonant frequency of the corrected motor, there will be high currents and voltages around the motor/capacitor circuit. This can result in sever damage to the capacitors and motor. It is imperative that motors are never over corrected or critically corrected when static correction is employed.

Static power factor correction should provide capacitive current equal to 80% of the **magnetizing current**, which is essentially the open shaft current of the motor.

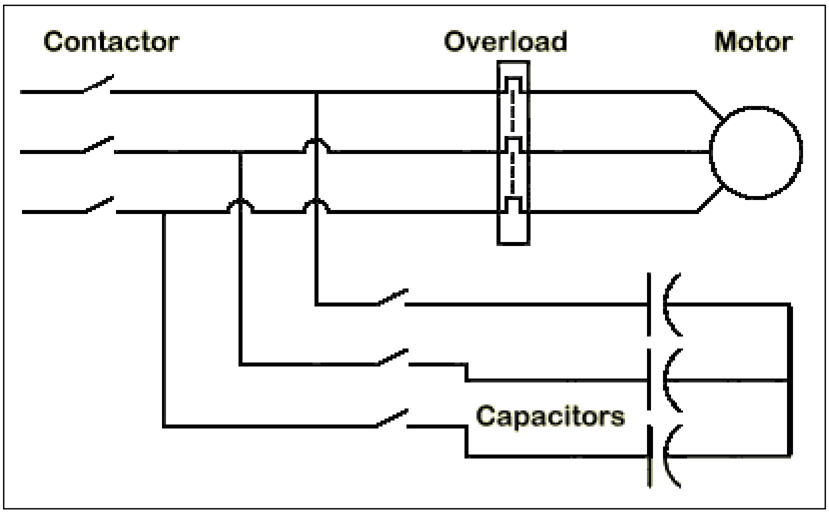
The magnetizing current for induction motors can vary considerably. Typically, magnetizing currents for large two pole machines can be as low as 20% of the rated current of the motor while smaller low speed motors can have a magnetizing current as high as 60% of the rated full load current of the motor.

It is not practical to use a "Standard table" for the correction of induction motors giving optimum correction on all motors. Tables result in under correction on most motors but can result in over correction in some cases. Where the open shaft current can not be measured, and the magnetizing current is not quoted, an approximate level for the maximum correction that can be applied can be calculated from the half load characteristics of the motor.

It is dangerous to base correction on the full load characteristics of the motor as in some cases, motors can exhibit a high leakage reactance and correction to 0.95 at full load will result in over correction under no load, or disconnected conditions.



Static correction is commonly applied by using one contactor to control both the motor and the capacitors. It is better practice to use two contactors, one for the motor and one for the capacitors. Where one contactor is employed, it should be up sized for the capacitive load. The use of a second contactor eliminates the problems of resonance between the motor and the capacitors.



Inverter

Static Power factor correction **must not be** used when the motor is controlled by a variable speed drive or inverter. The connection of capacitors to the output of an inverter can cause serious damage to the inverter and the capacitors due to the high frequency switched voltage on the output of the inverters.

The current drawn from the inverter has a poor power factor, particularly at low load, but the motor current is isolated from the supply by the inverter. The phase angle of the current drawn by the inverter from the supply is close to zero resulting in very low inductive current regardless of what the motor is doing. The inverter does not however, operate with a good power factor.

Many inverter manufacturers quote a cos Ø of better than 0.95 and this is generally true, however the current is non sinusoidal and the resultant harmonics cause a power factor (KW/KVA) of closer to 0.7 depending on the input design of the inverter. Inverters with input reactors and DC bus reac tors will exhibit a higher true power factor than those without.

The connection of capacitors close to the input of the inverter can also result in damage to the inverter. The capacitors tend to cause transients to be amplified, resulting in higher voltage impulses applied to the input circuits of the inverter, and the energy behind the impulses is much greater due to the energy storage of the capacitors.

It is recommended that capacitors should be at least 75 Meters away from inverter inputs to elevate the impedance between the inverter and capacitors and reduce the potential damage caused.

Switching capacitors, Automatic bank correction etc, will cause voltage transients and these transients can damage the input circuits of inverters. The energy is proportional to the amount of capacitance being switched. It is better to switch lots of small amounts of capacitance than few large amounts.

Solid State Soft Starter

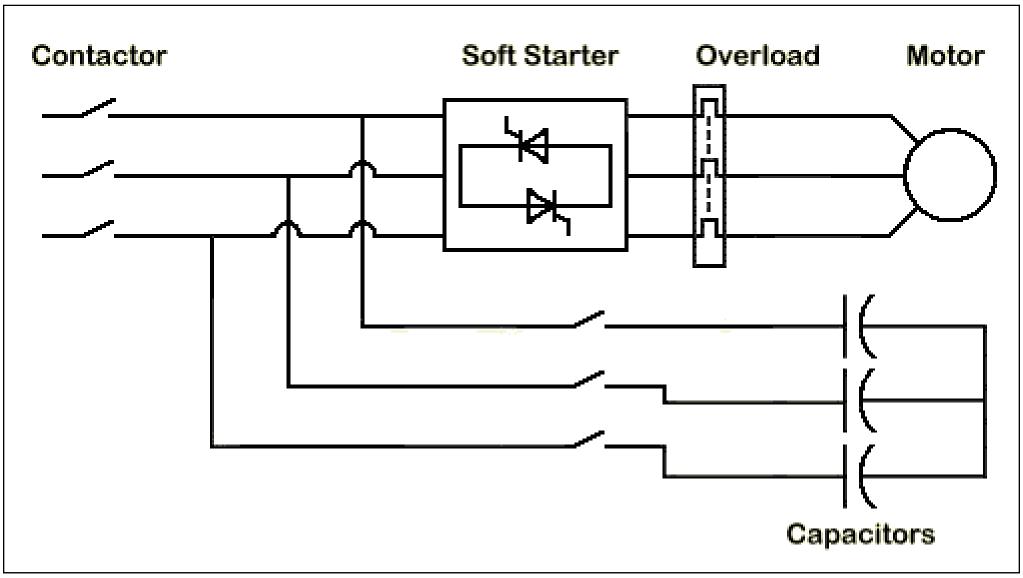
Static Power Factor correction capacitors **<u>must not</u>** be connected to the output of a solid state soft starter.

When a solid state soft starter is used, the capacitors must be controlled by a separate contactor, and switched in when the soft starter output voltage has reached line voltage. Many soft starters provide a *"top of ramp"* or *"bypass contactor control"* which can be used to control the power factor correction capacitors.

The connection of capacitors close to the input of the soft starter can also result in damage to the soft starter if an isolation contactor is not used. The capacitors tend to cause transients to be amplified, resulting in higher voltage impulses applied to the SCRs of the Soft Starter, and the energy behind the impulses is much greater due to the energy storage of the capacitors.

It is recommended that capacitors should be at least 50 Meters away from Soft starters to elevate the impedance between the inverter and capacitors and reduce the potential damage caused.

Switching capacitors, Automatic bank correction etc, will cause voltage transients and these transients can damage the SCRs of Soft Starters if they are in the Off state without an input contactor. The energy is proportional to the amount of capacitance being switched. It is better to switch lots of small amounts of capacitance than few large amounts.



Supply Harmonics

Harmonics on the supply cause a higher current to flow in the capacitors. This is because the impedance of the capacitors goes down as the frequency goes up. This increase in current flow through the capacitor will result in additional heating of the capacitor and reduce it's life

The harmonics are caused by many non linear loads, the most common in the industrial market today, are the variable speed controllers and switch-mode power supplies

Harmonic voltages can be reduced by the use of a harmonic compensator, which is essentially a large inverter that cancels out the harmonics. This is an expensive option.

Passive harmonic filters comprising resistors, inductors and capacitors can also be used to reduce harmonic voltages. This is also an expensive exercise.

In order to reduce the damage caused to the capacitors by the harmonic currents, it is becoming common today to install detuning reactors in series with the power factor correction capacitors. These reactors are designed to make the correction circuit inductive to the higher frequency harmonics. Typically, a reactor would be designed to create a resonant circuit with the capacitors above the third harmonic, but sometimes it is below. (Never tuned to a harmonic frequency!!)

Adding the inductance in series with the capacitors will reduce their effective capacitance at the supply frequency. Reducing the resonant or tuned frequency will reduce the the effective capacitance further.

The object is to make the circuit look as inductive as possible at the 5th harmonic and higher, but as capacitive as possible at the fundamental frequency. Detuning reactors will also reduce the chance of the tuned circuit formed by the capacitors and the inductive supply being resonant on a supply harmonic frequency, thereby reducing damage due to supply resonance amplifying harmonic voltages caused by non linear loads.

Supply Resonance

Capacitive Power factor correction connected to a supply caus es resonance between the supply and the capacitors.

If the fault current of the supply is very high, the effect of the resonance will be minimal, however in a rural installation where the supply is very inductive and can be a high impedance, the resonance can be very severe resulting in major damage to plant and equipment.

Voltage surges and transients of several times the supply voltage are not uncommon in rural areas with weak supplies, especially when the load on the supply is low.

As with any resonant system, a transient or sudden change in current will result in the resonant circuit ringing, generating a high voltage. The magnitude of the voltage is dependant on the 'Q' of the circuit which in turn is a function of the circuit loading. One of the problems with supply resonance is that the 'reaction' is often well remove from the 'stimulus' unlike a pure voltage drop problem due to an overloaded supply. This makes fault finding very difficult and often damaging surges and transients on the supply are treated as 'just one of those things'.

To minimize supply resonance problems, there are a few steps that can be taken, but they do need to be taken by all on the particular supply.

1) Minimize the amount of power factor correction, particularly when the load is light. The power factor correction minimizes losses in the supply. When the supply is lightly loaded, this is not such a problem.

2) Minimize switching transients. Eliminate open transition switching - usually associated with generator plants and alternative supply switching, and with some elect romechanical starters such as the star/delta starter.

3) Switch capacitors on to the supply in lots of small steps rather than a few large steps.

4) Switch capacitors on o the supply after the load has been applied and switch off the supply before or with the load removal.

Harmonic Power Factor correction is not applied to circuits that draw either discontinuous or distorted current waveforms

Most electronic equipment includes a means of creating a DC supply. This involves rectifying the AC voltage, causing harmonic currents. In some cases, these harmonic currents are insignificant relative to the total load current drawn, but in many installations, a large proportion of the current drawn is rich in harmonics.

If the total harmonic current is large enough, there will be a resultant distortion of the supply waveform which can interfere with the correct operation of other equipment. The addition of harmonic currents results in increased losses in the supply.

Power factor correction for distorted supplies can not be achieved by the addition of capacitors. The harmonics can be reduced by designing the equipment using active rectifiers, by the addition of passive filters (LCR) or by the addition of electronic power factor correction inverters which restore the waveform back to its undistorted state.

This is a specialist area requiring either major design changes, or specialized equipment to be used.

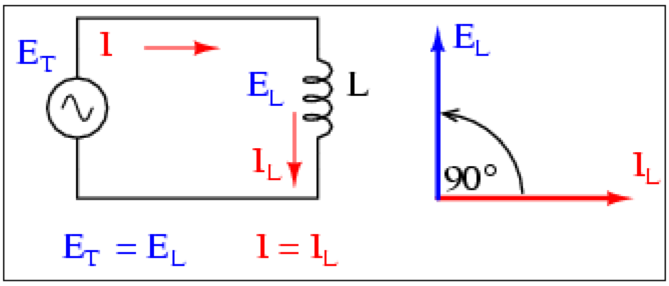
A.C. SERIES CIRCUITS WITH (I) RESISTANCE AND INDUCTANCE

Inductors do not behave the same as resistors. Whereas resistors simply oppose the flow of electrons through them (by dropping a voltage directly proportional to the current), inductors oppose *changes* in current through them, by dropping a voltage directly proportional to the *rate of change* of current. In accordance with *Lenz's Law*, this induced voltage is always of such a polarity as to try to maintain current at its present value. That is, if current is increasing in magnitude, the induced voltage will "push against" the electron flow; if current is decreasing, the polarity will reverse and "push with" the electron flow to oppose the decrease. This opposition to current change is called *reactance*, rather than resistance.

Expressed mathematically, the relationship between the voltage dropped across the inductor and rate of current change through the inductor is as such:

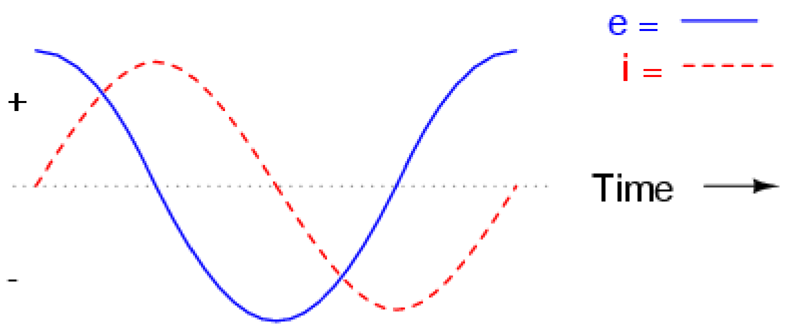
$$e = L\frac{di}{dt}$$

The expression *di/dt* is one from calculus, meaning the rate of change of instantaneous current (i) over time, in amps per second. The inductance (L) is in Henrys, and the instantaneous voltage (e), of course, is in volts. Sometimes you will find the rate of instantaneous voltage expressed as "v" instead of "e" (v = L di/dt), but it means the exact same thing. To show what happens with alternating current, let's analyze a simple inductor circuit: (Figure below)



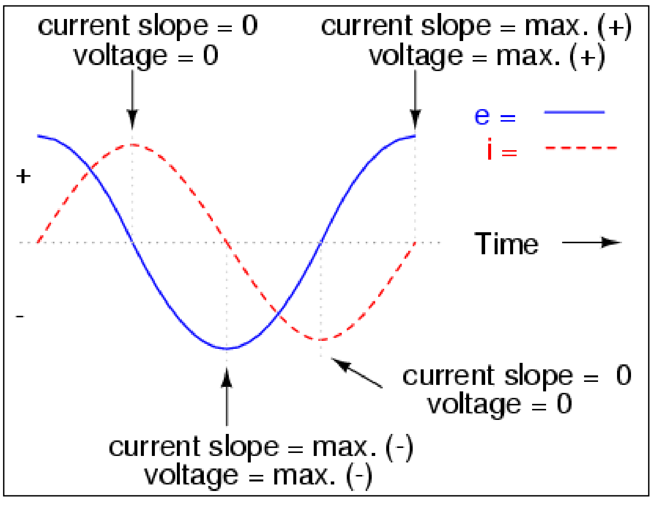
Pure inductive circuit: Inductor current lags inductor voltage by 90°.

If we were to plot the current and voltage for this very simple circuit, it would look something like this: (Figure below)



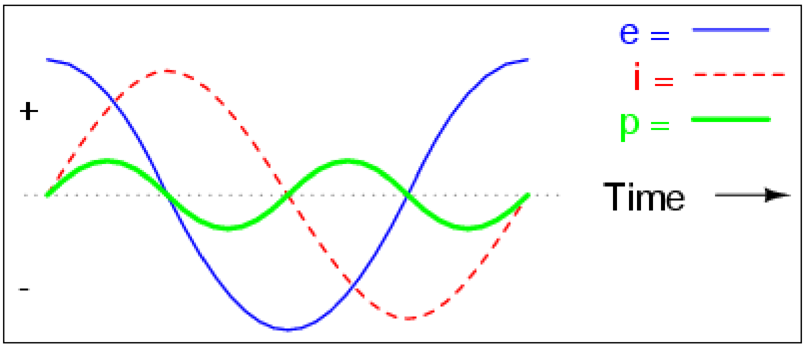
Pure inductive circuit, waveforms.

Remember, the voltage dropped across an inductor is a reaction against the *change* in current through it. Therefore, the instantaneous voltage is zero whenever the instantaneous current is at a peak (zero change, or level slope, on the current sine wave), and the instantaneous voltage is at a peak wherever the instantaneous current is at maximum change (the points of steepest slope on the current wave, where it crosses the zero line). This results in a voltage wave that is 90° out of phase with the current wave. Looking at the graph, the voltage wave seems to have a “head start” on the current wave; the voltage “leads” the current, and the current “lags” behind the voltage. (Figure below)



Current lags voltage by 90° in a pure inductive circuit.

Things get even more interesting when we plot the power for this circuit: (Figure below)



In a pure inductive circuit, instantaneous power may be positive or negative

Because instantaneous power is the product of the instantaneous voltage and the instantaneous current (p=ie), the power equals zero whenever the instantaneous current *or* voltage is zero. Whenever the instantaneous current and voltage are both positive (above the line), the power is positive. As with the resistor example, the power is also positive when the instantaneous current and voltage are both negative (below the line). However, because the current and voltage waves are 90^{o} out of phase, there are times when one is positive while the other is negative, resulting in equally frequent occurrences of *negative instantaneous power*.

But what does *negative* power mean? It means that the inductor is releasing power back to the circuit, while a positive power means that it is absorbing power from the circuit. Since the positive and negative power cycles are equal in magnitude and duration over time, the inductor releases just as much power back to the circuit as it absorbs over the span of a complete cycle. What this means in a practical sense is that the reactance of an inductor dissipates a net energy of zero, quite unlike the resistance of a resistor, which dissipates energy in the form of heat. Mind you, this is for perfect inductors only, which have no wire resistance.

An inductor's opposition to change in current translates to an opposition to alternating current in general, which is by definition always changing in instantaneous magnitude and direction. This opposition to alternating current is similar to resistance, but different in that it always results in a phase shift between current and voltage, and it dissipates zero power. Because of the differences, it has a different name: *reactance*. Reactance to AC is expressed in ohms, just like resistance is, except that its mathematical symbol is X instead of R. To be specific, reactance associate with an inductor is usually symbolized by the capital letter X with a letter L as a subscript, like this: X_L.

Since inductors drop voltage in proportion to the rate of current change, they will drop more voltage for faster-changing currents, and less voltage for slower-changing currents. What this means is that reactance in ohms for any inductor is directly proportional to the frequency of the alternating current. The exact formula for determining reactance is as follows:

$$X_L = 2\pi fL$$

If we expose a 10 mH inductor to frequencies of 60, 120, and 2500 Hz, it will manifest the reactances in Table Figure below.

Reactance of a 10 mH inductor:

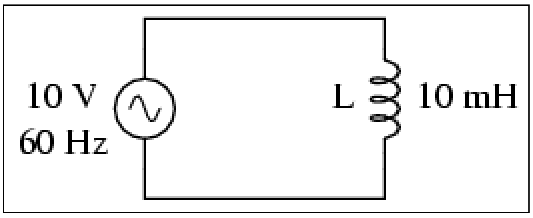
Frequency (Hertz)	**Reactance (Ohms)**
60	3.7699
120	7.5398
2500	157.0796

In the reactance equation, the term "2πf" (everything on the right-hand side except the L) has a special meaning unto itself. It is the number of radians per second that the alternating current is "rotating" at, if you imagine one cycle of AC to represent a full circle's rotation. A *radian* is a unit of angular measurement: there are 2π radians in one full circle, just as there are 360^o in a full circle. If the alternator producing the AC is a double-pole unit, it will produce one cycle for every full turn of shaft rotation, which is every 2π radians, or 360^o. If this constant of 2π is multiplied by frequency in Hertz (cycles per second), the result will be a figure in radians per second, known as the *angular velocity* of the AC system.

Angular velocity may be represented by the expression 2πf, or it may be represented by its own symbol, the lower-case Greek letter Omega, which appears similar to our Roman lower-case "w": ω. Thus, the reactance formula $X_L = 2\pi fL$ could also be written as $X_L = \omega L$.

It must be understood that this "angular velocity" is an expression of how rapidly the AC waveforms are cycling, a full cycle being equal to 2π radians. It is not necessarily representative of the actual shaft speed of the alternator producing the AC. If the alternator has more than two poles, the angular velocity will be a multiple of the shaft speed. For this reason, ω is sometimes expressed in units of *electrical* radians per second rather than (plain) radians per second, so as to distinguish it from mechanical motion.

Any way we express the angular velocity of the system, it is apparent that it is directly proportional to reactance in an inductor. As the frequency (or alternator shaft speed) is increased in an AC system, an inductor will offer greater opposition to the passage of current, and vice versa. Alternating current in a simple inductive circuit is equal to the voltage (in volts) divided by the inductive reactance (in ohms), just as either alternating or direct current in a simple resistive circuit is equal to the voltage (in volts) divided by the resistance (in ohms). An example circuit is shown here: (Figure below)



Inductive reactance

(*inductive reactance of 10 mH inductor at 60 Hz*)

$$X_L = 3.7699\ \Omega$$

$$I = \frac{E}{X}$$

$$I = \frac{10\ V}{3.7699\ \Omega}$$

$$I = 2.6526\ A$$

However, we need to keep in mind that voltage and current are not in phase here. As was shown earlier, the voltage has a phase shift of +90^{o} with respect to the current. (Figure below) If we represent these phase angles of voltage and current mathematically in the form of complex numbers, we find that an inductor's opposition to current has a phase angle, too:

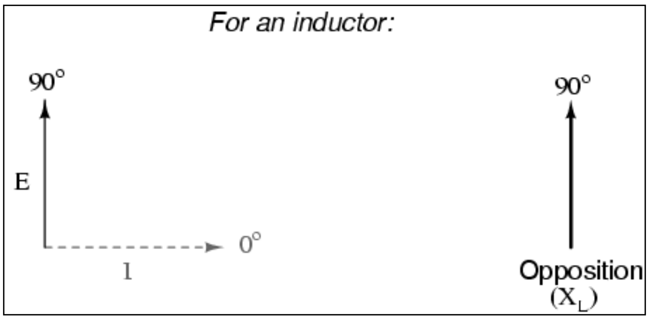
$$\text{Opposition} = \frac{\text{Voltage}}{\text{Current}}$$

$$\text{Opposition} = \frac{10\ V \angle 90^\circ}{2.6526\ A \angle 0^\circ}$$

$$\text{Opposition} = 3.7699\ \Omega \angle 90^\circ$$

or

$$0 + j3.7699\ \Omega$$



Current lags voltage by 90° in an inductor.

Mathematically, we say that the phase angle of an inductor's opposition to current is 90°, meaning that an inductor's opposition to current is a positive imaginary quantity. This phase angle of reactive opposition to current becomes critically important in circuit analysis, especially for complex AC circuits where reactance and resistance interact. It will prove beneficial to represent *any* component's opposition to current in terms of complex numbers rather than scalar quantities of resistance and reactance.

A.C. SERIES CIRCUITS WITH (II) RESISTANCE AND CAPACITANCE

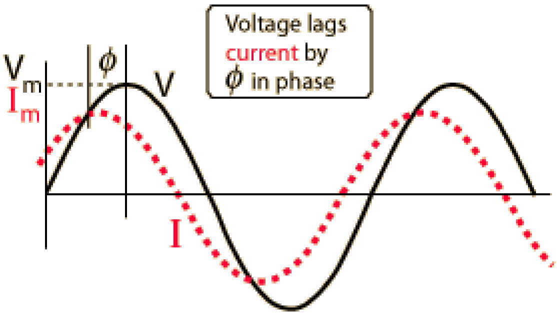
RC Circuit

[Impedance](#)

$$I = \frac{V}{Z}$$

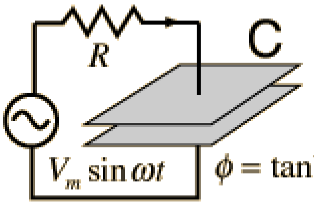
$$Z = \sqrt{R^2 + \left(\frac{1}{\omega C}\right)^2}$$

[Calculate](#)



Examine
[Capacitor](#)
[Resistor](#)

$I_m \sin(\omega t - \phi)$

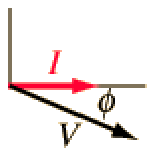


$V_m \sin \omega t$

Phase

$$\phi = \tan^{-1}\frac{-1/\omega C}{R}$$

$$I = \frac{I_m}{\sqrt{2}},\ V = \frac{V_m}{\sqrt{2}}$$

Contribution to [complex impedance](#)	[Phasor diagram](#)
$R - \dfrac{j}{\omega C}$	

You know that the voltage in a capacitive lags the current because the current must flow to build up the charge, and the voltage across the capacitor is proportional to that charge which is built up on the capacitor plates.

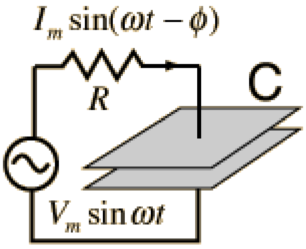
[Index](#)

[Capacitance concepts](#)

[Inductance concepts](#)

RC Impedance

The frequency dependent impedance of an RC series circuit.



$$Z = \sqrt{R^2 + \left(\frac{1}{\omega C}\right)^2}$$

at phase:

$$\phi = \tan^{-1} \frac{-1/\omega C}{R}$$

For C = [ ] x10^ [ ] F = [ ] μF = [ ] pF

at angular frequency ω = [ ] x10^ [ ] rad/s,

frequency = [ ] x10^ [ ] Hz = [ ] kHz = [ ] MHz

and resistance **R** = [ ] x10^ [ ] ohms = [ ] kohms = [ ] Megohms,

the impedance is

Z = [ ] x10^ [ ] ohms = [ ] kohms = [ ] Megohms

at phase ϕ = [ ] degrees.

Default values will be entered for unspecified parameters, but all component values can be changed. Click outside the box after entering data to initiate the calculation.

AC behavior of RC circuit

A.C. SERIES CIRCUITS WITH (II) RESISTANCE INDUCTANCE AND CAPACITANCE

Direct current (DC) circuits involve current flowing in one direction. In alternating current (AC) circuits, instead of a constant voltage supplied by a battery, the voltage oscillates in a sine wave pattern, varying with time as:

$$V = V_0 \sin \omega t$$

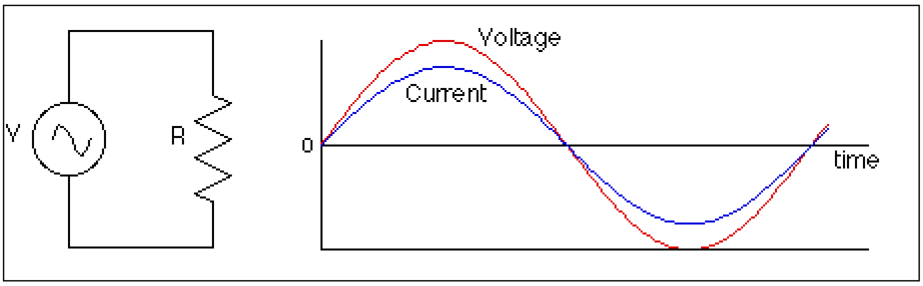
In a household circuit, the frequency is 60 Hz. The angular frequency is related to the frequency, f, by:

$$\omega = 2 \pi f$$

Vo represents the maximum voltage, which in a household circuit in North America is about 170 volts. We talk of a household voltage of 120 volts, though; this number is a kind of average value of the voltage. The particular averaging method used is something called root mean square (square the voltage to make everything positive, find the average, take the square root), or rms. Voltages and currents for AC circuits are generally expressed as rms values. For a sine wave, the relationship between the peak and the rms average is:

rms value = 0.707 peak value

Resistance in an AC circuit

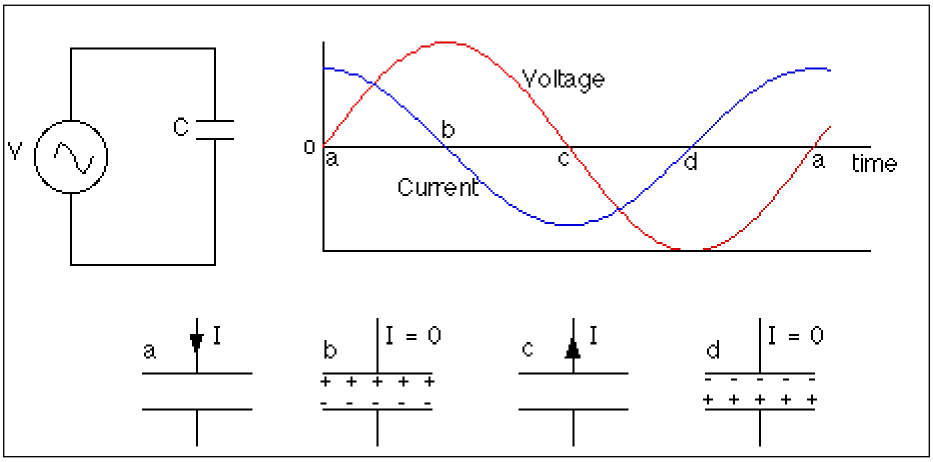


The relationship V = IR applies for resistors in an AC circuit, so

$$I = V / R = (V_0 / R) \sin(\omega t) = I_0 \sin(\omega t)$$

In AC circuits we'll talk a lot about the phase of the current relative to the voltage. In a circuit which only involves resistors, the current and voltage are in phase with each other, which means that the peak voltage is reached at the same instant as peak current. In circuits which have capacitors and inductors (coils) the phase relationships will be quite different.

