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SCHOOL OF MECHANICAL ENGINEERING

DEPARTMENT OF AUTOMOBILE ENGINEERING

UNIT – I - INTRODUCTION TO MATERIALS – SAUA1201

UNIT 1 - FUNDAMENTALS OF MATERIALS

1.1 Material Technology:

Materials technology is a relatively comprehensive discipline that begins with the production of goods from raw materials to processing of materials into the shapes and forms needed for specific applications.

Materials - metals, plastics and ceramics - typically have completely different properties, which means that the technologies involved in their production are fundamentally different. Materials technology is a constantly evolving discipline, and new materials with interesting properties lead to new applications. For example, the combination of different materials into composites gives rise to entirely new material properties.

1.2 Material Science:

Materials Science is closely related to materials technology. Materials Science is a multidisciplinary field that connects material properties to the material's chemical composition, micro-structure and crystal structure. Crystal structure is a description of the ordered arrangement of atoms, ions or molecules in a crystalline material. The crystalline lattice, is a periodic array of the atoms. When the solid is not crystalline, it is called amorphous. Examples of crystalline solids are metals, diamond and other precious stones, ice, graphite. Examples of amorphous solids are glass, amorphous carbon (a-C), amorphous Si, most plastics

1.3 Polymorphism and Allotropy:

Some materials may exist in more than one crystal structure, this is called **polymorphism**. If the material is an elemental solid, it is called **allotropy**. An example of allotropy is carbon, which can exist as diamond, graphite, and amorphous Crystallography

1.4 Crystallography, branch of science that deals with discerning the arrangement and bonding of atoms in crystalline solids and with the geometric structure of crystal lattices.

1.5 Crystalline and Amorphous Solids

The atoms, molecules or ions which make up solids may be arranged in an orderly repeating pattern, or irregularly.

Crystalline, if long-range ordering exists.

I. Single Crystal: long-range order in the entire volume. A single-crystal, or monocrystalline, solid is a material in which the crystal lattice of the entire sample is continuous and unbroken to the edges of the sample, with no grain boundaries. (e.g. quartz).
II. Polycrystalline: long-range order within grains but orientation differs. Polycrystalline materials, or polycrystals, are solids that are composed of many crystallites of varying size and orientation. Most inorganic solids are polycrystalline, including all common metals, many ceramics, rocks, and ice.
III. Almost all common metals, and many ceramics, are polycrystalline.
IV. Amorphous, if short-range ordering exists.(e.g. glass). In condensed matter physics and materials science, an amorphous or non-crystalline solid is a solid that lacks the long-range order that is characteristic of a crystal.

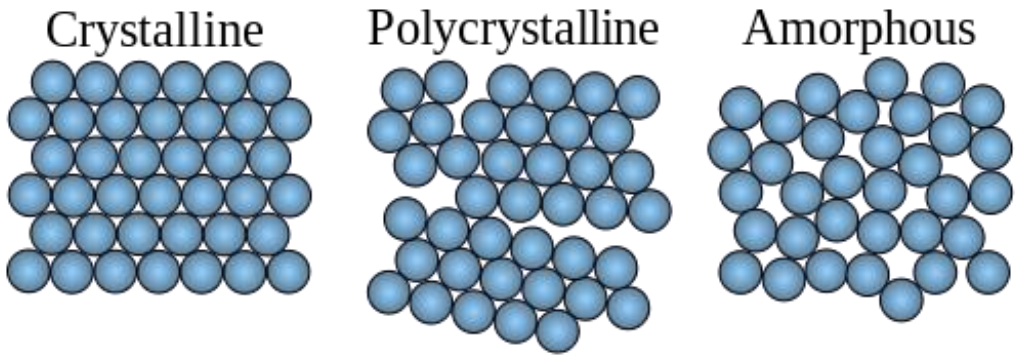


Figure 1.1 Crystal Geometry

Crystal: A 3D Periodic arrangement of atoms in space. Ex: NaCl shown in figure 1.1

Lattice:

- A 3D Periodic arrangement of points in space.
- Geometrical concepts can be applied.

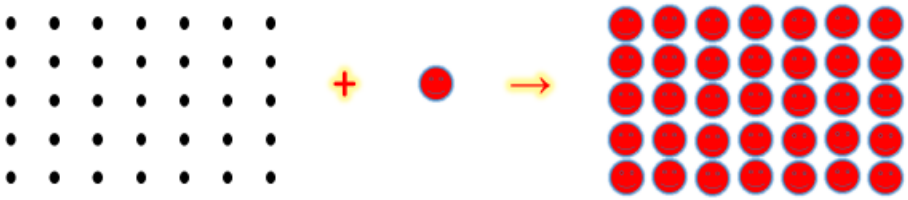
Motif or Basis:

- An atom or a group of atoms associated with each lattice point.
- Physical object possessing properties like weight, density, conductivity etc.

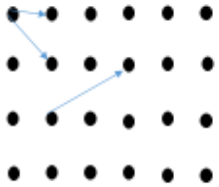
Table 1.1 Difference between crystal and lattice

Crystal	Lattice
A 3D Periodic arrangement of atoms in space	A 3D Periodic arrangement of points in space
Physical objects	Geometrical Concept
Weight, Density, Electrical conductivity	Geometrical Properties

Lattice + Motif = Crystal



Lattice translation: A lattice translation operator is defined as a displacement of a crystal with a crystal translation operator.



Unit Cell

The unit cell completely reflects the symmetry and structure of the entire crystal, which is built up by repetitive translation of the unit cell along its principal axes.

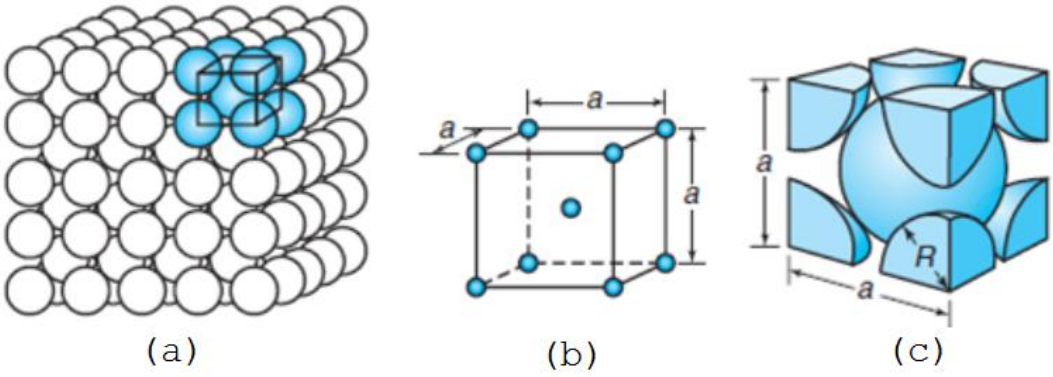


Fig., 1.2 (a) Single Crystal with many unit cells; (b) Unit Cell; (c) Hard-ball Model

Primitive Cell. A primitive cell is a unit cell that contains exactly one lattice point.

Non-primitive unit cells contain additional lattice points, either on a face of the unit cell or within the unit cell, and so have more than one lattice point per unit cell.

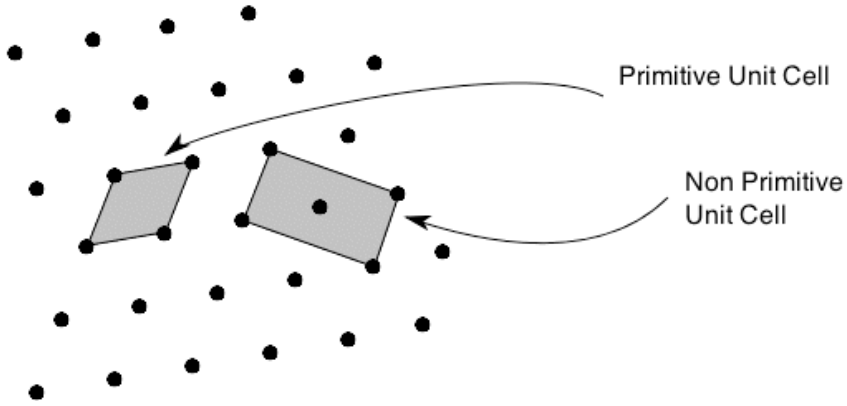
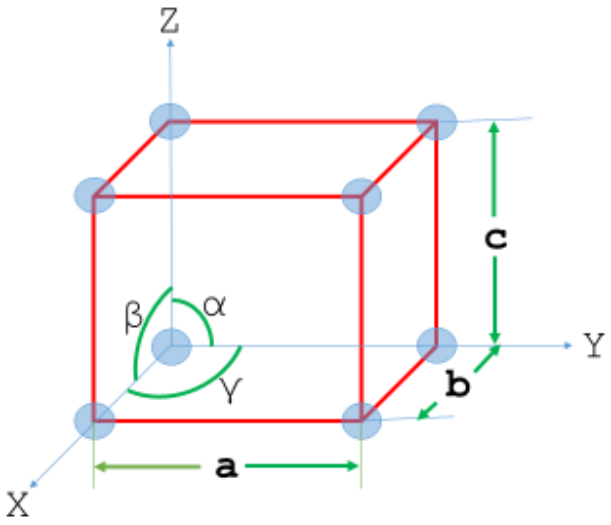


Fig., 1.3 Crystal Coordinate system

Crystal Coordinate system

Select a corner of the unit cell as the origin, the vectors from the corner along the edges of the unit cell define basis vectors of the lattice.



The length of 3 edges of the unit cell (or of the 3 basis vectors) and the 3 interaxial angles between them are called the lattice parameters.

a, b, c

Γ = angle b/w x & y

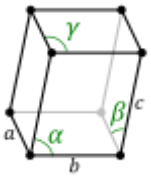
B = angle b/w x & Z

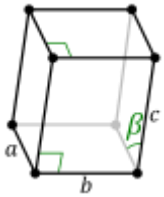
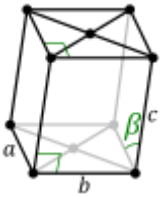
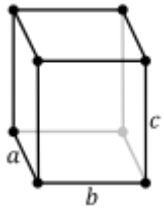
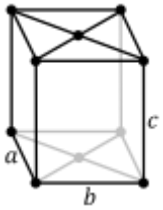
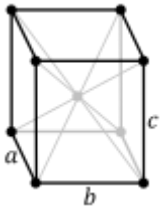
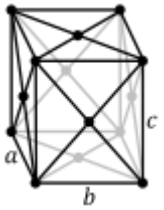
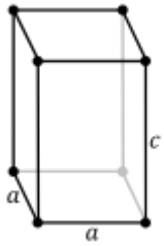
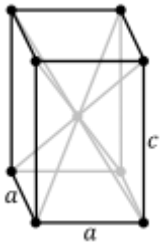
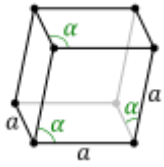
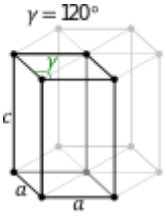
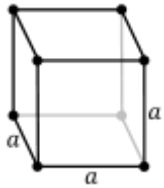
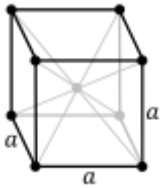
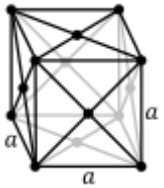
α = angle b/w x & Y

Cubic structure

For the special case of simple cubic crystals, the lattice vectors are orthogonal and of equal length (usually denoted a); similarly for the reciprocal lattice. So, in this common case, the Miller indices (ℓmn) and [ℓmn] both simply denote normals/directions in Cartesian coordinates.

$$d = \frac{a}{\sqrt{(l^2+m^2+n^2)}}$$

Crystal family	**Lattice system**	**14 Bravais Lattices**			
		Primitive	**Base-centered**	**Body-centered**	**Face-centered**
triclinic					

monoclinic					
orthorhombic					
tetragonal					
hexagonal	rhombohedral				
	hexagonal				
cubic					

1.6 Atomic packing factor

Atomic Radius: It is the half the distance between two nearest atoms in a crystal.

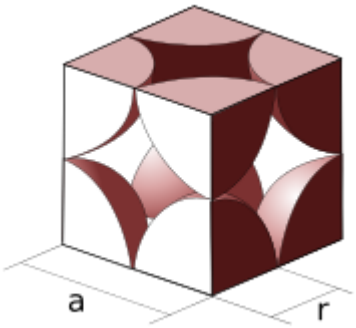
Coordination Number or Kissing Number: It is the maximum number atoms that can touch a given atom.

Number of atoms per unit cell: It is the product of (the number of atoms per lattice point) and (the number of lattice points per unit cell).

Atomic Packing Factor (APF): $\text{APF} = \frac{\text{Volume of atoms in a unit cell}}{\text{Volume of the unit cell}}$ (or)

$\text{APF} = \frac{\text{No. of atoms in a unit cell x Volume of } sphere}{\text{Volume of the unit cell}}$

1.6.1 Atomic Packing Factor for simple cubic: For a simple cubic packing, the number of atoms per unit cell is one. The side of the unit cell is of length 2*r*, where *r* is the radius of the atom.



Number of atoms per unit cell: = (8 corner atoms)$\left(\frac{1}{8}\right)$ = 1

Relationship between atomic radius (r) and lattice constant (a): $r = \frac{a}{2}$

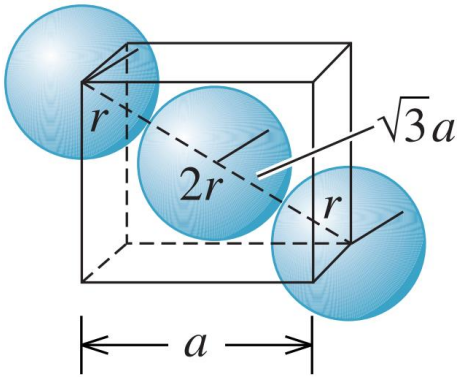
$$\text{APF} = \frac{\text{No. of atoms in a unit cell x Volume of } sphere}{\text{Volume of the unit cell}} = \frac{\mathbf{1}\left(\frac{4}{3}\right)\boldsymbol{\pi r 3}}{\mathbf{a3}} = \frac{\mathbf{1}\left(\frac{4}{3}\right)\boldsymbol{\pi}\left(\frac{a}{2}\right)\mathbf{3}}{(\mathbf{a})\mathbf{3}}$$

$$= \mathbf{1}\left(\frac{4}{3}\right)\boldsymbol{\pi}\left(\frac{1}{8}\right) = \frac{\pi}{6} = \mathbf{0.52}$$

1.6.2 Body centered cubic

The primitive unit cell for the body-centered cubic crystal structure contains several fractions taken from nine atoms (if the particles in the crystal are atoms): one on each corner of the cube and one atom in the center. Because the volume of each of the eight corner atoms is shared between eight adjacent cells, each BCC cell contains the equivalent volume of two atoms (one central and one on the corner).

