UNIT-3:

POWER FACTOR AND ENERGY INSTRUMENTS

Power Factor:

Traditionally, power factor has been defined as the ratio of the kilowatts of power divided by the kilovolt-amperes drawn by a load or system, or the cosine of the electrical angle between the kilowatts and kilovolt-amperes. However, this definition of power factor is valid only if the voltages and currents are sinusoidal. When the voltages and/or currents are nonsinusoidal, the power factor is reduced as a result of voltage and current harmonics in the system. Therefore, the discussion of power factor will be considered for the two categories, i.e., systems in which the voltages and currents are substantially sinusoidal and systems in which the voltages and currents are non-sinusoidal as a result of nonlinear loads.

THE POWER FACTOR IN SINUSOIDAL SYSTEMS:

The line current drawn by induction motors, transformers, and other inductive devices consists of two components: the magnetizing current and the power-producing current.

The magnetizing current is that current required to produce the magnetic flux in the machine. This component of current creates a reactive power requirement that is measured in kilovolt-amperes reactive (kilovars, kvar). The power-producing current is the current that reacts with the magnetic flux to produce the output torque of the machine and to satisfy the equation

$$\boldsymbol{T = K\emptyset I}$$

Where

T = output torque

Φ = net flux in the air gap as a result of the magnetizing current

I = power-producing current

K = output coefficient for a particular machine

The power-producing current creates the load power requirement measured in kilowatts (kW). The magnetizing current and magnetic flux are relatively constant at constant voltage. However, the power-producing current is proportional to the load torque required.

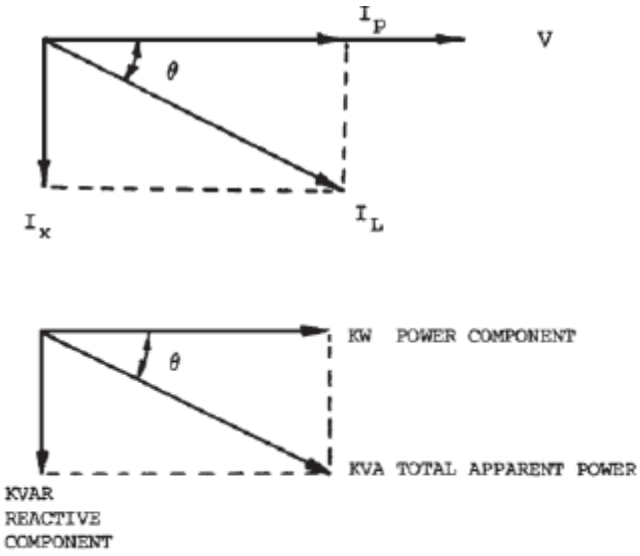
The total line current drawn by an induction motor is the vector sum of the magnetizing current and the power-producing current.

The vector relationship between the line current *IL* and the reactive component *Ix* and load component *Ip* currents can be expressed by a vector diagram, as shown in Fig. where the line current *IL* is the vector sum of two components. The power factor is then the cosine of the electrical angle θ between the line current and phase voltage.

This vector relationship can also be expressed in terms of the components of the total kilovolt-ampere input, as shown in Fig. Again, the power factor is the cosine of the angle θ between the total kilovolt-ampere and kilowatt inputs to the motor. The kilovolt-ampere input to the motor consists of two components: load power, i.e., kilowatts, and reactive power, i.e., kilovars.

The system power factor can be determined by a power factor meter reading or by the input power (kW), line voltage, and line current readings. Thus,

Power factor = kW / kVA



Disadvantages of Low Power Factor:

A low power factor causes poor system efficiency. The total apparent power must be supplied by the electric utility. With a low power factor, or a high-kilovar component, additional generating losses occur throughout the system. Figures below illustrate the effect of the power factor on generator and transformer capacity.

To discourage low-power factor loads, most utilities impose some form of penalty or charge in their electric power rate structure for a low power factor.

When the power factor is improved by installing power capacitors or synchronous motors, several savings are made:

1. A high power factor eliminates the utility penalty charge. This charge may be a separate charge for a low power factor or an adjustment to the kilowatt demand charge

2. A high power factor reduces the load on transformers and distribution equipment.

3. A high power factor decreases the I^2R losses in transformers, distribution cable, and other equipment, resulting in a direct saving of kilowatt-hour power consumption.

4. A high power factor helps stabilize the system voltage.

Methods of Power Factor Improvement:

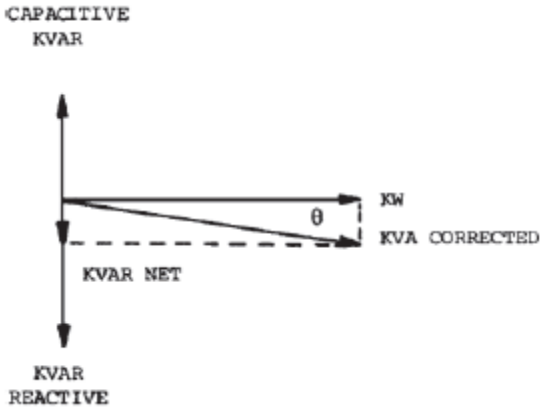
The more popular method of improving the power factor on low voltage distribution systems is to use power capacitors to supply the leading reactive power required. The amount and location of the corrective capacitance must be determined from a survey of the distribution system and the source of the low-power factor loads.

In addition, the total initial cost and payback time of the capacitor installation must be considered.

To reduce the system losses, the power factor correction capacitors should be electrically located as close to the low-power factor loads as possible. In some cases, the capacitors can be located at a particular power feeder. In other cases, with large-horsepower motors, the capacitors can be connected as close to the motor terminals as possible. The power factor capacitors are connected across the power lines in parallel with the low-power factor load.

The number of kilovars of capacitors required depends on the power factor without correction and the desired corrected value of the power factor.

The power factor and kilovars without correction can be determined by measuring the power factor, line amperes, and line voltage at the point of correction. For a three-phase system,



$$\text{kVA input} = \frac{\text{line amperes} \times \text{line volts} \times \sqrt{3}}{1000}$$

$$\text{kW} = \text{kVA} \times \text{PF}$$

$$\text{kvar} = \sqrt{(\text{kVA})^2 - (\text{kW})^2}$$

Or the line kilowatts, line amperes, and line voltage can be measured. Then,

$$\text{kVA input} = \frac{\text{line amperes} \times \text{line volts} \times \sqrt{3}}{1000}$$