Capacitance in an AC circuit



Consider now a circuit which has only a capacitor and an AC power source (such as a wall outlet). A capacitor is a device for storing charging. It turns out that there is a 90° phase difference between the current and voltage, with the current reaching its peak 90° (1/4 cycle) before the voltage reaches its peak. Put another way, the current leads the voltage by 90° in a purely capacitive circuit.

To understand why this is, we should review some of the relevant equations, including:

relationship between voltage and charge for a capacitor: CV = Q

relationship between current and the flow of charge : $I = \Delta Q / \Delta t$

The AC power supply produces an oscillating voltage. We should follow the circuit through one cycle of the voltage to figure out what happens to the current.

Step 1 - At point a (see diagram) the voltage is zero and the capacitor is uncharged. Initially, the voltage increases quickly. The voltage across the capacitor matches the power supply voltage, so the current is large to build up charge on the capacitor plates. The closer the voltage gets to its peak, the slower it changes, meaning less current has to flow. When the voltage reaches a peak at point b, the capacitor is fully charged and the current is momentarily zero.

Step 2 - After reaching a peak, the voltage starts dropping. The capacitor must discharge now, so the current reverses direction. When the voltage passes through zero at point c, it's changing quite rapidly; to match this voltage the current must be large and negative.

Step 3 - Between points c and d, the voltage is negative. Charge builds up again on the capacitor plates, but the polarity is opposite to what it was in step one. Again the current is negative, and as the voltage reaches its negative peak at point d the current drops to zero.

Step 4 - After point d, the voltage heads toward zero and the capacitor must discharge. When the voltage reaches zero it's gone through a full cycle so it's back to point a again to repeat the cycle.

The larger the capacitance of the capacitor, the more charge has to flow to build up a particular voltage on the plates, and the higher the current will be. The higher the frequency of the voltage, the shorter the time available to change the voltage, so the larger the current has to be. The current, then, increases as the capacitance increases and as the frequency increases.

Usually this is thought of in terms of the effective resistance of the capacitor, which is known as the capacitive reactance, measured in ohms. There is an inverse relationship between current and resistance, so the capacitive reactance is inversely proportional to the capacitance and the frequency:

A capacitor in an AC circuit exhibits a kind of resistance called capacitive reactance, measured in ohms. This depends on the frequency of the AC voltage, and is given by:

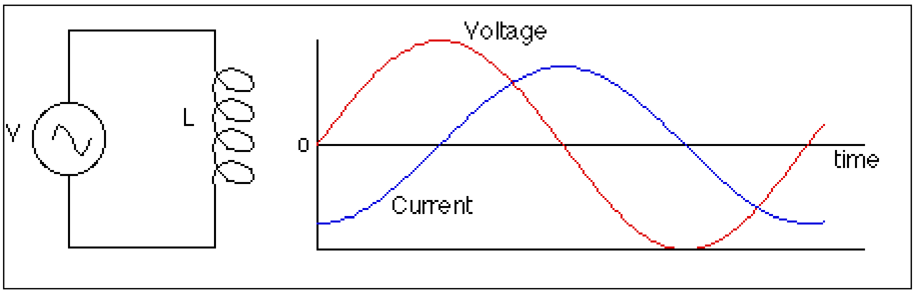
$$\text{capacitive reactance: } X_c = 1 / \omega C = 1 / 2\pi f C$$

We can use this like a resistance (because, really, it is a resistance) in an equation of the form V = IR to get the voltage across the capacitor:

$$V = I X_c$$

Note that V and I are generally the rms values of the voltage and current.

Inductance in an AC circuit



An inductor is simply a coil of wire (often wrapped around a piece of ferromagnet). If we now look at a circuit composed only of an inductor and an AC power source, we will again find that there is a 90° phase difference between the voltage and the current in the inductor. This time, however, the current lags the voltage by 90°, so it reaches its peak 1/4 cycle after the voltage peaks.

The reason for this has to do with the law of induction:

$$\varepsilon = -N \Delta\Phi / \Delta t \qquad \text{or} \quad \varepsilon = -L \Delta I / \Delta t$$

Applying Kirchoff's loop rule to the circuit above gives:

$$V - L \Delta I / \Delta t = 0 \qquad \text{so} \qquad V = L \Delta I / \Delta t$$

As the voltage from the power source increases from zero, the voltage on the inductor matches it. With the capacitor, the voltage came from the charge stored on the capacitor plates (or, equivalently, from the electric field between the plates). With the inductor, the voltage comes from changing the flux through the coil, or, equivalently, changing the current through the coil, which changes the magnetic field in the coil.

To produce a large positive voltage, a large increase in current is required. When the voltage passes through zero, the current should stop changing just for an instant. When the voltage is large and negative, the current should be decreasing quickly. These conditions can all be satisfied by having the current vary like a negative cosine wave, when the voltage follows a sine wave.

How does the current through the inductor depend on the frequency and the inductance? If the frequency is raised, there is less time to change the voltage. If the time interval is reduced, the change in current is also reduced, so the current is lower. The current is also reduced if the inductance is increased.

As with the capacitor, this is usually put in terms of the effective resistance of the inductor. This effective resistance is known as the inductive reactance. This is given by:

$$X_L = \omega L = 2\pi f L$$

where L is the inductance of the coil (this depends on the geometry of the coil and whether its got a ferromagnetic core). The unit of inductance is the henry.

As with capacitive reactance, the voltage across the inductor is given by:

$$V = IX_L$$

Where does the energy go?

One of the main differences between resistors, capacitors, and inductors in AC circuits is in what happens with the electrical energy. With resistors, power is simply dissipated as heat. In a capacitor, no energy is lost because the capacitor alternately stores charge and then gives it back again. In this case, energy is stored in the electric field between the capacitor plates. The amount of energy stored in a capacitor is given by:

$$\text{energy in a capacitor: Energy} = 1/2\ CV^2$$

In other words, there is energy associated with an electric field. In general, the energy density (energy per unit volume) in an electric field with no dielectric is:

$$\text{Energy density in an electric field} = 1/2\ \varepsilon_0\ E^2$$

With a dielectric, the energy density is multiplied by the dielectric constant.

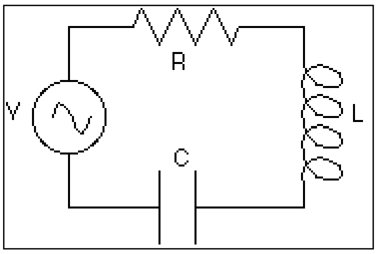
There is also no energy lost in an inductor, because energy is alternately stored in the magnetic field and then given back to the circuit. The energy stored in an inductor is:

$$\text{energy in an inductor: Energy} = 1/2\ LI^2$$

Again, there is energy associated with the magnetic field. The energy density in a magnetic field is:

$$\text{Energy density in a magnetic field} = B^2 / (2\mu_0)$$

RLC Circuits



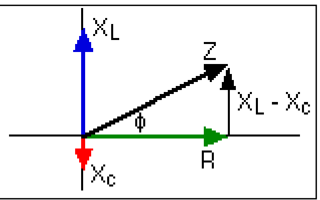
Consider what happens when resistors, capacitors, and inductors are combined in one circuit. If all three components are present, the circuit is known as an RLC circuit (or LRC). If only two components are present, it's either an RC circuit, an RL circuit, or an LC circuit.

The overall resistance to the flow of current in an RLC circuit is known as the impedance, symbolized by Z. The impedance is found by combining the resistance, the capacitive reactance, and the inductive reactance. Unlike a simple series circuit with resistors, however, where the resistances are directly added, in an RLC circuit the resistance and reactances are added as vectors.

This is because of the phase relationships. In a circuit with just a resistor, voltage and current are in phase. With only a capacitor, current is 90° ahead of the voltage, and with just an inductor the reverse is true, the voltage leads the current by 90°. When all three components are combined into one circuit, there has to be some compromise.

To figure out the overall effective resistance, as well as to determine the phase between the voltage and current, the impedance is calculated like this. The resistance R is drawn along the +x-axis of an x-y coordinate system. The inductive reactance is at 90° to this, and is drawn along the +y-axis. The capacitive reactance is also at 90° to the resistance, and is 180° different from the inductive reactance, so it's drawn along the -y-axis. The impedance, Z, is the sum of these vectors, and is given by:

$$Z = [R^2 + (X_L - X_C)^2]^{1/2}$$



The current and voltage in an RLC circuit are related by V = IZ. The phase relationship between the current and voltage can be found from the vector diagram: its the angle between the impedance, Z, and the resistance, R. The angle can be found from:

$$\tan\phi = (X_L - X_C) / R$$

If the angle is positive, the voltage leads the current by that angle. If the angle is negative, the voltage lags the currents.

The power dissipated in an RLC circuit is given by:

$P = VI \cos\phi$ $\cos\phi$ is known as the power factor in the circuit

Note that all of this power is lost in the resistor; the capacitor and inductor alternately store energy in electric and magnetic fields and then give that energy back to the circuit.

Q FACTOR OF R.L.C. SERIES CIRCUITS.

An **RLC circuit** (the letters R, L and C can be in other orders) is an electrical circuit consisting of a resistor, aninductor, and a capacitor, connected in series or in parallel. The RLC part of the name is due to those letters being the usual electrical symbols for resistance, inductance and capacitance respectively. The circuit forms a harmonic oscillator for current and will resonate in a similar way as an LC circuit will. The main difference that the presence of the resistor makes is that any oscillation induced in the circuit will die away over time if it is not kept going by a source. This effect of the resistor is called damping. The presence of the resistance also reduces the peak resonant frequency somewhat. Some resistance is unavoidable in real circuits, even if a resistor is not specifically included as a component. An ideal, pure LC circuit is an abstraction for the purpose of theory.

There are many applications for this circuit. They are used in many different types of oscillator circuits. Another important application is for tuning, such as in radio receivers ortelevision sets, where they are used to select a narrow range of frequencies from the ambient radio waves. In this role the circuit is often referred to as a tuned circuit. An RLC circuit can be used as a band-pass filter, band-stop filter, low-pass filter or high-pass filter. The tuning application, for instance, is an example of band-pass filtering. The RLC filter is described as a *second-order* circuit, meaning that any voltage or current in the circuit can be described by a second-order differential equation in circuit analysis.

The three circuit elements can be combined in a number of different topologies. All three elements in series or all three elements in parallel are the simplest in concept and the most straightforward to analyse. There are, however, other arrangements, some with practical importance in real circuits. One issue often encountered is the need to take into account inductor resistance. Inductors are typically constructed from coils of wire, the resistance of which is not usually desirable, but it often has a significant effect on the circuit.

An important property of this circuit is its ability to resonate at a specific frequency, the resonance frequency, f_0. Frequencies are measured in units of hertz. In this article, however, angular frequency, ω_0, is used which is more mathematically convenient. This is measured in radiansper second. They are related to each other by a simple proportion,

$$\omega_0 = 2\pi f_0$$

Resonance occurs because energy is stored in two different ways: in an electric field as the capacitor is charged and in a magnetic field as current flows through the inductor. Energy can be transferred from one to the other within the circuit and this can be oscillatory. A mechanical analogy is a weight suspended on a spring which will oscillate up and down when released. This is no passing metaphor; a weight on a spring is described by exactly the same second order differential equation as an RLC circuit and for all the properties of the one system there will be found an analogous property of the other. The mechanical property answering to the resistor in the circuit is friction in the spring/weight system. Friction will slowly bring any oscillation to a halt if there is no external force driving it. Likewise, the resistance in an RLC circuit will "damp" the oscillation, diminishing it with time if there is no driving AC power source in the circuit.

The resonance frequency is defined as the frequency at which the impedance of the circuit is at a minimum. Equivalently, it can be defined as the frequency at which the impedance is purely real (that is, purely resistive). This occurs because the impedances of the inductor and capacitor at resonance are equal but of opposite sign and cancel out. Circuits where L and C are in parallel rather than series actually have a maximum impedance rather than a minimum impedance. For this reason they are often described asantiresonators, it is still usual, however, to name the frequency at which this occurs as the resonance frequency.

Natural frequency

The resonance frequency is defined in terms of the impedance presented to a driving source. It is still possible for the circuit to carry on oscillating (for a time) after the driving source has been removed or it is subjected to a step in voltage (including a step down to zero). This is similar to the way that a tuning fork will carry on ringing after it has been struck, and the effect is often called ringing. This effect is the peak natural resonance frequency of the circuit and in general is not exactly the same as the driven resonance frequency, although the two will usually be quite close to each other. Various terms are used by different authors to distinguish the two, but resonance frequency unqualified usually means the driven resonance frequency. The driven frequency may be called the undamped resonance frequency or undamped natural frequency and the peak frequency may be called the damped resonance frequency or the damped natural frequency. The reason for this terminology is that the driven resonance frequency in a series or parallel resonant circuit has the value[1]

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

This is exactly the same as the resonance frequency of an LC circuit, that is, one with no resistor present. The resonant frequency for an RLC circuit is the same as a circuit in which there is no damping, hence undamped resonance frequency. The peak resonance frequency, on the other hand, depends on the value of the resistor and is described as the damped resonant frequency. A highly damped circuit will fail to resonate at all when not driven. A circuit with a value of resistor that causes it to be just on the edge of ringing is called critically damped. Either side of critically damped are described as underdamped (ringing happens) and over damped (ringing is suppressed).

Circuits with topologies more complex than straightforward series or parallel (some examples described later in the article) have a driven resonance frequency that deviates from $\omega_0 = \frac{1}{\sqrt{LC}}$ and for those the undamped resonance frequency, damped resonance frequency and driven resonance frequency can all be different.

Damping

Damping is caused by the resistance in the circuit. It determines whether or not the circuit will resonate naturally (that is, without a driving source). Circuits which will resonate in this way are described as under damped and those that will not are over damped. Damping attenuation (symbol α) is measured in nepers per second. However, the unit less damping factor (symbol ζ, zeta) is often a more useful measure, which is related to α by

$$\zeta = \frac{\alpha}{\omega_0}$$

The special case of $\zeta = 1$ is called critical damping and represents the case of a circuit that is just on the border of oscillation. It is the minimum damping that can be applied without causing oscillation.

Bandwidth

The resonance effect can be used for filtering, the rapid change in impedance near resonance can be used to pass or block signals close to the resonance frequency. Both band-pass and band-stop filters can be constructed and some filter circuits are shown later in the article. A key parameter in filter design is bandwidth. The bandwidth is measured between the 3dB-points, that is, the frequencies at which the power passed through the circuit has fallen to half the value passed at resonance. There are two of these half-power frequencies, one above, and one below the resonance frequency

$$\Delta\omega = \omega_2 - \omega_1$$

where $\Delta\omega$ is the bandwidth, ω_1 is the lower half-power frequency and ω_2 is the upper half-power frequency. The bandwidth is related to attenuation by,

$$\Delta\omega = 2\alpha$$

when the units are radians per second and nepers per second respectively[citation needed]. Other units may require a conversion factor. A more general measure of bandwidth is the fractional bandwidth, which expresses the bandwidth as a fraction of the resonance frequency and is given by

$$F_{\mathrm{b}} = \frac{\Delta\omega}{\omega_0}$$

The fractional bandwidth is also often stated as a percentage. The damping of filter circuits is adjusted to result in the required bandwidth. A narrow band filter, such as a notch filter, requires low damping. A wide band filter requires high damping.

Q factor

The Q factor is a widespread measure used to characterize resonators. It is defined as the peak energy stored in the circuit divided by the average energy dissipated in it per radian at resonance. Low Q circuits are therefore damped and lossy and high Q circuits are under damped. Q is related to bandwidth; low Q circuits are wide band and high Q circuits are narrow band. In fact, it happens that Q is the inverse of fractional bandwidth

$$Q = \frac{1}{F_{\mathrm{b}}} = \frac{\omega_0}{\Delta\omega}$$

Q factor is directly proportional to selectivity, as Q factor depends inversely on bandwidth.

For a series resonant circuit, the Q factor can be calculated as follows:[2]

$$Q = \frac{1}{\omega_0 RC} = \frac{\omega_0 L}{R}$$

Scaled parameters

The parameters ζ, F_{b}, and Q are all scaled to ω_0. This means that circuits which have similar parameters share similar characteristics regardless of whether or not they are operating in the same frequency band.

The article next gives the analysis for the series RLC circuit in detail. Other configurations are not described in such detail, but the key differences from the series case are given. The general form of the differential equations given in the series circuit section are applicable to all second order circuits and can be used to describe the voltage or current in any element of each circuit.

Series RLC circuit

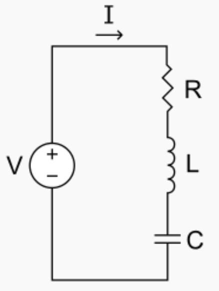


Figure 1: RLC series circuit

V – the voltage of the power source

I – the current in the circuit

R – the resistance of the resistor

L – the inductance of the inductor

C – the capacitance of the capacitor

In this circuit, the three components are all in series with the voltage source. The governing differential equation can be found by substituting intoKirchhoff's voltage law (KVL) the constitutive equation for each of the three elements. From KVL,

$$v_R + v_L + v_C = v(t)$$

where v_R, v_L, v_C are the voltages across R, L and C respectively and $v(t)$ is the time varying voltage from the source. Substituting in theconstitutive equations,

$$Ri(t) + L\frac{di}{dt} + \frac{1}{C}\int_{-\infty}^{\tau=t} i(\tau)\,d\tau = v(t)$$

For the case where the source is an unchanging voltage, differentiating and dividing by L leads to the second order differential equation:

$$\frac{d^2i(t)}{dt^2} + \frac{R}{L}\frac{di(t)}{dt} + \frac{1}{LC}i(t) = 0$$

This can usefully be expressed in a more generally applicable form:

$$\frac{d^2 i(t)}{dt^2} + 2\alpha \frac{di(t)}{dt} + {\omega_0}^2 i(t) = 0$$

and ω_0 are both in units of angular frequency. α is called the *neper frequency*, or *attenuation*, and is a measure of how fast the transient response of the circuit will die away after the stimulus has been removed. Neper occurs in the name because the units can also be considered to be nepers per second, neper being a unit of attenuation. ω_0 is the angular resonance frequency.

For the case of the series RLC circuit these two parameters are given by:[4]

$$\alpha = \frac{R}{2L} \text{ and } \omega_0 = \frac{1}{\sqrt{LC}}$$

A useful parameter is the *damping factor*, ζ which is defined as the ratio of these two,

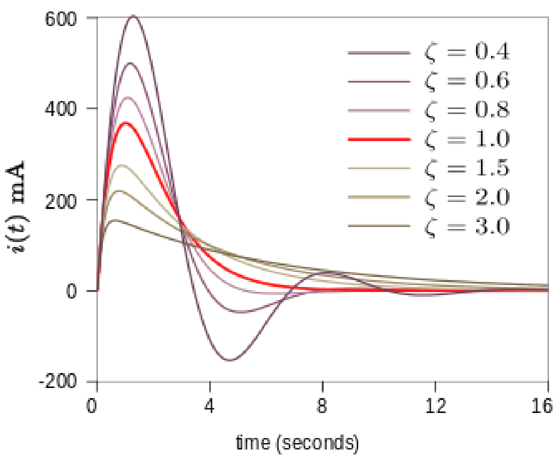
$$\zeta = \frac{\alpha}{\omega_0}$$

In the case of the series RLC circuit, the damping factor is given by,

$$\zeta = \frac{R}{2}\sqrt{\frac{C}{L}}$$

The value of the damping factor determines the type of transient that the circuit will exhibit.[5] Some authors do not use ζ and call α the damping factor.[6]

Transient response



Plot showing under-damped and over-damped responses of a series RLC circuit. The critical damping plot is the bold red curve. The plots are normalized for L = 1, C = 1 and $\omega_0=1$

The differential equation for the circuit solves in three different ways depending on the value of ζ. These are underdamped ($\zeta<1$), overdamped ($\zeta>1$) and critically damped ($\zeta=1$). The differential equation has the characteristic equation,[7]

$$s^2 + 2\alpha s + {\omega_0}^2 = 0$$

The roots of the equation in s are,[7]

$$s_1 = -\alpha + \sqrt{\alpha^2 - {\omega_0}^2}$$
$$s_2 = -\alpha - \sqrt{\alpha^2 - {\omega_0}^2}$$

The general solution of the differential equation is an exponential in either root or a linear superposition of both,

$$i(t) = A_1 e^{s_1 t} + A_2 e^{s_2 t}$$

The coefficients A_1 and A_2 are determined by the boundary conditions of the specific problem being analysed. That is, they are set by the values of the currents and voltages in the circuit at the onset of the transient and the presumed value they will settle to after infinite time.[8]

Over damped response

The over damped response ($\zeta>1$) is,

$$i(t) = A_1 e^{-\omega_0\left(\zeta+\sqrt{\zeta^2-1}\right)t} + A_2 e^{-\omega_0\left(\zeta-\sqrt{\zeta^2-1}\right)t}$$

The over damped response is a decay of the transient current without oscillation.[10]

Under damped response

The under damped response ($\zeta<1$) is,[11]

$$i(t) = B_1 e^{-\alpha t} \cos(\omega_d t) + B_2 e^{-\alpha t} \sin(\omega_d t)$$

By applying standard trigonometric identities the two trigonometric functions may be expressed as a single sinusoid with phase shift,[12]

$$i(t) = B_3 e^{-\alpha t} \sin(\omega_d t + \varphi)$$

The under damped response is a decaying oscillation at frequency ω_d. The oscillation decays at a rate determined by the attenuation α. The exponential in α describes the envelope of the oscillation. B_1 and B_2 (or B_3 and the phase shift φ in the second form) are arbitrary constants determined by boundary conditions. The frequency ω_d is given by,

$$\omega_d = \sqrt{{\omega_0}^2 - \alpha^2} = \omega_0 \sqrt{1 - \zeta^2}$$

This is called the damped resonance frequency or the damped natural frequency. It is the frequency the circuit will naturally oscillate at if not driven by an external source. The resonance frequency, ω_0, which is the frequency at which the circuit will resonate when driven by an external oscillation, may often be referred to as the undamped resonance frequency to distinguish it.

Critically damped response

The critically damped response ($\zeta=1$) is,[14]

$$i(t) = D_1 t e^{-\alpha t} + D_2 e^{-\alpha t}$$

The critically damped response represents the circuit response that decays in the fastest possible time without going into oscillation. This consideration is important in control systems where it is required to reach the desired state as quickly as possible without overshooting. D_1 and D_2 are arbitary constants determined by boundary conditions.

Laplace domain

The series RLC can be analyzed for both transient and steady AC state behavior using the Laplace transform.[16] If the voltage source above produces a waveform with Laplace-transformed $V(s)$ (where s is the complex frequency $s = \sigma + i\omega$), KVL can be applied in the Laplace domain:

$$V(s) = I(s)\left(R + Ls + \frac{1}{Cs}\right)$$

where $I(s)$ is the Laplace-transformed current through all components. Solving for $I(s)$:

$$I(s) = \frac{1}{R + Ls + \frac{1}{Cs}} V(s)$$

And rearranging, we have that

$$I(s) = \frac{s}{L\left(s^2 + \frac{R}{L}s + \frac{1}{LC}\right)} V(s)$$

Laplace admittance

Solving for the Laplace admittance $Y(s)$:

$$Y(s) = \frac{I(s)}{V(s)} = \frac{s}{L\left(s^2 + \frac{R}{L}s + \frac{1}{LC}\right)}$$

Simplifying using parameters α and ω_0 defined in the previous section, we have

$$Y(s) = \frac{I(s)}{V(s)} = \frac{s}{L\left(s^2 + 2\alpha s + {\omega_0}^2\right)}$$

Poles and zero

The zeros of $Y(s)$ are those values of s such that $Y(s) = 0$:

$$s = 0 \text{ and } |s| \rightarrow \infty$$

The poles of $Y(s)$ are those values of s such that $Y(s) \rightarrow \infty$. By the quadratic formula, we find

$$s = -\alpha \pm \sqrt{\alpha^2 - {\omega_0}^2}$$

The poles of $Y(s)$ are identical to the roots s_1 and s_2 of the characteristic polynomial of the differential equation in the section above.

*General solution[**edit**]*

For an arbitrary $E(t)$, the solution obtained by inverse transform of $I(s)$ is:

$$I(t) = \frac{1}{L}\int_0^t E(t-\tau)e^{-\alpha\tau}\left(\cos\omega_d\tau - \frac{\alpha}{\omega_d}\sin\omega_d\tau\right) d\tau \text{ in the underdamped case } (\omega_0 > \alpha)$$

$$I(t) = \frac{1}{L}\int_0^t E(t-\tau)e^{-\alpha\tau}(1-\alpha\tau)\, d\tau \text{ in the critically damped case } (\omega_0 = \alpha)$$

$$I(t) = \frac{1}{L}\int_0^t E(t-\tau)e^{-\alpha\tau}\left(\cosh\omega_r\tau - \frac{\alpha}{\omega_r}\sinh\omega_r\tau\right) d\tau \text{ in the overdamped case } (\omega_0 < \alpha)$$

where $\omega_r = \sqrt{\alpha^2 - {\omega_0}^2}$, and cosh and sinh are the usual hyperbolic functions.

Sinusoidal steady state

Sinusoidal steady state is represented by letting $s = i\omega$

Taking the magnitude of the above equation with this substitution:

$$|Y(s = i\omega)| = \frac{1}{\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}}.$$

and the current as a function of ω can be found from

$$|I(i\omega)| = |Y(i\omega)||V(i\omega)|.$$

There is a peak value of $|I(i\omega)|$. The value of ω at this peak is, in this particular case, equal to the undamped natural resonance frequency

$$\omega_0 = \frac{1}{\sqrt{LC}}.$$

UNIT-2

SINGLE PHASE TRANSFORMER

BASIC CONCEPT OF TRANSFORMER

The main function of the transformer is to transfer the electrical energy from one circuit to other without any direct electrical connection and without changing of frequency of electrical power.A transformer works on the principle of electromagnetic induction. The primary and secondary coil of the transformer electrically separated but magnetically linked at the same frequency.