Number of atoms per unit cell: = (8 corner atoms)$\left(\frac{1}{8}\right)$ + (1 centre atom) = 1 + 1 = 2



Relationship between atomic radius (r) and lattice constant (a):

$$AC^2 = (AB2 + BC2) = (a)2 + (a)2 = 2a^2$$

$$DC^2 = (DA2 + AC2) = (a)2 + (2a)2 = 3a^2$$

$$DC = a\sqrt{3} = 4r$$

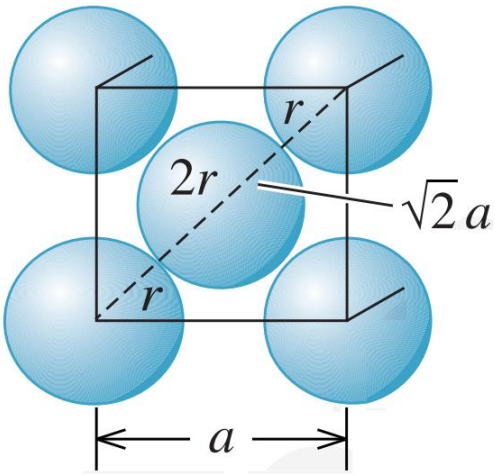
$$r = \frac{a\sqrt{3}}{4}$$

$$APF = \frac{\text{No. of atoms in a unit cell x Volume of } sphere}{\text{Volume of the unit cell}} = \frac{2\left(\frac{4}{3}\right)\pi r3}{a3} = \frac{2\left(\frac{4}{3}\right)\pi\left(\frac{a\sqrt{3}}{4}\right)3}{a3}$$

$$= 2\left(\frac{4}{3}\right)\pi\left(\frac{3\sqrt{3}}{64}\right) = \frac{\pi\sqrt{3}}{8} = 0.68$$

1.6.3 Atomic packing factor for FCC

Number of atoms per unit cell: =(8 corner atoms)$\left(\frac{1}{8}\right)$ + (6 Face-centre atoms) $\left(\frac{1}{2}\right)$ = 1 + 3 = 4



Relationship between atomic radius (r) and lattice constant (a):

$$AC^2 = (AB2 + BC2) = (a)2 + (a)2 = 2a^2$$

$$AC = a\sqrt{2} = 4r$$

$$r = \frac{a\sqrt{2}}{4}$$

$$APF = \frac{\text{No. of atoms in a unit cell x Volume of } sphere}{\text{Volume of the unit cell}} = \frac{4\left(\frac{4}{3}\right)\pi r3}{a3} = = \frac{4\left(\frac{4}{3}\right)\pi\left(\frac{a\sqrt{2}}{4}\right)3}{(a)3}$$

$$= 4\left(\frac{4}{3}\right)\pi\left(\frac{2\sqrt{2}}{64}\right) = \frac{\pi\sqrt{2}}{6} = 0.74$$

1.6.4 Hexagonal Close Packed Structure

For the hexagonal close-packed structure the derivation is similar. Here the unit cell (equivalent to 3 primitive unit cells) is a hexagonal prism containing six atoms (if the particles in the crystal are atoms). Indeed, three are the atoms in the middle layer (inside the prism); in addition, for the top and bottom layers (on the bases of the prism), the central atom is shared with the adjacent cell, and each of the six atoms at the vertices is shared with other five adjacent cells. So the total number of atoms in the cell is 3 + (1/2)×2 + (1/6)×6×2 = 6. Each atom touches other twelve atoms. The latter is twice the distance between adjacent layers, i. e., twice the height of the regular tetrahedron whose vertices are occupied by (say) the central atom of the lower layer, two adjacent non-central atoms of the same layer, and one atom of the middle layer "resting" on the previous three.

$$APF = \frac{\text{No. of atoms in a unit cell x Volume of } sphere}{\text{Volume of the unit cell}}$$

$$= \frac{6\left(\frac{4}{3}\right)\pi r3}{a3} \qquad = \frac{6\left(\frac{4}{3}\right)\pi\left(\frac{a}{2}\right)3}{\left(\frac{3\sqrt{3}}{2}\right)a^2c}$$

$$= \frac{16\,\pi\,a3}{8\,x\,3\sqrt{3}\,a2x\,1.633a}$$

$$= \frac{2\,\pi}{3\sqrt{3}\,x\,1.633} = 0.74$$

1.7 Allotropy

Allotropy is the property of some chemical elements to exist in more than one type of space lattice in the solid state.

Solid solution

- A homogeneous mixture of two or more solid elements.
- Vary in composition.
- Has the crystal structure of one of the constituent elements.

Intermediate alloy phase or compound

Compounds formed by atoms or ions of two or more elements by strong bonding, similar like pure metals.
Definite composition, which is intermediate between the pure elements.
Has the crystal structure different from the constituent elements.

1.8 Diffusion:

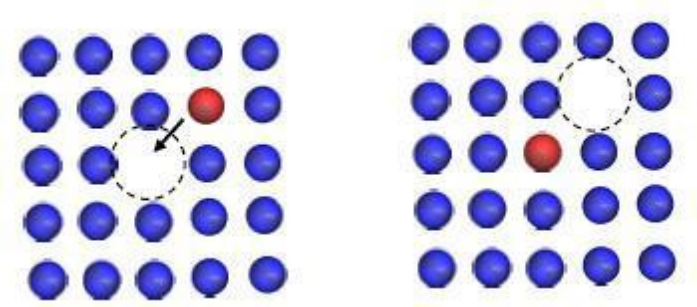
Diffusion is a process of mass transport by atomic movement under the influence of thermal energy and a concentration gradient. Atoms move from higher to lower concentration region. If this movement is from one element to another e.g. Cu to Ni, then it is termed *inter-diffusion*. If the movement is within similar atoms as in pure metals, it is termed *self-diffusion*.

1.8.1 Diffusion Mechanism:

Diffusion of atoms involves movement in steps from one lattice site to the another. An empty adjacent site and breaking of bonds with the neighbor atoms are the two necessary conditions for this.

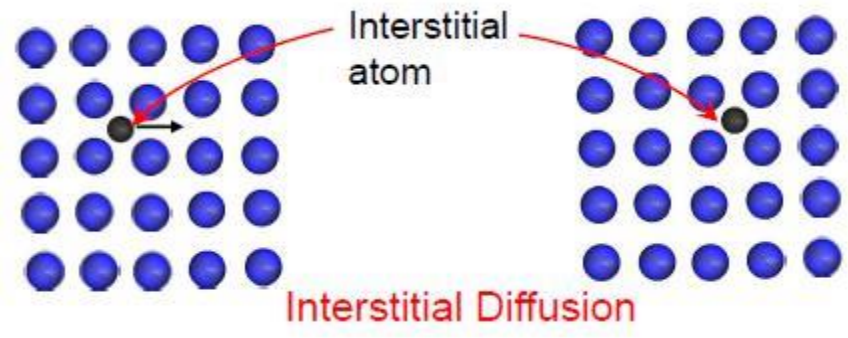
Vacancy Diffusion:

This mechanism involves movement of atoms from a regular lattice site to an adjacent vacancy. Since vacancy and atoms exchange position, the vacancy flux is in the opposite direction.



Interstitial Diffusion:

This mechanism involves migration of atoms from one interstitial site to a neighbouring empty interstitial site. This mechanism is more prevalent for impurity atoms such as hydrogen, carbon, nitrogen, oxygen which are small enough to fit in to an interstitial position. For substitutional diffusion atoms exchange their places directly or along a ring (ring diffusion mechanism).



Inter Diffusion or Impurities Diffusion:

Interdiffusion (or impurity diffusion) occurs in response to a concentration gradient.

1.8.2 Factors that influence diffusion:

1. **Diffusing species**
2. **Host solid**

3. **Temperature**
4. **Microstructure**

1.9 The Phase Rule:

The *Phase Rule* expresses the relation between phases, phase compositions, and intensive variables (temperature and pressure) in a system of a given composition at equilibrium.

System:

A substance that are isolated from their surrounding. (e.g. Iron-Carbon System)

Component:

Pure metals or compounds of which an alloy is made (Fe and C are the components, in Fe-C system).

Phase:

A physically and chemically homogeneous portion of a system that has uniform physical and chemical characteristics (e.g. Solid, Liquid and Gas).

Equilibrium:

A system is at equilibrium if its free energy is at minimum under some specified combination of temperature, pressure and composition.

State:

It is a physical condition governed by quantities such as pressure, temperature, mass etc.

Degree of Freedom:

Number of independent variables available to describe a state of the system.

Phase Diagram

Graphical representations that show the phases in equilibrium present in the system at various specified compositions, temperatures, and pressures.

Also known as equilibrium diagram. By the word 'equilibrium, we mean very slow heating and cooling rates are used to generate data for their construction.

For any constitution point (x, T), a phase diagram answers:

1. What are the phases present?
2. What are the compositions of the phases?
3. What are the relative amounts of phases?

Gibbs Phase Rule: The Gibbs phase rule describes the degrees of freedom available to describe a particular system with various phases and substances.

System: An assemblage of materials that is isolated in some manner from rest of the universe.

Isolated system: one that does not exchange matter or energy with its surroundings.

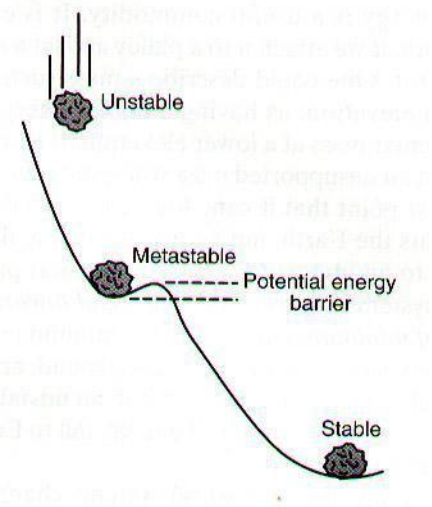
Closed system: one that exchanges only energy with its surroundings.

Open system: one that exchanges both matter and energy with its surroundings.

Adiabatic system: a system with changes in energy caused only by a change in volume as pressure changes.

Equilibrium: The lowest energy state of a system in which there is no tendency for a spontaneous change.

Metastable Equilibrium: state of a system, which is not in its lowest energy state at the imposed conditions, but cannot spontaneously change due to high activation energy for change.



Phase Rule:

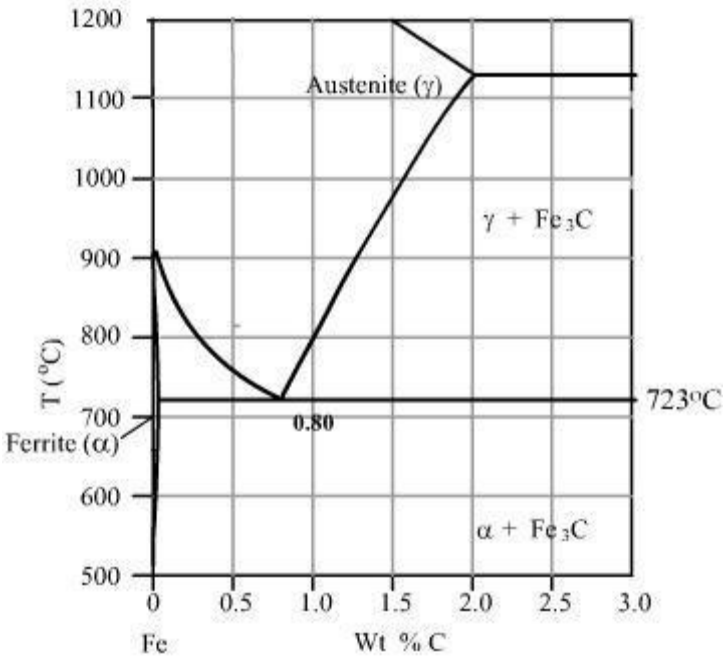
$$F=C-P+2$$

P - a phase is any portion of a system that is chemically and physically homogenous and can be mechanically isolated from any other portion of the system.
C -: minimum number of chemically distinct constituents necessary to describe the composition of each phase in the system.
"2" stands for temperature and pressure. Temperature (*T*) and pressure (*P*) are *intensive* parameters of a system. Intensive parameters do not depend on amount or mass. *Extensive* parameters (e.g., volume, number of moles) depend on mass.
F (degrees of freedom; variance):
number of attributes of a system (*T*, *P*, phase composition) that can be changed independently without creating or destroying a phase, or ...
number of parameters (*T*, *P*, system composition) that need to be described to completely define the composition and identity of each phase.

F = 3 : trivariant
F = 2 : divariant
F = 1 : univariant
F = 0 : invariant

if F < 0 then there must be disequilibrium.

The meaning of "C" - minimum number of components necessary to describe each phase in a system:
One-component system (unary):
The eutectoid reaction:
The eutectoid reaction describes the phase transformation of one solid into two different solids. In the Fe-C system, there is a eutectoid point at approximately 0.8wt% C, 723°C. The phase just above the eutectoid temperature for plain carbon steels is known as austenite or gamma. We now consider what happens as this phase is cooled through the eutectoid temperature (723°C).The phase diagram which we will be considering throughout this section is shown below:



Definitions

Component: pure metal or compound (e.g., Cu, Zn in Cu-Zn alloy, sugar, water, in a syrup.)

Solvent: host or major component in solution.

Solute: dissolved, minor component in solution.

System: set of possible alloys from same component (e.g., iron-carbon system.)

Solubility Limit: Maximum solute concentration that can be dissolved at a given temperature.

Phase: part with homogeneous physical and chemical characteristics

Solubility Limit:
Effect of temperature on solubility limit. Maximum content: saturation. Exceeding maximum content (like when cooling) leads to precipitation.
Phases:

One-phase systems are homogeneous. Systems with two or more phases are heterogeneous, or mixtures. This is the case of most metallic alloys, but also happens in ceramics and polymers.

A two-component alloy is called binary. One with three components, ternary.

Microstructure

The properties of an alloy do not depend only on concentration of the phases but how they are arranged structurally at the microscopy level. Thus, the microstructure is specified by the number of phases, their proportions, and their arrangement in space.

A binary alloy may be a single solid solution two separated, essentially pure components. Two separated solid solutions. A chemical compound, together with a solid solution.

The way to tell is to cut the material, polish it to a mirror finish, etch it a weak acid (components etch at a different rate) and observe the surface under a microscope.

Phase Equilibrium:

Equilibrium is the state of minimum energy. It is achieved given sufficient time. But the time to achieve equilibrium may be so long (the *kinetics* is so slow) that a state that is not at an energy minimum may have a long life and appear to be stable. This is called a *metastable state.*

A less strict, operational, definition of equilibrium is that of a system that does not change with time during observation.

1.Equilibrium Phase Diagrams

Give the relationship of composition of a solution as a function of temperatures and the quantities of phases in equilibrium. These diagrams do not indicate the dynamics when one phase transforms into another. Sometimes diagrams are given with pressure as one of the variables. In the phase diagrams we will discuss, pressure is assumed to be constant at one atmosphere.
Binary Isomorphous Systems

This very simple case is one complete liquid and solid solubility, an *isomorphous* system. The example is the Cu-Ni alloy of Fig. 9.2a. The complete solubility occurs because both Cu and Ni have the same crystal structure (FCC), near the same radii, electronegativity and valence.

The *liquidus line* separates the liquid phase from solid or solid + liquid phases. That is, the solution is liquid above the liquidus line.

The *solidus line* is that below which the solution is completely solid (does not contain a liquid phase.)

Interpretation of phase diagrams

Concentrations: Tie-line method

locate composition and temperature in diagram
In two phase region draw tie line or isotherm
note intersection with phase boundaries. Read compositions.

Fractions: lever rule

construct tie line (isotherm)
obtain ratios of line segments lengths.

Note: the fractions are inversely proportional to the length to the boundary for the particular phase. If the point in the diagram is close to the phase line, the fraction of that phase is large.

Development of microstructure in isomorphous alloys

a) Equilibrium cooling

Solidification in the solid + liquid phase occurs gradually upon cooling from the liquidus line. The composition of the solid and the liquid change gradually during cooling (as can be determined by the tie-line method.) Nuclei of the solid phase form and they grow to consume all the liquid at the solidus line.

b) Non-equilibrium cooling

Solidification in the solid + liquid phase also occurs gradually. The composition of the liquid phase evolves by diffusion, following the equilibrium values that can be derived from the tie-line method. However, diffusion in the solid state is very slow. Hence, the new layers that solidify on top of the grains have the equilibrium composition at that temperature but once they are solid their composition does not change. This lead to the formation of layered (cored) grains (Fig. 9.14) and to the invalidity of the tie-line method to determine the composition of the solid phase (it still works for the liquid phase, where diffusion is fast.)

Eutectic or invariant point. Liquid and two solid phases exist in equilibrium at the *eutectic composition* and the *eutectic temperature.*

Alloys which are to the left of the eutectic concentration (*hipoeutectic*) or to the right (*hypereutectic*) form a *proeutectic* phase before reaching the eutectic temperature, while in the solid + liquid region. The eutectic structure then adds when the remaining liquid is solidified when cooling further. The eutectic microstructure is lamellar (layered) due to the reduced diffusion distances in the solid state.

A *terminal phase* or *terminal solution* is one that exists in the extremes of concentration (0 and 100%) of the phase diagram. One that exists in the middle, separated from the extremes, is called an *intermediate phase* or solid solution.