$$\text{PF} = \frac{\text{kW}}{\text{kVA}}$$

$$\text{kvar} = \sqrt{(\text{kVA})^2 - (\text{kW})^2}$$

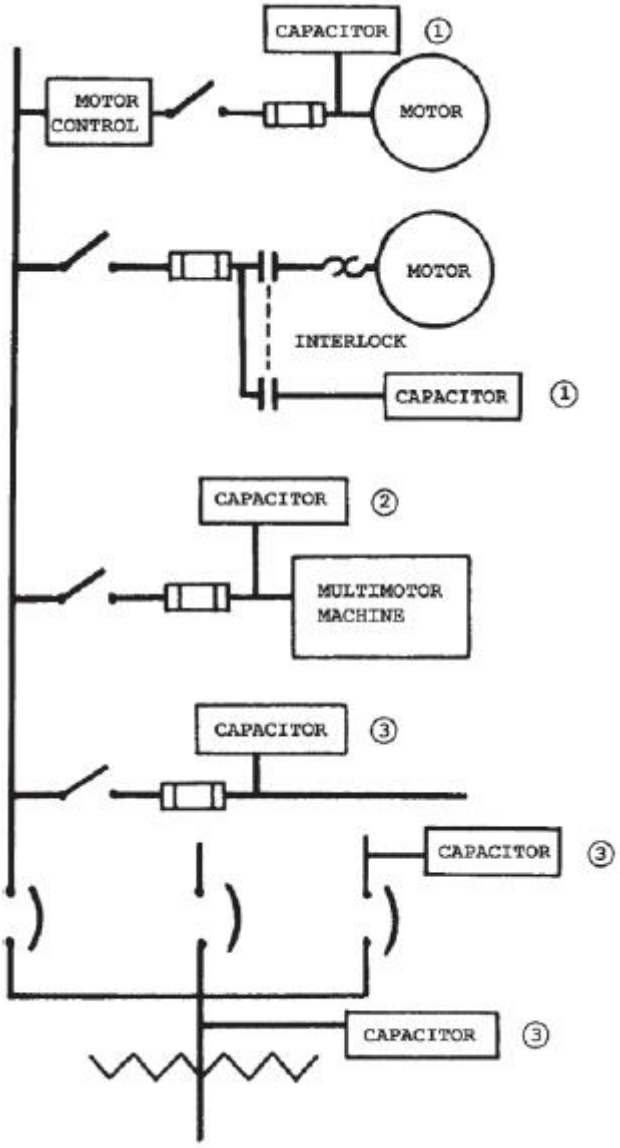
The capacitive kilovars required to raise the system to the desired power factor can be calculated as follows:

$$\text{kvar capacitance} = \text{kvar load} - \sqrt{\frac{1 - \text{PF}^2}{\text{PF}^2}(\text{kW load})^2}$$

Another method of improving powerfactor is connecting a synchronous motor in parallel with the system and operate it under over excitation condition.

Location of Capacitors:

The power factor correction capacitors should be connected as closely as possible to the low–power factor load. This is very often determined by the nature and diversity of the load. Figure illustrates typical points of installation of capacitors:



At the Motor Terminals:

Connecting the power capacitors to the motor terminals and switching the capacitors with the motor load is a very effective method for correcting the power factor. The benefits of this type of installation are the following: No extra switches or protective devices are required, and line losses are reduced from the point of connection back to the power source. Corrective capacitance is supplied only when the motor is operating. In addition, the correction capacitors can be sized based on the motor nameplate information, as previously discussed.

If the capacitors are connected on the motor side of the overloads, it will be necessary to change the overloads to retain proper overload protection of the motor. A word of caution: With certain types of electric motor applications, this method of installation can result in damage to the capacitors or motor or both.

Never connect the capacitors directly to the motor under any of the following conditions:

- The motor is part of an adjustable-frequency drive system.
- Solid-state starters are used.
- The motor is subject to repetitive switching, or plugging.
- A multispeed motor is used.
- A reversing motor is used.
- There is a possibility that the load may drive the motor (such as a high-inertia load).

In all these cases, self-excitation voltages or peak transient currents can cause damage to the capacitor and motor. In these types of installations, the capacitors should be switched with a contactor interlocked with the motor starter.

At the Main Terminal for a Multimotor Machine:

In the case of a machine or system with multiple motors, it is common practice to correct the entire machine at the entry circuit to the machine. Depending on the loading and duty cycle of the motors, it may be desirable to switch the capacitors with a contactor interlocked with the motor starters. In this manner, the capacitors are connected only when the main motors of a multimotor system are operating.

At the Distribution Center or Branch Feeder*:*

The location of the capacitors at the distribution center or branch feeder is probably most practical when there is a diversity of small loads on the circuit that require power factor correction. However, again, the capacitors should be located as close to the low–power factor loads as possible in order to achieve the maximum benefit of the installation.

THE POWER FACTOR WITH NONLINEAR LOADS:

The growing use of power semiconductors has increased the complexity of system power factor and its correction. These power semiconductors are used in equipment such as

Rectifiers (converters)

DC motor drive systems

Adjustable-frequency AC drive systems

Solid-state motor starters

Electric heating

Uninterruptible power supplies

Computer power supplies

In the earlier discussion about the power factor in sinusoidal systems, only two components of power contributed to the total kilovolt-amperes and the resultant power factor: the active or real component, expressed in kilowatts, and the reactive component, expressed in kilovars. When nonlinear loads using power semiconductors are used in the power system, the total power factor is made up of three components:

1. *Active, or real, component,* expressed in kilowatts.

2. *Displacement component*, of the fundamental reactive elements, expressed in kilovars or kilovolt-amperes.

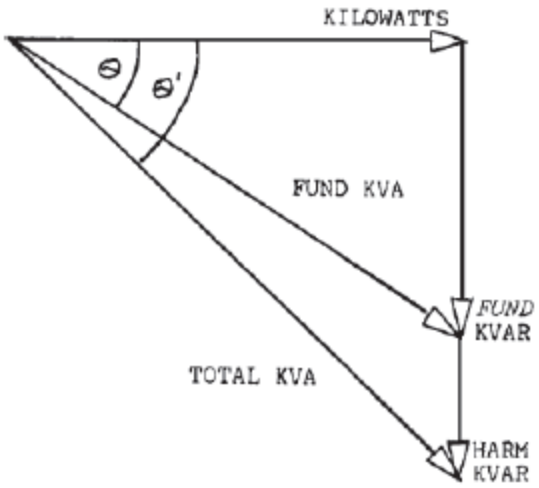
3. *Harmonic component.* The result of the harmonics and the distorted sinusoidal current and voltage waveforms generated when any type of power semiconductor is used in the power circuit, the harmonic component can be expressed in kilovars or kilovolt-amperes. The effect of these nonlinear loads on the distribution system depends on (1) the magnitude of the harmonics generated by these loads, (2) the percent of the total plant load that is generating harmonies, and (3) the ratio of the short-circuit current available to the nominal fundamental load current. Generally speaking, the higher the ratio of short-circuit current to nominal fundamental load current, the higher the acceptable level of harmonic distortion.

Therefore, more precise definitions of power factors are required for systems with nonlinear loads as follow: *Displacement power factor*: The ratio of the active power of the fundamental in kilowatts to the apparent power of the fundamental in kilovolt-amperes.