TYPES OF TRANSFORMER

1. Step-up transformer
2. Step-down transformer
3. Voltage transformer
4. Current transformer
5. Auto transformer

BASIC CONSTRUCTION AND WORKING PRINCIPLE OF TRANSFORMER

An elementary transformer consists of soft iron or silicon steel core and two winding. The winding are insulated fromthe core. The core lamination provides a path of low reluctance.Lamination of core is used to reduce eddy current loss to the magnetic flux. Energy may be efficiently transferred by induction from one set of coils to another by means of a varying magnetic flux. The EMF are induced by the variation in the magnitude of flux with time. The frequency of induced EMF is same as that of flux or that of supply voltage.

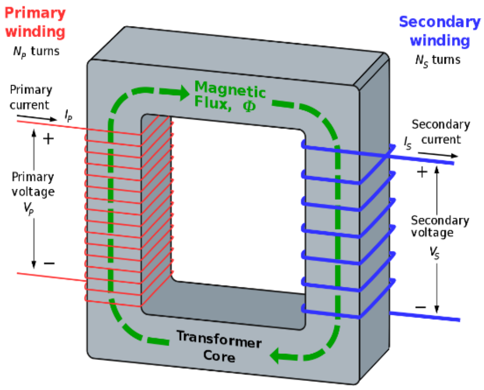


Fig1

EMF equation and voltage current transformation ratio of transformer -

For an alternating voltage the transformer generates alternating flux which links primary and secondary windings.

Let Φ_{max} = Maximum value of flux. F = Supply frequency.

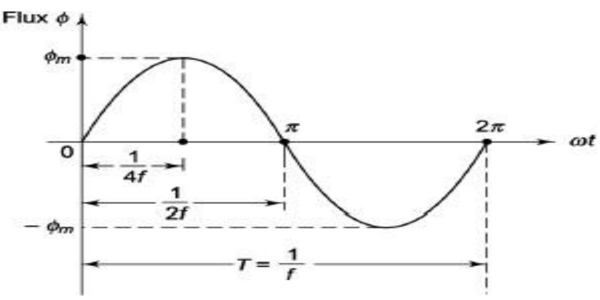


Fig2

Resulting magnetic flux raises from zero to Φ_{max}in quarte cycle.

Average rate of change of fluxdΦ/dt = Φ_{max}/1/4F = 4FΦ_{max}. Since average EMF induced per turn in volts is equal to the average rate of change of flux.

E1 = EMF induced per turn x number of primary turns= 4.44FΦ_{max}x N1 = 4.44FN1Φ_{max} volts.

Similarly RMS value of EMF induced in secondary

E2 = 4.44FΦ_{max}x N2 volts

By calculating E_1 and E_2 we can conclude emf lags by 90^0 to the main flux.

The EMF equation for primary and secondary are

E_1=4.44F Φ_{max} N_1

E_2=4.44F Φ_{max} N_2

$(E_2/E_1) = (N_2/N_1)= k$

Where k is a constant.

STEP UP AND STEP DOWN TRANSFORMER

A transformer can be either step up or stepdown depending on the windings of primary and secondary sides. In case of step up transformer secondary winding is more than primary winding. On the other hand the step down transformer has primary winding is more than secondary windings. An step up transformer transfers the voltage to secondary which is more than the input voltage whereas in step down transformer the voltage at output is less than that of the input voltage. Step down transformers are used in electronic circuits toget lower voltage.

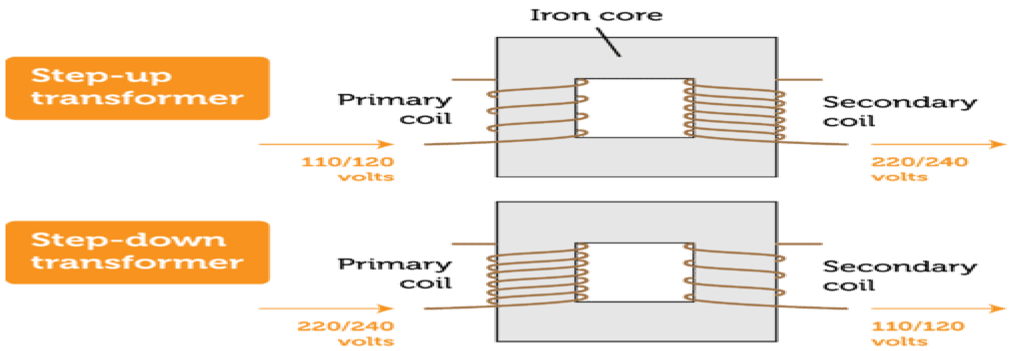


Fig.3

VOLTAGE AND CURRENT TRANSFORMER

To measure the power on a high voltage circuit we use both current and voltage transformer. The voltage transformer is also named as potential transformer.

1. CURRENT TRANSFORMER : the primary winding of current transformer consist of very few turns and the secondary winding has large number of turns. The ammeter is connected directly across the secondary winding terminals. The current transformer is a step up transformer (to Step Up voltage) or step down the current to the operating range of ammeter.

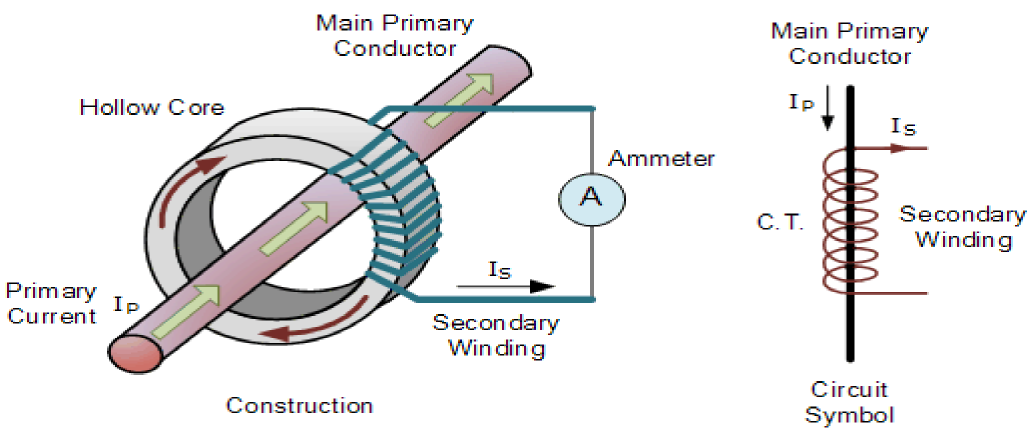


Fig.4

2. VOLTAGE TRANSFORMER- the voltage Transformer the steps down the voltage to the operating range of voltmeter. It consists of a few turns on secondary and more turns on primary. The primary winding is connected to the voltage being measured and secondary winding is connected to the voltmeter.

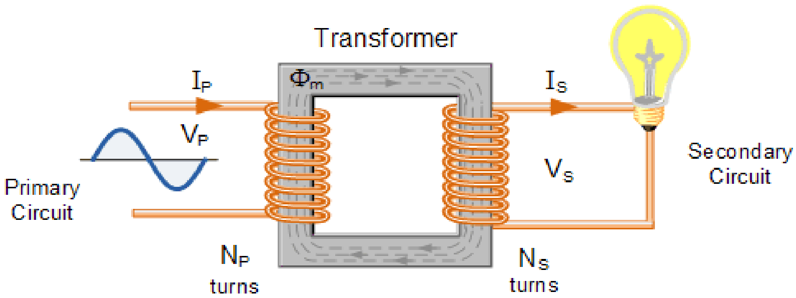


Fig.5

3 AUTO TRANSFORMER - it is a one winding transformer. This winding is used to provide primary and secondary winding turns and these two are not electrically isolated as in normal 2 winding transformer. The transformation ratio of auto transformer is near to Unity for the same voltage ratio and capacity, the auto Transformer require less amount of copper. The auto transformer may be step up or step down transformer.

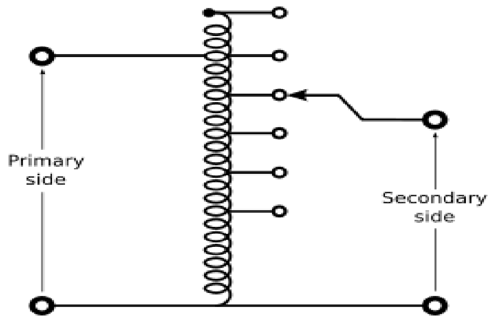


Fig.6

If the number of primary turns is N1 and Number of secondary turns is N2 and K is transformation ratio then (N1/N2) = K. If N1 is greater than N2, so the auto transformer is a step down transformer, otherwise it is step up transformer. In auto transformer power is transferred through two modes ie. Inductively and conductivity.Copper is saved in auto transformer because auto transformer has only one winding so it consumes less amount of copper. The volume of copper depends upon the area of cross section and length of conductor.

REWINDING OF TRANSFORMER

Following is the process of rewinding the transformer:

1. Tools and materials are required for rewinding the transformer
2. The core of transformer should be dismantle properly.
3. Remove the old secondary winding.
4. Determine the gauge of wire used for secondary winding.
5. Rewind the transformer with the same gauge as of previously wire.

COOLING OF TRANSFORMER - Practically ideal transformer produces some losses most of them transformed into heat which is not dissipated from the transformer properly. The increase in temperature may cause several error. Therefore transformer required cooling system for hustle free function.

Transformer can be divided in two types-

1. **Dry type transformer**
2. **Oil immersed transformer**

Cooling method for dry type transformers

1. **Natural air cooled transformer-** The small transformer of low rating up to 3MVA are provided cooling through natural passage of environmental air.
2. **Air blast-** In case of air blast cooling more than 3MVA transformer are considered where high pressure air passed to the windings for the cooling purpose.

Cooling method for oil immersed transformer

Oil Natural Air Natural (ONAN)

Due the presence of heat in the core winding of transformer the oil is heated and flows inside in circular motion the additional cooled oil is filled inside the transformer because of movement the heat is dissipated slowly to the atmosphere and widely used for high rating transformer up to 30 MVA transformer.

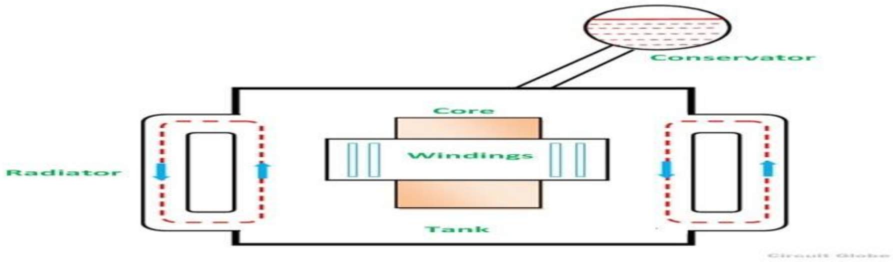


Fig.6

Oil Natural Air Forced (ONAF)

In this method of oil transformer fans are placed near by the radiator that turns on and off with increase and decrease in temperature above and below certain value. This type of cooling is used for high rating transformer up to 60MVA transformer.

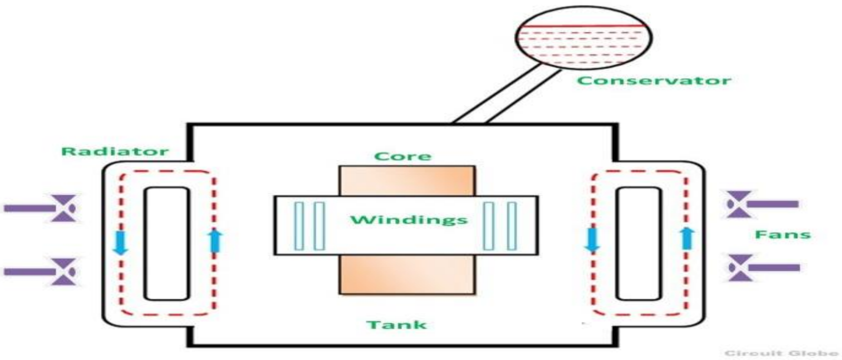


Fig.7

Oil Forced Air Forced (OFAF)

In this method of Transformer cooling pumping is used to circulate oil. The heat exchanger circulate oil resulting forced and compressed air inside the transformer additional fans sometimes required for cooling purpose. This type of cooling is used for power station and sub station because of their high load capacity.

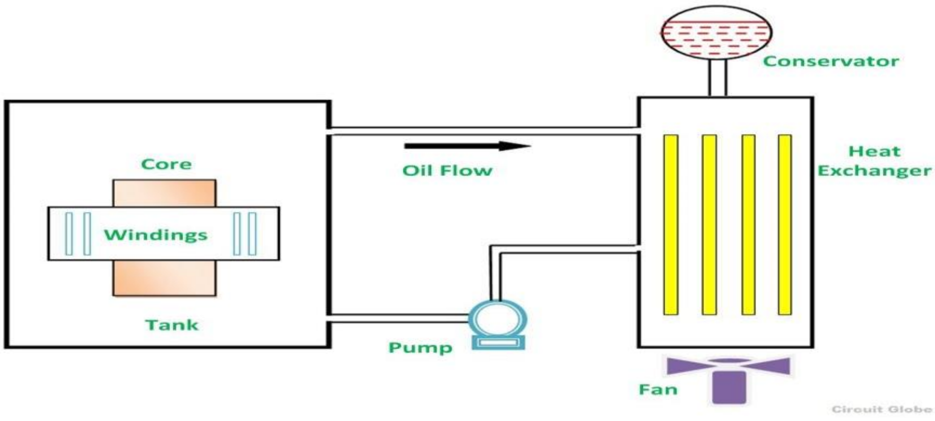


Fig.8

Safety measure precautions of Transformer from operational point of view -

1. Physical inspection required before installation.
2. Switch off power supply while working with the transformer.
3. Useinsulative equipment like gloves rubber shoe and keep all the standard setup by manufacturer.
4. Keep all the smaller objects away from the work place, so that they do not fall inside the transformer.
5. Insure transformer must be grounded before providing supply.
6. Place Transformer in such a way that it will always dry.
7. Keep people away by putting danger sign.

Application of transformer

1. Transformer is used for step up or step down the voltage.
2. Power Transformers are used for Transmission and distribution of electrical power.
3. The Transformer used for isolate two circuits electrically.
4. It is used in voltage regulators voltage stabilizers and power suppliers.
5. It is used for isolate two circuit electrically.
6. The Transformer used for Impedance matching.
7. It is used in rectifiers.
8. It is used in relays and protection purpose in different instruments in industries.

9. Transformers are used for conducting tests at high voltage.
10. It is used for a special application like furnace welding.

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UNIT-3

DC Motors

DC Motors: DC Motors is a machine which converts electrical energy into mechanical energy. It is based on the principle that when a current carrying conductor is placed in a magnetic field it will experience a mechanical force whose magnitude is given by the relation

$$F=BIL$$

F- mechanical force on conductor

B - magnetic flux density

I - current through conductor

L - length of conductor

Fig. 1

Construction of DC Motor

DC motor classified like shunt series and compound motor. In DC motor commutator provides unidirectional torque.

In DC motor one conductor placed in a slot of armature which is under the magnetic field of North Pole. Similarly a conductor which is directly opposite to this conductor is under the effect of South Pole.

When a current is passed through in this experience a force which is tangential to the circumference of armature. By applying Fleming left hand rule let the direction of force be downward under the north-pole force on the conductor under the South Pole will be upward. As the force are equal and opposite they form a couple. This force couple provides the turning effect or torque by which motor rotates. This torque is transferred to the shaft of motor and is utilised to drive mechanical load. In this way electrical energy is converted into mechanical energy.

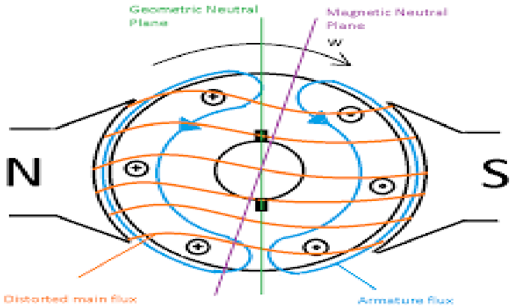

Fig.2

Voltage equation of DC motor

$$V = E_b + I_a R_a$$

V - input voltage

Eb - back EMF

Ia - armature current

Ra - armature resistance

Characteristics of DC motor

There are three main characteristics of DC motor. The characteristics and their characteristics curve give the relationship between torque, armature current and speed. On the basis of relationship between above quantities the characteristics are classified as:

1 - Torque and armature current characteristics is known as Electrical characteristics

2 - Speed and armature current characteristics gives the relationship between speeds of armature current

3 - Speed and torque characteristicsis known as mechanical characteristics

Characteristics of DC shunt motor

$$Ta \ \alpha \ \phi I_a$$

in DC motor ϕ is assumed constant

(ii) Speed armature current characteristic

$$N \alpha E_b$$

$$E_b = \text{back e.m.f}$$

The speed of DC shunt motor decreases linearly with increase of armature current.

(iii) Speed torque characteristics

$$Ta \alpha \phi I_a$$

Where ϕ is constant

As the flux remain constant the torque increases with armature current but back EMF decreases if speed decreases.

Characteristics of DC series motor

(i) Torque armature current characteristics

$$Ta \alpha \phi I_a$$

Because in series motor the field current is equal to the armature current then

$$Ta \alpha \phi I^2_a$$

The armature torque varies as the square of armature current so it produces high torque for a small current thus series motor is applicable when high starting torque is required.

(ii) Speed and armature current characteristics

$$N \alpha \{ V - Ia (Ra + Rse)\} / Ia$$

Ra and Rse are very small voltage drop across these resistance may be neglected hence

$$N \alpha V/Ia$$

as the applied voltage V also remain constant

The speed varies inversely as armature current when current is low. Speed is very high if current is high then speed become low.

(iii) Speed torque characteristic

$$Ta \ \alpha \ \phi \ I_a$$
$$N \ \alpha Eb/\phi$$

Flux is directly proportional to armature current

Characteristic of DC compound motor

As we know compound motor has shunt and series field winding both. So characteristic lies in between shunt and series motor compound motor are of two type

(i) Commulative compound

(ii) Differential compound

(i) Torque and Armature current characteristic

Torque in DC motor

$$Ta \ \alpha\phi Ia$$

In compound motor shunt field remains constant but series field increase with load current.

- in commulative compound motor both flux are added so torqe of this motor will be greater than that of shunt motor.

- in differential compound motor torque is less than that for the same armature current because shunt and series field oppose each other

(ii) Speed and Armature current characteristic

In compound motor when load current increase is flux also increase but speed is inversely proportional to flux

$$N \ \alpha \ I/\phi$$

- In commulative compound motor series field and the shunt field so its net flux increase in comparison of shunt field. So speed of motor falls as load increases.

- In differential compound motor series field oppose the shunt fields so it's net flux decreases and speed increases

(iii) Speed torque characteristics

- Commulative compound motor develops large amount of torque at low speed but on increasing the speed the torque decreases.

-   In differential compound motor on increasing the speed torque as also increased. This why differential compound motor rate rarely used.

Application of different types of DC Motors

Types & characteristics of motor	**Applications**
1 - Shunt motor: its speed is approx. remain constant and has medium starting torque.	1- lathe and drill machine 2- milling and shaper machine 3- blowers and fans 4- spinning and weaving machine in textile industry 5- machine tools
2- Series motor: it has high starting torque and variable speed is required	1- Elevators 2- electric traction 3- Hoist and cranes 4- trolley and conveyor belt system 5- air compressor 6- vacuum cleaner, hair dryer

	sewing machine
3- Compound motor	1- Rolling Mills
(i) Commulative compound motor	2- punch machine
it has high starting torque no load connection is permissible	3- Presses
	4- heavy planners
	5- shear machine
	6- reciprocating machine
(ii) differential compound motor	generally this type of motor is not used
its speed increases as load decreases	

DC motor starter

The current at the time of starting is very high and many times of the rated load current. This exercise current main damage the motor due to the excessive heat and short circuit which result in the damage of brushes, commulator and winding etc.

To avoid this stage we require a starter forstarting period third stage decorationi,e when motor runs with rated speed and back EMF is developed. Starter is necessary.

(i) To control the starting current up to safe value.

(ii) To protect the motor against the damage brushes commutator and winding.

To protect the motor with this excessive current we have to increase the armature circuit resistance we add a variable resistance in series with armature.

DC motor starter consists of starting resistance which is properly graded. In addition to starting resistance there are some protective devices like no volt release and overload release. The starting resistance r cut out in the steps till the motor gets its rated speed.

Fractional horsepower

The horsepower calculated on the basis of shaft torque is known
as break horsepower (BHP).

1 BHP = 746 watt

Single phase AC motor

Principle: conversion of electrical power into mechanical power takes place in the rotating part of an electric motor. In DC motor electrical power is conducted directly to the armature (i.e rotating part) through brushes and commutator. Hence in this sense a DC motor can be called a conduction motor. However in a AC motor the rotor does not receive electric power by conduction but the induction in exactly the same way as the secondary of two winding Transformer receives. Its power from the primary. That is why such Motors are known as induction motors.

Construction

it consists of two main parts:

(1) Stator (2) Rotor

(1) Stator: it is a stationary part of the motor which is made up of it number of stampings which are slotted at its end. The stator carries the three phase distributed winding. The outer part of the stator is called a stator frame. stator frame is made up of cast iron which covers the stator and rotor of the motor.it is wound for a definite number of poles the exact number of pole being determined by the requirement of speed. Greater the number of pole, lesser the speed.

Rotor: it is the rotating part of induction motor. The rotor is placed inside the starter which some air gap. It is cylindrical in shape having slots on its outer periphery or circumference. The slots are not parallel to the shaft axis to reduced the magnetic hum and to avoid magnetic locking rotors are of two types-

(1) Squirrel cage Rotor

(2) Phase wound Rotor

Squirrel cage Rotor: most of the induction motor have a squirrel cage motor. The rotor conductors which are in the form of bars are placed inside the slots. The bars are made of aluminium or copper. These bars are permanently short circuited with the help of conducting ends rings. Now the structure seems to be a cage forming a closed circuit due to its cage structure it is called a squirrel cage Rotor.

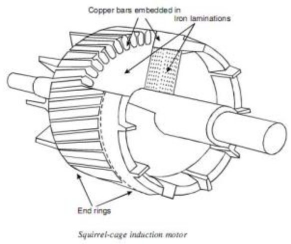

Fig.

Properties of a squirrel cage Rotor.

1- Rotor consists of bars in place of winding

2- Its construction is rugged and very simple

3- As it is permanently short circuit no external resistance can be inserted in the circuit

4- it is economical

Phase wound route: it is also called slip ring rotor and rotor winding is identical to the stator winding in phase wound rotor stator maybe Delta connected or star but rotor is always star connected.

It has laminated core the shape of core is cylindrical the cylindrical core has uniform slots on its outer Periphery. The rotor winding are placed in these slots. The number of rotor slots are less than stator slots.

Delta connected stator

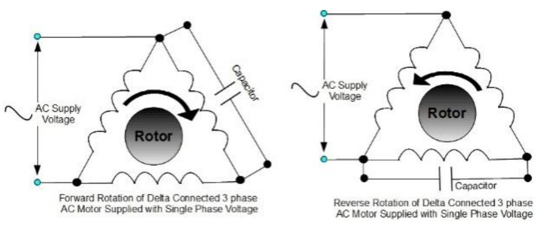

Fig.

Star connected stator

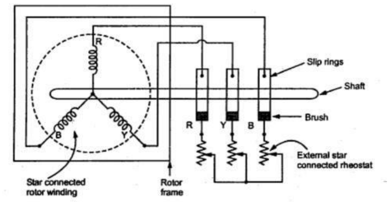

Fig.

The starting resistance is connected to get high starting torque. This is starting resistance is connected across the slip rings. At the time of starting full extra resistance is included in the rotor circuit. The starting resistance remains in the circuit only for starting.

In normal running condition the extra resistance is cut out from the circuit and rotor is short circuited through slip rings or rotor circuit get closed in itself. This external resistance is also used to control the speed by putting it in the circuit under running condition.

Comparison between squirrel cage and slip ring induction motor

Squirrel cage	**Slip ring**
1- lower starting torque	high starting torque
2- starting current is 5 to 6 times of full load current	starting current is 2 to 3 times of full load current
3- starter is required	can be started directly online with the help of external resistance
4- high efficiency	lower efficiency
5- minimum maintenance	high degree of maintenance
6- no speed control	speed control is possible
7- no slip rings, brushes, gears	slip ring, brushes, gears are required
8- it is economical	it has higher coast

Single phase induction motor

Single phase induction motor runs with single phase supply. The efficiency of the single phase induction motor is less than that of the three phase induction motor. Single phase induction motor are extensively used for domestic application like fans, coolers, geysers, mixies, washing machines etc. The rating of single phase induction motor is less than 1 KW or we can say that the single phase moter has fractional horsepower rating.

The single phase induction motor looks like a three phase induction motor. It is constructionally same as three phase induction motor except that the starter has a single phase winding instead of 3 phase winding.

Types of single phase induction motor

(1) Split phase motor

(2) Capacitor start motor

(3) Shaded pole motor

(4) Capacitor start capacitor run motor

(5) Permanent split capacitor motor

(1) Split phase motor

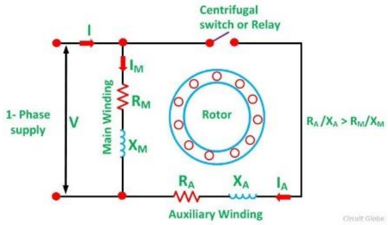

Fig.

It is also known as resistance start motor. In a split phase motor the main winding has low resistance so it is found with thick wire. The auxiliary winding has high resistance and low reactance and is wound with fewer turns of wire. In other words we can say that the auxiliary winding is designed to have higher resistance and reactance ratio then the main winding. Both winding are connected directly across a single phase supply. A centrifugal switch is also connected in series with auxiliary winding.

As the Split phase motor have low starting torque so their use is limited to 1 KW. Due to it's low cost it is mainly used in washing machines, grinders, food mixers, air conditioners etc.

Capacitor start motor:

It is the modified form of a split phase motor (resistance start). A capacitor C is also inserted in series with auxiliary winding.

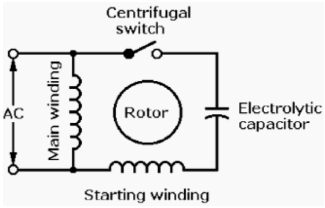

Fig.

The capacitor is electrolytic capacitor. It is a short duty type and guaranteed for 20 operation per hour. The value of a capacitor ranges from 50 to a few hundred . Capacitor is usually mounted in a metal casing on the top of the motor enclosure with the help of capacitor the angle between current in main winding Im and current in a starting winding I is improved to nearly 90 degree.

The torque is directly proportional to sin. So in capacitor start motor the starting torque is increased. Generally torque of the capacitor start motor is approximately double of the torque of the split phase motor. When the motor gets the rated Speed the auxiliary winding and switch are automatically disconnected by centrifugal switch.

Precautions with this motor-

1- It is not used for the application having long duration of starting. ie.more than 3 seconds.

2- The capacitor start motor should not be started to frequently

3- The voltage rating should not exceed. Tf voltage exceeds more than 25% the electrolytic capacitor when get damaged.