An important phase is the *intermetallic compound*, that has a precise chemical compositions. When using the lever rules, intermetallic compounds are treated like any other phase, except they appear not as a wide region but as a vertical line.

The *eutectoid* (eutectic-like) reaction is similar to the eutectic reaction but occurs from one solid phase to two *new* solid phases. It also shows as V on top of a horizontal line in the phase diagram. There are associated eutectoid temperature (or temperature), eutectoid phase, eutectoid and proeutectoid microstructures.

Solid Phase 1 = Solid Phase 2 + Solid Phase 3

The *peritectic* reaction also involves three solid in equilibrium, the transition is from a solid + liquid phase to a *different* solid phase when cooling. The inverse reaction occurs when heating.

Solid Phase 1 + liquid = Solid Phase 2

Congruent transformation is one where there is no change in composition, like allotropic transformations (e.g., a-Fe to g-Fe) or melting transitions in pure solids.

Ternary phase diagrams are three-dimensional. Example: Ceramic phase diagrams

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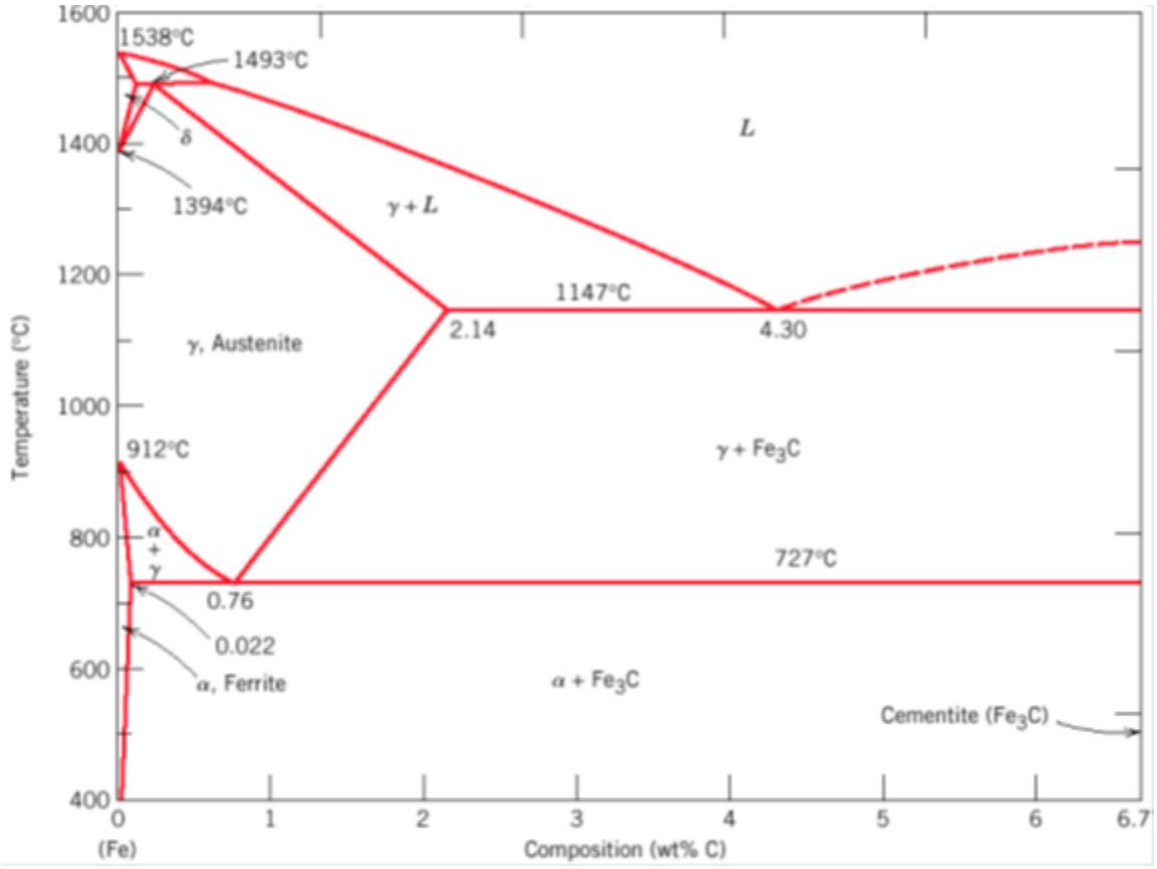
DEPARTMENT OF AUTOMOBILE ENGINEERING

UNIT – II - FERROUS AND NON – FERROUS ALLOYS – SAUA1201

UNIT 2 – FERROUS AND NON - FERROUS ALLOYS

2.1 The Iron–Iron Carbide (Fe–Fe_3C) Phase Diagram



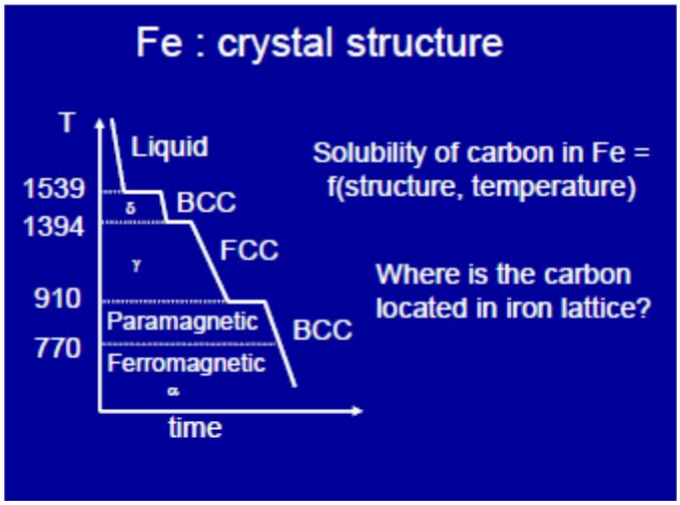


Fig. 2.1 Fe–Fe_3C Phase Diagram

The sketch in slide 1 is a typical cooling curve of pure iron. Solidification begins with nucleation and growth of crystals of iron at 1539°C. It is BCC (body centered cubic). At 1394°C it transforms into FCC (face centered cubic) structure. This is stable till 910°C where it again

transforms into BCC. Each of these transformations appears as steps on the cooling curve. Apart from this there is another transformation which may not get detected by thermal analysis. This is the transformation from paramagnetic to ferromagnetic state. It occurs at 770°C. This is known as its Curie temperature.

The property which is most sensitive to detect it, is magnetic permeability. The three different forms of iron are known as ferrite, stable until 910°C, austenite, stable from 910°-1394°C and ferrite, stable from1394°– 1539°C. Note that the BCC form of iron is known as ferrite. Therefore in order to distinguish between the two, the high temperature form is termed as delta ferrite. If carbon atoms are introduced into iron these are likely to occupy the interstitial sites because the atoms carbon are much smaller than those of iron atoms. The solubility of carbon in iron is a function of temperature and crystal structure.

2.2 Phases in iron – carbon binary system:

Iron can exist in three different crystalline forms each having limited solubility of carbon. The stability of these depends on temperature and composition. The two high temperature forms of iron are ferrite which is BCC (stable above 1394°C) and austenite (stable above 910°C) which is FCC. The room temperature form of iron is ferrite which is BCC. The solubility of carbon in ferrite is limited. The maximum solubility is around 0.025wt% as against this the solubility of carbon in austenite is a little more. It is about 2wt%. Apart from this iron carbon system may have iron carbide (Fe3C) called cementite. It has 6.67% carbon. It is considered as an inter-metallic compound having relatively more complex crystal structure than those of ferrite and austenite. It is a meta-stable phase. It may exist for indefinite periods of time at room temperature. However on prolonged thermal exposure at 600°C or beyond it transforms into ferrite and graphite. Therefore iron carbon alloys of commercial importance may be considered as a binary alloy of iron and cementite. Let us first look at its phase diagram. It is also known as iron cementite meta-stable phase diagram. Although it is a binary system there are five different phases including the liquid. This is likely to have more than one invariant reaction involving three phases.

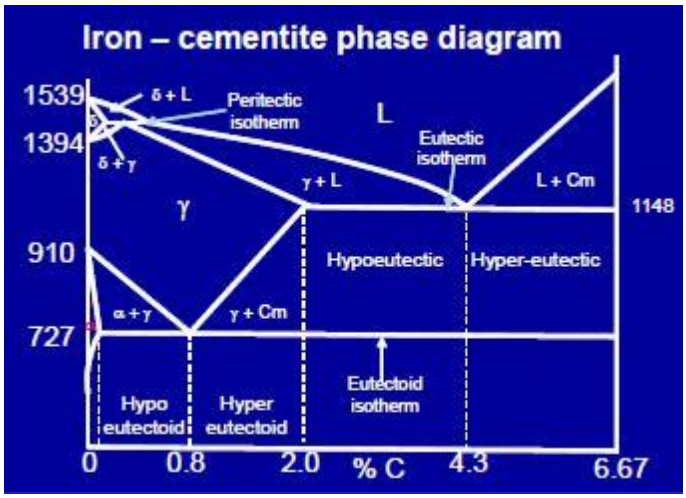


Fig. 2.2 Fe–Cementite Phase Diagram

The above figure gives a schematic Fe-Fe3C phase diagram. It has 3 invariant reactions (transformation). These are given in slide 4. The one occurring at 1495°C is the peritectic reaction. The delta ferrite reacts with liquid to form austenite. The one at 1148°C is known as the eutectic reaction where the liquid transforms into a mixture of austenite and cementite. The eutectic is known as Ledeburite. The one at 727°C is known as eutectoid transformation where austenite decomposes into a mixture of ferrite and cementite. This is known as Pearlite. On the basis of this diagram iron – carbon alloys having less than 2.0% carbon are known as steel, whereas those having more than 2.0% carbon are known as cast iron. This classification is based on their ability to undergo large plastic deformation. Steel is ductile but cast iron is brittle.

2.3 Steel:

It is an iron carbon alloy where most of the carbon is present as meta-stable iron carbide called cementite. The upper limit of carbon content is 2%. Phase diagram helps us guess the structure of alloys and their properties. Let us look at what kinds of structure steel could have depending on its composition. We would only consider the structure that develops under equilibrium rate of cooling. The steel on solidification is expected to have fully austenitic structure. It may be assumed to be homogeneous since the rate of cooling is considered to be slow. Depending on its composition we may have three types of structures. (i) % carbon < 0.02 (ii) 0.02 < % carbon < 0.8 (iii) 0.8 < % Carbon < 2.0.

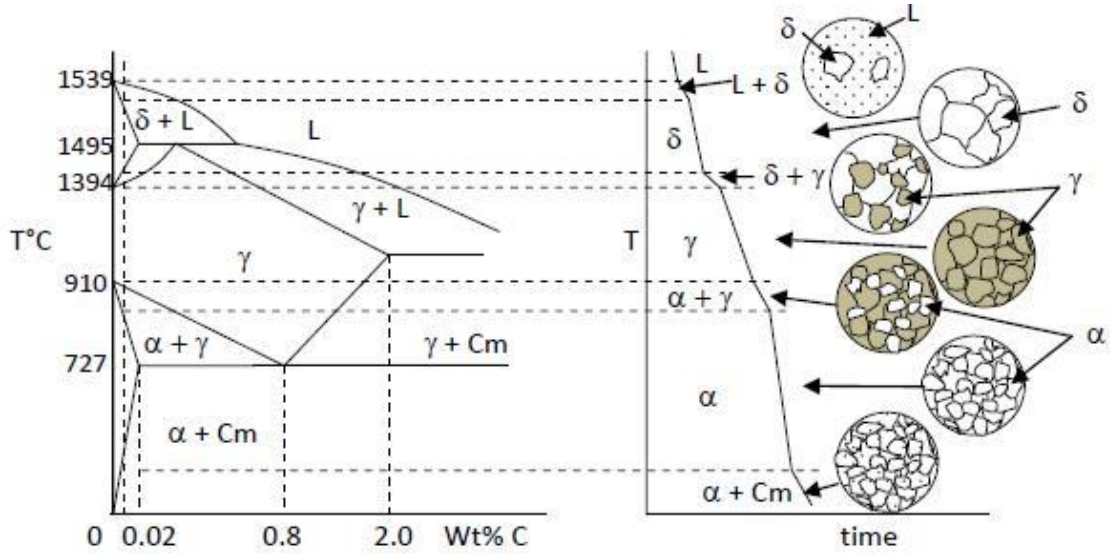


Fig. 2.3 Solidification behaviour of steel

The above figure explains the solidification behavior of steel having less than 0.02% carbon with the help of schematic diagrams. The sketch on the left shows a part of the equilibrium diagram (Fe-Fe3C) with the location of the alloy by a vertical dotted line. It intersects the liquidus, solidus, and a set of solvus curves. These are projected on to the cooling curve shown on the right with the help of a set of horizontal lines. The cooling curve exhibits inflection points at each of these intersections. Solidification begins with precipitation of a few grains of δ ferrite. The top most microstructure corresponds to this stage. The solidification takes place by nucleation and growth. The composition of the liquid and the solid keeps changing during this stage. When solidification is complete the entire liquid is replaced by δ ferrite having the same composition as that of the alloy. This is shown by the second schematic structure from the top Figure. The structure remains unchanged until the temperature crosses the boundary between δ /δ + γ phase fields. Thereafter austenite precipitates from δ ferrite. The grain corners and boundaries are the preferred sites

where grains of austenite nucleate. The third microstructure from the top in Figure represents its main features. It consists of grains of δ (white) and a few grains of

γ (grey). There is partition of carbon between these two phases. Bulk of the carbon goes into austenite. The composition of the two keeps changing as the temperature drops. The volume fraction of γ increases at the cost of δ. When the %carbon in austenite becomes equal to that of the steel δ ferrite disappears. The structure now consists of 100% austenite. Note the main features of the fourth microstructure from the top in Figure. The grain size is finer than that of 100% δ ferrite. The structure remains as 100% austenite until the temperature drops below the line representing the boundary between γ and α + γ phase fields of the equilibrium diagram. This is where α ferrite starts precipitating from austenite. The grain boundaries and the grain corners are the preferred sites for precipitation. The fifth sketch from the top of Figure is a typical representation of its microstructure at this stage. Ferrite grains are shown as white and austenite grains are shown as grey. This continues through nucleation of new grains and growth of the existing ones until the temperature drops below the line between α + γ and α phase fields of the phase diagram. At this stage the structure is 100% ferrite (α). The 6th sketch in Figure is a typical representation of the microstructure. This remains unchanged till the temperature drops below the solvus. At this stage excess carbon precipitates as cementite. The last sketch in Fig 2 is a typical representation of its microstructure. The amount of cementite keeps increasing as the room temperature drops. It can be estimated by lever rule. From the phase diagram it is evident that the steel at room temperature would consist of ferrite with a few specks of cementite. If % carbon in the steel is 0.01 the amount of cementite is given by (0.01/6.67)x100 = 0.15%. The grains are relatively finer than that after solidification.

2.4 Cast Iron (C.I):

Cast Iron is the name applied to a family of high-carbon content Fe-C alloys, specifically, those containing more than 2.14 wt. % C. Generally, most cast irons fall within the 3.0 to 4.2 wt. % range. Many contain silicon. Many cast irons are strong, but also brittle. As such, they find uses as small cylinder blocks, cylinder heads, pistons, clutch plates, transmission cases, diesel engine casting.. There are four types of cast irons: gray, nodular, white, and malleable. Cast irons melt between ~ 1150oC and 1300oC; since this range is lower than for steels, they are easier to melt and cast than steels

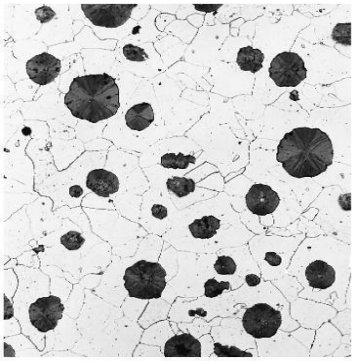
Constituents of Cast iron:

Cast irons consists of varying amounts of ferrite, cementite (Fe3C), and graphite (C). In most cast irons, the carbon-rich phase is graphite, not cementite.