Total power factor: The ratio of the active power of the fundamental in kilowatts to the total kilovolt-amperes. *Distortion factor*, or *harmonic factor.* The ratio of the root-mean square (rms) value of all the harmonics to the root-mean square value of the fundamental. This factor can be calculated for both the voltage and current. Figure illustrates the condition in which the total power factor is lower than the displacement power factor as a result of the harmonic currents.

$$\text{Displacement power factor} = \frac{\text{kW}}{\sqrt{\text{kW}^2 + \text{fund. kvar}^2}}$$

$$\text{Total power factor} = \frac{\text{kW}}{\sqrt{\text{kW}^2 + (\text{fund. kvar} + \text{harm. kvar})^2}}$$



Unfortunately, conventional var-hour meters do not register the total reactive energy consumed by nonlinear loads. If the voltage is non sinusoidal, the var-hour meter measures only the displacement volt-ampere-hours and ignores the distortion volt-ampere-hours.
Therefore, for nonlinear loads, the calculated power factor based on kilowatt-hour and var-hour meter readings will be higher than the correct total power factor. The amount of the error in the power factor calculation depends on the magnitude of the total harmonic distortion.

Energy meter (Watt hour meter)

An instrument that is used to measure either quantity of electricity or energy, over a period of time is known as energy meter or watt-hour meter. In other words, energy is the total power delivered or consumed over an interval of time t may be expressed as:

$$Energy = \int_0^t v(t)i(t)dt$$

If V(t) is expressed in volts, *i(t)* in amperes and t in seconds, the unit of energy is joule or watt second. The commercial unit of electrical energy is kilowatt hour (KWh). For measurement of energy in a.c. circuit, the meter used is based on "electro-magnetic induction" principle. They are known as induction type instruments. For the meter to read correctly, the speed of the moving system must be proportional to the power in the circuit in which the meter is connected.

Construction: Induction type energy meter essentially consists of following components (a) Driving system (b) Moving system (c) Braking system and (d) Registering system.

Driving system: It consists of two electromagnets, called "shunt" magnet and "series" magnet, of laminated construction. A coil having large number of turns of fine wire is wound on the middle limb of the shunt magnet. This coil is known as "pressure or voltage" coil and is connected across the supply mains. This voltage coil has many turns and is arranged to be as highly inductive as possible. In other words, the voltage coil produces a high ratio of inductance to resistance. This causes the current, and therefore the flux, to lag the supply voltage by nearly 90degrees. Adjustable copper shading rings are provided on the central limb of the shunt magnet to make the phase angle displacement between magnetic field set up by shunt magnet and supply voltage is approximately 90degrees. The copper shading bands are also called the power factor compensator or compensating loop. The series electromagnet is energized by a coil, known as "current" coil which is connected in series with the load so that it carry the load current. The flux produced by this magnet is proportional to, and in phase with the load current.

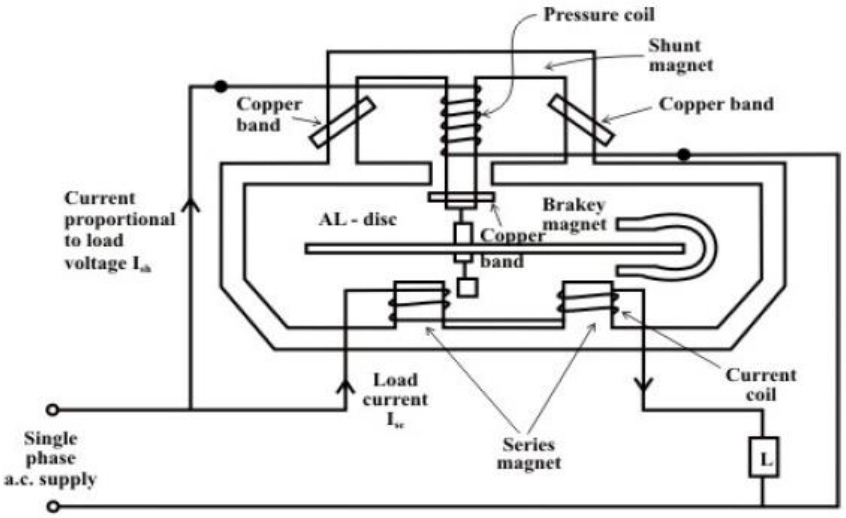
Moving system: The moving system essentially consists of a light rotating aluminium disc mounted on a vertical spindle or shaft. The shaft that supports the aluminium disk is connected by a gear arrangement to the clock mechanism on the front of the meter to provide information that consumed energy by the load. The time varying (sinusoidal) fluxes produced by shunt and series magnet induce eddy currents in the aluminium disc. The interaction between these two magnetic fields and eddy currents set up a driving torque in the disc. The number of rotations of the disk is therefore proportional to the energy consumed by the load in a certain time interval and is commonly measured in killowatt-hours (Kwh).

Braking system: Damping of the disk is provided by a small permanent magnet, located diametrically opposite to the a.c magnets. The disk passes between the magnet gaps. The movement of rotating disc through the magnetic field crossing the air gap sets up eddy currents in the disc that reacts with the magnetic field and exerts a braking torque. By changing the position of the brake magnet or diverting some of the flux there form, the speed of the rotating disc can be controlled.

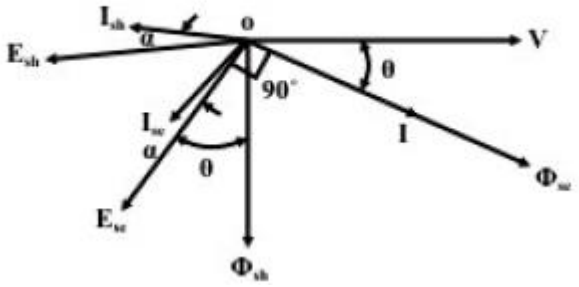
Registering or Counting system: The registering or counting system essentially consists of gear train, driven either by worm or pinion gear on the disc shaft, which turns pointers that indicate on dials the number of times the disc has turned. The energy meter thus determines and adds together or integrates all the instantaneous power values so that total energy used over a period is thus known. Therefore, this type of meter is also called an "integrating" meter.

Operation:

Induction instruments operate in alternating-current circuits and they are useful only when the frequency and the supply voltage are approximately constant. The most commonly used technique is the shaded pole induction watt-hour meter, shown in fig. The rotating element is an aluminium disc, and the torque is produced by the interaction of eddy currents generated in the disc with the imposed magnetic fields that are produced by the voltage and current coils of the energy meter.



Let us consider a sinusoidal flux $\varphi(t)$ is acting perpendicularly to the plane of the aluminium disc, the direction of eddy current by Lenz's law is indicated in figure Fig. It is now quite important to investigate whether any torque will develop in aluminium disc by interaction of a sinusoidally varying flux and the eddy currents induced by itself.