Advantages of single phase motor over three phase IM

1- It is simple and robust in construction

2- It is less expensive for a small letting up to 1 Kw

3- It is used mostly in low power drivers

4- It is used in small industrial and domestic application

Disadvantages of 1 over 3 phase induction motor

1- It’s efficiency is only 50% of the output

2- A starting torque is very low

3- It is not self-starting

4- It is costlier due to the centrifugal switch and capacitor

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UNIT- 4

Three Phase Induction Motors

4.1 Definition:

Induction motor is an a.c. motor in which currents in the stator winding (which is connected to the supply) set up a flux which causes currents to be induced in the rotor winding ; these currents interact with the flux to produce rotation . Also called asynchronous motor. The rotor receives electrical power in exactly the same way as the secondary of a two winding transformer receiving its power from primary. That is why an induction motor can be called as a rotating transformer i.e., in which primary winding is stationary but the secondary is free to rotate.

4.2 Introduction:

The three-phase induction motors are the most widely used electric motors in industry. They run at essentially constant speed from no-load to full-load. It works on the principle of induction and hence the name induction motor. However, the speed is frequency dependent and consequently these motors are not easily adapted to speed control. We usually prefer d.c. motors when large speed variations are required. Nevertheless, the 3-phase induction motors are simple, rugged, low-priced, easy to maintain and can be manufactured with characteristics to suit most industrial requirements. Three-Phase Induction Motor Like any electric motor, has a stator and a rotor. The stator carries a 3-phase winding (called stator winding) while the rotor carries a short-circuited winding (called rotor winding). Only the stator winding is fed from 3-phase supply. The rotor winding derives its voltage and power from the externally energized stator winding through electromagnetic induction and hence the name. The induction motor may be considered to be a transformer with a rotating secondary and it can, therefore, be described as a “transformer type” a.c. machine in which electrical energy is converted into mechanical energy.

4.3 Advantages:

(i) It has simple and rugged construction.

(ii) It is relatively cheap.

(iii) It requires little maintenance.

(iv) It has high efficiency and reasonably good power factor.

(v) It has self starting torque.

4.4 Principle of operation

4.4.1 Brief working principle

The principle of working of 3 phase induction motor is Mutual induction. Here supply is not directly given to the rotor. When the three phase stator winding of an induction motor is fed from a three phase A.C supply, a magnetic flux is set up in the stator windings. This magnetic flux is of constant magnitude but rotating round the air gap at synchronous speed (Ns). This rotating magnetic flux passes through the air gap and cuts the rotor conductors which are stationary. Therefore an emf will be induced in the rotor conductors. As the rotor forms a closed circuit, a current will flow and hence a torque is produced in the rotor. According to Lenz's law, the induced e.m.f always opposes the cause which produces it. Here the cause is the relative speed between magnetic field and the rotor. Hence to reduce the relative speed, the rotor start to rotate in the same direction as that of the magnetic flux and tries to catch up the rotating magnetic field. But the rotor never catches up the speed of the rotating magnetic field and only rotates at a speed less than the synchronous speed.

4.4.2 Detailed working principle

An AC current is applied in the stator armature which generates a flux in the stator magnetic circuit. This flux induces an emf in the conducting bars of rotor as they are "cut" by the flux while the magnet is being moved (E = BVL (Faraday's Law)) A current flows in the rotor circuit due to the induced emf, which in term produces a force, (F = BIL) can be changed to the torque as the output. In a 3-phase induction motor, the three-phase currents ia, ib and ic, each of equal magnitude, but differing in phase by 120°. Each phase current produces a magnetic flux and there is physical 120 °shift between each flux. The total flux in the machine is the sum of the three fluxes. The summation of the three ac fluxes results in a rotating flux, which turns with constant speed and has constant amplitude. Such a magnetic flux produced by balanced three phase currents flowing in three-phase windings is called a rotating magnetic flux or rotating magnetic field (RMF).RMF rotates with a constant speed (Synchronous Speed). Existence of a RFM is an essential condition for the operation of an induction motor. If stator is energized by an ac current, RMF is generated due to the applied current to the stator winding. This flux produces magnetic field and the field revolves in the air gap between stator and rotor. So, the magnetic field induces a voltage in the short circuited bars of the rotor. This voltage drives current through the bars. The interaction of the rotating flux and the rotor current generates a force that drives the motor and a torque is developed consequently. The torque is proportional with the flux density and the rotor bar current (F=BLI). The motor speed is less than the synchronous speed. The direction of the rotation of the rotor is the same as the direction of the rotation of the revolving magnetic field in the air gap. However, for these currents to be induced, the speed of the physical rotor and the speed of the rotating magnetic field in the stator must be different, or else the magnetic field will not be moving relative to the rotor conductors and no currents will be induced. If by some chance this happens, the rotor typically slows slightly until a current is re induced and then the rotor continues as before. This difference between the speed of the rotor and speed of the rotating magnetic field in the stator is called slip. It is unit less and is the ratio between the relative speed of the magnetic field as seen by the rotor the (slip speed) to the speed of the rotating stator field. Due to this an induction motor is sometimes referred to as an asynchronous machine.

4.5 Slip

The relationship between the supply frequency, f, the number of poles, p, and the synchronous speed (speed of rotating field), n_s is given by $n_s = 120 \times f / p$. The stator magnetic field (rotating magnetic field) rotates at a speed, n_s, the synchronous speed. If, n= speed of the rotor, the slip, s for an induction motor is defined as $s = (n_s - n)/n_s$. At stand still, rotor does not rotate, n = 0, so s = 1. At synchronous speed, $n = n_s$, s = 0. The mechanical speed of the rotor, in terms of slip and synchronous speed is given by, $n = (1-s)\,n_s$.

4.6 Construction

A typical motor consists of two parts namely stator and rotor like other type of motors.

1. An outside stationary stator having coils supplied with AC current to produce a rotating magnetic field,

2. An inside rotor attached to the output shaft that is given a torque by the rotating field.

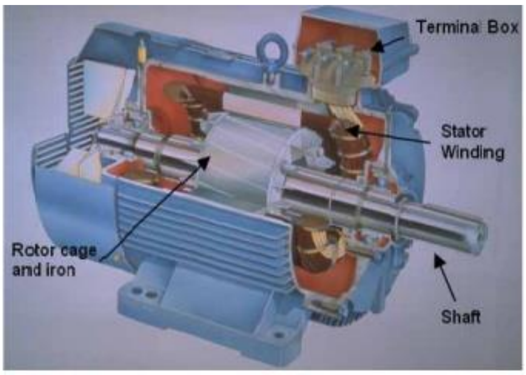

Figure. 1 Induction motor construction

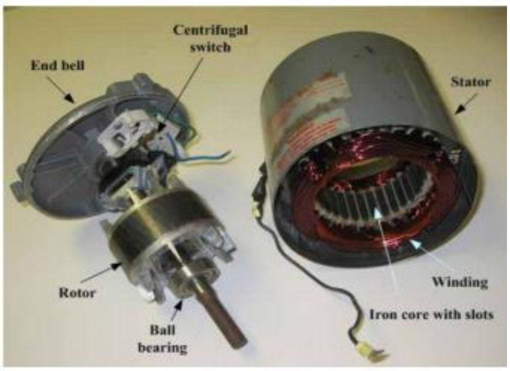

Figure. 2 Induction motor components.

4.6.1 Stator construction

The stator of an induction motor is laminated iron core with slots similar to a stator of a synchronous machine. Coils are placed in the slots to form a three or single phase winding. It consists of a steel frame which encloses a hollow, cylindrical core made up of thin laminations of silicon steel to reduce hysteresis and eddy current losses. A number of evenly spaced slots are provided on the inner periphery of the laminations. The insulated connected to form a balanced 3-phase star or delta connected circuit. The 3-phase stator winding is wound for a definite number of poles as per requirement of speed. Greater the number of poles, lesser is the speed of the motor and vice-versa. When 3-phase supply is given to the stator winding, a rotating magnetic field of constant magnitude is produced. This rotating field induces currents in the rotor by electromagnetic induction.

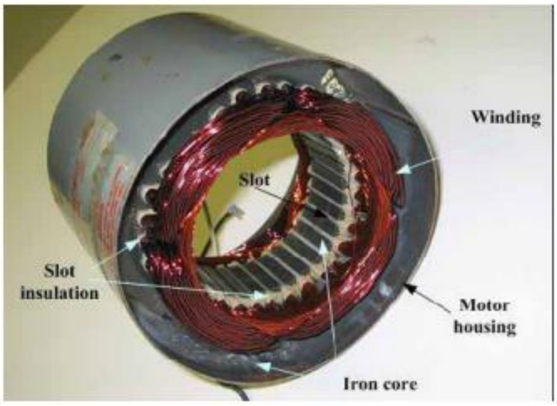

Figure 3.Stator with windings.

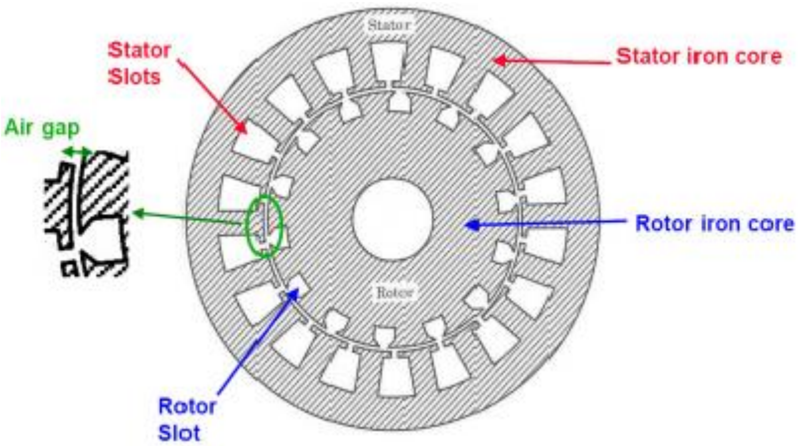

Figure 4. Induction motor magnetic circuit showing stator and rotor slots

4.6.2 *Rotor Construction*

4.6.2.1 *Squirrel-Cage Rotor*

It consists of a laminated cylindrical core having parallel slots on its outer periphery. One copper or aluminum bar is placed in each slot. All these bars are joined at each end by metal rings called end rings. This forms a permanently short-circuited winding which is indestructible. The entire construction (bars and end rings) resembles a squirrel cage and hence the name. The rotor is not connected electrically to the supply but has current induced in it by transformer action from the stator. Those induction motors which employ squirrel cage rotor are called squirrel cage induction motors. Most of 3-phase induction motors use squirrel cage rotor as it has a remarkably simple and robust construction enabling it to operate in the most adverse circumstances. However, it suffers from the disadvantage of a low starting torque. It is because the rotor bars are permanently short-circuited and it is not possible to add any external resistance to the rotor circuit to have a large starting torque.

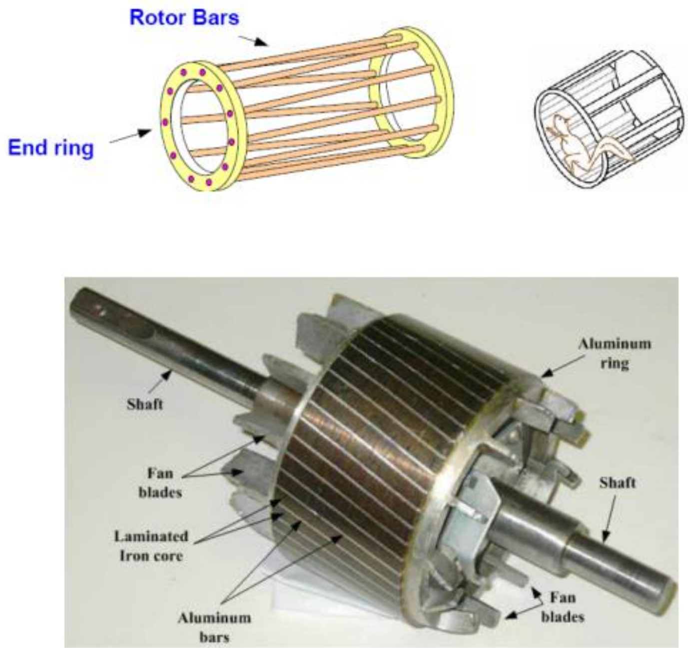

Figure 5. Squirrel Cage Motor

4.6.2.2 Wound Rotor or Slip Ring Rotor

In the wound rotor, an insulated 3-phase winding similar to the stator winding wound for the same number of poles as stator, is placed in the rotor slots. The ends of the star-connected rotor winding are brought to three slip rings on the shaft so that a connection can be made to it for starting or speed control. It is usually for large 3 phase induction motors. Rotor has a winding the same as stator and the end of each phase is connected to a slip ring. Compared to squirrel cage rotors, wound rotor motors are expensive and require maintenance of the slip rings and brushes, so it is not so common in industry applications. It consists of a laminated cylindrical core and carries a 3- phase winding, similar to the one on the stator [See Fig. (8.3)]. The rotor winding is uniformly distributed in the slots and is usually star-connected. The open ends of the rotor winding are brought out and joined to three insulated slip rings mounted on the rotor shaft with one brush resting on each slip ring. The three brushes are connected to a 3-phase star-connected rheostat as shown in Fig. (8.4). At starting, the external resistances are included in the rotor circuit to give a large starting torque. These resistances are gradually reduced to zero as the motor runs up to speed.

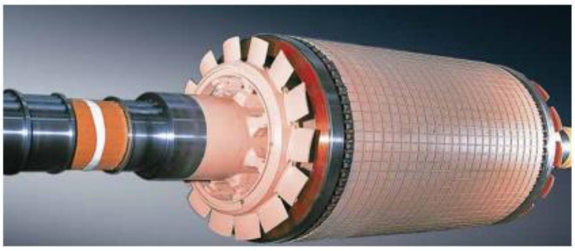

Figure. 6. Wound rotor of a large induction motor. (Courtesy Siemens).

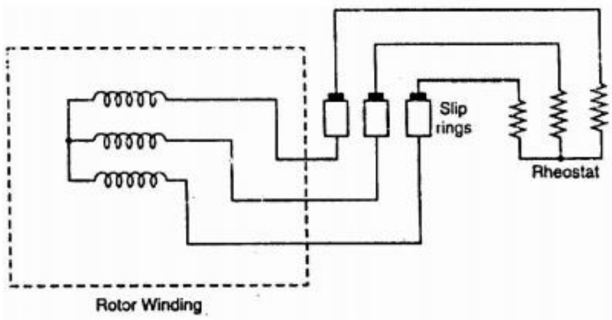

Figure 6. Rotor Winding connected with Rheostat

By adjusting the rheostat we can adjust the resistance of the rotor circuit externally. This is employed during the starting period of the motor. The motors which use this type of rotor are called slip ring motors.

4.7 Comparison between Squirrel cage and Slip ring motor

Sl.No.	Particulars	Squirrel cage	Slip Ring
1	Construction of rotor	Rotor conductors are shorted at the ends by endrings.	Ends of rotor windings are connected to slip rings
2	Cost	Cheap	Costly
3	Efficiency	High	Low
4	Starting torque	Low	High
5	Maintenance cost	Less	More

4.8 Need for Starters in Induction Motor

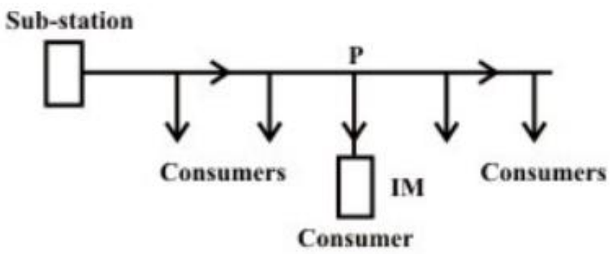

Figure. 7 Distribution line fed from substation for supply to various consumers

The main problem in starting induction motors having large or medium size lies mainly in the requirement of high starting current, when started direct-on-line (DOL). Assume that the distribution line is starting from a substation (Fig.7), where the supply voltage is constant. The line feeds a no. of consumers, of which one consumer has an induction motor with a DOL starter, drawing a high current from the line, which is higher than the current for which this line is designed. This will cause a drop (dip) in the voltage, all along the line, both for the consumers between the substation and this consumer, and those, who are in the line after this consumer. This drop in the voltage is more than the drop permitted, i.e. higher than the limit as per ISS, because the current drawn is more than the current for which the line is designed. Only for the current lower the current for which the line is designed, the drop in voltage is lower the limit. So, the supply authorities set a limit on the rating or size of IM, which can be started DOL. Any motor exceeding the specified rating, is not permitted to be started DOL, for which a starter is to be used to reduce the current drawn at starting.

4.9 Types of Starters for Three phase Induction Motor

4.9.1 Star-Delta Motor Starter

The Star Delta starting method is a motor starting mechanism that minimizes the large amount of starting current that motors draw in. The Star Delta, as the name suggests basically involves feeding the motor with 1/√3 (58%) of the full load current until it attains speed then applying the full load current. It is required three contactors i.e., the Star Contactor (K3), the Delta Contactor (K4) and the Main Contactor (K1). However for the motor to be started in Star Delta, its internal connection at the terminal box has to be wired in Delta-giving it capability of receiving the full-load current at any instant. When the power is fed into the circuit, K1 allows current to flow to the motor. Current flows into the motor and out to the K3 which is the star-connected starter. After a specified period defined by the clock delay (usually 5 sec) the K4 (Delta) Closes and K3 opens to allow the motor to receive the full load current and run at delta. Traditionally, in many regions there was a requirement that all motor connections be fitted with a reduced voltage starter for motors greater than 4KW (5HP).This was to curb the high inrush of starting currents associated with starting induction motors. The star and delta contactors are mechanically interlocked i.e., if one of them is closed the other cannot close. This is done to avoid dead short circuit in case both the contactors closing simultaneously. Electrical interlocking has also been provided, by using contactors control contacts. An advantage of this method could be low or reduced cost as compared to other methods.

Connection:

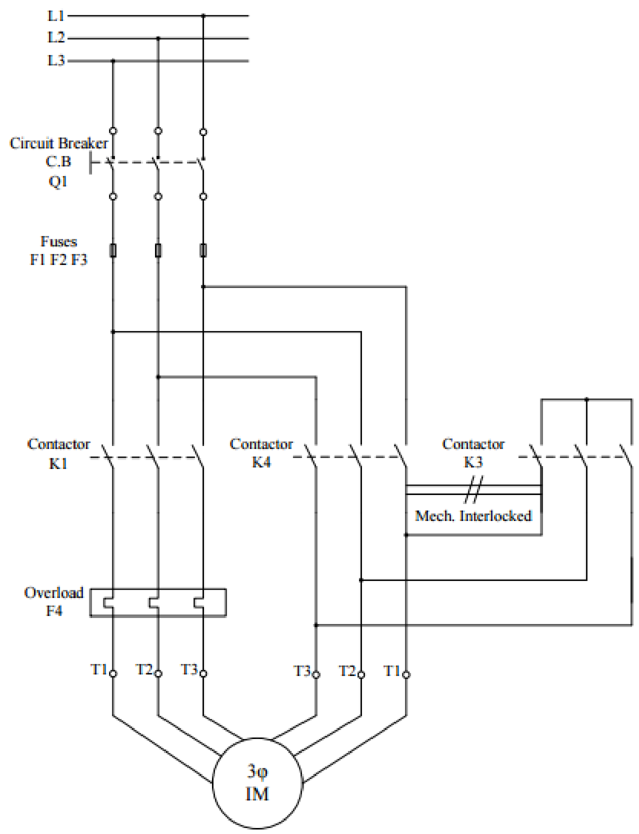

Figure 8. Power Circuit(Star-Delta)

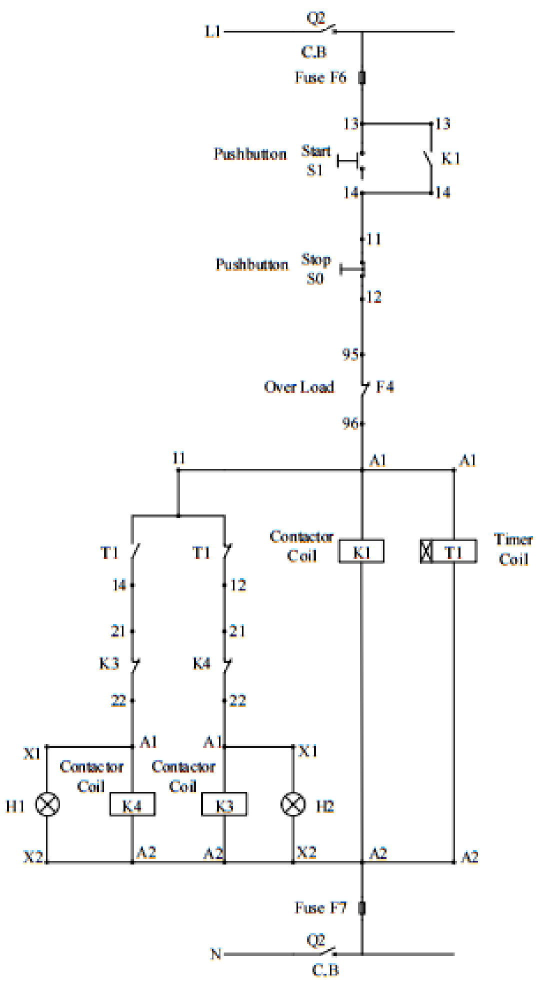

Figure 9. Control Circuit (Star-Delta)

4.9.2 Direct Online Motor Starter (DOL Starter)

To start and stop a three phase induction motor by Direct On Line (DOL) Starter. 2- Theory A Direct On Line (DOL) or across the line starter applies the full line voltage to the motor terminals. This is the simplest type of motor starter. A DOL motor starter also has protection devices and, in some cases, condition monitoring. Smaller sizes of direct on-line starters are manually operated; larger sizes use an electromechanical contactor (relay) to switch the motor circuit. Solid-state direct on line starters also exist. A direct on line starter can be used if the high inrush current of the started motor does not cause excessive voltage drop in the supply circuit. The maximum size of a motor allowed on a direct on line starter may be limited by the supply utility for this reason. For example, a utility may require rural customers to use reduced-voltage starters for motors larger than 4KW (5HP). DOL starting is sometimes used to start small water pumps, compressors, fans and conveyor belts. In the case of an asynchronous motor, such as the 3-phase squirrel-cage motor, the motor will draw a high starting current until it has run up to full speed. This starting current is typically 6-7 times greater than the full load current. To reduce the inrush current, larger motors will have reduced voltage starters or variable speed drives in order to minimize voltage dips to the power supply, or series resistance and inductance can be added.

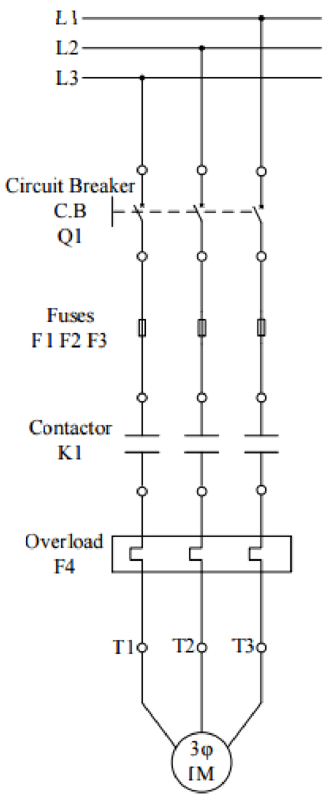

Figure 10.(i) Power Circuit

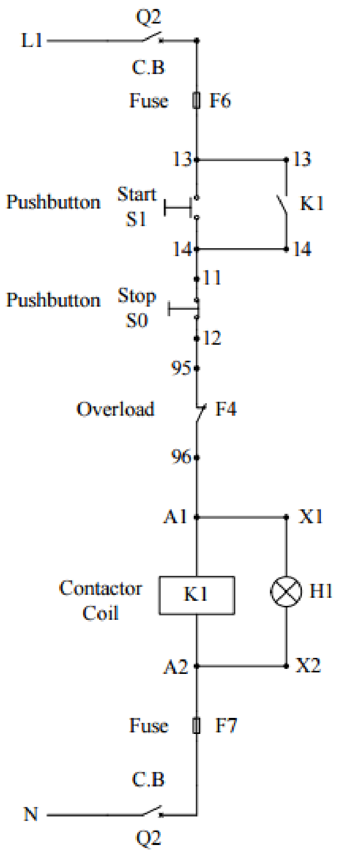

Figure 10.(ii) Control Circuit

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Unit - 5

Measuring Instruments -II:

5.1 Induction type Energy Meter

5.1.1 Definition:

The **instrument** used for **measuring** the electricity or **energy** is known as the energy meter. The **energy** is the total **power consumed** and utilised by the load at a **particular interval** of **time**. It is used in **domestic** and **industrial** AC circuits for measuring the power consumption.

Fig. 1: Single Phase Induction type Energy Meter

5.1.2 Construction of Single phase Induction type Energy Meter

The construction of the single phase energy meter is shown in the figure below.

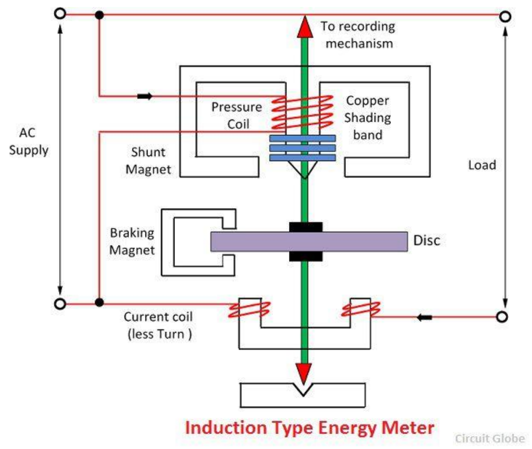


Fig. 2: Inside of Induction type Meter

The induction type energy meter has four main parts. They are the

1. Driving System
2. Moving System
3. Braking System
4. Registering System

1. Driving System – The electromagnet is the main component of the driving system. It is the temporary magnet which is excited by the current flow through their coil. The core of the electromagnet is made up of silicon steel lamination. The driving system has two electromagnets. The upper one is called the shunt electromagnet, and the lower one is called series electromagnet. The series electromagnet is excited by the load current flow through the current coil. The coil of the shunt electromagnet is directly connected with the supply and hence carry the current proportional to the shunt voltage. This coil is called the pressure coil. The centre limb of the magnet has the copper band. These bands are adjustable. The main function of the copper band is to align the flux produced by the shunt magnet in such a way that it is exactly perpendicular to the supplied voltage.

2. Moving System – The moving system is the aluminium disc mounted on the shaft of the alloy. The disc is placed in the air gap of the two electromagnets. The eddy current is induced in the disc because of the change of the magnetic field. This eddy current is cut by the magnetic flux. The interaction of the flux and the disc induces the deflecting torque. When the devices consume power, the aluminium disc starts rotating, and after some number of rotations, the disc displays the unit used by the load. The number of rotations of the disc is counted at particular interval of time. The disc measured the power consumption in kilowatt hours.

3. Braking system – The permanent magnet is used for reducing the rotation of the aluminium disc. The aluminium disc induces the eddy current because of their rotation. The eddy current cut the magnetic flux of the permanent magnet and hence produces the braking torque. This braking torque opposes the movement of the disc, thus reduces their speed. The permanent magnet is adjustable due to which the braking torque is also adjusted by shifting the magnet to the other radial position.