2.4.1 Gray Cast iron:

Gray Cast iron contains 2.5 to 4.0 wt. % C and also 1.0 to 3.0 wt. % silicon. The Si promotes formation of graphite instead of cementite. Graphite is dispersed throughout a ferrite or pearlite matrix in the form of flakes. The graphite flakes have sharp edges and tips. Consequently, the flakes act as stress raisers which can induce fracture near their tips. For this reason, gray iron is brittle in tension. It is also good at damping vibrations. Gray iron is inexpensive and relatively easy to cast with minimal shrinkage.

2.4.2 Nodular Cast iron:

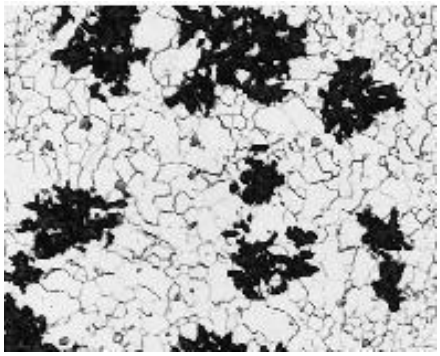


The nodular cast iron contains 2.5 to 4.0 wt. % C, 1.0 to 3.0 wt. % Si, plus Mg &/or Ce. The Mg &/or Ce cause the flakes to spherodize (hence nodular). Graphite is dispersed throughout a ferrite or pearlite matrix in the form of spheres or nodules. The graphite nodules have no sharp features; therefore, the resulting material is much more ductile than gray iron. The mechanical properties of nodular iron are similar to steel. Nodular iron is frequently used in valves, crankshafts, gears, and other automotive components.

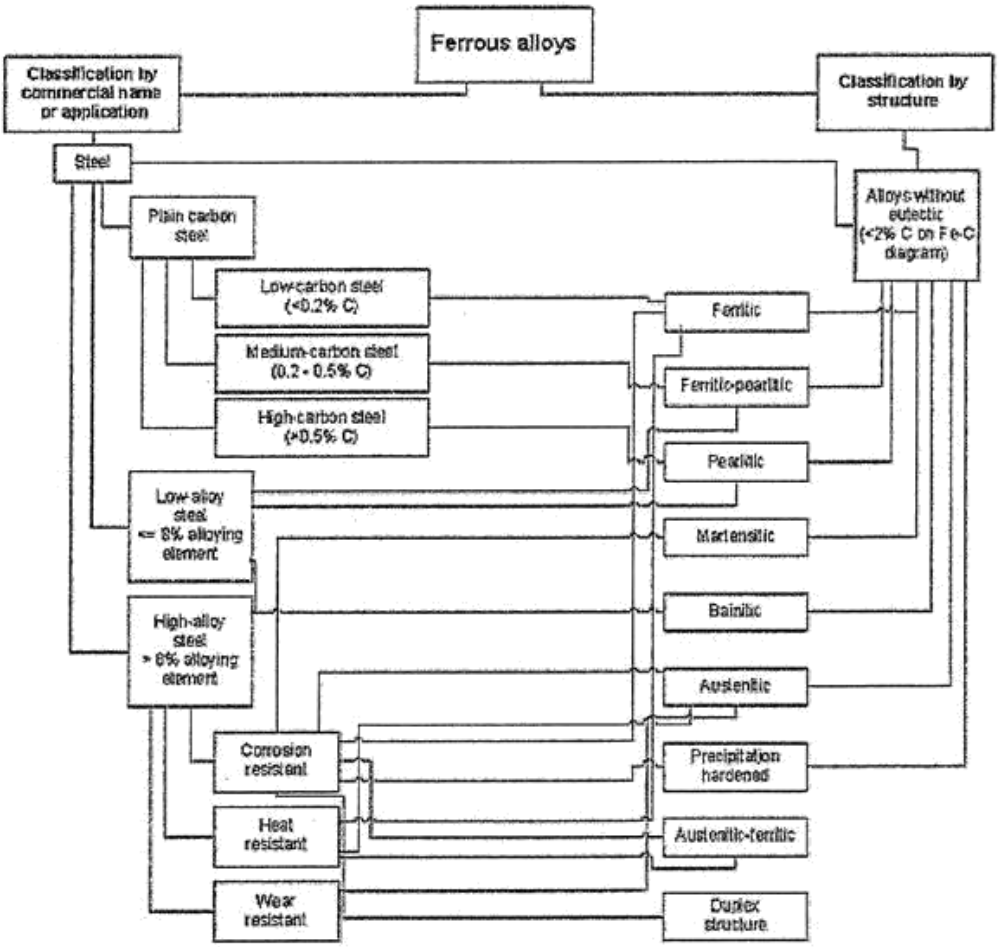
2.4.3 White Cast Iron:

White iron contains 2.5 to 4.0 wt. % C and less than 1.0 wt. % Si. Because of the low Si content, the carbon forms Fe3C instead of graphite. Cementite is dispersed throughout pearlite (ferrite + cementite) matrix. White iron contains a considerable volume fraction of cementite (Fe3C), a hard and brittle compound. Because of the amount of cementite, white iron is extremely hard and extremely brittle. Limited usage - mainly applications requiring hardness and wear resistance (such a rollers in rolling mills). Also used as a precursor to malleable iron.

2.4.4 Malleable Cast Iron:



Malleable iron (just like white iron) contains 2.5 to 4.0 wt. % C and less than 1.0 wt. % Si. Unlike white iron, the C exists in the form of graphite instead of cementite. Graphite rosettes are dispersed throughout a ferrite (or pearlite) matrix. Malleable iron is produced by heating white iron in order to decompose the cementite into graphite. The graphite forms clusters, similar to nodular iron. Reduction in the amount of cementite causes the material to become relatively ductile (or malleable). Used in connecting rods, transmission gears, differential cases, flanges, pipe fittings.



Steel:

The term steel is used for many different alloys of iron. These alloys vary both in the way they are made and in the proportions of the materials added to the iron. All steels, however, contain small amounts of carbon and manganese. In other words, it can be said that steel is a crystalline alloy of iron, carbon and several other elements, which hardens above its critical temperature. Like stated above, there do exist several types of steels which are (among others) plain carbon, stainless steel, alloyed steel and tool steel.

Plain carbon steel.

Carbon steel is by far the most widely used kind of steel. The properties of carbon steel depend primarily on the amount of carbon it contains. Most carbon steel has a carbon content of less than 1%. Carbon steel is made into a wide range of products, including structural beams, car bodies, kitchen appliances, and cans. In fact, there are three types of plain carbon steel and they are low carbon steel, medium carbon steel, high carbon steel, and as their names suggests all these types of plain carbon steel differs in the amount of carbon they contain. Indeed, it is good to precise that plain carbon steel is a type of steel having a maximum carbon content of 1.5% along with small percentages of silica, sulphur, phosphorus and manganese.

General properties of plain carbon steel.

Generally, with an increase in the carbon content from 0.01 to 1.5% in the alloy, its strength and hardness increases but still such an increase beyond 1.5% causes appreciable reduction in the ductility and malleability of the steel.

Low carbon steel or mild steel, containing carbon up to 0.25% responds to heat treatment as improvement in the ductility is concerned but has no effect in respect of its strength properties.

Medium carbon steels, having carbon content ranging from 0.25 to 0.70% improves in the machinability by heat treatment. It must also be noted that this steel is especially adaptable for machining or forging and where surface hardness is desirable.

High carbon steels, is steel-containing carbon in the range of 0.70 to 1.05% and is especially classed as high carbon steel. In the fully heat-treated condition it is very hard and it will withstand high shear and wear and will thus be subjected to little deformation.

Moreover, at maximum hardness, the steel is brittle and if some toughness is desired it must be obtained at the expense of hardness. Depth hardening ability (normally termed as hardenability) is poor, limiting the use of this steel.

Furthermore, as it has been seen that hardness, brittleness and ductility are very important properties as they determine mainly the way these different carbon content steels are used. Considering the microstructure of slowly cooled steel; for mild steel, for instance, with 0.2% carbon. Such steel consists of about 75% of proeutectoid ferrite that forms above the eutectoid temperature and about 25% of pearlite (pearlite and ferrite being microstructure components of steel). When the carbon content in the steel is increased, the amount of pearlite increases until we get the fully pearlitic structure of a composition of 0.8% carbon. Beyond 0.8%, high carbon steel contain proeutectoid cementide in addition to pearlite.

However, in slowly cooled carbon steels, the overall hardness and ductility of the steel are determined by the relative proportions of the soft, ductile ferrite and the hard, brottle cementite. The cementite content increases with increasing carbon content, resulting in an increase of hardness and a decrease of ductility, as we go from low carbon to high carbon steels.

Limitations of plain carbon steel.

Like everything, the plain carbon steels do have some appreciable properties but also consists of some limitations. These are:

1. There cannot be strengthening beyond about 100000 psi without significant loss in toughness (impact resistance) and ductility.
2. Large sections cannot be made with a martensite structure throughout, and thus are not deep hardenable.
3. Rapid quench rates are necessary for full hardening in medium-carbon leads to shape distortion and cracking of heat-treated steels.
4. Plain-carbon steels have poor impact resistance at low temperatures.
5. Plain-carbon steels have poor corrosion resistance for engineering problems.
6. Plain-carbon steel oxidises readily at elevated temperatures.

Influence of residual elements on the properties of

Carbon steel:

Steel, is an alloy, which is mainly produced from pig iron. In fact, the manufacture of steel is quite a long process as it comprises of numerous stages and one of these stages is refining. Indeed, once produced in furnace, the steel does contain quite significant amount of impurity and thus, it requires to be refined to a certain degree. However, even after the refining process, the steel still contain small amounts of residual elements (also termed as trace elements) which has some negative influence on the properties of steel. For instance, carbon steel is an alloy made up of mainly iron and carbon but still other elements do exists in this alloy as shown in table below:

Elements	Maximum weight %
C	1.00
Cu	1.60
Mn	1.65
P	0.40
Si	0.60
S	0.05

Out of these elements, Phosphorus, Sulphur and Silicon are considered as trace elements as they have negative impacts on the steel. Indeed, there are many elements which are considered as being residual elements and these elements are:

Residual Elements	Symbol
Phosphorus	P
Sulphur	S
Oxygen	O

Hydrogen	H
Tin	Sn
Arsenic	As

Effects of residual elements on steel.

Like stated above, the presence of these trace elements are undesirable due to their bad effects on the steel and its properties. In fact, here is in more details, the description of these elements as well as their drawbacks they cause on steel.

Phosphorus:

Phosphorus is an element, which affects primarily the ductility and the toughness of steel and this mostly when the steel is in the quenched and tempered conditions. In fact, the phosphorus has a tendency to react with the iron to form a compound known as iron phosphide (Fe3P) which has the particularity of being brittle. Hence, phosphorus renders steel less tough and ductile while it increases brittleness.

Silicon:

Although the fact, that silicon is not that harmful to steel, still it has some bad effects on its properties. In fact, silicon has the particularity of impairing hot and cold workability and machinability. The presence of Silicon in low carbon steel is also detrimental since it affects the surface quality of the steel.

Oxygen:

Oxygen is really a poison to steel. Indeed, when present in steel, it has a very bad effect on its mechanical properties. To be more precise, oxygen reduces the impact strength of steel, whereas it has the tendency to increase its ageing brittleness, red shortness, woody and slanty fractures. In brief Oxygen reduces the toughness of steel.

Hydrogen:

Like Oxygen, Hydrogen also is injurious to steel as it causes embrittlement by decreasing of elongation and reduction of area without any increase of yield point and tensile strength. Indeed, hydrogen is the source of redoubtable snowflake formation and it favors the formation of ghost lines in the steel structure. Furthermore, atomic hydrogen engendered by pickling penetrates into the steel and forms blowholes. This element also acts as a decarburising agent when it is in the moisted form (at high temperatures).

Sulphur:

Sulphur is a trace element, which has a great tendency to segregate (that is to isolate itself in the structure). It also reacts with iron to form iron sulphide which produces red or hot-shortness, since the low melting eutectic forms a network around the grains so that these hold but loosely together, and the grain boundaries may easily break up during hot forming. Sulphur plays a great role also in the drop in weldability, impact toughness and ductility of steel.

Tin:

Tin is also considered as being a residual element and this simply because, just as steel, it causes hot shortness. In addition to this, tin is also a source of temper embrittlement.

Arsenic:

Arsenic, for its part, plays an important role in the rise of temper embrittlement in the properties of steel. Furthermore, it causes a considerable drop in toughness and it also impairs weldability.

Antimony:

This has as effect similar to Arsenic which also cause temper embrittlement and it affects quite considerably the toughness and the ductility of steel.

Nitrogen:

This is not the most harmful trace element since it only causes a decrease in toughness of the steel.

Effects of alloying elements in an alloy:

An alloy is a mixture of two or more metals, or a metal and some other material. Most alloy contain a large amount of one metal, called the base metal, and smaller amounts of one or more other metals or nonmetallic materials. Many pure metals are too soft, corrode too easily, or have other mechanical or chemical disadvantages can be overcome if the metals are combined with other metals into alloys. Most alloys are harder than the metals from which they are made. They are also less malleable. They are harder to hammer into shape. Most alloys are less ductile than pure metals. That is, they are less easily drawn into fine wires and similar shapes. But most alloy are more fusible and more easily melted, than the pure metals of which they are composed. Some alloys will even melt at the comparatively low temperature of hot water. Few alloys can conduct electricity as well as many metals in their pure forms.

General effects of alloying elements are:

(i) Improves tensile strength without appreciably lowering ductility.

(ii) Improves toughness.

(iii) Improves hardenability which permits hardening of larger sections than possible with plain carbon steels or allows quenching with less drastic rates.

(iv) Reducing the hazard of distortion and quench cracking.

(v) Retain strength at elevated temperatures.

(vi) Obtain better corrosion resistance.

(vii) Improves wear resistance.

(viii) Imparts a fine grain structure to the steel.

(ix) Improves special properties such as abrasion resistance and fatigue behaviour.

In fact, the properties of alloys are quite dependent on the relationship between chemical composition, processing and their microstructure. For instance, whenever an element is added to a pure metal, the latter alters the size of the lattice structure of the metal and depending on the alloy formed, it can also change its lattice type. Sometimes metals do react together to form intermetallic compounds with very complex lattice structure. Such compounds melt at a fixed temperature and have a lower conductivity and ductility but greater strength and hardness than an alloy of face centered body, centered or hexagonal lattice structure. Thus, alloys increses strength and hardness of metal by changing its structure. Furthermore, like stated above, alloying enables the formation of fine grain size since it favours the ability of the metal to be hardened by quenching in oil or air rather than in water. Indeed, oil is a cooling agent offering slow cooling rate and thus the grain form more regularly with time and hence they are finer.

Effects of alloying elements in steel:

Steel is one of the world's cheapest and useful metals. Indeed, steel founds application in numerous fields, from building construction purposes to kitchen utensils. Hence, so as to be able to respond to such a great demand and to suit the requirements to different applications, steel needs to offer several desired properties and these properties is achieved by alloying it. Like stated above, several other elements need to be added to iron and carbon to form adequate alloys with enhanced properties. Alloyed steel in brief is made by adding a small percentage of alloying metals to liquid steel to subsequently alter the hardness, toughness, elasticity or durability. Naturally each of the alloying elements will have a specific property on the steel and are added to it in certain proportions on the different properties required.

The different alloying elements on steel are:

(i) Carbon

(ii) Magnesium

(iii) Silicon

(iv) Copper

(v) Chromium

(vi) Molybdenum

(vii) Vanadium

(viii) Nickel

(ix) Aluminium

(x) Boron

(xi) Titanium

(xii) Zirconium

(xiii) Calcium

(xiv) Lead

(xv) Nitrogen

(xvi) Tungsten

The effects of the above alloying elements in steel are:

Carbon:

Carbon is an element whose presence is imperative in all steel. Indeed, carbon is the principle hardening element of steel. That is, this alloying element determines the level of hardness or strength that can be attained by quenching. Furthermore, carbon is essential for the formation of cementite (as well as other carbides) and of pearlite, spheridite, bainite, and iron-carbon martensite, with martensite being the hardest of the microstructures. Carbon is also responsible for increase in tensile strength, hardness,

resistance to wear and abrasion. However, when present in high quantities it affects the ductility, the toughness and the machinability of steel.