The flux generated by the current coil is in phase with the current and flux generated by the voltage coil is adjusted to be exactly in quadrature with the applied voltage by means of the copper shading ring on the voltage or shunt magnet. The average torque acting upon the disc is given by

$$T_{d(av)} \propto \left[\Phi_{sh(rms)} I_{se} \cos(\angle\Phi_{sh(rms)}, I_{se}) - \Phi_{se(rms)} I_{sh} \cos(\angle\Phi_{se(rms)}, I_{sh})\right]$$

$$\propto \left[\Phi_{sh(rms)} I_{se} \cos(\theta+\alpha) - \Phi_{se(rms)} I_{sh} \cos(180+\alpha-\theta)\right]$$

$$\propto \left[k' V k \frac{I}{Z} \cos(\theta+\alpha) + k I k' \frac{V}{Z} \cos(\theta-\alpha)\right]$$

$$\propto \left(\frac{2 k k'}{Z} \cos\alpha\right) VI \cos\theta$$

$$\propto VI\cos\theta = \text{power in the circuit}$$

where $\Phi_{sh}, \Phi_{se}, I_{sh}, I_{se}, V,$ *and* I are all expressed as r.m.s.

Now the breaking torque is produced by the eddy currents induced in the disc by its rotation in a magnetic field of constant intensity, the constant field being provided by the permanent magnet (called brake magnet). The eddy current i_b produced in the aluminium–disc by the brake magnet flux φ_b is proportional to the speed (N) of rotation of the disc N.

Thus braking torque

$$T_b \propto \Phi_b i_b \propto \Phi_b \frac{e_b}{r}$$

$$\propto \Phi_b \frac{N\Phi_b}{r}$$

$$\propto N\Phi_b^2$$

, where r = eddy current path resistance

Since Φ_b is constant, this implies that

$$T_b \propto N$$

where N = speed of rotation of disc.

Now when the speed becomes steady, driving and braking torques become

$T_d = T_b$

Therefore, $VI\cos\theta \propto N$ i.e. speed of the disc is proportional to the power consumed by the load. The total number of revolution i.e. $\int N\,dt = \int VI\cos\theta\,dt \propto$ Energy consumed. This means that the speed of rotation of the disc is proportional to the average power. The integral of the number of revolutions of the disc is proportional to the total energy supplied.

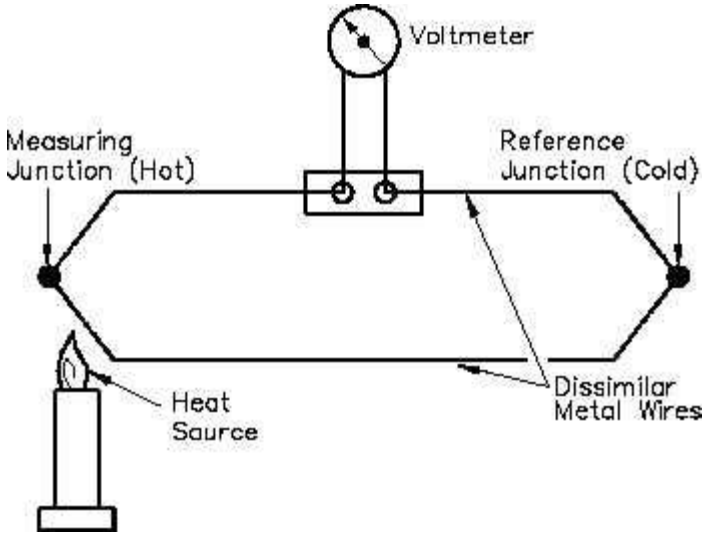
THERMO COUPLE

When two conductors made from dissimilar metals are connected forming two common junctions and the two junctions are exposed to two different temperatures, a net thermal emf is produced, and net thermal emf value being dependent on the materials used and the temperature difference between hot and cold junctions. The thermoelectric emf generated, in fact is due to the combination of *Peltier effect* and *Thomson effect*.

The emf generated can be approximately expressed by the relationship:

$$e_o = C_1(T_1 - T_2) + C_2\left({T_1}^2 - {T_2}^2\right) uV$$

C_1, C_2 are constants depending upon the type of materials. T_1, T_2 are hot and cold junction temperatures in K. For Copper/ Constantan thermocouple, C_1=62.1 and C_2=0.045.



Thermocouples are extensively used for measurement of temperature in industrial situations. The major reasons behind their popularity are: (i) they are rugged and readings are consistent, (ii) they can measure over a wide range of temperature, and (iii) their characteristics are almost linear with an accuracy of about 0.05%. However, the major shortcoming of thermocouples is low sensitivity compared to other temperature measuring devices (e.g. RTD, Thermistor).

Laws of Thermo Couple:

The Peltier and Thompson effects explain the basic principles of thermoelectric emf generation.

First Law (Law of homogeneous circuit):

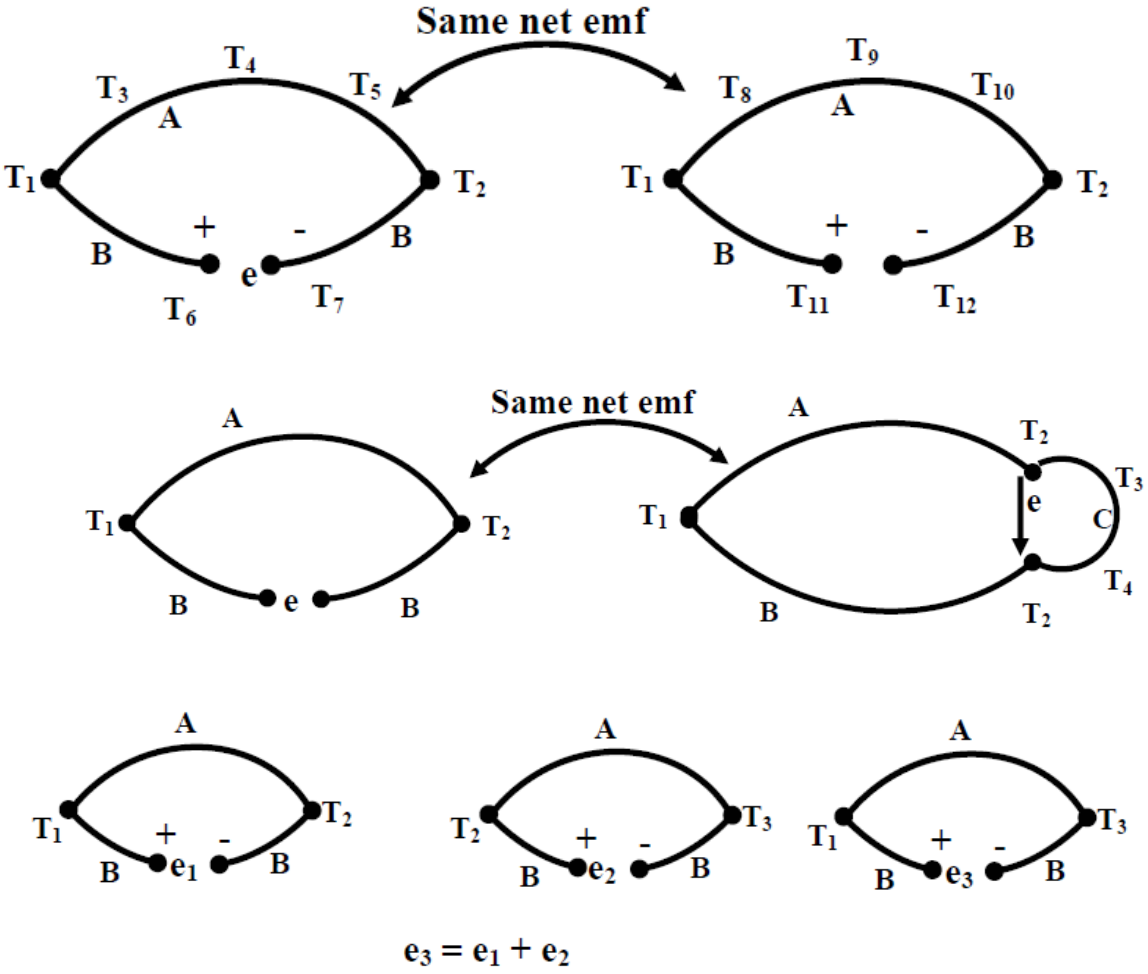
A thermo electric current cannot be sustained in a circuit of a single homogeneous material however varying in c.s. by the application of heat alone. The implication is that two different materials are needed to form a thermocouple.