4. Registration (Counting Mechanism) – The main function of the registration or counting mechanism is to record the number of rotations of the aluminium disc. Their rotation is directly proportional to the energy consumed by the loads in the kilowatt hour. The rotation of the disc is transmitted to the pointers of the different dial for recording the different readings. The reading in kWh is obtained by multiply the number of rotations of the disc with the meter constant. The figure of the dial is shown below.

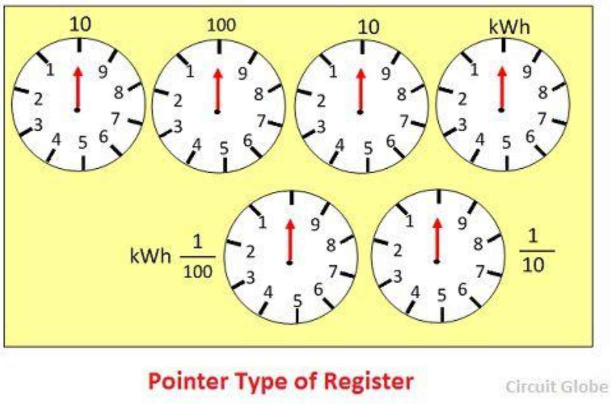


Fig. 3: Pointer type Register

5.1.3 Working of Single phase induction type Energy Meter

The basic working of Single phase induction type Energy Meter is only focused on two mechanisms:

1. Mechanism of rotation of an aluminum disc which is made to rotate at a speed proportional to the power.

2. Mechanism of counting and displaying the amount of energy transferred.

1. Mechanism of rotation of an aluminum disc

Which is made to rotate at a speed proportional to the power.

The metallic disc is acted upon by two coils. One coil is connected 0r arranged in such a way that it produces a magnetic flux in proportion to the voltage and the other produces a magnetic flux in proportion to the current. The field of the voltage coil is delayed by 90 degrees using a lag coil. This produces eddy currents in the disc and the effect is such that a force is exerted on the disc in proportion to the product of the instantaneous current and voltage. A permanent magnet exerts an opposing force proportional to the speed of rotation of the disc – this acts as a brake which causes the disc to stop spinning when power stops being drawn rather than allowing it to spin faster and faster. This causes the disc to rotate at a speed proportional to the power being used.

2. Mechanism of displaying the amount of energy transferred

Based on number of rotation of aluminum disc.

The aluminum disc is supported by a spindle which has a worm gear which drives the register. The register is a series of dials which record the amount of energy used. The dials may be of the cyclometer type, an odometer-like display that is easy to read where for each dial a single digit is shown through a window in the face of the meter, or of the pointer type where a pointer indicates each digit. It should be noted that with the dial pointer type, adjacent pointers generally rotate in opposite directions due to the gearing mechanism.

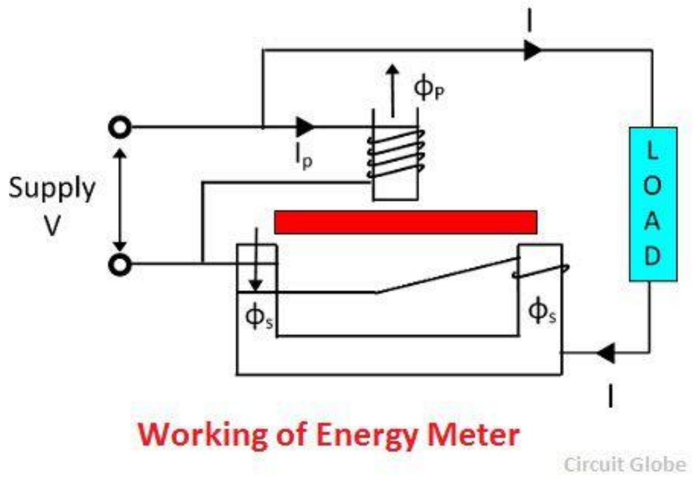


Fig. 4: Working of Energy Meter

5.2 Analog Multimeter

5.2.1 Working Principle

Analog multimeter uses an electromechanical component called a **D'Arsonval movement** to move the pointer along the scales to display measured values when the test leads are connected to a circuit, device, or circuit component.
As shown in **Fig. 5**, most analog multimeters have several calibrated scales for the single meter movement as shown in Figure 5. On the GM Instruments VOM shown, the calibrated scales correspond to the different function/range switch settings that include OFF; AC V (volts), Batteries Check, Ohms, DC A (amps), and DC V (volts). The meter is normally stored with the function/range switch set to the OFF position.The different **function/range switch settings** require placement of the test leads in two of the three jacks. The lead jacks are identified as: the DC 10A (DC 10-amp scale) jack; the + V-W-A (volt-ohms-DC mA) jack; and the – COM (Common) jack. Most measurements are taken with the red test lead plugged into the + V-W-A jack, and the black test lead plugged into the – COM jack. For the DC amperage scales, only the red test lead is moved to the appropriate jack.

5.2.2 Linear or Nonlinear Scale.

A **linear scale** is a scale that is divided into equally-spaced segments. A **nonlinear scale** is a scale that is divided into unequally-spaced segments.

Normally, the voltage and amperage scales on an analog multimeter are linear, whereas the ohmic scales are nonlinear.

When using an analog multimeter, the correct scale must be used to obtain either a voltage, current, or ohmic reading. As shown in Figure 5, the AC voltage settings include the 1000-volt scale; the 250-volt scale; the 50-volt scale; and the 10-volt scale. On the scales display, only the 250-volt scale, the 50-volt scale, and the 10-volt scale are shown. The 10-volt scale doubles for both the 10-volt and the 1000-volt scales: the correct voltage reading is according to the function/range-switch setting.

Fig. 5. Although replaced with DMM in many hand-held operations, analog multimeter or VOM is still around

5.2.3 Analog Multimeter Scales

As shown in Figure 5, there is only one log scale (nonlinear) for the **resistance measurements**, although there are three resistance scales indicated on the function/range switch. The three ranges indicated are (R) ´ 1K; (R) ´ 10; and (R) ´ 1. The measured resistance value on the scale readout is the (R) or resistance value that must be multiplied by either 1000 (1K), 10, or 1, according to which resistance range was selected. The **DC voltage settings** include the 1000-volt scale; the 250-volt scale; the 50-volt scale; and the 10-volt scale. On the scales display, the same 250-volt, 50-volt, and the 10-volt scales are shown double for both AC voltage measures and DC voltage measures. The 10-volt scale doubles for both the 10-volt and the 1000-volt scales: the correct voltage reading is according to the function/range-switch setting.

*The **analog scales on an analog multimeter** are normally divided using **primary divisions, secondary divisions, and subdivisions**.*

When reading an analog scale, the primary, secondary, and subdivision readings are added to determine the voltage, current, or resistance reading. On the GM Instruments VOM shown in **Fig. 6**, a measure is indicated by the pointer located about midway on the scales display. What is being measured is totally dependent on what is not shown in the picture, and that is the selected setting of the function/range switch.

Fig. 6. Taking a reading with an analog multimeter

5.2.4 Analyzing from top to bottom on the scale display:

The **top scale** is the ohmic or resistance scale. The pointer needle is past 50 but less than 100. The **primary divisions** on the scale are 50 and 100. Between 50 and 100, a difference of 50 exists, which represents the secondary divisions. With the five**secondary divisions**, each of these secondary division indicates 10 to be added to the 50. Each **secondary division** of 10 contains one subdivision, so each subdivision indicates 5 to be added to the 50. In Fig. 6, since the pointer is between 50 and the first subdivision and is almost touching the first subdivision, the readout is approximately 54. Now according to the function/range-switch setting, the readout is either 54Ω, 540Ω, or 54 kΩ (54,000Ω).

5.2.5 Block Diagram:

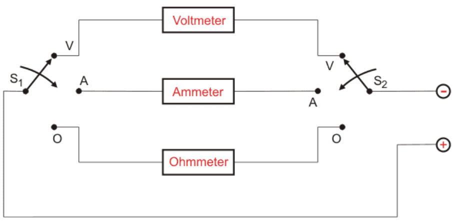


Fig. 7: Block Diagram of Analog Multimeter

5.2.6 The Function/Range Switch in an Analog Multimeter

If the function/range switch is set on either an AC or DC voltage range, the three voltage scales are analyzed in the same manner. The DC scale is above the three voltage-range scales, whereas the AC scale is below the three voltage-range scales. Both the DC and AC voltage scales contain **five primary divisions**, with one secondary division and four subdivisions between each primary and secondary division.

5.2.7 Disadvantages

The pointer needle is between the 100 and 150 readouts on the **250-volt scale**. There are 50 volts between the 100- and 150-volt readouts. The **single secondary division**in the center between these two readout points divides the 50 volts in half to 25 volts. Between the 100 readouts and the center secondary division, the 25 volts are divided into four 5-volt subdivisions. On the DC voltage scale, the readout appears to be exactly 120 volts.

On the **AC voltage scale**, the pointer needle appears to be about midway between the last subdivision and the center secondary division: the AC voltage readout appears to be about 123 volts.

A phenomenon referred to as "**parallax error**" occurs when reading the pointer against the selected scale on an analog multimeter**:**

If you read the scale from a side-angle view, a measured value of 120 volts may appear as 123 volts or 117 volts according to which side of the pointer you are viewing from. The 120-volt reading only occurs when you are looking straight on at the pointer suspended over the scale.

The pointer needle is between the 20 and 30 readouts on the **50-volt scale**. Ten volts are between the 20- and 30-volt readouts. The **single secondary division** in the center between these two readout points (20 and 30) divides the 10 volts in half to 5 volts. The **four subdivisions** between the 20 readouts and the center secondary division divide the 5 volts into 1-volt subdivisions.

On the **DC voltage scale**, the readout appears to be exactly 24 volts. On the **AC voltage scale**, the pointer needle appears to be about midway between the last subdivision and the center secondary division: the AC voltage readout appears to be about 24.5 volts.

The pointer needle is between the 4 and 6 readouts on the **10-volt scale**. There are 2 volts between the 4- and 6-volt readouts. The **single secondary division** in the center between these two readout points divides the 2 volts in half. The four subdivisions between the 4 readouts and the center secondary division divide the 1 volt into 0.2-volt or $2/10^{ths}$ of a volt subdivision.

On the **DC voltage scale**, the readout appears to be exactly 4.8 volts. On the **AC voltage scale**, the pointer needle appears to be about midway between the last subdivision and the center secondary division: the AC voltage readout appears to be about 4.9 volts.

If the **1000-volt scale** is selected, the readout appears to be exactly 480 volts on the **DC voltage scale** and about 490 volts on the **AC voltage scale**.

5.3 Digital Multimeter:

5.3.1 What is a Digital Multimeter?

A **Digital multimeter** or **DMM** is a test equipment used for resistance, voltage, current measurement and other electrical parameters as per requirement and displaying the results in the mathematical digits form on an LCD or LED readout. It is a type of multimeter which functions digitally. Digital multimeters are widely accepted worldwide as they have better accuracy levels and ranging from simple 3 ½ to 4 ½ digit handheld DMM to very special system DMM.

Fig. 8. Features of Digital Multimeter

Digital multimeter is most advanced instruments that make use of modern Integrated circuits for making electrical measurements. Some of its features which make it famous in the eyes of professional technicians are:

1. It is light in weight.
2. Capable of giving more accurate readings.
3. It measures lots of physical quantities like voltage, current, resistance, frequency etc.
4. It is less costly.
5. It measures different electrical parameters at high frequencies with the help of special probes.

5.3.2 Schematic diagram of Digital multimeter

In digital multimeter, we can incorporate many types of meters like ohmmeter, ammeter, a voltmeter for the measurement of electrical parameters. Its block diagram is shown below in the figure. Let us have a look at its working and specification one by one.

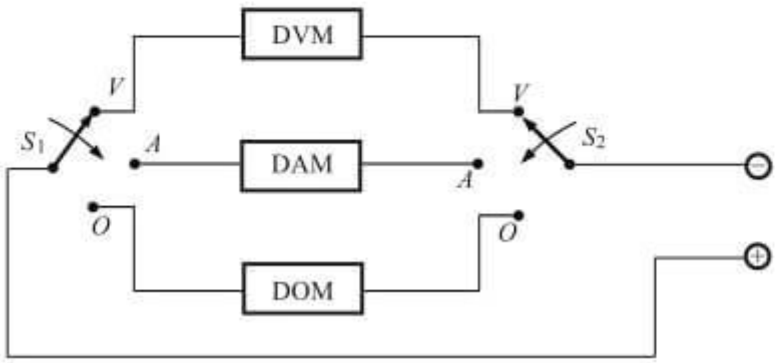


Fig. 9. Schematic Diagram of DMM

(i) Digital voltmeter (DVM):

Digital voltmeter is the basic instrument used for measurement of voltage through the use of Analog to Digital converter. The basic principle behind the digital multimeters is the Analog to Digital Converter (ADC) because without this we are not able to convert the analog output into digital form. There are several ADC available in the market, but we mainly use Flash type ADC due to its simplicity and fastest speed.

(ii) Digital Ammeter (DAM):

Digital ammeter uses a shunt resistor to produce a calibrated voltage proportional to the current flowing. As shown in the diagram, to read the current we must first convert the current to be measured into a voltage by using a known resistance R. The voltage so developed is calibrated to read the input current.

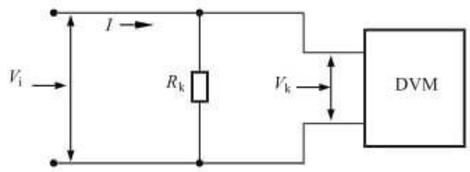


Fig. 10. DAM

(iii) Digital ohm meter (DOM):

A digital ohmmeter is used to measure electrical resistance which obstructs the path to the flow of current.

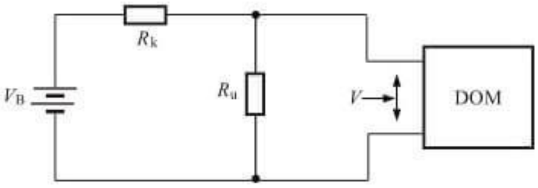


Fig. 11. DOM

As shown in Fig. 11, resistance network comprising a known resistance RK and unknown resistance Ru used to develop a voltage across the unknown resistance. The voltage is given by:

V = VB Ru / RK + Ru
where VB = Voltage of the built-in battery
After calibrating voltage, the meter can be calibrated in terms of ohms.

5.3.3 Working Principle of Digital Multimeter

As shown in block diagram, in a typical Digital multimeter the input signal i.e ac or dc voltage, current, resistance, temperature or any other parameter is converted to dc voltage within the range of the ADC. The analog to digital converter then converts the pre-scaled dc voltage into its equivalent digital numbers which will be displayed on the display unit. Sometimes, digital controller block is implemented with a microcontroller or a microprocessor manages the flow of information within the instrument. This block will coordinate all the internal functions as well as transferring information to external devices such as printers or personal computer. In the case of some hand held multimeter, some of or all of these blocks may be implemented in a VLSI circuit while A/D converter and display driver can be in the same IC.

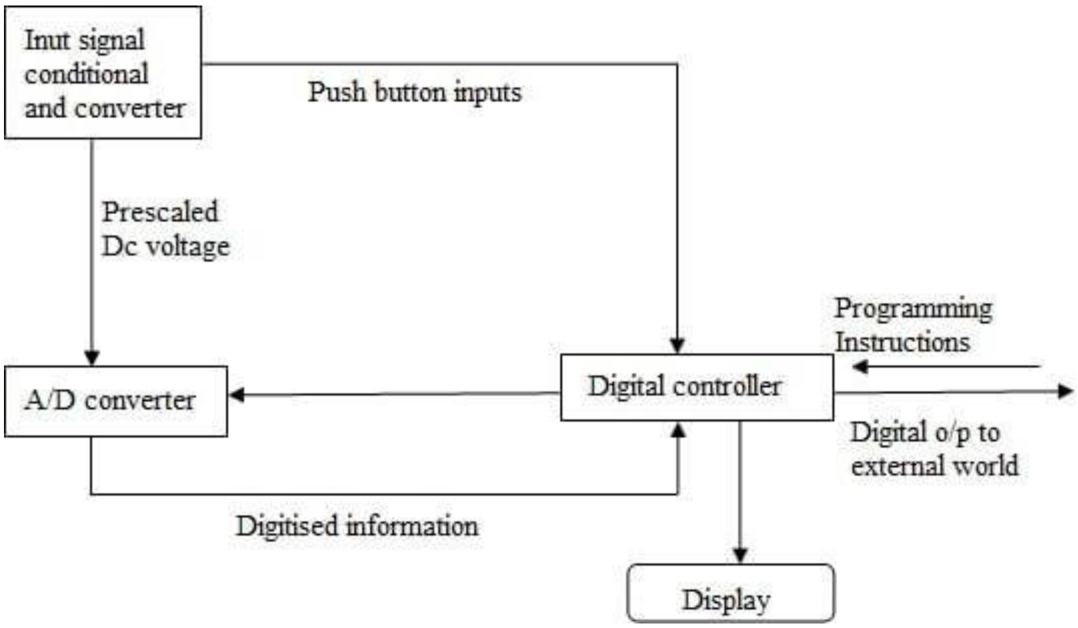
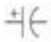


Fig. 12. Block Diagram

5.3.4 Digital Multimeter symbols:

Some common Digital multimeter symbols and its description are given in the table below. These symbols are often found on the multimeter & its schematics are designed to symbolize components and reference values of electrical parameters.

Symbol	**Measurement function**	**Description**
~	AC voltage	Measures amount of Ac voltage
	DC voltage	Measures amount of Dc voltage
Hz	Hertz	Measures Frequency
Ω	Ohms	Measurement of resistance to the flow of electron
	Diode	Device used to control direction of flow of current
µF	Microfarad	Unit of capacitor
	Capacitor	Device used to store electrical charge
	Continuity	Audible indication of continuity for low resistance
A	Ampere	Measures amount of electron flow
	Ground	Used for grounding the device
CE	European union directive	It indicates the guarantee of instrument
	Caution	Refers to the instruction before use and indicates that its misuse results in equipment failure
Δ	REL	Measures relative or offset reading
Min/max	Measures relative	It shows highest and lowest

	or offset reading	recorded readings

5.3.5 DMM Parts and functions

A Digital Multimeter is divided into three parts:

(i) Display: The LCD screen present on the upper portion of the multimeter basically displays four or more digits and also shows negative value if necessary. A few or today's multimeters have illuminated the display for better viewing in low light situations.
(ii) Selection Dial: It allows the user to set the multimeter to read different electrical parameter such as milliamps (mA) of current, voltage, resistance, capacitance etc. You can easily turn the dial anywhere for specific parameter measurement.
(iii) Ports: Two ports are available on the front of every multimeter except in some four ports are available for measuring current in mA or A. We plugged two probes into these ports which are of different colour i.e. one is of red colour and other is of black color. Ports are:
(a) COM: It stands for common and is almost connected to ground or considered as a -ve connection of a circuit. We generally insert the black color probe into COM port.
(b) mAVΩ: This port allows the measurement of current (up to 200 mA), voltage and resistance or considered as a +ve connection of a circuit. We generally insert the red color probe into mAVΩ port.

5.3.6 DMM leads:

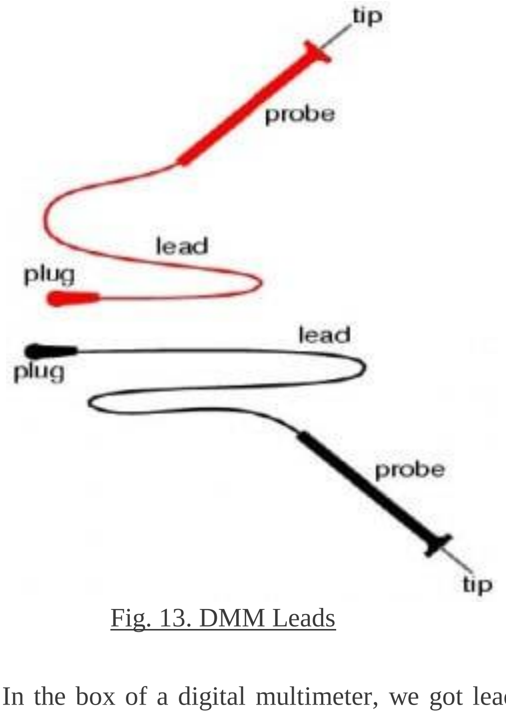


Fig. 13. DMM Leads

In the box of a digital multimeter, we got leads of different colors. Here we are going to explain these leads in detail. DMM leads are subdivided into four parts:

(i) Red lead
1. Connected to voltage, resistance or ampere port.
2. Considered as a +ve connection of a circuit

(ii) Black lead
1. Connected to the common or ground port
2. Considered as a -ve connection of a circuit

(iii) Probes:
These are the handles used to hold the tip on the tested connection. There are different types of probes available, they are:

- Banana to Alligator Clips: These are great cables for connecting to large wires or pins on a breadboard. Good for performing longer term tests where you don't have to hold the probes in place while you manipulate a circuit.
- Banana to IC Hook: IC hooks work well on smaller ICs and legs of ICs.
- Banana to Tweezers: Tweezers are handy if you need to test SMD components.
- Banana to Test Probes: If you ever break a probe, they are cheap to replace.

(iv) Tip:
These are present at the end of the probes and basically, provide a connection point.

5.3.7 DMM Safety Precaution:

Before operating multimeters, we have to follow some safety precautions. Here we are going to explain you some safety information of DMM.

1. If the DMM test leads are damaged then never use the meter.
2. Always ensures that the test leads and dial are in right position for the desired measurement.
3. When a test lead is plugged into the 10 A or 300mA input jack then never touch the probes to a voltage source.
4. When power is applied never measure resistance in a circuit.
5. While making measurements always keep your fingers behind the finger guards on the test probes.
6. To avoid damage or injury, never use the meter on circuits that exceed 4800 watts.
7. Replace the battery as soon as possible to avoid false readings which could lead to possible electric shock or personal injury.
8. Be careful when working with voltages above 60 V DC or 30 V AC RMS. Such voltages pose a shock hazard.

5.4 Dynamometer Type Wattmeter | Electrodynamometer

5.4.1 Principle of operation

In a dc circuit, the power supplied to a load can be determined by measuring the load voltage and current and multiplying them together: P=EI. However, it is much more convenient to have an instrument that indicates power directly. The meter used for this purpose is called a wattmeter, and the instrument that can be applied as a wattmeter is known as a dynamometer, or sometimes as an electrodynamic instrument. The construction of a dynamometer instrument to some extent resembles the PMMC instrument. The major difference from the PMMC construction is that the permanent magnet is replaced by two coils, as illustrated in figure (14). The magnetic field in which the lightweight moving coil is situated is generated by passing current through the fixed field coils. Then, when a current is passed through the moving coil, the moving coil and the meter pointer are deflected.

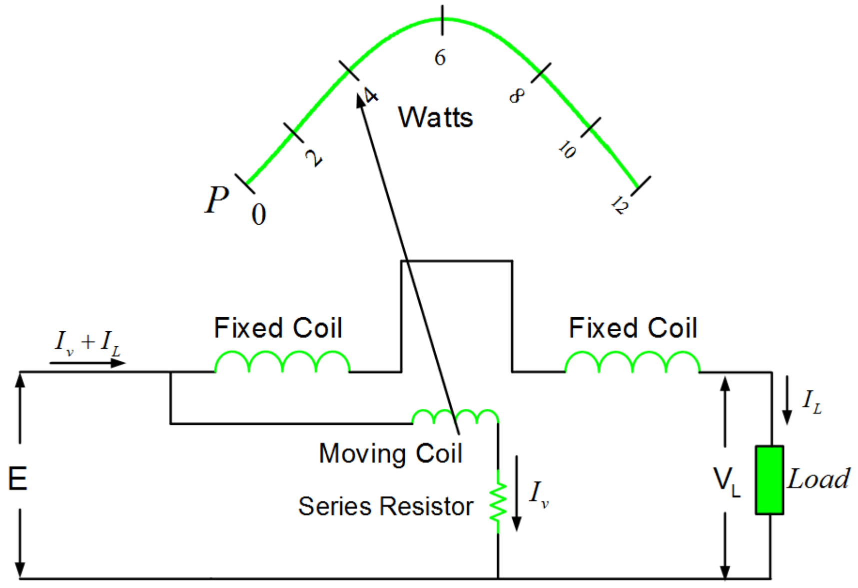


Fig.14. Dynamometer Instrument (Circuit Connection)

The deflection of the pointer of a dynamometer instrument is proportional to the current through the moving coil, but it is also proportional to the flux density of the magnetic field set up by the fixed field coils. This means, of course, the deflection is also proportional the current through the fixed field coils.

- You May Also Read: PMMC Instrument Working Principle

The scale of the instrument can be calibrated to indicate watts, and thus it becomes a dynamometer type wattmeter. The scale of the wattmeter is illustrated in figure 15 in which upper scale is calibrated in milli-watts while the lower one measures the power in watts range.

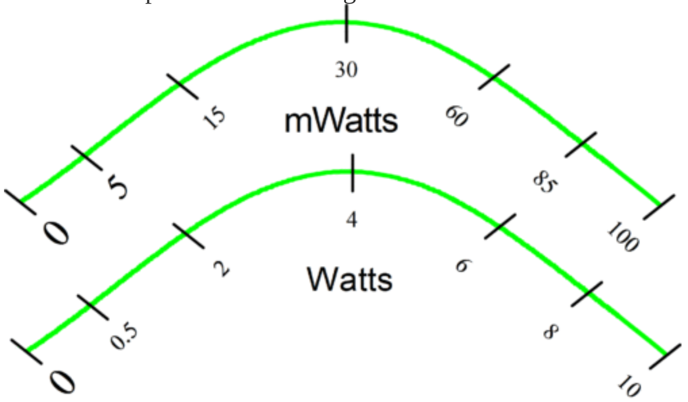


Fig.15. Wattmeter Scale

Because fairly large currents are required to set up the necessary field flux, the dynamometer instrument is not as sensitive as a PMMC instrument. Consequently, its major application is as a wattmeter. One advantage that the dynamometer has over a PMMC instrument is that it can be used for both direct and alternating current/voltage instruments.

5.4.2 Types of Dynamometer Wattmeter:

Dynamometer wattmeters may be divided into two classes:

- Suspended-coil torsion instruments.
- Pivoted-coil, direct indicating instruments.

1. Suspended-coil Torsion Wattmeters:

These instruments are used largely as standard wattmeters.

- The moving, or voltage, the coil is suspended from a torsion head by a metallic suspension which serves as a lead to the coil. This coil is situated entirely inside the current or fixed coils and the winding in such that the system is static. Errors due to external magnetic fields are thus avoided.
- The torsion heads carry a scale, and when in use, the moving coil is bought back to the zero position by turning this head; the number of divisions turned through when multiplied by a constant for the instrument gives the power.
- Eddy currents are eliminated as far as possible by winding the current coils of standard wire and by using no metal parts within the region of the magnetic field of the instrument.
- The mutual inductance errors are completely eliminated by making zero position of the coil such that the angle between the planes of moving coil and the fixed coil is 90 degree. i.e. the mutual inductance between the fixed and moving coil is zero.
- The elimination of pivot friction makes possible the construction of extremely sensitive and accurate electrodynamic instruments of this pattern.

2. Pivoted-coil Direct-indicating Wattmeters:

These instruments are commonly used as a switchboard or portable instruments.