Manganese:

Manganese also contributes greatly towards increasing strength and hardness, but to a less extent than carbon. To be more precise, the degree to which manganese increases hardness and strength is dependent upon the carbon content of the steel. In fact, manganese contributes to the increasing

the strength of the ferrite, and also toward increasing the hardness of penetration of steel in the quench by decreasing the critical quenching speed. Moreover, still consisting of a considerable amount of manganese can be quenched in oil rather than in water, and are therefore less susceptible to cracking because of reduction in the shock of the quenching. This alloying is also considered as a degasifier reacting favorably with sulfur to improve forging ability and surface quality. This is achieved by interacting with the sulphur to give manganese sulphide. Naturally in doing so, the risk of hot shortening is considerably decreased. In addition, manganese enhance the tensile strength, the hardness, the harden ability, the resistance to wear, and it increases also the rate of carbon penetrating in the coefficient of thermal expansion of steel whereas it is detrimental to both thermal and electrical conductivity.

Copper:

Although being favourable when it comes to render steel more resistant to corrosion, copper is not considered as such as being a good alloying element since it does have some bad repercussions on the steel. Indeed, copper is harmful to the surface quality of steel and it renders the steel less machinable at high temperatures.

Chromium:

Among the alloying elements of steel, chromium forms part of those which best promote hardenability. In fact, its effect on steel is quite similar to that of manganese in the way that it enhances much hardness penetration. When being present in reasonable quantities, chromium contributes much in reducing the quenching speed. In fact, such a slow quenching is achieved thereby enabling steel to be oil or air hardened. Chromium is also recommended when there is good wear resistant steel of appreciable toughness required. Chromium is also very popular as alloying element as it is quite efficient in rendering steel resistant to staining and corrosion. Moreover, chromium forms carbides that improve edge-holding capacity. Steel, rich in chromium have also high temperature strength and they are quite resistant to high-pressure hydrogenation.

Nickel:

Nickel is beneficial to steel in the way that it boost up the strength of ferrite. It is a fact that nickel causes considerable increase in the impact strength of steel. Nickel found its common use generally in low alloy steels. This is so because this alloying element increases appreciably toughness and hardenability. In addition, nickel also exhibits the tendency of reducing distortion and cracking of the steel.

Vanadium:

Vanadium has for main effect on steel that it helps controlling the grain growth during heat treatment. It is used rather in medium carbon steel where when added in relatively large quantities it causes a reduction in the hardenability of the steel. Indeed, vanadium is known as a strong carbide former and these carbide former and these carbide dissolves very difficulty in austenite thereby explaining why vanadium reduces hardness of steel.

Molybdenum:

Molybdenum is an alloying element which is seldomly used on its own. In fact, molybdenum is used in combination with other alloying elements. This alloying element increases the hardness penetration of steel and also contributes in slowing down the critical quenching speed. Molybdenum proves to be useful also for increasing tensile strength of steel. Furthermore, it prevents temper brittleness and it favours the formation of a fine grain structure. It is good also to mention that molybdenum forms carbides readily and it thus improves the cutting properties in high-speed steels. Hence, it can be said that molybdenum helps much in increasing machinability.

Aluminium

Aluminium is mainly used as an alloying element of steel because of its ability to deoxidize the steel and also because of its capacity of extracting gases from the steel. Aluminium also does offer to steel resistance to ageing. Moreover, aluminium helps in the formation of fine grain structure, and since it combines well with nitrogen to form very hard nitride, it is considered to be a favourable alloying constituent of nitriding steels.

Boron

Boron, is an alloying element that can be placed in the category of those whose main function is to enhance the hardenability of steel. However, the main interest in using boron to alloy steel is that it increases the hardenability of the material and this is, without having any effect on the ductility nor on the ferrite strength of the steel. As a result, formability and machineability of steel are boosted due to the presence of Boron.indeed thus alloying element finds most of its applications in low carbon steels.

Titanium

Titanium can be associated to boron as it plays also a great role in increasing the hardenability of steel. In fact, titanium helps much towards increasing the effectiveness of boron as an alloying element of steel.

Calcium

Calcium, for its part, is mainly used in a silicocalcium combination. In truth, calcium (as well as silicon) has for main function to deoxidize the steel. In doing so, the calcium does also contribute towards imparting the steel with a non-scaling property. In addition to this, calcium is also recommended for alloying purposes, as it is quite good in enhancing the toughness, the formability and the machinability of the alloyed material.

Nitrogen

Being a residual element, nitrogen is present, in small quantities, in all steels. In fact, the nitrogen will normally combine with other elements in the steel (like Aluminium, for example) to form hard nitrides. Thus nitrogen increases hardness, tensile and yield strength, but still, there are certain drawbacks related to nitrogen as it causes a considerable decrease in toughness and in ductibility of steel.

Tungsten

Being a very powerful carbide former, and the fact that its carbides are very hard, tungsten, do provide to steel good toughness and it inhibits grain growth. Tungsten is also quite good towards increasing the strength and hardness retention as well as wear resistance at high temperatures and cutting power.

Classification (composition, properties, codes) of steel used by SAE/AISI:

Generally, steel is classified according to the alloying element it contains, whereas these alloying elements are in turn classified according to their readiness to form carbides, austenites and ferrites. Being the main constituents, as well as the most important element used in alloyed steel, carbon is taken as reference for classifications purposes.

Classification of steel (SAE/AISI)

Concerning, the alloy steel, some standards do exists so as to facilitate its analysis and its classification. One of these standards is the one established by the Society of Automotive Engineer(SAE) which uses a four digits numeration system to classify steel. Out of this four

digits, the first one, generally indicates whether the steel is a plain carbon typed one, whereas the second number give an idea about the type of modification to which the steel has been subjected. Regarding the last two digits; they simply point out the composition of carbon in the steel. For example, considering the type of steel referred to as SAE1040; it can be said that it is a plain carbon one , with a carbon content of 0.40%.generally, alloyed steel are written as 2xxx, 3xxx etc.

However, the American iron and steel institute (AISI) has redefined the percentages of alloying elements used in steel manufacture and prefixes have been added to the SAE classification system so as to indicate the method of production of the steel. The different prefixes are as follows:

A: Alloy, basic open hearth

B: Carbon, acid Bessemer

C: Carbon, basic open hearth.

D: Carbon, acid open hearth

E: Electric furnace.

Sometimes, over letters may be added to this classification system to designate hardenability (normally denoted by the letter H)

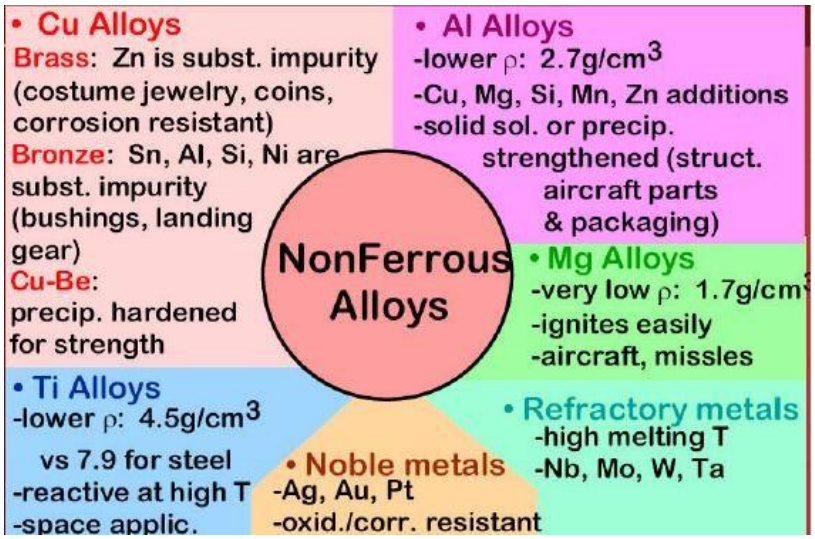
ALLOY ELEMENT	RANGE	EFFECT
CARBON	0-25 % 0.25-0.70% 0.70-1.50% >1.50%	_ Improves heat treatment and ductility _ Improves machinability _ Considerably increase in strength and hardness _ Reduction in ductility and malleability
MANGANESE	1.65-2.10% 10%-14%	_ Improve electrical resistance and magnetic property of steel and reduces its coefficient of expansion _ Improves hardness and toughness.
SILICON	0-0.30% 0.30-1%	_ Imparts good casting fluidity _ Increase heat resistance
COPPER	0.20-0.50%	_ Improves steel resistance to

	High amounts	atmospheric corrosion _ Harmful to steel as it affects surface finish.
CHROMIUM	0-5% 14% -	_ Quenching speed reduced, increased toughness, and wear resistance imparted to steel. _ Stainless steel: resistance to corrosion increased, higher critical temperature imparted
VANADIUM	0-0.05% > 0.25% around 1 %	_ Harden ability is boosted up _ Induces resistance to softening at high temperatures _ Retain hardness at high temperature
NICKEL	0-5% 8-12% 15-25% 25-35% 36%	_ Favours refined grain structure and causes hardening abilities _ Resistance to low temperature impact _ High magnetic properties is imparted to steel _ Corrosion resistance is increased _ Invar is obtained, which has a low coefficient of temperature
BORON	0.0005-0.03%	_ Increased harden ability of steel
LEAD	0.15-0.35%	_ Increased machinability

		_ (favours formation of small chips)
TUNGSTEN	3-6%	- Improves cutting
MOLYBNENUM	0.15 – 0.25 %	- Used in combination with Chromium to improve hot hardness

Aluminum and its Alloys:

Pure aluminum is a silvery-white metal with many desirable characteristics. It is light, nontoxic (as the metal), nonmagnetic and nonsparking. It is easily formed, machined, and cast. Pure aluminum is soft and lacks strength, but alloys with small amounts of copper, magnesium,



silicon, manganese, and other elements have very useful properties. Aluminum is an abundant element in the earth's crust, but it is not found free in nature. The Bayer process is used to refine aluminum from bauxite, an aluminum ore. Because of aluminum's mechanical and physical properties, it is an extremely convenient and widely used metal. Aluminium alloys can be classified as; cast or wrought alloys, examples are; Al--Li, Al-Cu-Si etc

Properties

- Very lightweight (about 1/3 the mass of an equivalent volume of steel or copper) but with alloying can become very strong.
- excellent thermal conductor
- excellent electrical conductor (on a weight-for-mass basis, aluminium will conduct more than twice as much electricity as copper)
- highly reflective to radiant energy in the electromagnetic spectrum
- highly corrosion resistant in air and water (including sea water).
- highly workable and can be formed into almost any structural shape
  non-magnetic, non-toxic

Applications

- door and window frames
- high tension power lines, wires, cables, bus bars, components for television, radios, refrigerators and air-conditioners
- beverage cans, bottle tops
- propellers, airplane and vehicle body sheet, gear boxes, motor parts
- Al-Cu food/ chemicals handing and storage equipments.
- Al-Cu-Mn-Zn- Cooking utensils.

Al-Zn-Mg-Cu-Cr Aircraft structural parts

Copper and its Alloys

Copper alloys are metal alloys that have copper as their principal component. They have high resistance against corrosion. There are as many as 400 different copper and copper-alloy compositions loosely grouped into the categories: copper, high copper alloy, brasses, bronzes, copper nickels, copper–nickel–zinc (nickel silver), leaded copper, and special alloys. The best known traditional types are bronze, where tin is a significant addition, and brass, using zinc instead.

Brasses: Brass A brass is an alloy of copper with zinc. Brasses are usually yellow in color. The zinc content can vary between few % to about 40%; as long as it is kept under 15%, it does not markedly decrease corrosion resistance of copper. Brasses can be sensitive to selective leaching corrosion under certain conditions, when zinc is leached from the alloy (dezincification), leaving behind a spongy copper structure.

Bronzes: A bronze is an alloy of copper and other metals, most often tin, but also aluminium and silicon. Aluminium bronzes are alloys of copper and aluminium. The content of aluminium ranges mostly between 5-11%. Iron, nickel, manganese and silicon are sometimes added. They have higher strength and corrosion resistance than other bronzes, especially in marine environment, and have low reactivity to sulfur compounds. Aluminium forms a thin passivation layer on the surface of the metal. Example: Bell metal Phosphor bronze Nickel bronzes, e.g. nickel silver and cupronickel Speculum metal

Properties

- Good thermal and electrical conductivity
- Ease of forming, ease of joining, and color.
- However, copper and its alloys have relatively low strength-to-weight ratios
- Low strengths at elevated temperatures.

Copper is resistant to corrosion in most atmospheres including marine and industrial environments. It is corroded by oxidizing acids, halogens, sulphides and ammonia based solutions

- Copper and its alloys -- the brasses and bronzes -- are available in rod, plate, strip, sheet, tube shapes, forgings, wire, and castings.

Applications

 Pure Cu Electrical and thermal conductors (cast Cu), transistor components, coaxial cables rectifiers, lead in wires (cold--worked Cu)

 Cu- Be- Co moulds for plastic parts, bearings, valves, gears(cast Cu)

 Cu--30Zn & Cu --40Zn (cold --work brass) fasteners, locks, heal exchange components, large nuts and bolts, plumbing accessories, pints and rivets.

 Cu--4Si bearing, belts, marine fittings

Titanium and its Alloys

Titanium alloys are metals that contain a mixture of titanium and other chemical elements. Such alloys have very high tensile strength and toughness (even at extreme temperatures). They are light in weight, have extraordinary corrosion resistance and the ability to withstand extreme temperatures. However, the high cost of both raw materials and processing limit their use to military applications, aircraft, spacecraft, medical devices, highly stressed components such as connecting rods on expensive sports cars and some premium sports equipment and consumer electronics. Although "commercially pure" titanium has acceptable mechanical properties and has been used for orthopedic and dental implants, for most applications titanium is alloyed with small amounts of aluminium and vanadium, typically 6% and 4% respectively, by weight.

Titanium alloys are generally classified into four main categories:

[1] Alpha alloys which contain neutral alloying elements (such as tin) and/ or alpha stabilisers (such as aluminium or oxygen) only. These are not heat treatable. Examples include: Ti-5AL-2SN-ELI, Ti-8AL-1MO-1V.

[2] Near-alpha alloys contain small amount of ductile beta-phase. Besides alpha-phase stabilisers, near-alpha alloys are alloyed with 1–2% of beta phase stabilizers such as molybdenum, silicon or vanadium. Examples include: Ti-6Al-2Sn-4Zr-2Mo, Ti-5Al-5Sn-2Zr- 2Mo, IMI 685, Ti 1100.

[3] Alpha and beta alloys, which are metastable and generally include some combination of both alpha and beta stabilisers, and which can be heat treated. Examples include: Ti-6Al-4V, Ti-6Al-4V-ELI, Ti-6Al-6V-2Sn.

[4] Beta and near beta alloys, which are metastable and which contain sufficient beta stabilisers (such as molybdenum, silicon and vanadium) to allow them to maintain the beta phase when quenched, and which can also be solution treated and aged to improve strength. Examples include: Ti-10V-2Fe-3Al, Ti-13V-11Cr-3Al, Ti-8Mo-8V-2Fe-3Al, Beta C, Ti-15-3.

Properties

Low density metal (4.5 g/cm cm3)
High melting point = 1668oC
elastic modulus = 107MPa

Chemical reactivity with other material at elevated temperatures Corrosion resistanceApplications

• Pure Ti - Jet engine cases and airframe skins, corrosion--resistance equipment for marine's applications chemical processing, industries.

• Ti--5Al--2.55Sn – Gas turbine engine casing

• Ti--6Al-4V – High strength prosthetic implants, orthopedics, airframe structured components

Nickel and nickel alloys

Nickel is a versatile element and will alloy with most metals. Complete solid solubility exists between nickel and copper. Wide solubility ranges between iron, chromium, and nickel make possible many alloy combinations. It has strength, toughness, and corrosion resistance to metals. It is used in stainless steels and nickel-base alloys. Nickel alloys are used for high temperature applications, such as jet-engine components and rockets.