Second Law (Law of intermediate materials):

Insertion of an intermediate metal into a thermocouple circuit will not effect the net emf provided the two junctions introduced by the intermediate metal are at identical temperature. This means that there can be a measuring instrument, soldered or brazed between the two metals in order to monitor the emf generated.

Third Law (Law of intermediate temperature):

If a thermocouple develops an e.m.f e1 when the junctions are at T1 and T2 and an e.m.f e2 when the junctions are at T2 and T3, it will develop an e.m.f e1 + e2 when the junctions are at T1 and T3.



$e_3 = e_1 + e_2$

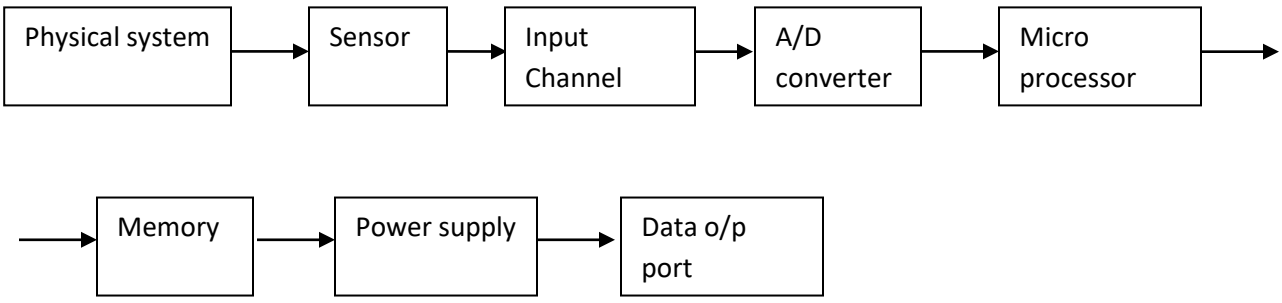
It is imminent that the thermocouple output voltage will vary if the reference junction temperature changes. So, for measurement of temperature, it is desirable that the cold junction of the thermocouple should be maintained at a constant temperature. Ice bath can be used for this purpose, but it is not practical solution for industrial situation. An alternative is to use a thermostatically controlled constant temperature oven. In this case, a fixed voltage must be

added to the voltage generated by the thermocouple, to obtain the actual temperature. But the most common case is where the reference junction is placed at ambient temperature.

DATA LOGGER

A data logger is an electronic instrument that records environmental parameters such as temperature, relative humidity, wind speed and direction, light intensity, water level and water quality over time. Typically, data loggers are compact, battery-powered devices that are equipped with microprocessor input channels and data storage.

As the price of PC components dropped, data loggers became more affordable for a wider array of applications. Before then, chart recorders were commonly used as well as manual measurements. Both of these methods were labour intensive and time consuming so the advent of standalone data loggers was welcomed. users of data loggers span from a single installation for measure temperature to meteorological networks of hundreds of stations monitoring temperature, relative humidity, barometric pressure, solar radiation, precipitation and wind speed & direction.



A data logger is used to collect readings, or output, from sensors. These sensors could be measuring industrial parameters such as pressure, flow and temperature or environmental parameters such as water level, wind speed or solar radiation. Today there are sensors available which can measure virtually any physical parameter.

The main components of Data loggers are,

Input channel:

The output from a sensor is inputted or connected to a data logger channel. A channel consists of circuitry designed to 'channel' a sensor signal (typically a voltage or current) from the sensor to the data logger processor. A single data logger can have a variety of channel types and from one

to many channels (multi-channel data logger) - one channel is required for every sensor signal output. For example, four sensors can be connected to a four channel data logger and eight sensors to a eight channel logger. Typically, a multi-channel logger will have from four to 16 channels. Three types of channels are typically found on a multi-channel data logger, they are: Analog channel, Digital channel, Serial digital interface.

Analog to Digital converter:

All sensor signals, analog, digital and SDI-12, must be in binary format in order for the data logger to record them. Binary data format is not specific to data loggers but is the fundamental data format used by virtually all computers.

Analog signals however need to be converted to binary data via an A/D converter (Analog to Digital Converter). The amount of bits the A/D converter utilizes will determine the resolution to which the signal can be recorded.

Microprocessor:

A processor is the logic circuitry that responds to and processes the basic instructions that drive a computer or data logger. A microprocessor is a computer processor on a microchip. It's sometimes called a logic chip. A microprocessor is designed to perform arithmetic and logic operations that make use of small number-holding areas called registers. Typical microprocessor operations include adding, subtracting, comparing two numbers, and fetching numbers from one area to another. These operations are the result of a set of instructions that are part of the microprocessor design. When a data logger is powered on, the microprocessor is designed to get instruction from the operating system that is loaded in the data logger memory. The operating system is "driving" the microprocessor and giving it instructions to perform. The operating system of the microprocessor usually resides on an EEPROM chip.

Memory:

Two types of memory are used in data loggers:

RAM (Random Access Memory):

Unlike a PC's RAM which is used as a 'workshop area', a data logger can use RAM to store data (readings from the input channel). RAM chips are inexpensive but must be battery backed up in order to retain the data. RAM chips are downloaded via the serial port of a PC.

EEPROM (Electronically Erasable & Programmable Read Only Memory):

Developed for data loggers in the late 1980's EEPROM memory does not need to be backed up by a battery. Many data loggers use EEPROM chips for both storing the operating system of the

microprocessor, as well as for data storage. An EEPROM chip can be programmed, read (stored data) and erased via the serial port of a PC. Data loggers may also use PCMCIA data cards for memory; these cards consist of EEPROM memory.

Power Supply

A feature that clearly distinguishes data loggers from PC's is the low power requirements of data loggers. Data loggers are designed to operate in remote locations for long periods of time void of main AC power. Most data loggers require a 12 VDC power source. Battery capacities are measured in Milli-Amp hours (mAh) which determines the length of time that the battery can provide power for a given load. Increased capacity requires greater battery size and weight.