- In these instruments, the fixed coil is wound in two halves, which are placed in parallel to another at such a distance, that uniform field is obtained. The moving coil is wound of such a size and pivoted centrally so that it does not project outside the field coils at its maximum deflection position.
- The springs are pivoted for controlling the movement of the moving coil, which also serves as currents lead to the moving coil.
- The damping is provided by using the damping vane attached to the moving system and moving in a sector-shaped box.
- The reading is indicated directly by the pointer attached to the moving system and moving over the calibrated scale.
- The eddy current errors, within the region of the magnetic field of the instrument, are minimized by the use of non-metallic parts of high resistivity material.

5.4.3 Advantages and disadvantages of dynamometer type wattmeter:

The advantages and disadvantages of dynamometer type wattmeters are as under:

Advantages:

1) In dynamometer type wattmeter, the scale of the instrument is uniform (because deflecting torque is proportional to the true power in both DC as well as AC and the instrument is spring controlled.)

2) High degree of accuracy can be obtained by careful design; hence these are used for calibration purposes.

Disadvantages:

1) The error due to the inductance of the pressure coil at low power factor is very serious (unless special features are incorporated to reduce its effect)

2) In dynamometer type wattmeter, a stray field may affect the reading of the instrument. To reduce it, magnetic shielding is provided by enclosing the instrument in an iron case.

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Unit – 6

Electrical Appliances

Electric Immersion Heaters

These are manufactured in different shapes and sizes and the element is also designed for different power ratings to suit the purpose. The rating of the designed element may be from 1000 to 3000 W etc. Some immersion heaters consist of simply U shaped metal tube and the element is passed through the tube insulated with non-affecting heat material. The two ends of the element are brought out of the tube at the terminal housing to give the supply. The ends of metal tube are sealed with black compound. The water level strip is attached with the metal tube to hung the heater vertically ion the bucket

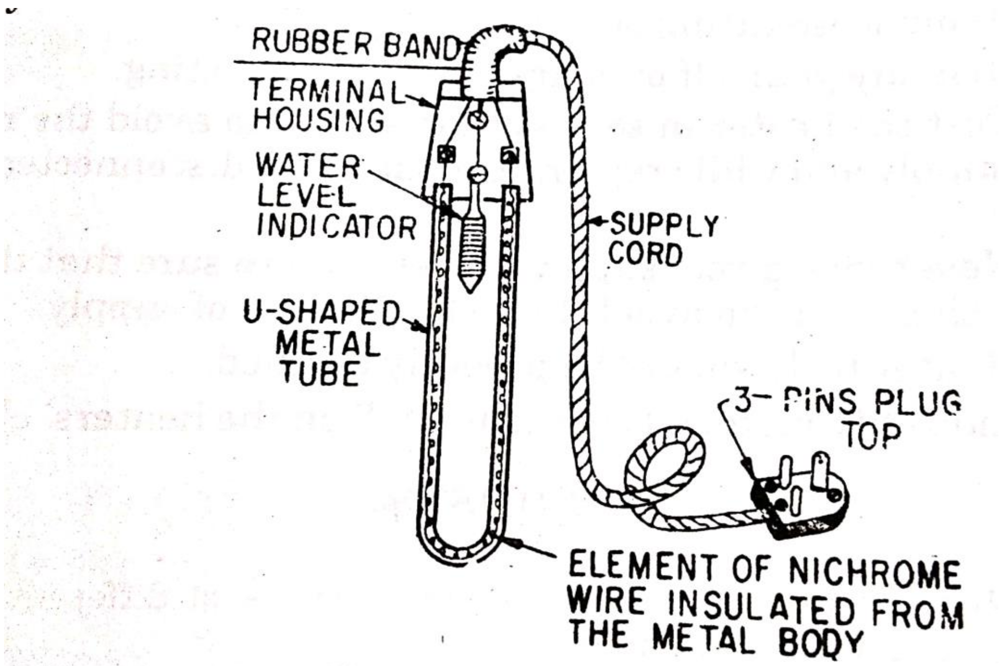


Fig. 6.29. Shows U-shaped metal tube immersion heater

The other type of immersion heater consists of resistance element in a U-shaped moulded (turned) metal tube insulated with non-affecting heat material. The two ends are brought out of the tube at the ebonite or Bakelite terminal housing attached with metal tube in two halves to give the power supply. The corners of the tube are sealed with black compound. The water level indicator strip is also fixed in the terminal housing with a screw with which the earth wire of the cord is connected and the two halves of the terminal housing are tightened with nuts and bolts after connecting the three wire cord with the specific ends of the element and the a earth point.

PRACTICAL OF MOULDED SHAPE IMMERSION HEATER

Material and Tools Required

Insulated combination pliers (150 mm) 1 piece; Connector screw driver (75 mm) – 1 piece; Test lamp 40 W with testing leads of 2 m each

Main Components of Immersion Heater

1. Metal body of water-heater – Moulded shape of U-shaped.
2. Terminal housing – made of ebonite or Bakelite to hold terminals.
3. Rubber Band for cord to protect the cord from being damaged.
4. Three core cord for supply.
5. 3 – Pin plug to give supply.
6. Terminals with screws and housing screws to tight the wire ends and terminal housing cover.

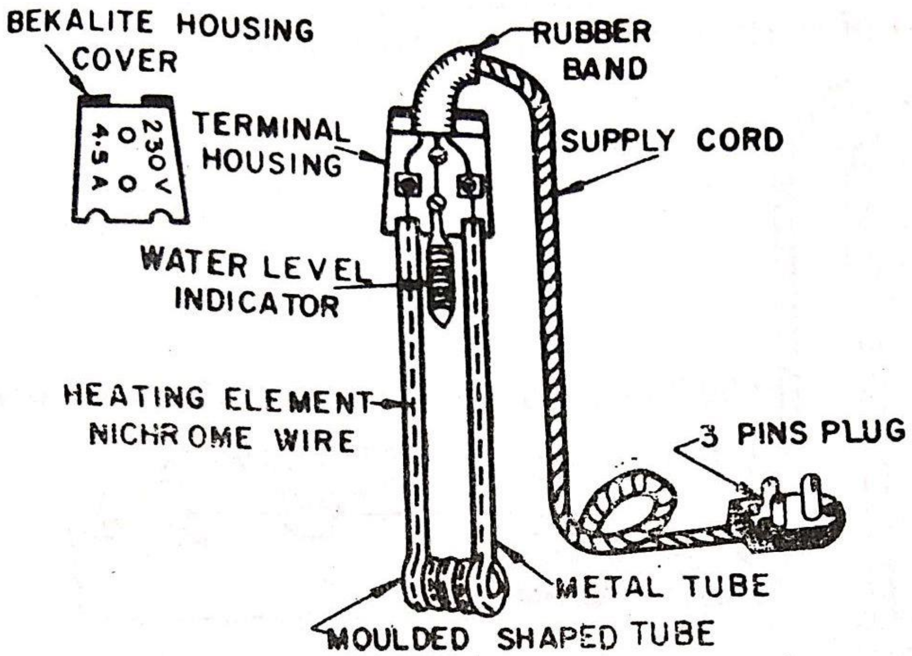


Fig. 6.30. Shows parts of water heater.

Possible Faults

1. Elements end may touch the corner of the metal tube which is known as short circuit and earth fault.
2. Connections of supply cord may be broken at the terminals; breakage of wire in the plug top which causes discontinuity and known as open circuit.
3. Breakage of element wire in the metal tube or element may burnt which is known as open circuit.
4. Leakage in supply cord which causes short circuit or cord too old.
5. Metal tube may be burst when not dipped inside the water.
6. Terminal housing may be broken which may cause leakage fault.
7. Any screw may be missing which causes loose fitting or connections.

Testing

Prepare the series testing leads to test the water heater for open, closed, short and earth or leakage test. By connecting the two ends of te4stings leads to the terminals of plug top of the water heater, if the lamp does not give light, it means there is an open circuit i.e. leakage of element wire inside the body of the water heater; disconnection of wire ends from the terminals of water heater from the terminals of plug top; there may be breakage in the cord of water later. If the lamp gives bright light, it means, there is short circuit, wire ends at the terminals or at the plug top or touching together insulation of both wires in the cord is leaking.

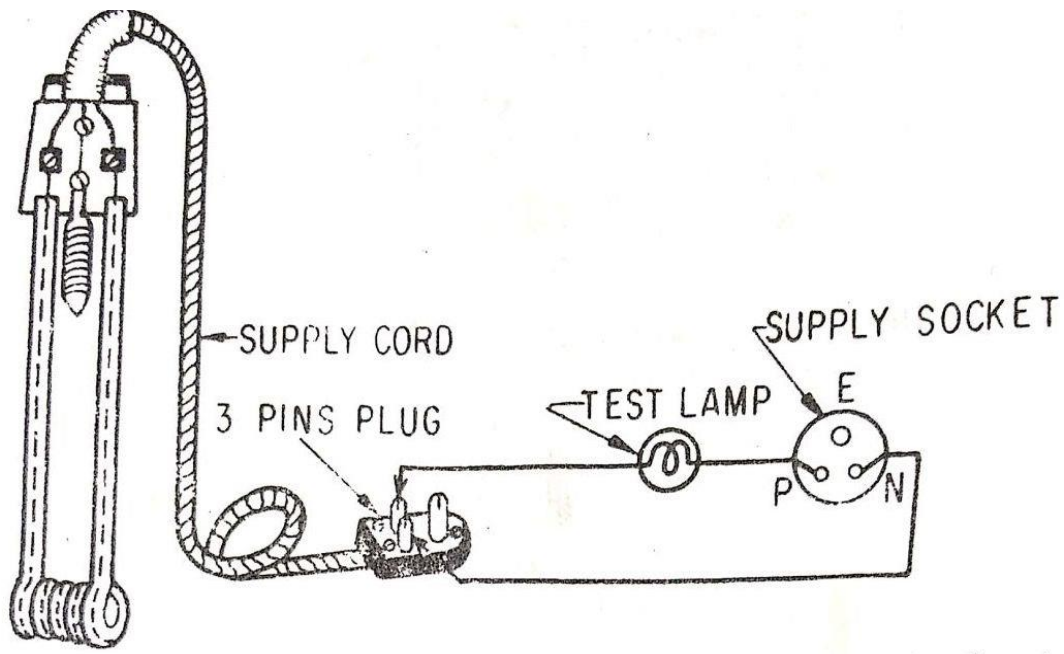


Fig. 6.31. Shows continuity, open, short circuit test on immersion heater.

If the lamp glows dimly, it means the element of the water heater is in working order and it is known as a closed circuit.

Now to perform the testing for earth fault, connect one end of testing lead to one terminal of plug top and another to the metal part or body of water heater, if the lamp glows, it means there is an earth fault, i.e. any part of the element is touching the metal body of water heater; if any spark occurs on the metal body, it means the insulation inside the body is leaking from somewhere which known as leakage fault.

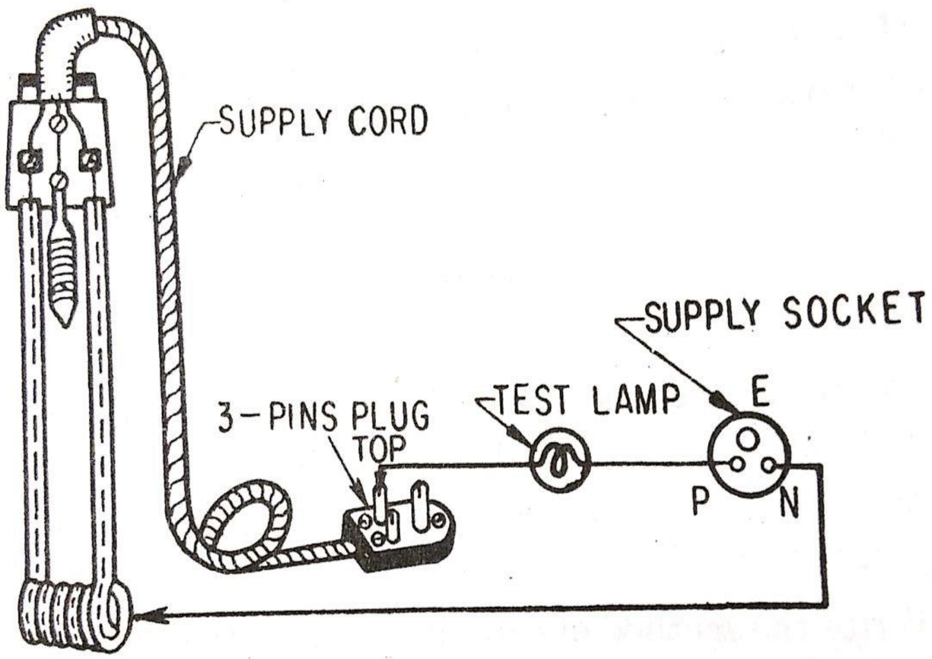


Fig. 6.32. Shows earth or leakage test on immersion heater.

Repairing

In the case of open or short circuit defects, check the cord and plug top and the wire ends at the terminals in the connector of water heater for their discontinuity and touching ends and correct them. If the cord is too old, replace it. If terminals housing is broken, replace it. If any screw is missing, get another one and tighten it.

In the case of earth fault, check the coming ends of element from inside of body of water heater that they should not touch the corners of metal part of water heater or if the earth fault is from inside the metal body of water heater, it cannot be repaired but the rod needs replacement.

Precautions

1. Before testing water heater, insulate yourself on the dry wood.
2. Test the water heater in series of the electric supply to avoid the risk of failure of supply.
3. Never give direct supply unless you are sure that there is no fault in the water heater to avoid the risk of failure of supply.
4. Use three-wire cord for the supply.
5. The water should be switched on to mains only after it is dipped in the water.
6. Dip the water heater up to the indicated mark and don't allow terminal housing to be immersed in water.
7. First switch off the current then remove water heater from the water.
8. Don't take out the rod from water at once as soon as you switched off the supply.
9. Don't use the immersion heater in other liquids because it is meant for water only and in other liquids, it will have a corroding affect on its surface.

EXERCISES

1. Write in brief the use and constructional details of immersion rod and draw the labeled diagram.
2. What faults may be possible in the immersion rod and how will you remove them?
3. Write the method of testing and show the testing diagrams.
4. What precautions will you take at the time of using an immersion rod?

Electric Geysers (Water Heater)

To get the hot water, either continuously or intermittently, an electric water heater is more useful device. It can be easily installed anywhere with the electric power. Its water temperature can easily be regulated automatically by a thermostat. It works on the principle of thermal storage i.e. the water is preheated by immersion water in a storage vessel and is kept for future use. To get the water in a storage vessel and is kept for future use. To get the hot water from time to time, the storing vessel is provided with thick insulation or it is properly legged to dissipate the heat. The heating element is fixed at the bottom horizontally or vertically. As the water heater is switched 'on' the cold water is heated up, becomes lighter and starts moving up while the cold water being heavier comes down. Thus due to this circulation of water, we can get hot water from the outlet valve. If the element is fixed horizontally, the water above it, is heated very slowly but when the element is fixed vertically, the water surrounding this is heated up very soon. So the vertical fitting of the element in the water heater is more referred.

Water heater may be classified in the following ways:

(a) Immersion Heater or Rod. It can be put in any vessel full of water and by switching on, the water is heated up. It is a portable and cheap and has been described before.

(b) Self-contained Heaters. These are of two types: (1) Non-Pressure type (II) Pressure type These consist of a storage vessel, heavily legged, electrically heated and provided with a thermostat system.

(a) **Non-pressure Type Water Heater.** This type of water heater is used at that place where the hot water is required only at one service point e.g. for wash-basins and sinks etc. Such water heaters have an open outlet i.e. not having any stop-cock. Its water is controlled from the inlet side. These contain two cylindrical vessels, one fitted inside the outer. The inner vessel consists of heating chamber made of tinned copper. Inside it, the heating element and thermostat are fixed vertically at the bottom. The outer vessel is made of lead-coated-steel and painter outside with enamel paint. The space between the two vessels is filled with heat resisting insulating material to reduce heat loss. The temperature of the water is controlled automatically with thermostat. The inlet and outlet pipes are chromium plated to avoid corrosion. The cold water flows from the cold water supply pipe (inlet pipe) and enters in the heating chamber and is controlled by a valve. The hot water flows out from the top of the heating chamber through the hot water pipe (outlet pipe). An anti drip device is provided with the hot water pipe to cut off the quick hot water supply and to prevent the water to be drained off through the cold water pipe valve when the supply of cold water fails. As the hot water pipe is an open outlet, when the cold water inlet valve is opened, the cold water rushes into the heating chamber, displaces and forces out an equal quantity of hot water through the hot water o

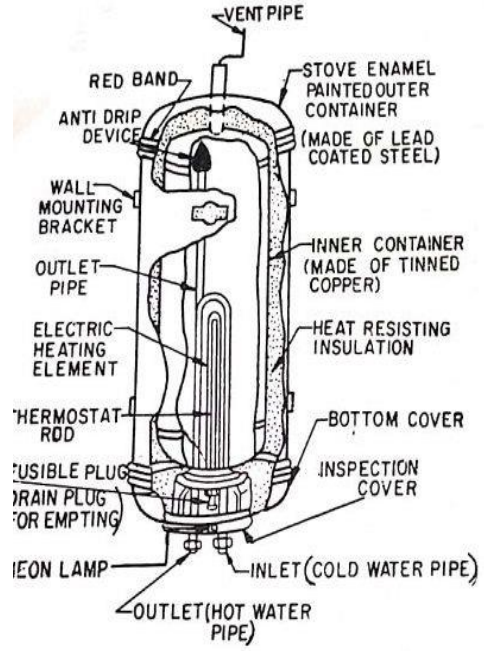


Fig. 6.33. Shows the internal structure of non-pressure type water heater.

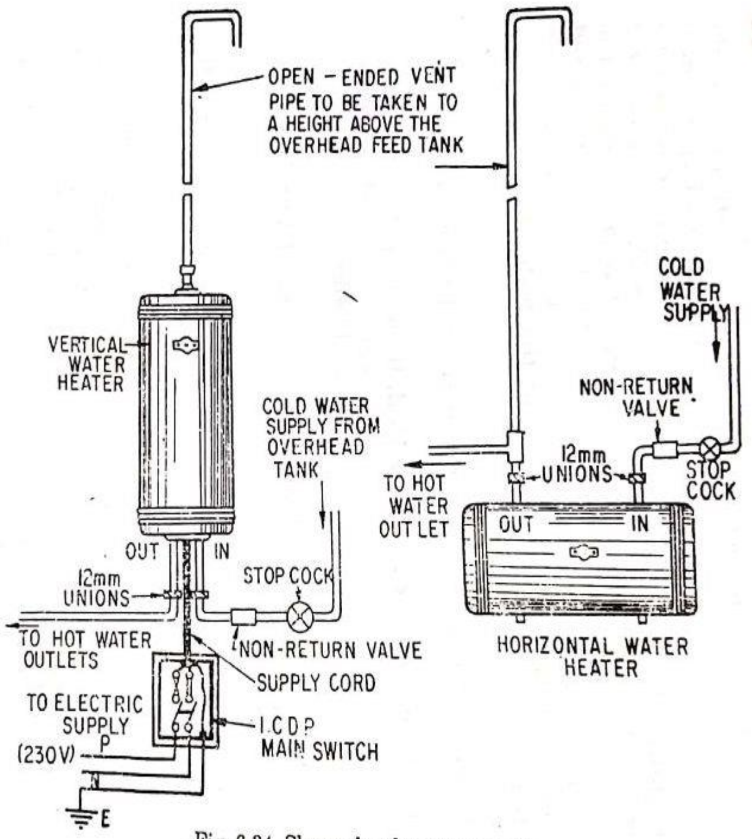


Fig. 6.34. Shows the electric connection of non-pressure type water heater.

utlet pipe.

To save the water heater from the developed pressure inside the heating chamber, a vent plug is fitted at the top which allows extra pressure in atmosphere. The wattage of this water heater is about 750 to 2000 W etc.

(ii) **Pressure Type Water Heater.** In other words it is called cistern type water heater as it works on atmospheric pressure. This type of water heater is used at that place where the hot water is required at more than one service points with one heater only. This heater gets its supply of cold water from the cistern (over head tank) connected with the water mains and the water controlled with the help of a float valve. The copper pipes connected with the heating chamber are used to supply the hot water under pressure to different service points which are controlled with a tap. The element and thermostat are fixed at the removable plate fitted on the base of the water heater for their easy service and to remove them easily. The water is of 750 to 3000 W. These are of two types:

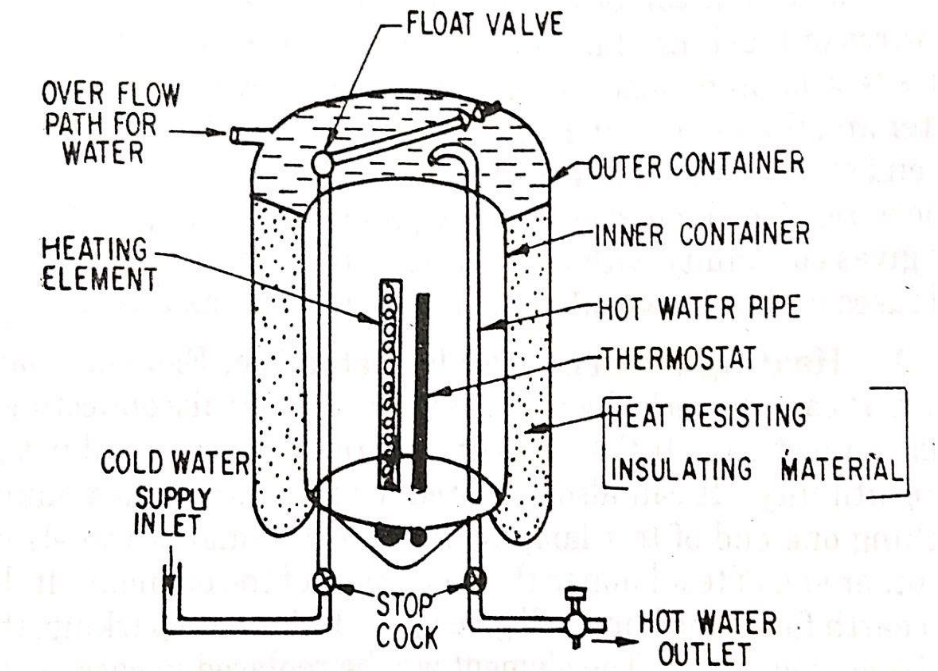


Fig. 6.35. Shows the Internal Structure of pressure type water heater.

(i) **Constant volume pressure type water heater.** In this water heater, the hot water drained off is replaced equally with cold water having equal volume. So it is called a constant pressure type water heater

(ii) **Non-constant volume pressure type water heater.** In this water heater, the rate at which the hot water flows out is not the same at which the cold water enters into the heating chamber. So it is known as non-constant or varying volume pressure type water heater.

POSSIBLE FAULTS AND THEIR REMEDIES

If the water heater does not work properly, check for the following faults:

1. **Failing of Supply Mains.** Fuses blown or the blades of the main switch do not make contact with main blades or supply is cut off in the main switch.
   Fuse elements can be checked physically after switching off the main switch and opening its cover by taking out the grips. Supply can be checked by simple test lamp by connecting it with the main terminals in the main switch. Blades of the main switch can be adjusted with the help of pliers.
2. **Open and Short Circuit in the Wiring Circuit.** Breakage of wire ends from the terminals or breakage inside the wires and touching of wire ends together or bare wire may touch together somewhere.
   The wire ends can be checked physically. The breakage inside the wires or touching of bare wire can be checked with the help of series test lamp by disconnecting the connections from the water heater and the main switch. By connecting one end of test lamp at on end of wire and other end of test lamp with the other end of the same wire, if the lamp does not glow, there is breakage in the wire, if it gives continuity with another wire, then there is short circuit and fuses will be blown off. Replace the wire or insulate it.
3. **Heating Element may be defective.** Element may be burnt. It can be checked with series test lamp by disconnecting the main connections. If the element is burnt, the lamp will not give any continuity. It can also be tested for earth or leakage fault by touching one end of test lamp to any one terminal of the element and other end of test lamp to the metal part of the element. If there is an earth fault, the lamp will give light, if there is sparking, there will be leakage fault. The element will be replaced in case of earth fault.
4. **Thermostat device may be defective.** Setting may be not proper or there may be leakage. This can also be tested by series test lamp and replaced.

EXERCISES

1. What is the use of water heaters? What are its types?

2. Write the constructional details of all type of water heaters?
3. Draw the labeled diagrams of water heaters?

Electric-Mixer

It is one of the most useful domestic appliances. In other words, it is called a Liquidizer, Mixi and Food grinder. It is used to grind the fruits, coffee seeds, nuts and to prepare delicious creamy, smooth milk shakes, lassi or other drinks etc. to make them tasty. It mostly consists of an a. c. motor of high speed (15000 to 17000 RPM) connected with a switch and supply leads fixed in the bottom bowl. The motor is fixed in such a way that its shaft is brought out vertically in the top bowl with which the blade is fixed to mix the liquid products or to grind the fruits etc. The two bowls are set in such a way that even a drop of water does not pass through the shaft and enter in the bottom bowl. If it happens, it means the mixer has become defective and motor is damaged very soon. The top bowl is covered with top cover. A handle is fixed on the side of the top bowl to use it. The lower part of bowl of mixer is made mostly with plastic, or ebonite. The upper bowl is made of thick transparent glass to see the mixed material easily. The upper bowl is set on the coupling fixed to the lower bowl and is removed easily.

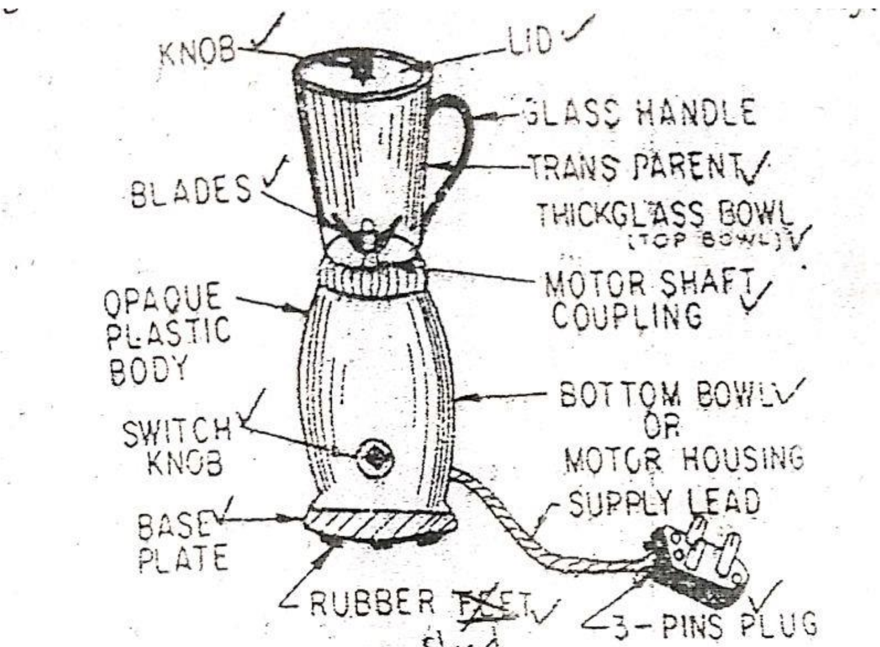


Fig. 6.63. Shows the main parts of mixer.

The operation of mixer can be understood in this way. Different fruits or liquid products are put in top bowl and covered with top cover. The supply plug is connected with the supply and switched on. Then the switch of the motor is turned on and the motor works at high speed. The blade attached with the shafts moves fast and grinds the fruits and mixes the liquid products. The speed of the motor can be controlled with the switch knob. Before pouring out the mixed products, the supply is switched 'off' first. To grind the solid things, the special type blades with separate bowls are attached to the motor shaft, after removing the original bowl.