Types of resistance alloys containing nickel include:

Cu-Ni alloys containing 2 to 45% Ni Ni-Cr-Al alloys containing 35 to 95% Ni Ni-Cr-Fe alloys containing 35 to 60% Ni Ni-Cr-Si alloys containing 70 to 80% Ni

Types of resistance heating alloys con-taining nickel include:

Ni-Cr alloys containing 65 to 80% Ni with 1.5% Si Ni-Cr-Fe alloys containing 35 to 70% Ni with 1.5% Si + l% Nb

Soft Magnetic Alloys.

Two broad classes of magnetically soft materials have been developed in the Fe-Ni system. The high-nickel alloys (about 79% Ni with 4 to 5% Mo; bal Fe) have high initial permeability and low saturation induction.

Shape Memory Alloys:

Metallic materials that demonstrate the ability to return to their previously defined shape when subjected to the appropriate heating schedule are referred to as shape memory alloys. Nickel-titanium alloys (50Ni-50Ti) are one of the few commercially important shape memory alloys.

Superalloys: Superalloys are high-temperature alloys use in jet engines, gas turbines and reciprocating engines.

Nickel and nickel alloys are used for a wide variety of applications:

The majority of which involve corrosion resistance and/or heat resistance. Some of these include: Aircraft gas turbines Steam turbine power plants Medical applications Nuclear power systems Chemical and petrochemical industries

A number of other applications for nickel alloys involve the unique physical properties of special-purpose nickel-base or high-nickel alloys. These include: Low-expansion alloys Electrical resistance alloys Soft magnetic alloys Shape memory alloys.

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SCHOOL OF MECHANICAL ENGINEERING

DEPARTMENT OF AUTOMOBILE ENGINEERING

UNIT – III - HEAT TREATMENT OF STEEL – SAUA1201

3. Heat Treatment

Heat Treatment is the controlled heating and cooling of metals to alter their physical and mechanical properties without changing the product shape. Heat treatment is sometimes done inadvertently due to manufacturing processes that either heat or cool the metal such as welding or forming. Heat Treatment is often associated with increasing the strength of material, but it can also be used to alter certain manufacturability objectives such as improve machining, improve formability, restore ductility after a cold working operation. Thus it is a very enabling manufacturing process that can not only help other manufacturing process, but can also improve product performance by increasing strength or other desirable characteristics. Steels are particularly suitable for heat treatment, since they respond well to heat treatment and the commercial use of steels exceeds that of any other material.

Steels are heat treated for one of the following reasons:

1. Softening 2. Hardening 3. Material Modification

1.Softening: Softening is done to reduce strength or hardness, remove residual stresses, improve toughnesss, restore ductility, refine grain size or change the electromagnetic properties of the steel. Restoring ductility or removing residual stresses is a necessary operation when a large amount of cold working is to be performed, such as in a cold-rolling operation or wiredrawing. Annealing — full Process, spheroidizing, normalizing and tempering — austempering, martempering are the principal ways by which steel is softened.

2.Hardening: Hardening of steels is done to increase the strength and wear properties. One of the pre-requisites for hardening is sufficient carbon and alloy content. If there is sufficient Carbon content then the steel can be directly hardened. Otherwise the surface of the part has to be Carbon enriched using some diffusion treatment hardening techniques.

3.Material Modification: Heat treatment is used to modify properties of materials in addition to hardening and softening. These processes modify the behavior of the steels in a beneficial manner to maximize service life, e.g., stress relieving, or strength properties, e.g., cryogenic treatment, or some other desirable properties, e.g., spring aging.

Heat Treatment of Steel Steels can be heat treated to produce a great variety of microstructures and properties. Generally, heat treatment uses phase transformation during heating and cooling to change a microstructure in a solid state. In heat treatment, the processing is most often entirely thermal and modifies only structure. Thermomechanical treatments, which modify component shape and structure, and thermochemical treatments which modify surface chemistry and structure, are also important processing approaches which fall into the domain of heat treatment. The iron-carbon diagram is the base of heat treatment.

According to cooling rate we can distinguish two main heat treatment operations: • annealing – upon slow cooling rate (in air or with a furnace) • quenching – upon fast cooling (in oil or in water) annealing - produces equilibrium structures according to the Fe-Fe_3C diagram quenching - gives non-equilibrium structures Among annealing there are some important heat treatment processes like: • normalising • spheroidising • stress relieving

Normalising: The temperature depends on carbon content. After soaking the alloy is cooled in still air. This cooling rate and applied temperature produces small grain size. The small grain structure improve both toughness and strength (especially yield strenght). During normalising we use grain refinement which is associated with allotropic transformation upon heating $\gamma \rightarrow \alpha$

Spheroidising: The process is limited to steels in excess of 0.5% carbon and consists of heating the steel to temperature about A1 (727°C). At this temperature any cold worked ferrite will recrystallise and the iron carbide present in pearlite will form as spheroids or –ball up‖. As a result of change of carbides shape the strength and hardness are reduced.

Quenching: Material is heated up to the suitable temperature and then quenched in water or oil to harden to full hardness according to the kind of steels. Material is heated to the suitable temperature for hardening, then cooled rapidly by immersing the hot part is water, oil or another suitable liquid to transform the material to a fully hardened structure. Parts which are quenched usually must be aged, tempered or stress relieved to achieve the proper toughness, final hardness and dimensional stability. Alloys may be air cooled, or cooled by quenching in oil, water, or another liquid, depending upon the amount of alloying elements in the material and final mechanical properties to be achieved. Hardened materials are tempered to improve their dimensional stability and toughness.

Tempering: Tempering is done to develop the required combination of hardness, strength and toughness or to relieve the brittleness of fully hardened steels. Steels are never used in the as quenched condition. The combination of quenching and tempering is important to make tough parts. This treatment follows a quenching or air cooling operation. Tempering is generally considered effective in relieving stresses induced by quenching in addition to lowering hardness to within a specified range, or meeting certain mechanical property requirements. Tempering is the process of reheating the steel at a relatively low temperature leading to precipitation and spheroidization of the carbides present in the microstructure. The tempering temperature and times are generally controlled to produce the final properties required of the steel. The result is a component with the appropriate combination of hardness, strength and toughness for the intended application. Tempering is also effective in relieving the stresses induced by quenching.

Critical Temperatures: The "critical points" of carbon tool steel are the temperatures at which certain changes in the chemical composition of the steel take place, during both heating and cooling. Steel at normal temperatures has its carbon (which is the chief hardening element) in a certain form called pearlite carbon, and if the steel is heated to a certain temperature, a change occurs and the pearlite becomes martensite or hardening carbon. If the steel is allowed to cool slowly, the hardening carbon changes back to pearlite. The points at which these changes occur are the decalescence and recalescence or critical points, and the effect of these molecular changes is as follows: When a piece of steel is heated to a certain point, it continues to absorb

heat without appreciably rising in temperature, although its immediate surroundings may be hotter than the steel. This is the **decalescence point**. Similarly, steel cooling slowly from a high heat will, at a certain temperature, actually increase in temperature, although its surroundings may be colder. This takes place at the **recalescence point**. The recalescence point is lower than the decalescence point by anywhere from 85 to 215 degrees F., and the lower of these points does not manifest itself unless the higher one has first been fully passed. These critical points have a direct relation to the hardening of steel. Unless a temperature sufficient to reach the decalescence point is obtained, so that the pearlite carbon is changed into a hardening carbon, no hardening action can take place; and unless the steel is cooled suddenly before it reaches the recalescence point, thus preventing the changing back again from hardening to pearlite carbon, no hardening can take place. The critical points vary for different kinds of steel and must be determined by tests in each case. It is the variation in the critical points that makes it necessary to heat different steels to different temperatures when hardening.

Hardening: The use of this treatment will result in an improvement of the mechanical properties, as well as an increase in the level of hardness, producing a tougher, more durable item. Alloys are heated above the critical transformation temperature for the material, then cooled rapidly enough to cause the soft initial material to transform to a much harder, stronger structure. Alloys may be air cooled, or cooled by quenching in oil, water, or another liquid, depending upon the amount of alloying elements in the material.

Hardened materials are usually tempered or stress relieved to improve their dimensional stability and toughness. Steel parts often require a heat treatment to obtain improved mechanical properties, such as increasing increase hardness or strength. The hardening process consists of heating the components above the critical (normalizing) temperature, holding at this temperature for one hour per inch of thickness cooling at a rate fast enough to allow the material to transform to a much harder, stronger structure, and then tempering.

Steel is essentially an alloy of iron and carbon; other steel alloys have other metal elements in solution. Heating the material above the critical temperature causes carbon and the other elements to go into solid solution. Quenching "freezes" the microstructure, inducing stresses. Parts are subsequently tempered to transform the microstructure, achieve the appropriate hardness and eliminate the stresses.

Annealing Heat Treatment: Annealing heat treatment process is heating the material above the critical temperature, holding long enough for transformation to occur and slow cooling. Full annealing heat treatment differs from normalizing heat treatment in that the annealing temperature is typically 150-200F lower than the normalizing temperature and the cooling rate is slower. This establishes a soft microstructure and thus a soft product.

Austenitizing: Austenitizing heat treatment is heating a steel above the critical temperature, holding for a period of time long enough for transformation to occur. The material will be hardened if austenitizing is followed by quenching at a rate that is fast enough to transform the austenite into martensite.

Normalizing: Normalizing Heat Treatment process is heating a steel above the critical temperature, holding for a period of time long enough for transformation to occur, and air cooling. Normalized heat treatment establishes a more uniform carbide size and distribution which facilitates later heat treatment operations and produces a more uniform final product. Solution Annealing - Solution Heat Treatment Definition Some alloys (aluminum, PH stainless steels, Ti) harden by precipitating microscopic particles during aging. Solution heat treatment /

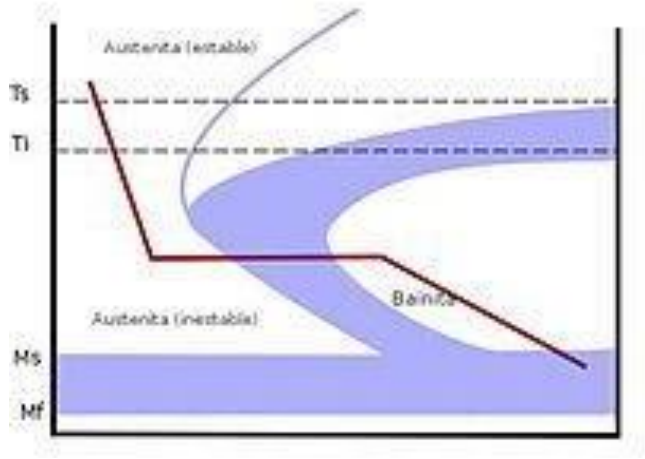
solution annealing takes these particles and puts them back into solution. In the solution annealing process, the alloy is heated to a high temperature, held for a period of time related to the section size of the material and air cooled or faster. This traps the precipitates in solution.

Steel Aging (also referred to as Precipitation Hardening): Precipitation Hardening is the heating of alloys, in the solution treated condition, to a lower temperature, which allows a relatively uniform distribution of microscopic particles throughout the alloy. The aging process results in alloy strengthening.

Stress Relieving Heat Treatment: Stress Relieving heat treatment process is heating to a temperature in order to relieve internal stresses in the material and lower the hardness of the surface of the material.

Austempering: Austempering is a technique used to form pure bainite, a transitional microstructure found between pearlite and martensite. In normalizing, both upper and lower bainite are usually found mixed with pearlite. To avoid the formation of pearlite or martensite, the steel is quenched in a bath of molten metals or salts. This quickly cools the steel past the point where pearlite can form, and into the bainite-forming range. The steel is then held at the bainite-forming temperature, beyond the point where the temperature reaches an equilibrium, until the bainite fully forms. The steel is then removed from the bath and allowed to air-cool, without the formation of either pearlite or martensite.

Depending on the holding-temperature, austempering can produce either upper or lower bainite. Upper bainite is a laminate structure formed at temperatures typically above 350 °C (662 °F) and is a much tougher microstructure. Lower bainite is a needle-like structure, produced at temperatures below 350 °C, and is stronger but much more brittle.In either case, austempering produces greater strength and toughness for a given hardness, which is determined mostly by composition rather than cooling speed, and reduced internal stresses which could lead to breakage. This produces steel with superior impact resistance. Modern punches and chisels are often austempered. Because austempering does not produce martensite, the steel does not require further tempering.



In the above given Time-temperature transformation (TTT) diagram. The red line shows the cooling curve for austempering.

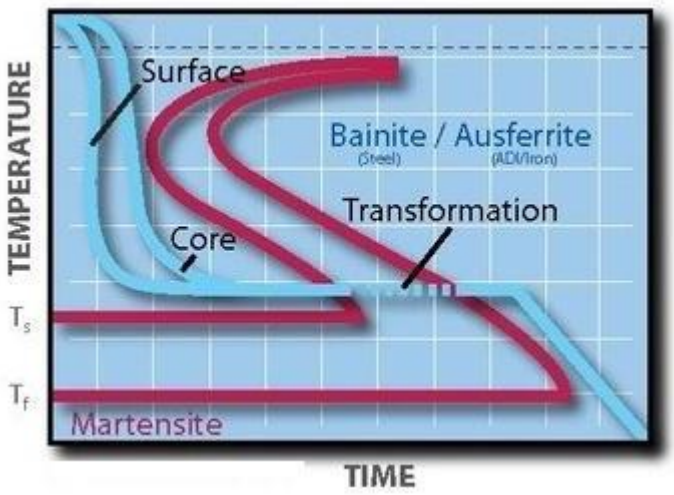
Martempering: Martempering is similar to austempering, in that the steel is quenched in a bath of molten metal or salts to quickly cool it past the pearlite-forming range. However, in martempering, the goal is to create martensite rather than bainite. The steel is quenched to a much lower temperature than is used for austempering; to just above the martensite start temperature. The metal is then held at this temperature until the temperature of the steel reaches an equilibrium. The steel is then removed from the bath before any bainite can form, and then is allowed to air-cool, turning it into martensite. The interruption in cooling allows much of the internal stresses to relax before the martensite forms, decreasing the brittleness of the steel. However, the martempered steel will usually need to undergo further tempering to adjust the hardness and toughness, except in rare cases where maximum hardness is needed but the accompanying brittleness is not. Modern files are often martempered

Embrittlement: Embrittlement occurs during tempering when, through a specific temperature range, the steel experiences an increase in hardness and a reduction in ductility, as opposed to the normal decrease in hardness that occurs to either side of this range. The first type is called tempered martensite embrittlement (TME) or one-step embrittlement. The second is referred to as temper embrittlement (TE) or two-step embrittlement.

Recrystallization: Recrystallization is a process by which deformed grains are replaced by a new set of defects-free grains that nucleate and grow until the original grains have been entirely consumed. Recrystallization is usually accompanied by a reduction in the strength and hardness of a material and a simultaneous increase in the ductility. Thus, the process may be introduced as a deliberate step in metals processing or may be an undesirable byproduct of another processing step. The most important industrial uses are the softening of metals previously hardened by cold work, which have lost their ductility, and the control of the grain structure in the final product.