Data Output Port (PC Communication Port or RS-232 Port)

Most data loggers communicate with a PC via a serial port, which allows data to be transmitted in a series (one after the other). The RS-232 interface has been a standard for decades as an electrical interface between data terminal equipment, such as a PC, and data communications equipment employing serial binary data interchange, such as a data logger or modem. Data can be sent in both directions, and many loggers use 9600 baud as a standard communication speed. Since the RS-232 is so popular, many modems are available that can be connected to a data logger to retrieve data remotely or to program the data logger.

Applications of Data logger:

- Weather station recording (such as wind speed / direction, temperature, relative humidity, solar radiation)
- Hydro graphic recording (such as water level, water depth, water flow, water pH, water conductivity).
- Soil moisture level recording.
- Gas pressure recording.
- Measure temperatures (humidity, etc.) of perishables during shipments.
- Measure variations in light intensity.
- Monitoring of relay status in railway signalling.
- Load profile recording for energy consumption management.
- Temperature, Humidity and Power use for Heating and Air conditioning efficiency studies.

PYROMETER

The word is derived from pyros + metron. The methods under this are primarily thermal radiation measurement. There are two distinct instruments. Under this category:

(i) Optical pyrometer

(ii) Total Radiation Pyrometer

Optical pyrometer:

- A target object whose temperature is to be measured is placed in front of the pyrometer.
- A field lens will gather light coming from this target, and then it will be focused on to the plane of a filament.
- The filament is run by a battery, a variable resistor, an ammeter.
- The radiation coming from the target is made to pass through an aperture so that straight light does not enter the instrument.
- Then it passes through a gray filter which will, if necessary, reduce the brightness by a known factor. Then it falls on the filament.

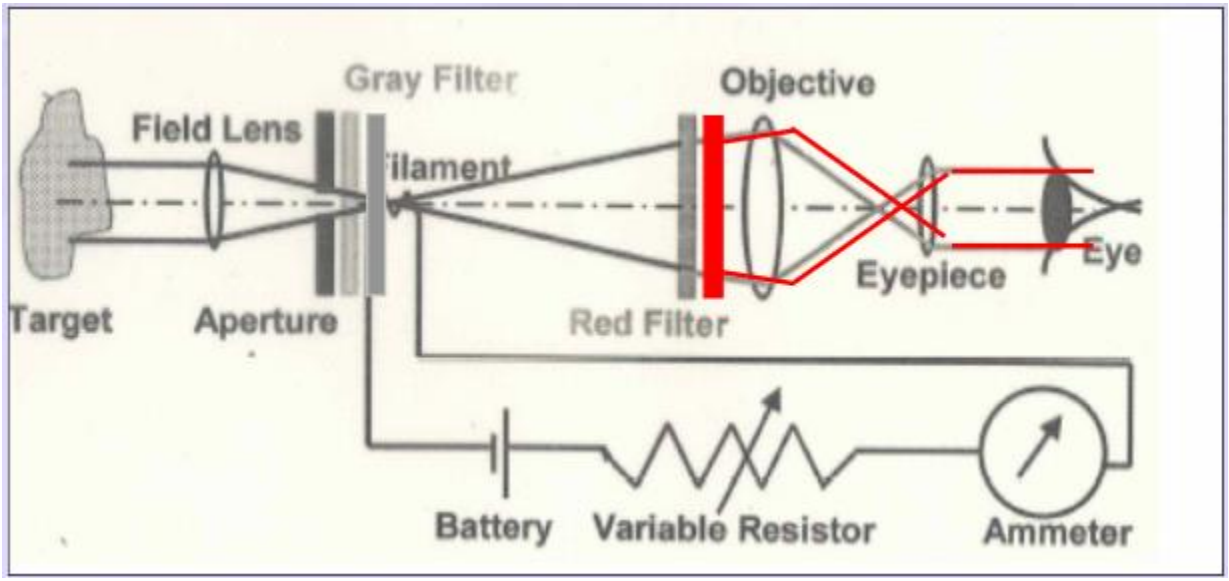
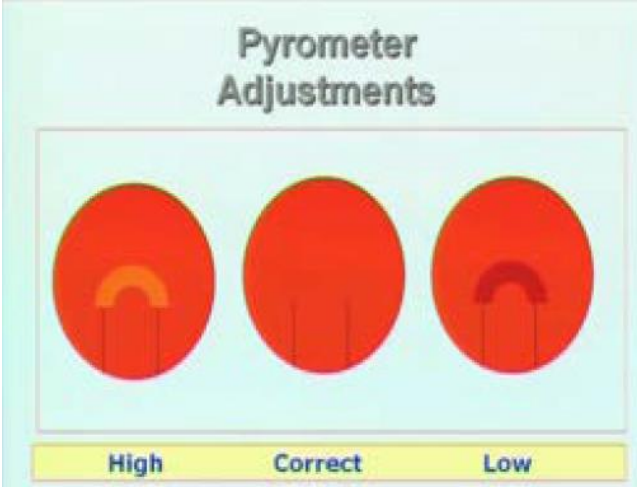


Fig. Schematic diagram of optical pyrometer

- The objective lens receives light which is coming, both from the target which has passed through the gray filter, and then it also gets, receives radiation from the filament which is run by the battery.
- By using the variable resistor, the current passing through the filament can be varied thereby changing the brightness and temperature of the filament.
- Therefore, the amount of radiation which comes from the filament can be varied by changing the variable resistor position.

- The red filter, along with the eye of the person who is looking at it, it has got a certain response to the light which is falling on the retina, so the two together will help us in finding out, or selecting a certain wavelength of operation for this instrument.
- The observer looks simultaneously at two things:
  (i) the object whose temperature I want to measure
  (ii) the filament whose brightness can be varied
- So the operator will have to adjust the resistance such that the two, the target and the filament, appear equally bright, and which can be verified by making the proper adjustment.
  (i) If the temperature of the filament is very high, the filament appears bright in red background, which appears to be dull.
  (ii) If the temperature of the filament is too small, then it appears dark, looks like a shadow in the background, which is brighter.
  (iii)If the adjustment has been made properly then the brightness, the filament, and the background are equally bright. There is no contrast between them.

The filament becomes invisible when a proper adjustment is done, and therefore, it has vanished. Therefore, it is also called vanishing filament pyrometer.



Because the filament cannot appear at any temperature you want, it has got a limitation. If it goes beyond some particular value, the filament will melt and you will have to replace the filament. So the filament has a maximum temperature up to which it can go, and therefore, theoretically the maximum brightness temperature I can measure using this filament is the maximum temperature of the filament itself.

Therefore, if the target is at a temperature higher than the filament temperature, a gray filter is used which will reduce the intensity by a factor which can be calibrated or known factor, half or one-fourth or one-eighth, and so on, so that the intensity of light which is coming from the target is equal to or less than the maximum, the intensity of the filament at the maximum of the temperature.