POSSIBLE FAULTS AND THEIR REMOVALS

If the mixer does not work properly, follow the following instructions:

(a) By switching on the supply, if the shaft of the motor does not rotate, check the supply, supply leads, connections at the switch and connections at the motor terminals and also test the continuity of the motor with the help of series test lamp. If the connections are broken, connect them. If the motor is defective, repair it or replace it.
(b) If the tip bowl leaks, set it properly with the leak proof insulation.
(c) If the blades are broken, replace them.
(d) If the switch knob is loose, tighten it properly.
(e) If the motor burns, get it rewound or replace it.
(f) If the blade does not rotate properly (freely), reduce the load.

Cautions

1. Do not operate the motor for more than two minutes at a stretch. There should be a gap of 15 second between each operation.
2. Avoid the ice cubes to be used but use only crushed ice.
3. Boiling liquids must be avoided to put in the liquidizer.
4. Only two – third of the bowl should be filled for mixing.
5. When the motor is in motion, do not remove grinder.
6. When the motor is 'on' do not put any metal part from the centre stopper.

EXERCISE

1. Write the constructional details of an electric mixer.
2. Draw the labeled diagram of electric mixer.
3. What faults may be possible in an electric mixer and how will you remove them?
4. What cautions will you take at the time of using it?

Room Cooler

It is used to supply cool air in the hot season. The room cooler consists for two speed capacitor start or capacitor run type motor having extended shaft on both sides. The motor is fitted vertically in the water tank of room cooler. On the top of motor shaft, a air blower is fitted which throws cool air through grill provided in the front of room cooler after sucking from outside through khas-has matting and on the bottom of motor shaft a small water pump is tithed which pump sweater from water tank OT distributing channel fitted on the top of ‘wood wool pads’ or ‘khas-khas matting’. The water from the holes of distributing channel drops on the khas-khas matting and keep it moistened from top to bottom that is why the cool air can be changed according to the choice by the help of guide vanes which are provided on the front chase of the cooler. The speed of the motor or blower can be controlled by the select switch fitted in the front panel of cooler. When switch knob is kept on ‘Hi’ position, whole of the voltage is applied across running winding and capacitor gets nearly double supply voltage due to transformer action of the auxiliary winding along with running winding and high action of the auxiliary winding along with running winding and high speed of the motor is obtained and we get more cool air from the blower. When the switch knob is kept on ‘LO’ position, voltage across the running winding is reduced which reduces the speed of the motor and blower throws less cool air out of the grill. The water level of the water in the wait tank of the panel which indicates the level of the water in the water tank of the cooler

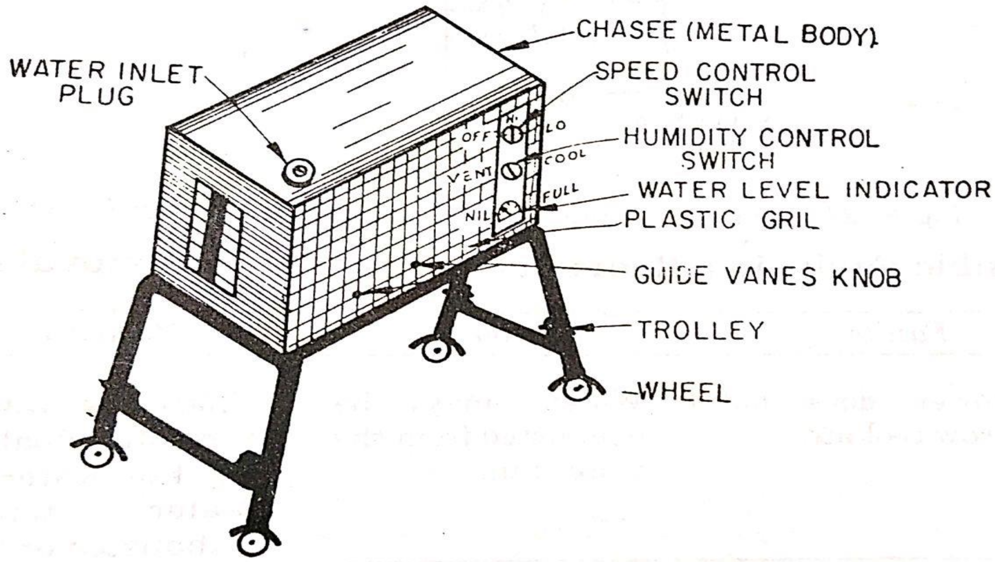


Fig. 6.125. Assembled Diagram of Room Cooler.

The humidity control valve also provided to regulate the quantity of water fed to distributing channel. On the top of the chase of the cooler a hole is provided to drain out the water from the water tank when the cooler is not be used for a long time. The assembled diagram along with a motor of room cooler is shown in Fig. 6.125.

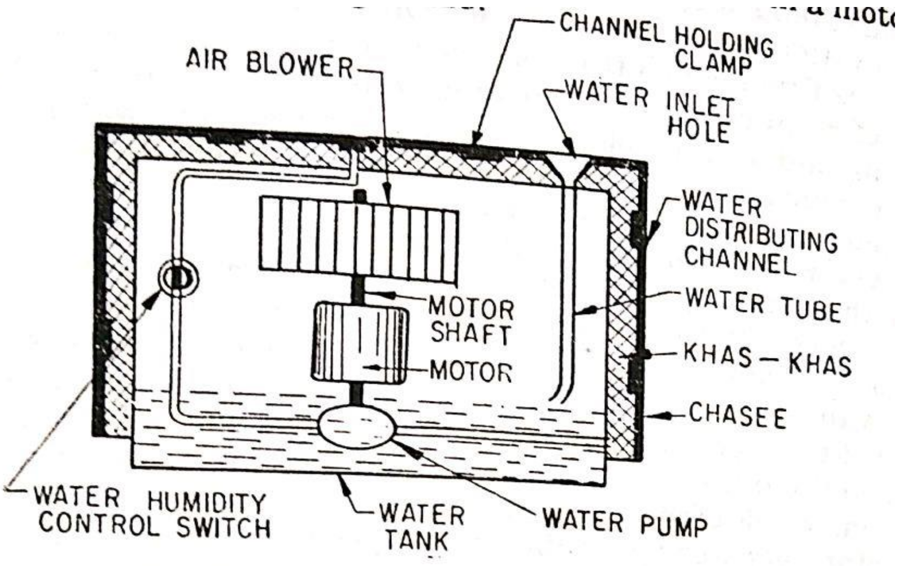


Fig. 6.126. Internal Structure of Room Cooler

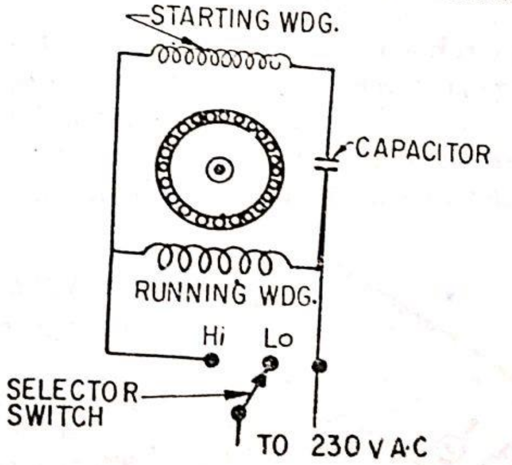


Fig. 6.127. Connection of capacitor motor with the Selector Switch.

Possible Faults in a Room Cooler and Their Removals

Faults	**Reasons**	**Remedies**
1. Blower does not throw cool air	Water may be exhausted from the water tank.	Check the water level indicator, float and fill up the water in the water tank if exhausted or less
2. Pump may not be working properly	1. Breakage in the plastic fan/propeller	Check and replace

	2. The inlet and outlet holes of the pump may be closed.	Check and clean them.
	3. Direction of rotation may be reversed	Check and change the connections to get correct rotation
3. Motor fails to start.	1. Supply cord may be defective.	Check the cord with test lamp and replace.
	2. Disconnection of wire ends from the terminals in the plug top or switch.	Check the connections and connect them.
	3. Motor coils open or short circuited.	Check the Motor with test lamp or megger or replace it.
4. Room cooler gives shock.	1. Earth connection loose.	Check and tight
	2. Motor may be earthed.	Check the motor with test lamp and remove the defect.

EXERCISE

1. Explain the constructional details of a room cooler.
2. Draw the internal structure diagram of a room cooler.
3. What faults may be possible in a room cooler and how will you remove them?

Single Phase Induction Motors

A single phase induction motor has only one set of winding on the stator. It may be also wound to produce more number of pair of poles. When connected to A.C. supply mains, the polarity of these poles would alternately be North and South but the field would not be rotating field in the same sense as in the case of two or three phase motors. The rotor of a single phase induction motor is identical with that of the squirrel cage type but it is not self starting.

At starting, the two fields will produce equal torque on the rotor in the opposite direction with the result that the motor will not be self starting. If the rotor is rotated in any direction by other means, the relative speed of the two fields will differ and the resultant torque will be produced causing the rotor to rotate.

It is possible however by means of a second winding put upon a stator to produce a rotating field, under the influence of which the motor may be started under load. Such a winding is called a split-phase winding and consists of coils producing a field having its poles between the main poles. This split phase winding has very high resistance and inductance, so that the current in it lags nearly 90° behind that in the running winding. This produces the effect of two phases from the single phase supply and a rotating field under which the motor starts in a definite direction. But it produces only a small torque just to start itself like a self starting motor. When it attains some speed, the starting winding is automatically cut off and the load is thrown on by means of a clutch (centrifugal switch) and the motor then works on only the running winding.

Universal Motors

These motors are exactly same as D.C. series motors. They can be operated both on A.C. (Single Phase) and D.C supply. In these motors, the field and the armature are connected in series with each other. For changing the directions of rotation either armature or field connections are changed. The principle of this motor is the same as that of D.C series motor. The speed of universal motor is inversely proportional to the load i.e. at high load, its speed is low but at small load, its speed is high. The torque of this motor is directly proportional to the current taken by the motor. The motor is started on putting the load. The starting device used with this type of motor is auto-transformer with the help of which the voltage is raised on the motor gradually so that the motor is saved from high starting current.

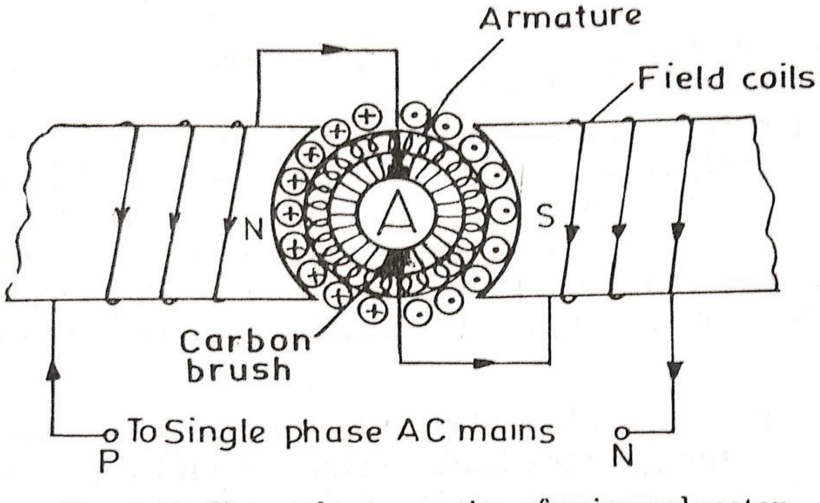


Fig. 6.69. Shows the connection of universal motor.

Applications These motors are used for household appliances such as table fan, vacuum cleaner, hair drier, sewing machine and small electric drill machine etc.

Split Phase Motors

1. **Capacitor Motor.** This motor consists of one main winding (running winding) and one auxiliary winding (starting winding) and the capacitor. The main winding is connected directly to the mains and the starting winding is connected in series with the capacitor. The capacitor and the starting winding remain in the circuit while the motor is even in full operation. These motors are used where the low starting torque is required i.e. in fans, blowers, oil burners etc. the direction of rotation of such type of motors can easily be reversed by using the reversible switch in the circuit of main and starting winding. After the direction has been changed, the main winding behaves as starting winding and the starting winding as main winding. Such types of reversible motors are used for rheostats, furnace controls, arc welding controls, valves and induction regulators etc.

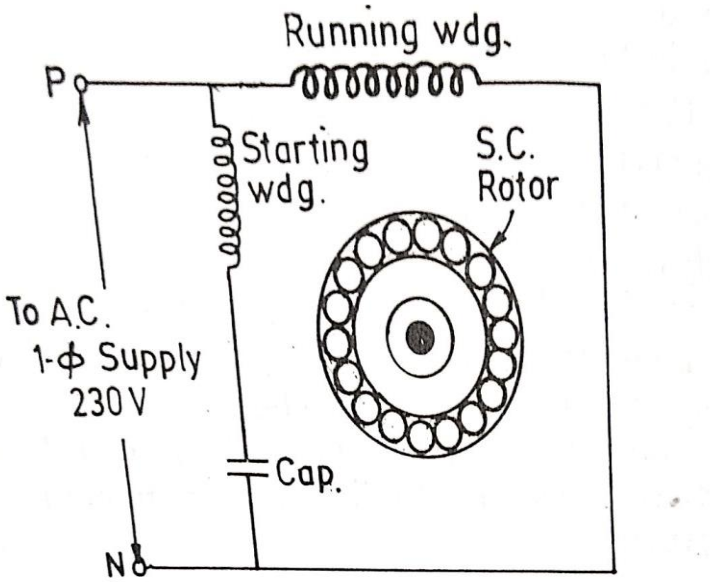


Fig. 6.70. Shows the connection of running wdg., starting wdg. and capacitor for capacitor motor.

2. **Capacitor Start Motor.** This motor consists of running wdg. Starting wdg. Capacitor and centrifugal switch. The capacitor is connected in series with starting wdg. And centrifugal switch. When the motor attains speed after connecting with the single phase A.C. mains, the

centrifugal switch automatically cut off the capacitor and starting wdg. And the motor is operated on the running wdg.

The direction of rotation of such motors can easily be reversed simply by interchanging the leads of running and starting winding each other. These motors are used for refrigerators and water pumps etc.

3. **Capacitor Start Capacitor Run Motor.** This type of motors are similar to capacitor start motors except that the auxiliary (Starting wdg.) and capacitor remain in the circuit all the time even after the motor attains full speed. These motors are very useful because the capacitor remaining in the circuit all the time serves many purposes.

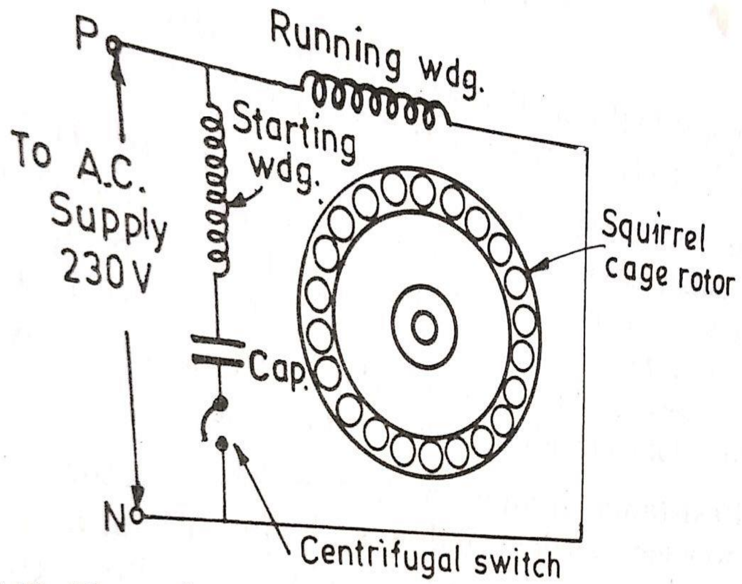


Fig. 6.71. Shows the connection of running wdg. starting wdg., capacitor and centrifugal switch for cap. start motor.

(a) It improves the over load capacitor of the motor.
(b) It improves the power factor.
(c) It increases the efficiency of the motor.
(d) It reduces the noise of the motor.

These motors are used in the drill machines and in the laboratories and office equipments.

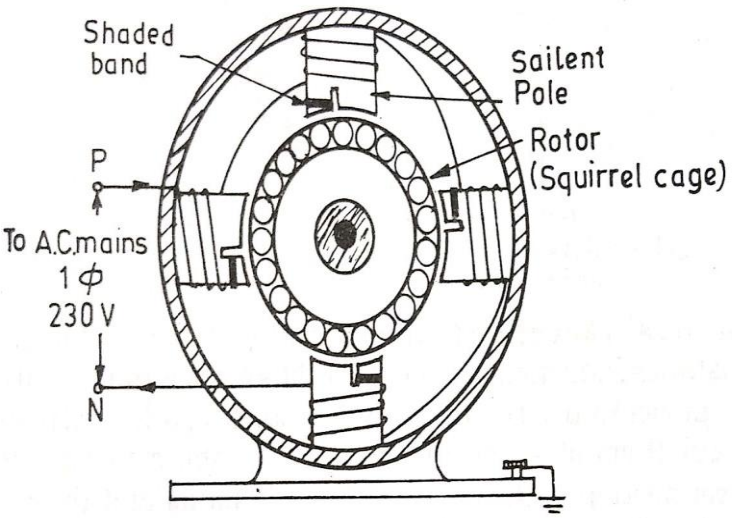


Fig. 6.72. Shows the shaded pole arrangement and winding of four poles for shaded pole motor.

4. **Shaded Pole Motor.** This motor consists of salient poles on the stator and squirrel cage rotor. The motor is made self starting by making a one third cut in each of the laminated pole and the cut is short circuited with a copper ring which is known as shaded pole and so the motor is called shaded pole motor. The shaded poles are independent of the stator winding and have no connection with the winding. When the alternating current is sent through the winding surrounding the whole pole, the axis of the pole is shifted from the un-shaded part to the shaded part which results the rotation of the rotor and the motor works as a self starting motor.

   These motors are made from 1/25 H.P. to 1/6 H.P. They are simple in construction and cheap but have very low starting torque, low efficiency and low overload capacity. Its efficiency varies from 5 to 35%. These motors are used for clocks, phonographs, hair driers, small fans, record players, ventilators, circulators, toys, instruments, projectors and advertising displays etc.

5. **Resistance Induction Motor.** This motor consists of running winding, starting winding and sme resistance coil connected in series with the starting winding and the squirrel cage rotor. The motor is operated in the same way as the split phase induction motor. In this motor, the resistance and starting wdg. Remains in the circuit even if the motor attains full speed.

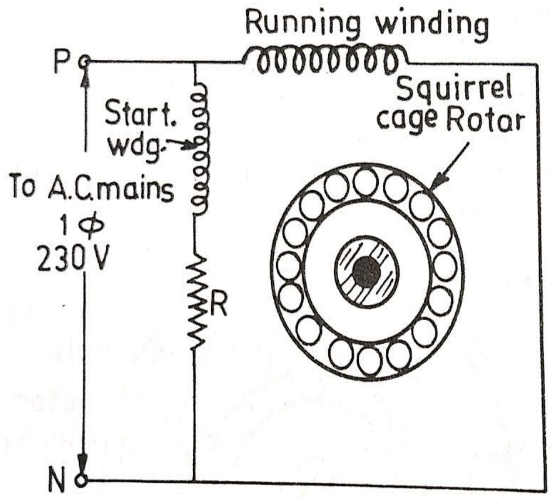


Fig. 6.73. Shows the connection of running winding, starting wdg. and resistance for resistance induction motor.

6. **Resistance Start Induction Motor.** This motor is similar to Resistance Induction motor but the difference is that a centrifugal switch (device) is used in series with the starting wdg. And resistance which cut them off from the circuit when the motor attains full speed connecting with A.C. single phase mains and the motor is operated on the running wdg.

Repulsion Type Motors

Principle of Repulsion As soon as the current is passed through the stator winding; it makes North Pole at one end and the South Pole at the other end. The alternating flux produced in the stator winding induces the e.m.f. can be obtained by Lenz's Law and the direction of induced current in the armature conductors depends upon the position of the short circuited main poles, the armature becomes an electromagnet with a north pole one side under the main north pole and a south pole under the main south pole on the order side. Due to face to face positioning of the main and induced magnetic poles, no torque is produced. Similar is the case if the brushes are kept at 90° to the magnetic axis of the main poles. The voltages induced in the armature conductors neutralizes the voltages induced in the main poles so that there is no voltage across brushes to obtain armature current and where there is no current, no torque is produced.

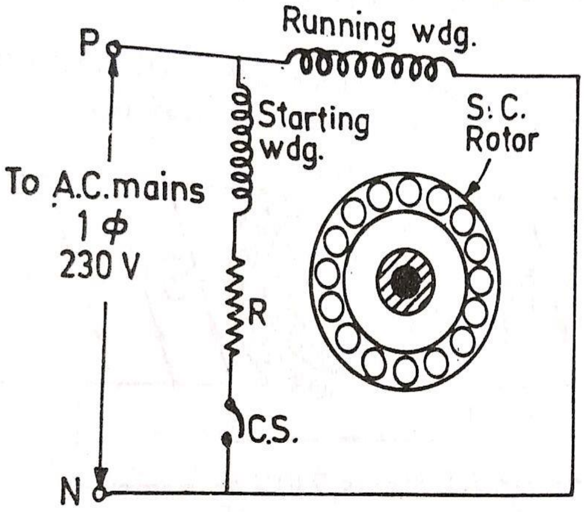


Fig. 6.74. Shows the connection of running wdg., starting wdg., resistance and centrifugal switch for Resistance Start Induction motor.

So to obtain the torque, the brushes are kept neither in such a position that the brush axis is neither in line nor in 90° from the magnetic axis of the main poles. This system induced the voltage between the brush terminals whicdh produces armature current. The armature becoming an electromagnet produces north and south poles which do not face the respective main poles but the rotor north pole is repelled by the main north pole and the rotor south pole is repelled by the main south pole so that the rotor rotates in the clockwise direction and the motor is called a repulsion type motor because the forces oppose each other. The direction of motor can be changed by changing the position of the brushes.

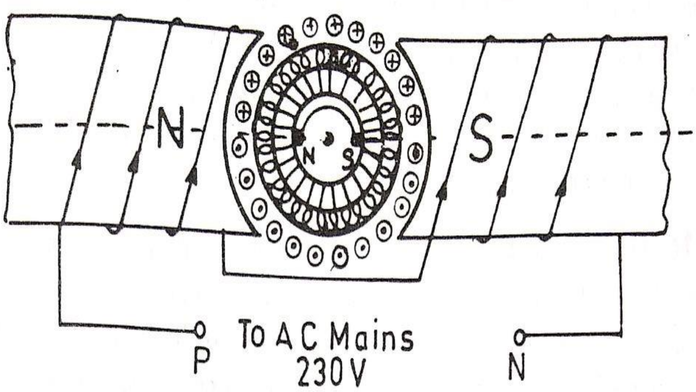


Fig. 6.75. Shows the position of North and South poles face to face due to which no torque is produced.

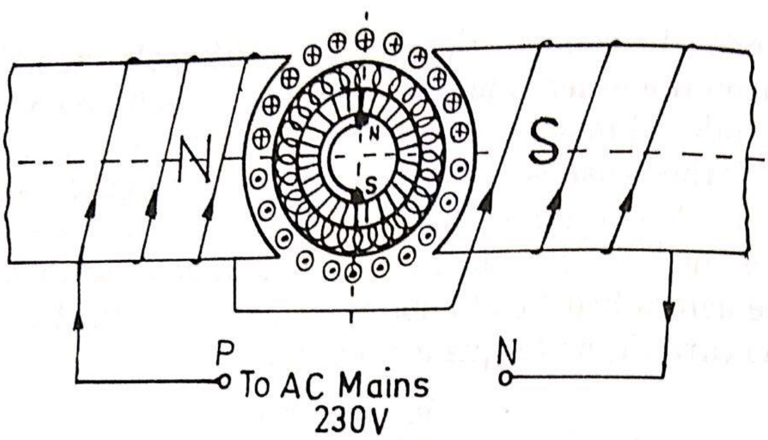


Fig. 6.76. Shows the position of brushes at 90° to the magnetic axis of the main poles, so no torque is produced.

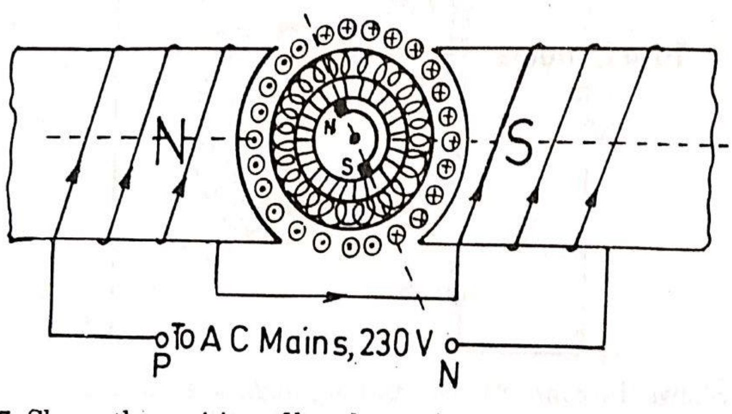


Fig. 6.77. Shows the position of brushes at less than 90° to the magnetic axis of main poles to produce the torque.

Types of Repulsion Motors

1. **Repulsion Motor.** It consists of (a) stator which is wound for four to eight poles; (b) a rotor which is like a D.C. armature and the connections are done on the commutator; (c) a short circuited set of brushes which remain in contact with the commutator all the time and placed in such a way that they are in inclined to the main winding of stator winding. This motor has varying speed characteristics.
2. **Compensated Repulsion Motor.** It is similar to the repulsion motor except that (a) it consists of an additional stator winding which is called a compensating winding (b) and also another set of two brushes, placed midway between the already used short circuited brush set. The additional set of brushes are connected in series with the compensating winding
3. **Repulsion Induction Motor.** This motor consists of (a) stator winding (b) two rotor windings: Squirrel cage wdg. And usual D.C. winding connected to the commutator (c) a short circuited set of two brushes. This motor is operated on the principle of repulsion and induction type motors. It is mostly used due to its good starting characteristics. It has constant and varying speed characteristics. When the voltage is supplied to the motor, the commutated winding produces high torque and when the rotor comes in the motion, then squirrel-cage winding works under the larger portion of the load. The short circuited brushes continuously ride on the commutator.

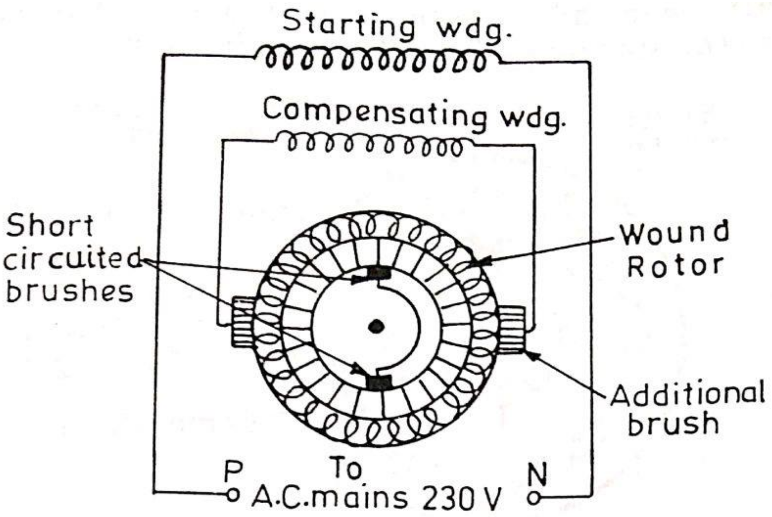


Fig. 6.78. Shows the connection of additional set of brushes, compensating wdg. and rotor and stator for compensating repulsion motor.