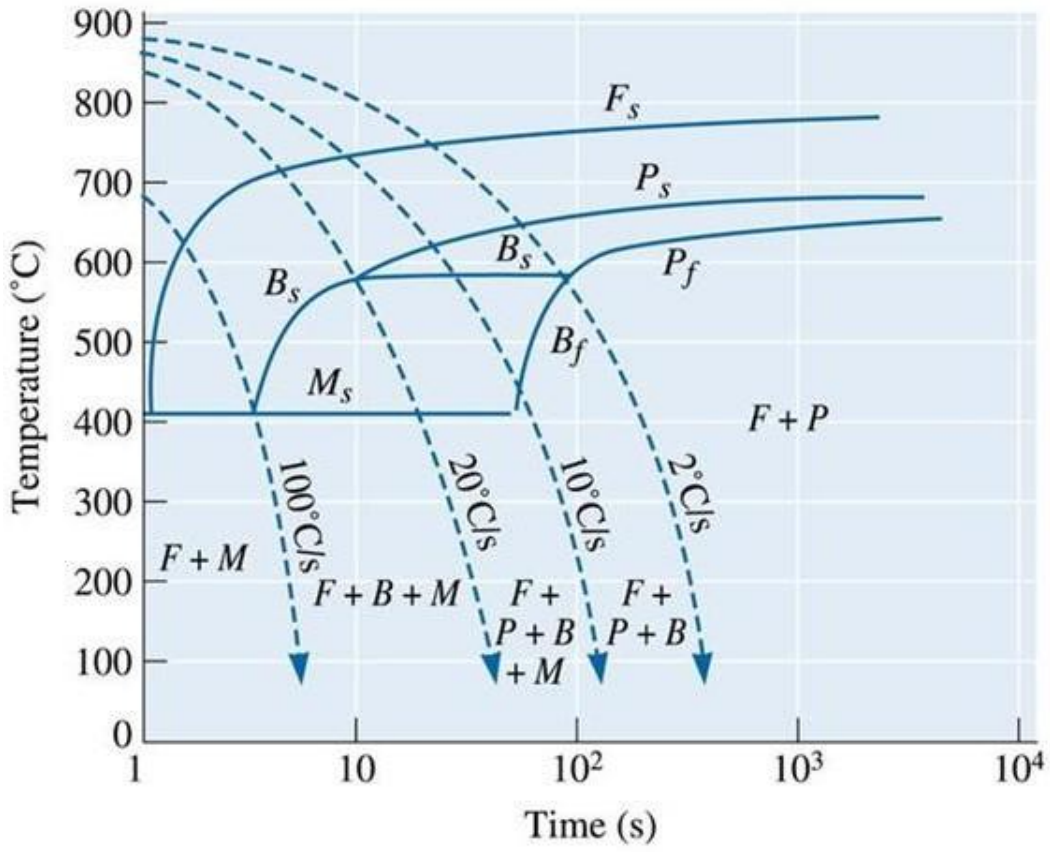
There are two main types of transformation diagram that are helpful in selecting the optimum steel and processing route to achieve a given set of properties. These are time-temperature transformation (TTT) and continuous cooling transformation (CCT) diagrams. CCT diagrams are generally more appropriate for engineering applications as components are cooled (air cooled, furnace cooled, quenched etc.) from a processing temperature as this is more economic than transferring to a separate furnace for an isothermal treatment. Time-temperature transformation (TTT) diagrams measure the rate of transformation at a constant temperature. In other words a sample is austenitised and then cooled rapidly to a lower temperature and held at that temperature whilst the rate of transformation is measured, for example by dilatometry. Obviously a large number of experiments is required to build up a complete TTT diagram. Continuous cooling transformation (CCT) diagrams measure the extent of transformation as a function of time for a continuously decreasing temperature. In other words a sample is austenitised and then cooled at a predetermined rate and the degree of transformation is measured, for example by dilatometry. Obviously a large number of experiments is required to build up a complete CCT diagram. TTT diagrams are time temperature transformation or isothermal transformation diagrams.

The essential difference between both the diagrams is the method of cooling. In TTT diagrams, after cooling to a transformation temperature, you keep the temperature constant until the transformation of austenite to the required transformation product (usually pearlite or bainite) is complete and then cool to the room temperature. One such process is austempering in which austenite is transformed to bainite isothermally. Below is a TTT diagram showing the austempering process.



The red lines form the transformation diagram and blue line denote the process. In this case the component which had an austenitic structure was cooled to just above Ts temperature; held at that temperature until the transformation was complete and then cooled further to the room temperature.

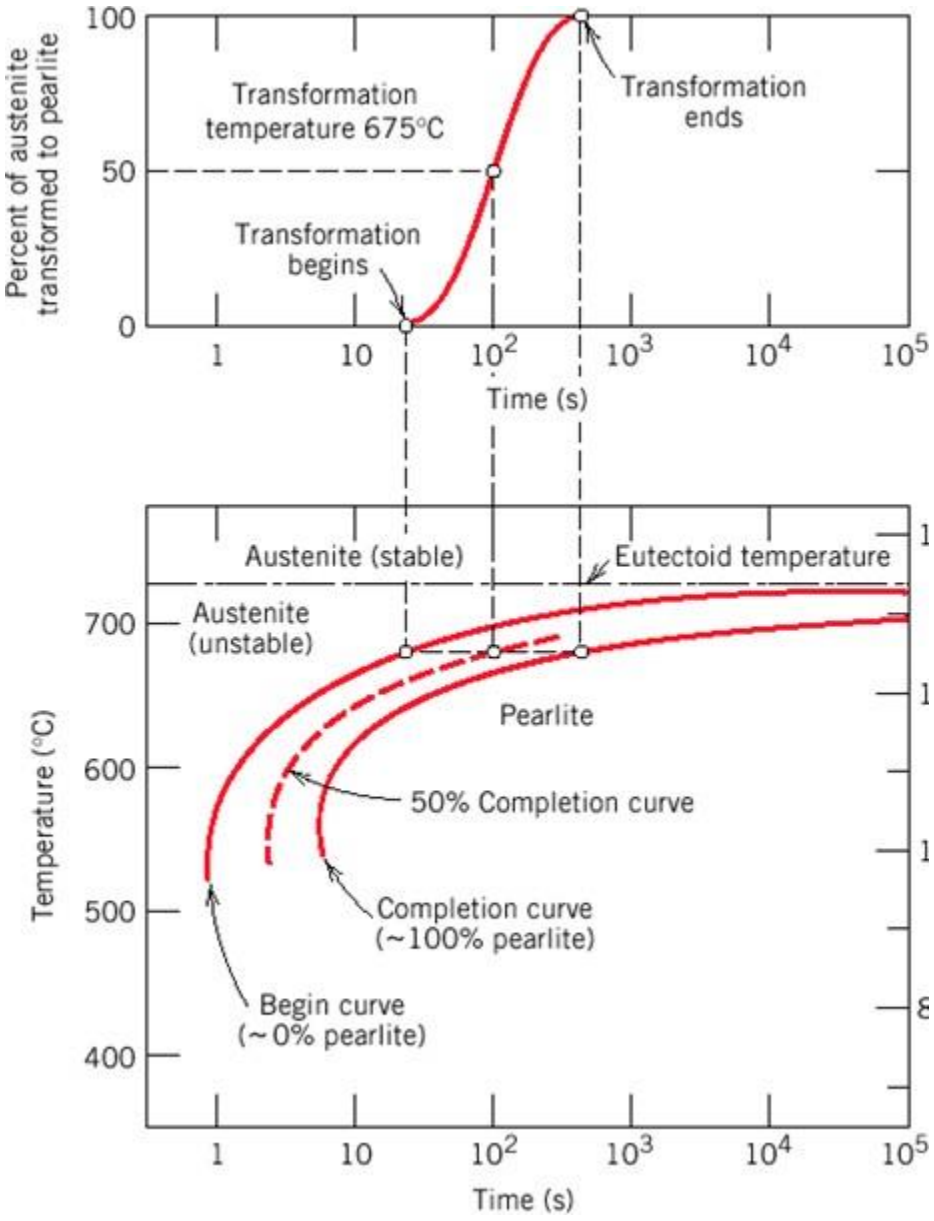
In CCT diagrams, there is continuous cooling i.e. there is no holding of temperature. The components are cooled at a constant or varying rates. The end products are usually martensite or pearlite depending on the cooling media as well as the material of components. Fully bainitic structure cannot be obtained using continuous cooling. Below is a CCT diagram:



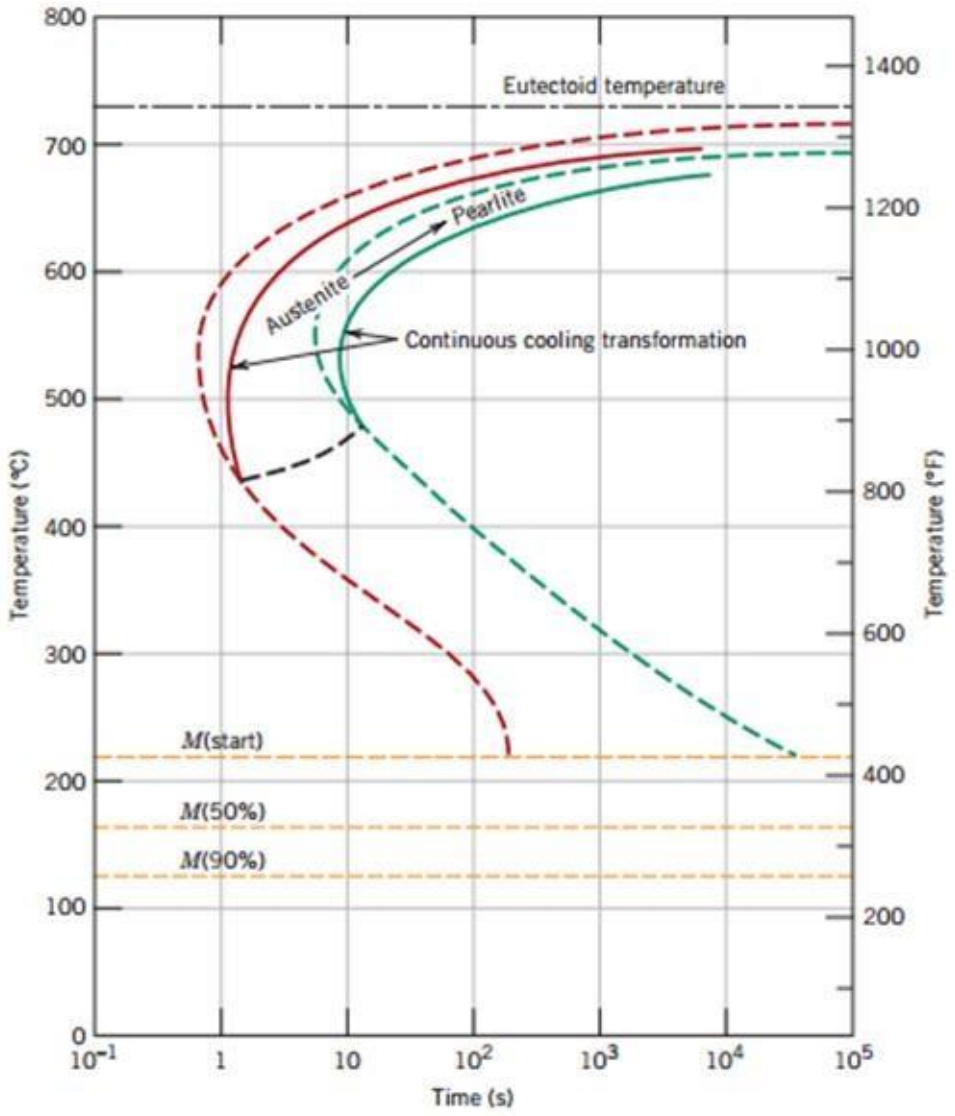
In the above figure: F – Ferrite, P – Pearlite: B – Bainite: M – Martensite: s subscript denotes start temperature and f subscript denotes finish temperature.

So a CCT diagrams simply gives the various transformation products which will be obtained at different cooling rates. It can be seen from the diagram that at cooling rates of more than 100 degrees celsius, ferrite and martensite will be obtained; for cooling rates between 20 and 100 degrees celsius, ferrite, bainite and martensite will be obtained and so on. These cooling rates are dependent on the cooling media. CCT diagrams are more practical than TTT diagrams as most of the processes employ continuous cooling rather than isothermal transformation. Also it is more difficult to hold the temperature constant.

Different steels have different TTT and CCT diagrams. In the diagram the time is noted where the transformation of austenite to a particular product (in this case, it is pearlite) begins and the time at which the transformations ends.



Then these transformation start times and transformation end times are plotted for different temperatures as shown. These points, when joined, give us the TTT diagrams. For continuous cooling, the time required for the transformation to begin and end is delayed. Thus the TTT diagram's curves are shifted to longer times and lower temperatures.

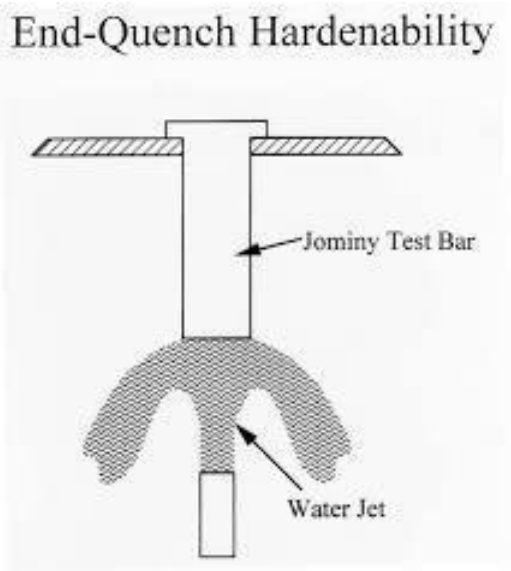


The dashed lines form TTT diagrams and the solid lines form the CCT diagrams. It can be seen that CCT diagram can be obtained by moving the TTT curves a little to the downward right.

Hardenability:

To achieve a full conversion of austenite into hard martensite, cooling needs to be fast enough to avoid partial conversion into perlite or bainite. If the piece is thick, the interior may cool too slowly so that full martensitic conversion is not achieved. Thus, the martensitic content, and the hardness, will drop from a high value at the surface to a lower value in the interior of the piece. Hardenability is the ability of the material to be hardened by forming martensite.

Hardenability is measured by the Jominy end-quench test (shown in figure). Hardenability is then given as the dependence of hardness on distance from the quenched end. High hardenability means that the hardness curve is relatively flat.



Influence of Quenching Medium, Specimen Size, and Geometry:

The cooling rate depends on the cooling medium. Cooling is fastest using water, then oil, and then air. Fast cooling brings the danger of warping and formation of cracks, since it is usually accompanied by large thermal gradients.

The shape and size of the piece, together with the heat capacity and heat conductivity are important in determining the cooling rate for different parts of the metal piece. Heat capacity is the energy content of a heated mass, which needs to be removed for cooling. Heat conductivity measures how fast this energy is transported to the colder regions of the piece.

Precipitation Hardening: Hardening can be enhanced by extremely small precipitates that hinder dislocation motion. The precipitates form when the solubility limit is exceeded. *Precipitation hardening is also called age hardening* because it involves the hardening of the material over a prolonged time. Precipitation hardening is achieved by:

a) solution heat treatment where all the solute atoms are dissolved to form a single-phase solution.

b) rapid cooling across the solvus line to exceed the solubility limit. This leads to a supersaturated solid solution that remains stable (metastable) due to the low temperatures, which prevent diffusion.

c) precipitation heat treatment where the supersaturated solution is heated to an intermediate temperature to induce precipitation and kept there for some time (aging).

If the process is continued for a very long time, eventually the hardness decreases. This is called overaging.

Carburizing

Carburizing, also referred to as Case Hardening, is a heat treatment process that produces a surface which is resistant to wear, while maintaining toughness and strength of the core. This treatment is applied to low carbon steel parts after machining, as well as high alloy steel bearings, gears, and other components.

Carburizing increases strength and wear resistance by diffusing carbon into the surface of the steel creating a case while retaining a substantially lesser hardness in the core. This treatment is applied to low carbon steels after machining.

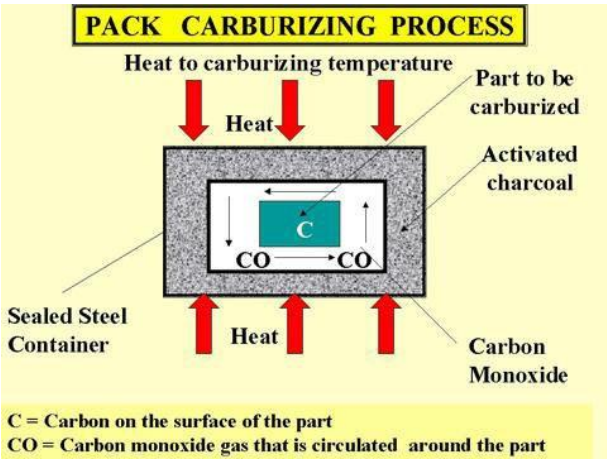
Strong and very hard-surface parts of intricate and complex shapes can be made of relatively lower cost materials that are readily machined or formed prior to heat treatment.