Total Radiation Pyrometer:

Total radiation pyrometer accepts a controlled sample of total radiation and through determination of the heating effect of the sample obtains a measure of temperature. All bodies above absolute zero temperature radiate energy, not only do they radiate or emit energy, but they also receive and absorb from other sources. It is known that all substances emit and absorb radiant energy at a rate depending on the absolute temperature and physical properties of the substance. According to Stefan – Boltzman law the net rate of exchange of energy between two ideal radiators A and B is,

$$q = \sigma\,(T_A^4 - T_B^4)$$

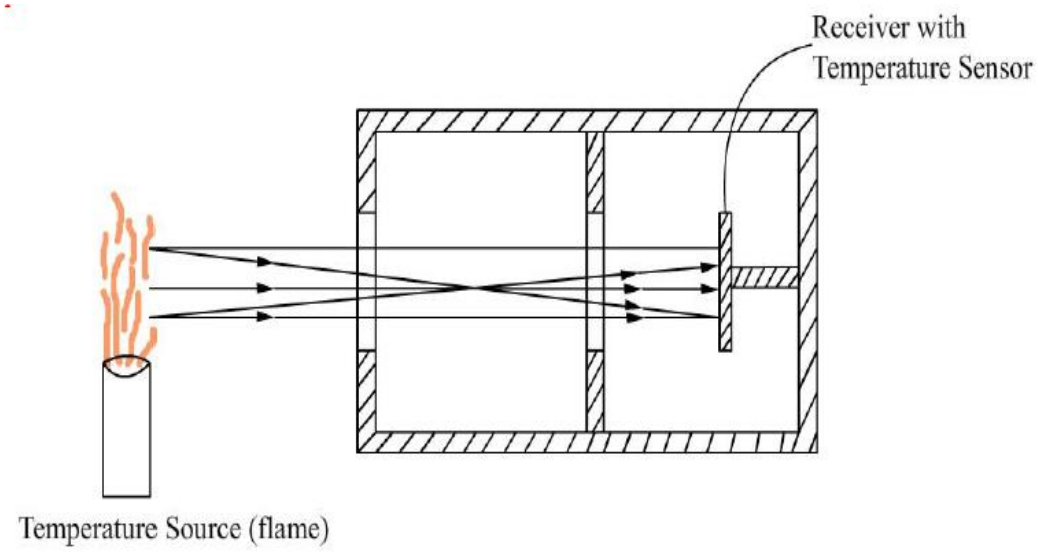


Fig. Total radiation pyrometer

In total radiation pyrometers, the radiation from the measured body is focused on some sort of radiation detector which produces an electric signal.

Detectors may be classified as

1. thermal detectors
2. photon detectors

Thermal detectors are blackened elements designed to absorb a maximum of the incoming radiation at all wavelengths. The absorbed radiation causes the temperature of the detector to rise until equilibrium is reached with heat losses to the surroundings. The thermal detectors measure this temperature using a resistance thermometer, thermistor or thermocouple.

In photon detectors, the incoming radiation frees electrons in the detector structure and produces a measurable electrical effect. These events occur on an atomic or molecular time scale and hence are faster than the thermal detectors. But photon detectors have a sensitivity

that varies with wavelength, thus incoming radiation of all wavelengths are not equally treated.

LUX METER

Lux meters, sometimes called light meters, measure the intensity of illumination as distinguished by the human eye. This value does not correlate to an objective value of energy radiated or reflected, as different wavelengths within the visible spectrum are perceived with varying sensitivity by the eye, and lux meters evaluate light intensity in consideration of this variable.

Measurement

The human eye distinguishes colors of light according to two complementary models of visual physiology. Trichromatic theory states that each of the three types of cones in the eye are activated by a certain range of wavelength: β cones perceive light within 400-500 nm, Y cones between 450-630 nm, and ρ cones between 500-700 nm. Opponent process theory states that colours are perceived by rods and cones antagonistically: black vs. white, blue vs. yellow, and red vs. green.

The result is an eye that perceives certain colors more accurately. More shades of green are identified than any other color and this is the primary reason night vision equipment amplifies green light reflection. Visible light intensity accounting for these inherent biological preferences is known as luminous flux. Lux meters cannot compensate for individual visual deficiencies or variances. Total power output is measured as radiant flux.

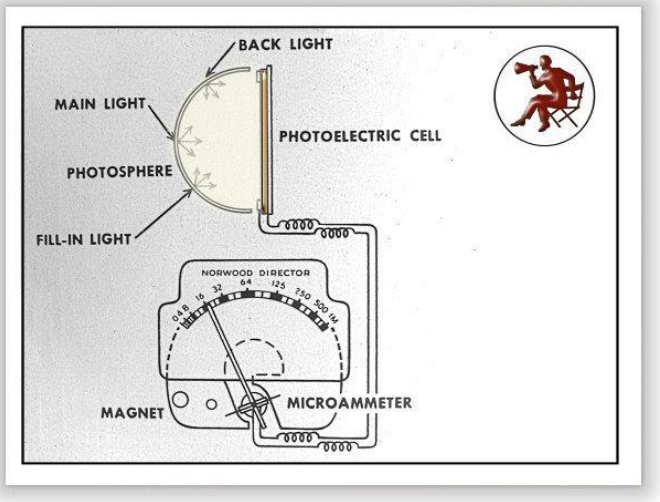
Operation

Most lux meters register brightness with an integrated photo detector. The photo detector is positioned perpendicular to the light source for optimal exposure—many lux meters use an articulated or tethered photo detector for this purpose. Readouts are presented to the user via analog instrument or digital LCD. Digital types often include basic operator inputs. Many digital types can save measurements and have an adjustable detection range.

Photo detectors composed of selenium or silicon determine brightness photo voltaically. Generated current is proportional to the photons received. Silicon-based detectors need to amplify the voltage generated by light exposure. Selenium-based detectors convert photons to a

high enough voltage that they be directly connected to a galvanometer, but have difficulty determining lux measurements for light sources below 1,000 lumens.

Photo detectors that measure brightness via photo resistance are composed of a ceramic substrate doped with cadmium sulfide. An electronic switching current is supplied to the cell and resistance increases as more photons are detected to ultimately provide a proportional readout. Legislation curtails the availability of cadmium devices in certain territories.



Correction

Photo detectors are sensitive to all colours of visible light, including wavelengths not identified by the eye. Therefore, after exposure to a sample, photo detectors need to apply a correction factor to readings. Different light sources require different correction factors. Many commercial lux meters are preconfigured to register incandescent light, but have problems reading high intensity discharge, metal halide, high pressure sodium, and cool white fluorescent lights. Meters with preconfigured correction factors can provide accurate lux measurements for these sources. More advanced light meters are tuned to particular light sources with optical filters and lenses, removing correction factor uncertainty.