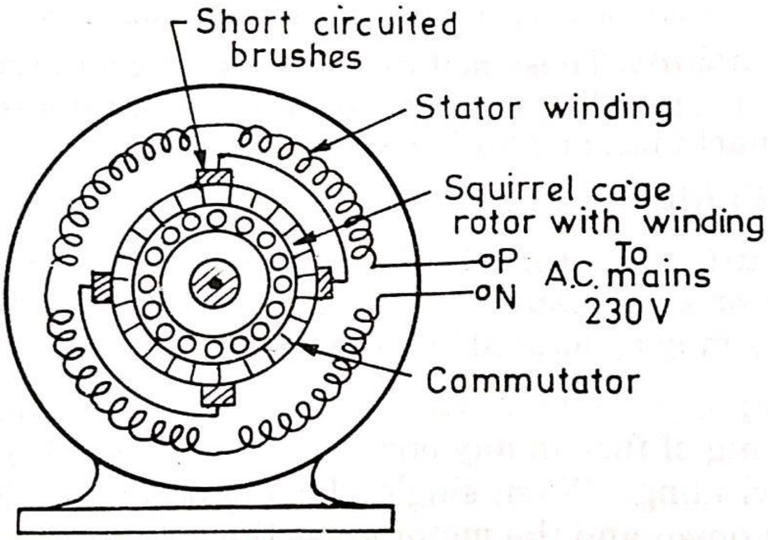


Fig. 6.79. Shows the arrangement of stator winding, rotor and brushes for repulsion induction motor.

Applications These motors are used for heavy duty stokers, refrigeration equipments, air-conditioning equipment, air compressors, wood working machines, lathe machines, garage air pumps, machine tools, petrol pumps, lifts, and hoists and mixing machines

Repulsion Start Induction Motor This motor consists of (a) stator winding (b) a rotor which is wound like D.C. armature (c) a commutator (d) a centrifugal device which short circuits the commutator all round with the help of

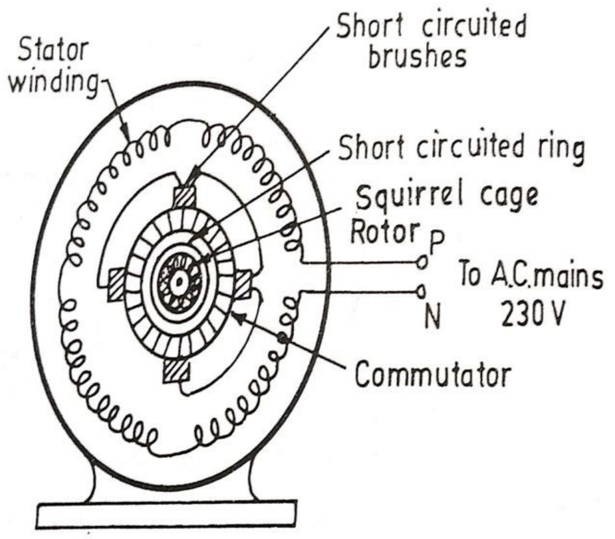


Fig. 6.80. shows the arrangement of stator wdg. commutator brushes, rotor and short circuiting ring for repulsion start ind. motor.

Short circuiting ring when the motor reaches up to 75% of the full speed. This motor is operated as repulsion motor but works as an induction motor with constant speed. After the commutator is short circuited, the brushes do not carry any current and are lifted from the commutator and avoid the unnecessary wear and tear and friction losses. It is particularly used where the starting period is for long duration.

Applications These motors are used for commercial refrigerators, pumps, grinding devices, machine tools, compressors, floor polishing machines, and for hoists.

Common Faults in A.C. Motors

1. **Faults in stator winding**. (a) Short circuit (b) open circuit (c) leakage or earth fault (d) wrong connections of the winding. These faults may be located by megger set.
2. **Single Phasing of Induction Motor.** This fault is caused due to blowing of fuse in any one line or open circuit in any of the phase winding. When single phasing occurs in the motor, its speed drops down and the motor gives the noise.

3. **Faults in the Rotor.** (i) (a) Short circuit (b) Open circuit (c) Slip troubles due to bad contacts of brushes, sticking of brushes in holders. This is all for slip-ring induction motor.

(ii.) Squirrel Cage Rotor. (a) Open circuit. Loose connections between the bars and short circuiting rings, this can be physically checked, soldered or welded.

(iii) D.C. Rotor. In the case of D.C. rotors used in the synchronous motor and repulsion motor, the faults and procedure of locating the faults is similar to the faults in the field circuit of D.C. motor.

(iv) Mechanical faults

(v) Other faults may be bending of shafts, dry bearing or the brushes, loose fitting, poor alignment etc.

EXERCISES

1. What are the types of A.C. motors?
2. Write briefly about the principle and starting of synchronous motor. Write its applications?
3. Write about the const. of induction motors.
4. Describe about the const. of squirrel cage induction motor. How its speed can be regulated? Draw the diagrams of the devices which are used to control the speed of 3 ph. Squirrel cage motor.
5. Describe about the slipping ind. Motor.
6. Describe about the const. and working of single ph. Ind. Motors and give their diagrams.
7. Write the uses of all types of single ph. Motors.
8. What may be possible faults in A.C. motors and give their reasons?

Practical of Capacitor Start Single Phase A.C. Motor

Tools Required

Insulated combination pliers (150 mm) – 1; Screw driver (150 mm) – 1; Connector screw driver (75 mm) – 1; D/E set of spanners; mallet (100 gm) – 1

Material Required

Test lamp (200 watts) with testing leads of 2 m each; insulation tape and cotton tape, if required.

Possible Faults

1. Open circuit in the running winding or main winding.
2. Short circuit in the running winding or main winding.

3. Open circuit in the starting winding or aux. winding.
4. Short circuit in the starting winding or aux. winding.
5. Open circuit in the capacitor or condenser.
6. Short circuit in the capacitor or condenser.
7. Earth fault in running winding, starting winding, capacitor and centrifugal switch.
8. Short circuit test between running and starting winding.

Tests

1. **Continuity and Short Circuit Test on Running winding.** By connecting testing leads of R1 amd R2 as shown in figure 6.82, if lamp glows dimly, it is continuity. If lamp does not give light, it is an open circuit. If lamp gives full light, it is a short circuit.

Removal of Defects

In case of open circuit, connect the disconnected or broken ends of wires.

Separate the touching wires in case of short circuit or if the coils are burnt, get them rewound.

2. **Earth Test on Running Winding or Main Winding.** By connecting one end of testing lead to the metal part of the machine and other end to any one end of running winding as shown in Figure 6.83, if the lamp gives light it is an earth fault.

Removal of Defects

Separate the bare wires from the metal part of the machine and insulate them by cotton tape or varnish them.

3. **Continuity, Short and Earth Test on Starting Winding, Capacitor and Centrifugal Switch.** Test them similarly as you tested running winding or main winding.

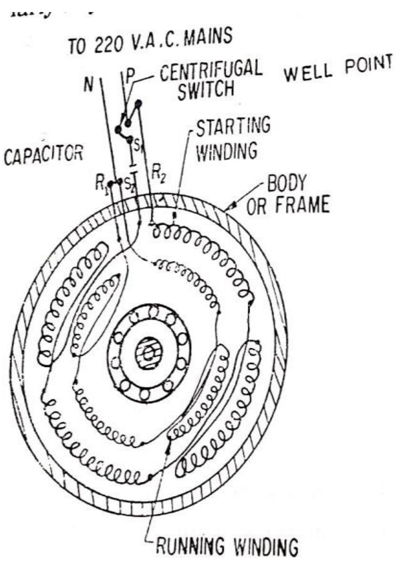


Fig. 6.81. Internal structure of A.C. Single Phase Capacitor Start Motor.

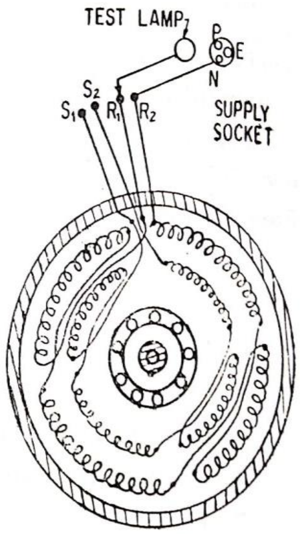


Fig. 6.82. Continuity and Short Circuit Test on Running Winding.

4. **Short Circuit Test between Running and Starting Winding.** By connecting testing leads to any one terminals of running winding and starting winding as shown in Figure 6.84, if the lamp gives light it is a short circuit. Check it and remove the defect by varnishing.

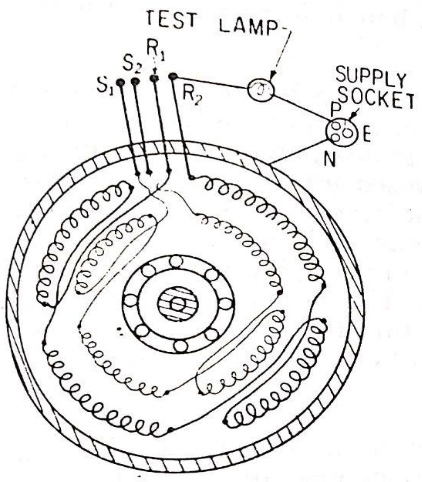


Fig. 6.83. Shows Earth Test on Running Winding.

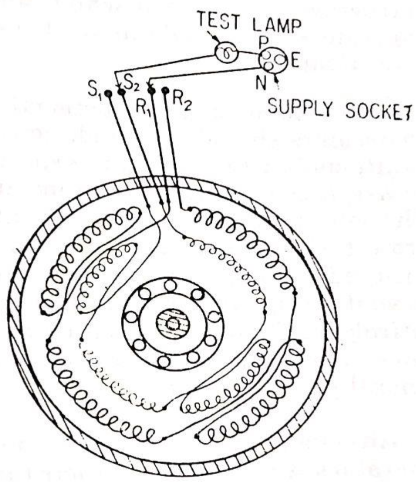


Fig. 6.84. Shows short Circuit Test between Running Winding and Starting Winding.

Precautions

1. Test running winding, starting winding, capacitor and centrifugal switch separately in series of the supply.
2. If there is open circuit or short circuit fault in more than one coil, then disconnect each coil and test them turn by turn with test lamp or insulation testing megger.

EXERCISE

1. What tools and materials will you require to test and repair an A.C. single phase motor?
2. What faults may be possible in a capacitor start single phase A.C. motor?
3. Write the method of testing the various faults and how will you remove them? Draw testing diagrams also.

ELECTRICAL SAFETY

We rely on electricity, but sometimes underestimate its capability of causing injury. Even household current (120 volts) can stop your heart. UW personnel need to be aware of the hazards electricity poses, such as shock, fire and explosion, and either eliminate or control those hazards.

Shock

Electrical shock happens when current passes through the body. Electricity travels through closed circuits, and people, sometimes tragically, can become part of the circuit. When a person receives a shock, electricity flows between parts of the body or through the body to a ground. This can happen if someone touches both wires of an energized circuit, touches one wire of the circuit while standing unprotected or touches a metal part that has become energized.

Electrocution refers to the injury or lethal dose of electrical energy. Electricity can also cause forceful muscle contraction or falls. The severity of injury depends on the amount of current flowing through the body, the current's path through the body, the length of time the body remains in the circuit and the current's frequency.

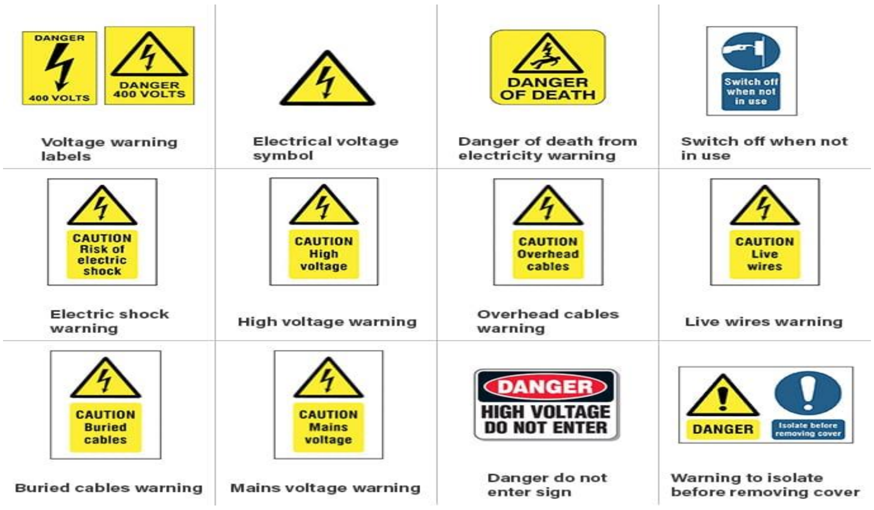
Fire/Explosion

Electrical fires may be caused by excessive resistance that generates heat from any of the following:

- Too much current running through wiring where overcurrent protection fails or does not exist
- Faulty electrical outlets resulting in poor contact or arcing
- Poor wiring connections and old wiring that is damaged and cannot support the load

An explosion can occur when electricity ignites a flammable gas or combustible dust mixture in the air. Ignition from a short circuit or static charge is possible.

Electricity Safety Sign.



Electrical Safety Basics

- Don't work with exposed conductors carrying 50 volts or more.
- Make sure electrical equipment is properly connected, grounded and in good working order.
- Extension cords may not be used as permanent wiring and should be removed after temporary use for an activity or event.
- Surge suppressors with built-in circuit breakers may be used long-term and are available with three, six and 15 foot-long cords.
- High amperage equipment such as space heaters, portable air conditioners and other equipment must be plugged directly into permanent wall receptacles.
- Do not access, use or alter any building's electrical service, including circuit breaker panels, unless you are specifically qualified and authorized to do so.
- Wet environments can increase the risk of an electrical shock.

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Housekeeping and Maintenance

- Maintain at least 30 inches of clearance in front of electrical panels to ensure a safe environment for facilities workers.
- Make sure that all junction boxes are covered.

What you can do to stay safe

Avoid Activities That Requires Training

- Working with exposed conductors carrying 50 volts or more
- Making repairs or alterations to any electrical equipment
- Opening up the case, or removing barrier guards, of any equipment that utilizes electricity
- Using any tools or a meter to measure for the presence of electricity
- Reseting a tripped circuit breaker, or replace a blown fuse

Ask a qualified person to perform these tasks.

Grounding

To prevent electrical hazards, always make sure equipment is properly grounded. Electrical grounding provides an alternate path for electricity to follow, rather than going through a person. Equipment with a grounding prong must be plugged into an extension cord with a ground; the grounding plug should not be removed from the equipment.

Wet Locations

When using electricity in a wet or damp location, including outdoor locations, a Ground Fault Circuit Interrupter (GFCI) must be used. The GFCI ensures that any electrical shock is brief. Although painful, it wouldn't be fatal because the GFCI creates a ground fault or leak in the current.

Lockout/Tagout

When servicing and maintenance tasks involve electricity and electrical equipment, you must prevent the unexpected startup of equipment.

FIRST AID BASICS

The first step in any emergency is the recognition of the problem and providing help. When in doubt or when someone is seriously injured or ill, you should always activate the emergency response system by calling 911. If you're not sure how serious the situation is, the 911 operator will ask you a series of questions to determine the seriousness of it.

Remain on the line until additional help arrives, or until the 911 operator tells you to hang up. Emergency system dispatchers can guide you through the steps of performing cardiopulmonary resuscitation (CPR), using an automatic external defibrillator (AED), or delivering basic care until additional help arrives.

Whether you are at home, work, or school, know where the first aid kit and the AED are kept and be familiar with their contents. Know how to activate the emergency response system (by calling 911 if in the United States). Be aware of any policies in the workplace regarding medical emergencies.

After determining the problem, the next step in providing help is to determine the unresponsiveness of the injured or ill person. The best way to determine this is to tap the person and talk loudly to them: "Are you okay?" After determining unresponsiveness, yell for help. Look for any medical identifications, such as a necklace or a bracelet. This may provide a valuable clue to the cause of the situation.

Rescue of a person from live wire

Electricity, even at small voltages (110V) can cause severe injury or death by causing a person's heart or lungs to stop working. In addition, electricity can also cause minor to severe burns. Serious electrical burns often times appear to be minor, due to the fact that body tissues and organs are damaged internally. If a co-worker has come into contact with electricity they may not be able to remove themselves from the electrical source. DO NOT ATTEMPT TO PULL THE PERSON FROM THE ELECTRICAL SOURCE WITH YOUR BARE HANDS, YOU MAY BE ELECTROCUTED. Remember, your body is a good conductor of electricity, if you touch the person while they are connected to the electrical source, the electricity will flow through your body causing electrical shock. You should first attempt to turn off the source of the electricity (disconnect). If you cannot locate the electrical isolating source, you can use a non-conducting object, such as a wooden pole, to remove the person from the electrical source. Emergency medical services should be called as soon as possible.

- Once you have removed the victim from the electrical source, check to see if the person is breathing and if they have a pulse. If necessary, administer CPR (if you are trained) until emergency personnel arrive at the scene.

- Never go near a victim that has been electrocuted by a high voltage line, because the electricity can travel several feet through the air and you could be electrocuted during rescue procedures.

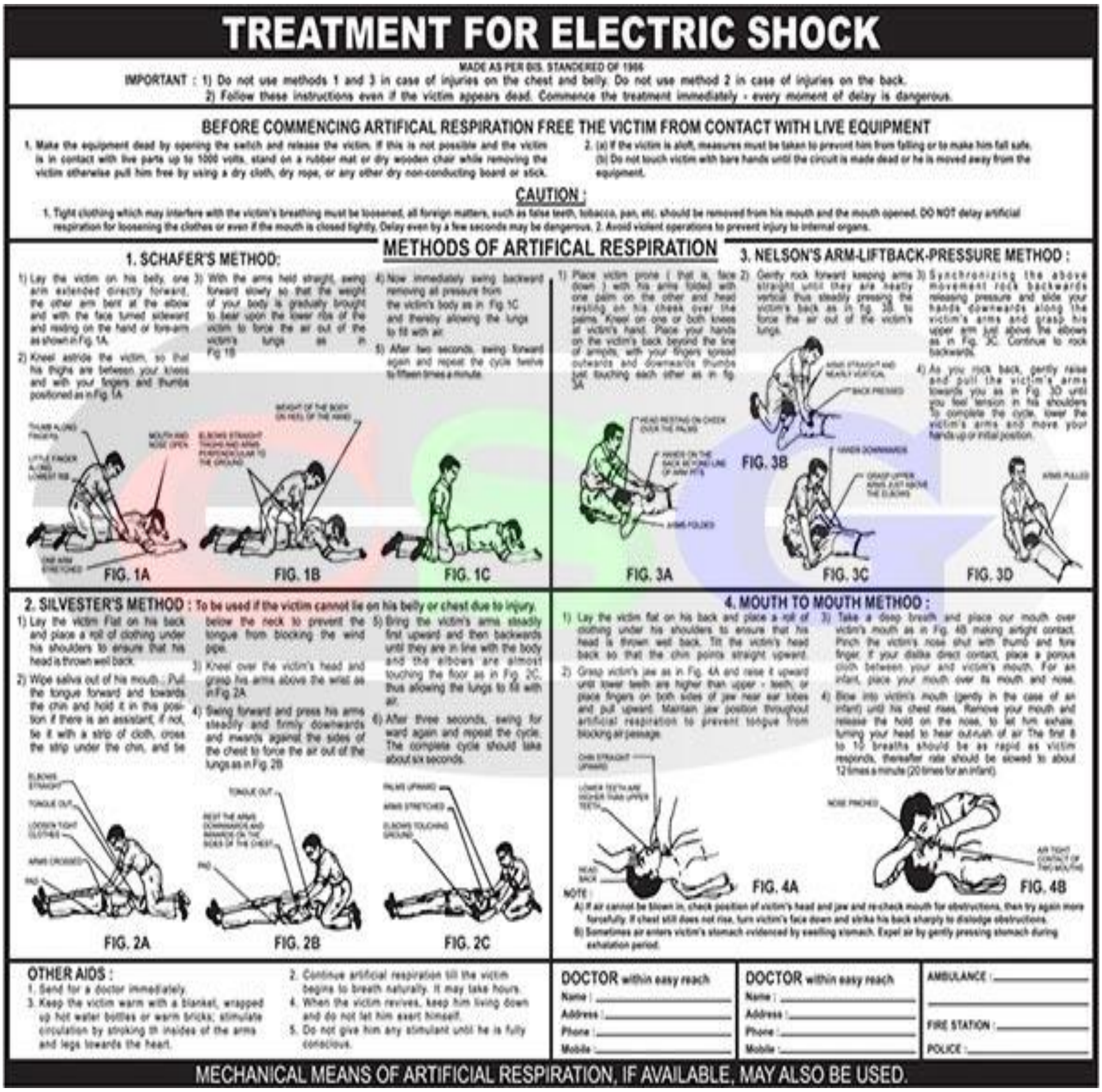
Artificial respiration any method of forcing air into the lungs in a person who still has a pulse but whose breathing hasstopped. Artificial respiration can be given with no equipment, so that it is an ideal emergency first aid procedure. Ideally,it should be given using a pocket face mask or a bag valve mask; in the absence of emergency resuscitation equipment,**mouth-to-mouth RESUSCITATION** may be done.

INDICATIONS. Artificial respiration can save a life whenever breathing has stopped but heartbeat has not, as in near-drowning, electric shock, choking, gas poisoning, drug poisoning, injury to the chest, or suffocation from other causes.It is also administered along with other procedures in cases of cardiac arrest. Usually one can tell that breathing hasstopped by listening, observing, and feeling for respiratory movement. The cause of the stoppage of breathing may beobvious (as when a drowning person is pulled out of the water) or unknown.

PROCEDURE. To be effective, artificial respiration must be begun immediately. At the same time artificial respiration isbegun someone should call for emergency medical assistance, but if there is no one to send, artificial respirationshould be given in preference to going for help. Any obstruction must be removed from the victim's mouth that wouldinterfere with the passage of air, such as mud, sand, chewing gum, or displaced false teeth. Once begun, artificialrespiration should be continued until the victim begins to breathe regularly by himself, until trained emergencypersonnel take charge, until the rescuer cannot continue because of fatigue, or until a physician determines that thepatient is dead. Do not give up easily; victims have recovered as long as 4 hours after artificial respiration was started.If **CARDIAC ARREST** occurs, **CARDIOPULMONARY RESUSCITATION** should be started. If only one person is present, thatperson should provide both alternately.Once revived, the victim is kept quiet, covered to prevent chills, and given otherfirst aid for **SHOCK**.

Schaffer's Method -

Lay the victim on his belly with one arm extended directly overhead and the other arm bent at elbow, with the face turned outward and resting on hand or forearm, so that the nose and mouth are free for breathing, pull the tongue forward, but do not hold it. Kneel, straddling on the victim's thighs, with your hands on the small of the back with fingers resting on the ribs, the little finger just touching the lowest rib, with the thumb and fingers in a natural position and the tips of the fingers just out of sight. Keep your arms straight, lean forward slowly over the victim bringing the weight of your body gradually to bear on the victim for about 2–3 seconds, release the pressure slowly and return to the first position by sliding your palms sideways as shown in fig 1.2 Repeat this procedure about 12–15 times a minute. It will help victim to restore breathing gradually. A victim may require 1–3 hours to re-establish the natural breathing. After the victim starts natural breathing, the artificial respiration should be stopped, keep a watch on the victim till he breaths naturally.



LIFTING AND HANDELING LOADS

Manual handling causes over a third of all workplace injuries. These include work-related musculoskeletal disorders (MSDs) such as pain and injuries to arms, legs and joints, and repetitive strain injuries of various sorts.

The term manual handling covers a wide variety of activities including lifting, lowering, pushing, pulling and carrying. If any of these tasks are not carried out appropriately there is a risk of injury.

Case study one

Why is dealing with manual handling important?

Manual handling injuries can have serious implications for the employer and the person who has been injured. They can occur almost anywhere in the workplace and heavy manual labour, awkward postures, repetitive movements of arms, legs and back or previous/existing injury can increase the risk.

What do I have to do?

To help prevent manual handling injuries in the workplace, you should avoid such tasks as far as possible. However, where it is not possible to avoid handling a load, employers must look at the risks of that task and put sensible health and safety measures in place to prevent and avoid injury.

For any lifting activity

Always take into account**:**

- individual capability
- the nature of the load
- environmental conditions
- training
- work organisation

If you need to lift something manually

- Reduce the amount of twisting, stooping and reaching
- Avoid lifting from floor level or above shoulder height, especially heavy loads
- Adjust storage areas to minimise the need to carry out such movements
- Consider how you can minimise carrying distances
- Assess the weight to be carried and whether the worker can move the load safely or needs any help – maybe the load can be broken down to smaller, lighter components

If you need to use lifting equipment

- Consider whether you can use a lifting aid, such as a forklift truck, electric or hand-powered hoist, or a conveyor
- Think about storage as part of the delivery process – maybe heavy items could be delivered directly, or closer, to the storage area
- Reduce carrying distances where possible

Case study two

Good handling technique for lifting

There are some simple things to do before and during the lift/carry:

- Remove obstructions from the route.
- For a long lift, plan to rest the load midway on a table or bench to change grip.
- Keep the load close to the waist. The load should be kept close to the body for as long as possible while lifting.
- Keep the heaviest side of the load next to the body.
- Adopt a stable position and make sure your feet are apart, with one leg slightly forward to maintain balance

Think before lifting/handling. Plan the lift. Can handling aids be used? Where is the load going to be placed? Will help be needed with the load? Remove obstructions such as discarded wrapping materials. For a long lift, consider resting the load midway on a table or bench to change grip.

Adopt a stable position. The feet should be apart with one leg slightly forward to maintain balance (alongside the load, if it is on the ground). Be prepared to move your feet during the lift to maintain your stability. Avoid tight clothing or unsuitable footwear, which may make this difficult.

Get a good hold. Where possible, the load should be hugged as close as possible to the body. This may be better than gripping it tightly with hands only.

Start in a good posture. At the start of the lift, slight bending of the back, hips and knees is preferable to fully flexing the back (stooping) or fully flexing the hips and knees (squatting).

Don't flex the back any further while lifting. This can happen if the legs begin to straighten before starting to raise the load.

Keep the load close to the waist. Keep the load close to the body for as long as possible while lifting. Keep the heaviest side of the load next to the body. If a close approach to the load is not possible, try to slide it towards the body before attempting to lift it.

Avoid twisting the back or leaning sideways, especially while the back is bent. Shoulders should be kept level and facing in the same direction as the hips. Turning by moving the feet is better than twisting and lifting at the same time.

Keep the head up when handling. Look ahead, not down at the load, once it has been held securely.

Move smoothly. The load should not be jerked or snatched as this can make it harder to keep control and can increase the risk of injury.

Don't lift or handle more than can be easily managed. There is a difference between what people can lift and what they can safely lift. If in doubt, seek advice or get help.