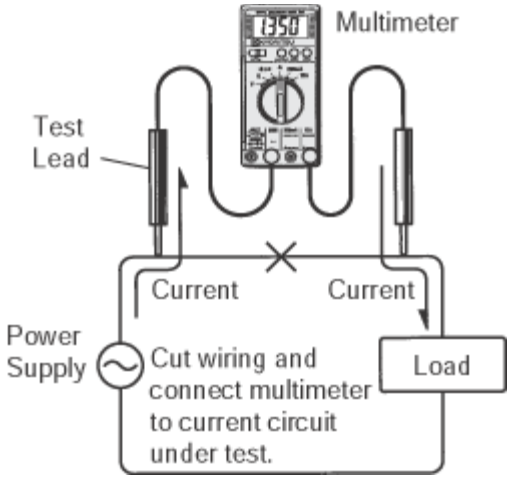
Configuration

Most lux meters are handheld devices and are easily transported to the job site. Articulated and tethered photo detectors may require both hands to optimally position the photo detector and the module, but they also provide measurement flexibility. Some handheld models may include a stand or mounting structure, such as a tripod.

CLAMP METER OR TONG TESTER

Clamp meters are a very convenient testing instrument that permits current measurements on a live conductor without circuit interruption. When making current measurements with the ordinary multimeter, we need to cut wiring and connect the instrument to the circuit under test as shown in Fig.1

Using the clamp meter, however, we can measure current by simply clamping on a conductor as illustrated in Fig.2. One of the advantages of this method is that we can even measure a large current without shutting off the circuit being tested.



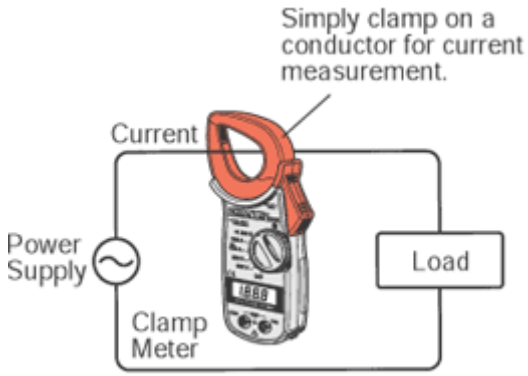


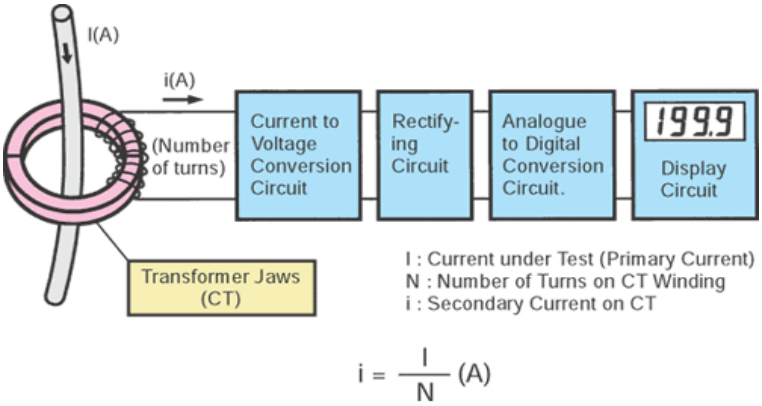
Fig.1 Measurement using multimeter **Fig.2 Measurement using clamp meter**

Clamp on to a conductor just the same way as with AC current measurement using an AC current clamp meter. In the case of DC clamp meters the reading is positive (+) when the current is flowing from the upside to the underside of the clamp meter.

AC Clamp Meter

- AC clamp meters operate on the principle of current transformer (CT) used to pick up magnetic flux generated as a result of current flowing through a conductor.
- The current flowing through the conductor is the primary current.
- A current proportional to the primary current is induced by electromagnetic induction in the secondary side (winding) of the transformer which is connected to a measuring circuit of the instrument.

- The current is converted into a proportional voltage by current-to-voltage conversion circuit.
- The AC voltage is rectified to DC by a rectifier.
- An ADC (Analog to Digital Converter) circuits converts the analog data to digital data



DC Clamp Meter

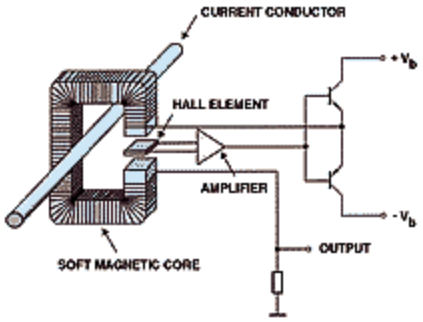
Hall elements are used as a sensor to detect DC current because it is not possible to employ an electromagnetic induction method as used for dedicated AC clamp meters.

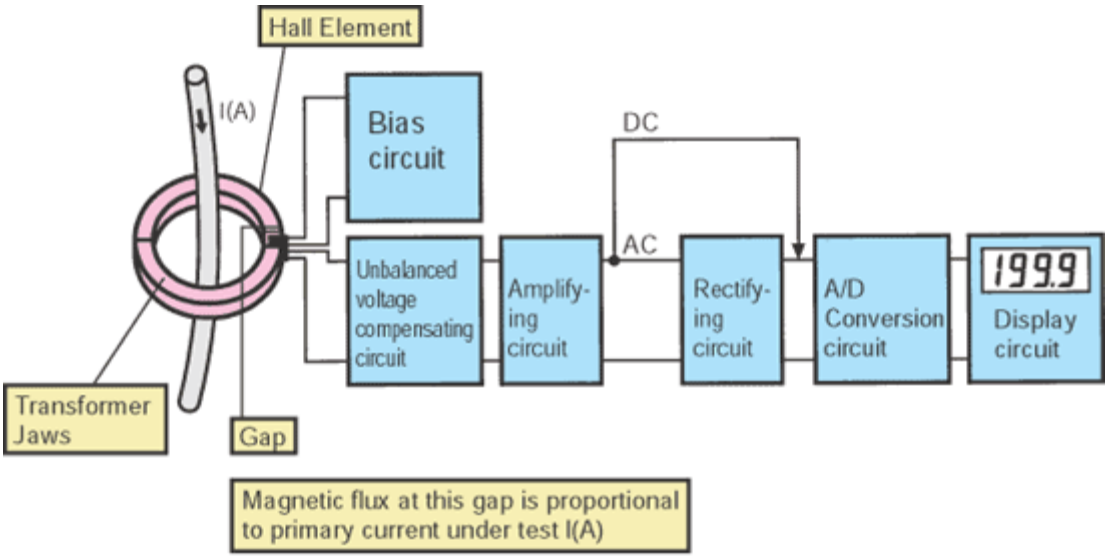
Hall element is a semiconductor which generates a voltage (at the output terminal) proportional to the product of bias current and magnetic field, when bias current is applied to the input terminal.

A hall element is placed across a gap created by cutting off part of the transformer jaws.

When current flows in the conductor, a magnetic flux is produced, which is proportional to both AC and DC primary currents in the transformer jaws.

The hall element detects the magnetic flux and produces an output voltage proportionally.




Hall Element
I(A)
Bias circuit
DC
AC
Unbalanced voltage compensating circuit
Amplify-ing circuit
Rectify-ing circuit
A/D Conversion circuit
199.9
Display circuit
Transformer Jaws
Gap
Magnetic flux at this gap is proportional to primary current under test I(A)