Most carburizing is done by heating components in either a pit furnace, or sealed atmosphere furnace, and introducing carburizing gases at temperature. Gas carburizing allows for accurate control of both the process temperature and carburizing atmosphere (carbon potential). Carburizing is a time/temperature process; the carburizing atmosphere is introduced into the furnace for the required time to ensure the correct depth of case. The carbon potential of the gas can be lowered to permit diffusion, avoiding excess carbon in the surface layer.

After carburizing, the work is either slow cooled for later quench hardening, or quenched directly into oil. Quench selection is made to achieve the optimum properties with acceptable levels of dimensional change. Hot oil quenching may be used for minimal distortion, but may be limited in application by the strength requirements for the product. Alternatively, bearing races may be press quenched to maintain their dimensional tolerances, minimizing the need for excessive post heat treatment grinding. In some cases, product is tempered, then cryogenically processed to convert retained austenite to martensite, and then retempered.

Metlab has the ability to carburize and harden gears and other components that are small enough to be held in one's hand, up to 14' in diameter and 16' tall, weighing as much as 50,000 pounds. Shallow cases only 0.002 - 0.005", and deep cases, up to 0.350" have been specified and readily achieved.

The press quench located in the facility allows for the dimensional control, therefore precise hardening of gears and bearings up to 16" in diameter.

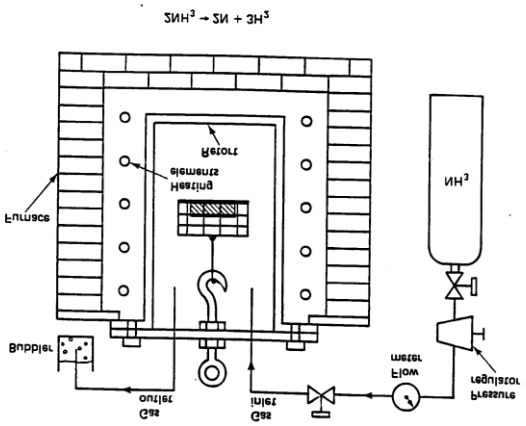


Nitrading

Gas nitriding is a surface hardening process, where nitrogen is added to the surface of steel parts using dissociated ammonia as the source. Gas nitriding develops a very hard case in a component at relatively low temperature, without the need for quenching.

Nitriding is carried out at temperatures below the transformation temperature of alloy steels, so that with proper manufacturing techniques, there is little or no distortion as a result of the process. Parts

to be nitrided are heat treated to the proper strength level, and final machined. The parts are then exposed to active nitrogen at a carefully controlled temperature, typically in the range of 925°F to 985°F. This temperature is typically below the final tempering temperature of the steel so that nitriding does not affect the base metal mechanical properties. As a result, a very high strength product with extremely good wear resistance can be produced, with little or no dimensional change.
The components to be nitrided are often stress relieved prior to final machining so that the only size changes observed are growth of about 0.0005". In some cases, nitrided components are surface ground after nitriding to remove the most outermost brittle layer produced by the process, or to bring



parts into a tight tolerance.

Induction Hardening

Induction hardening is a process used for the surface hardening of steel and other alloy components. The parts to be heat treated are placed inside a water cooled copper coil and then heated above their transformation temperature by applying an alternating current to the coil. The alternating current in the coil induces an alternating magnetic field within the work piece, which if made from steel, caused the outer surface of the part to heat to a temperature above the transformation range. Parts are held at that temperature until the appropriate depth of hardening has been achieved, and then quenched in oil, or another media, depending upon the steel type and hardness desired. The core of the component remains unaffected by the treatment and its physical properties are those of the bar from which it was machined or preheat treated. The hardness of the case can be HRC 37 - 58. Carbon and alloy steels with a carbon content in the range 0.40 - 0.45% are most suitable for this process. In some cases, parts made from alloy steels such as 4320, 8620 or 9310, like steel and paper mill rolls, are first carburized to a required case depth and slow cooled, and then induction hardened. This is to realize the benefit of relatively high core mechanical properties, and surface hardness greater than HRC 60, which provides excellent protection.
While induction hardening is most commonly used for steel parts, other alloys such as copper alloys, which are solution treated and tempered, may be induction hardened as well. Applications include hardening bearing races, gears, pinion shafts, crane (and other) wheels and treads, and threaded pipe used for oil patch drilling.
Induction Flame Hardening

Flame hardening is similar to induction hardening, in that it is a surface hardening process. Heat is applied to the part being hardened, using an oxy- acetylene (or similar gas) flame on the surface of the steel being hardened and heating the surface above the upper critical temperature before quenching the steel in a spray of water. The result is a hard surface layer ranging from 0.050" to 0.250" deep. As with induction hardening, the steel component must have sufficient carbon (greater

than 0.35%). The composition of the steel is not changed; therefore core mechanical properties are unaffected. Flame hardening produces results similar to conventional hardening processes but with less hardness penetration. Applications for flame hardening are similar to those for induction hardening, although an advantage of flame hardening is the ability to harden flat surfaces. Flat wear plates, and knives can be selectively hardened using this process.

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SCHOOL OF MECHANICAL ENGINEERING

DEPARTMENT OF AUTOMOBILE ENGINEERING

UNIT – IV - INTRODUCTION TO METROLOGY AND LINEAR MEASUREMENT – SAUA1201

1.1 GENERAL CONCEPT

1.1.1 Introduction to Metrology

Metrology word is derived from two Greek words such as metro which means measurement and logy which means science. Metrology is the science of precision measurement.

The engineer can say it is the science of measurement of lengths and angles and all related quantities like width, depth, diameter and straightness with high accuracy.

Metrology demands pure knowledge of certain basic mathematical and physical principles. The development of the industry largely depends on the engineering metrology.

Metrology is concerned with the establishment, reproduction and conservation and transfer of units of measurements and their standards. Irrespective of the branch of engineering, all engineers should know about various instruments and techniques.

1.1.2 Introduction to Measurement

Measurement is defined as the process of numerical evaluation of a dimension or the process of comparison with standard measuring instruments. The elements of measuring system include the instrumentation, calibration standards, environmental influence, human operator limitations and features of the work-piece.

The basic aim of measurement in industries is to check whether a component has been manufactured to the requirement of a specification or not.

1.1.3 Types of Metrology

- Legal Metrology

'Legal metrology' is that part of metrology which treats units of measurements, methods of measurements and the measuring instruments, in relation to the technical and legal requirements. The activities of the service of 'Legal Metrology' are:

(ii) Control of measuring instruments;
(iii) Testing of prototypes/models of measuring instruments;
(iv) Examination of a measuring instrument to verify its conformity to the statutory requirements etc.

- Dynamic Metrology

'Dynamic metrology' is the technique of measuring small variations of a continuous

nature. The technique has proved very valuable, and a record of continuous measurement, over a surface, for instance, has obvious advantages over individual measurements of an isolated character.

- Deterministic metrology

Deterministic metrology is a new philosophy in which part measurement is replaced by process measurement. The new techniques such as 3D error compensation by CNC (Computer Numerical Control) systems and expert systems are applied, leading to fully adaptive control. This technology is used for very high precision manufacturing machinery and control systems to achieve micro technology and nanotechnology accuracies.

1.2 OBJECTIVES OF METROLOGY

Although the basic objective of a measurement is to provide therequired accuracy at a minimum cost, metrology has further objectives ina modern engineering plant with different shapes which are:

1. Complete evaluation of newly developed products.
2. Determination of the process capabilities and ensure that these are better than the relevant component tolerances.
3. Determination of the measuring instrument capabilities andensure that they are quite sufficient for their respective measurements.
4. Minimizing the cost of inspection by effective and efficient use of available facilities.
5. Reducing the cost of rejects and rework through application of Statistical Quality Control Techniques.
6. To standardize the measuring methods
7. To maintain the accuracies of measurement.
8. To prepare designs for all gauges and special inspection fixtures.

1.2.1 Necessity and Importance of Metrology

1. The importance of the science of measurement as a tool for scientific research (by which accurate and reliable information can be obtained) was emphasized by Galileo and Gvethe. This is essential for solving almost all technical problems in the field of engineering in general, and in production engineering and experimental design in particular. The design engineer should not only check his design from the point of view of strength or economical production, but he should also keep in mind how the dimensions specified can be checked or

measured. Unfortunately, a considerable amount of engineering work is still being executed without realizing the importance of inspection and quality control for improving the function of product and achieving the economical production.

2. Higher productivity and accuracy is called for by the present manufacturing techniques. This cannot be achieved unless the science of metrology is understood, introduced and applied in industries. Improving the quality of production necessitates proportional improvement of the measuring accuracy, and marking out of components before machining and the in-process and post process control of the dimensional and geometrical accuracies of the product. Proper gauges should be designed and used for rapid and effective inspection. Also automation and automatic control, which are the modem trends for future developments, are based on measurement. Means for automatic
gauging as well as for position and displacement measurement with feedback control have to be provided.

1.3 METHODS OF MEASUREMENTS

These are the methods of comparison used in measurement process. In precision measurement various methods of measurement are adopted depending upon the accuracy required and the amount of permissible error.

The methods of measurement can be classified as:

l. Direct method
2. Indirect method
3. Absolute or Fundamental method
4. Comparative method
5. Transposition method
6. Coincidence method
7. Deflection method
8. Complementary method
9. Contact method
10. Contact less method

1. Direct method of measurement:

This is a simple method of measurement, in which the value of the quantity to be measured is obtained directly without any calculations. For example, measurements by using scales, vernier callipers, micrometers, bevel protector etc. This method is most widely used

in production. This method is not very accurate because it depends on human insensitiveness in making judgment.

2. Indirect method of measurement:

In indirect method the value of quantity to be measured is obtained by measuring other quantities which are functionally related to the required value. E.g. Angle measurement by sine bar, measurement of screw pitch diameter by three wire method etc.

3. Absolute or Fundamental method:

It is based on the measurement of the base quantities used to define the quantity. For example, measuring a quantity directly in accordance with the definition of that quantity, or measuring a quantity indirectly by direct measurement of the quantities linked with the definition of the quantity to be measured.

4. Comparative method:

In this method the value of the quantity to be measured is compared with known value of the same quantity or other quantity practically related to it. So, in this method only the deviations from a master gauge are determined, e.g., dial indicators, or other comparators.

5. Transposition method:

It is a method of measurement by direct comparison in which the value of the quantity measured is first balanced by an initial known value A of the same quantity, and then the value of the quantity measured is put in place of this known value and is balanced again by another known value B.

If the position of the element indicating equilibrium is the same in both cases, the value of the quantity to be measured is AB. For example, determination of amass by means of a balance and known weights, using the Gauss double weighing.

6. Coincidence method:

It is a differential method of measurement in which a very small difference between the value of the quantity to be measured and the reference is determined by the observation of the coincidence of certain lines or signals. For example, measurement by vernier calliper micrometer.

7. Deflection method:

In this method the value of the quantity to be measured is directly indicated by a deflection of a pointer on a calibrated scale.

8. Complementary method:

In this method the value of the quantity to be measured is combined with a known

value of the same quantity. The combination is so adjusted that the sum of these two values is equal to predetermined comparison value. For example, determination of the volume of a solid by liquid displacement.

9. Method of measurement by substitution:

It is a method of direct comparison in which the value of a quantity to be measured is replaced by a known value of the same quantity, so selected that the effects produced in the indicating device by these two values are the same.

10. Method of null measurement:

It is a method of differential measurement. In this method the difference between the value of the quantity to be measured and the known value of the same quantity with which it is compared is brought to zero.

1.4 GENERALIZED MEASUREMENT SYSTEM

A measuring system exists to provide information about the physical value of some variable being measured. In simple cases, the system can consist of only a single unit that gives an output reading or signal according to the magnitude of the unknown variable applied to it.

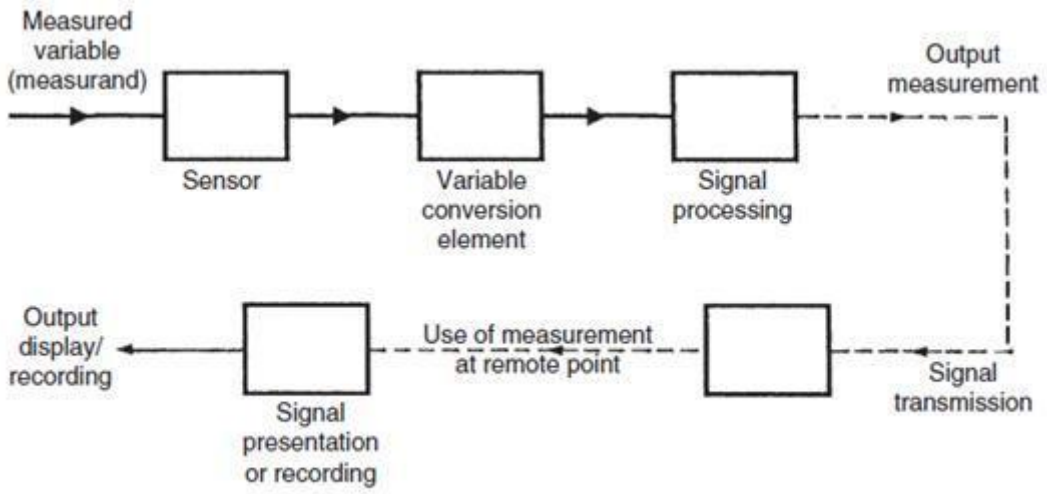


Fig 1.1 Generalised Measurement system

However, in more complex measurement situations, a measuring system consists of several separate elements as shown in Figure1.1.

1.4.1 Units

Table 1.1 Physical Quantities and its unit

Physical Quantity	Standard Unit	Definition
Length	Meter	Length of path traveled by light in an interval of 1/299,792,458 seconds
Mass	Kilogram	Mass of a platinum–iridium cylinder kept in the International Bureau of Weights and Measures, Sevres, Paris
Time	Second	9.192631770×10^9 cycles of radiation from vaporized cesium 133 (an accuracy of 1 in 10^{12} or one second in 36,000 years)
Temperature	Degrees	Temperature difference between absolute zero Kelvin and the triple point of water is defined as 273.16 K
Current	Amphere	One ampere is the current flowing through two infinitely long parallel conductors of negligible cross section placed 1 meter apart in vacuum and producing a force of 2×10^{-7} newtons per meter length of conductor
Luminous intensity	Candela	One candela is the luminous intensity in a given direction from a source emitting monochromatic radiation at a frequency of 540 terahertz (Hz $\times 10^{12}$) and with a radiant density in that direction of 1.4641 mW/steradian (1 steradian is the solid angle, which, having its vertex at the centre of a sphere, cuts off an area of the sphere surface equal to that of a square with sides of length equal to the sphere radius)
Matter	Mole	Number of atoms in a 0.012-kg mass of carbon 12

ELEMENTS OF GENERALIZED MEASUREMENT SYSTEM

2.1 Introduction

Scientists, engineers and other humans use a vast range of instruments to perform their measurements. These instruments may range from simple objects such as ruler scales and stopwatches to electron microscopes and particle accelerators used by scientists and engineers.

An *instrument* is as a device or a system which is designed to maintain a functional relationship between prescribed properties of physical variables being measured. It provides the means of communication to a human observer or the operator of a machine or equipment. The above stated functional relationship remains valid, only as long as the static calibration of system remains constant. The performance of an instrument of a measurement system is usually described in terms of a set of its *static and dynamic characteristics*. These characteristics have been described in detail in lessons 6 and 7.

2.2 Functional Elements of a Measurement System

To understand a measuring instrument/system, it is important to have a systematic organization and analysis of measurement systems. The operation of a measuring instrument or a system could be described in a generalized manner in terms of functional elements. Each functional element is made up of a component or groups of components which perform required and definite steps in the measurement. The functional elements do not provide the intricate details of the physical aspects of

a specific instrument or a system. These may be taken as basic elements, whose scope is determined by their functioning rather than their construction.

The main functional elements of a measurement system are:

i) Primary sensing element
ii) Variable conversion element
iii) Variable manipulation element
iv) Signal conditioning element
v) Data transmission element
vi) Data presentation element.

2.2.1 Primary sensing element

The quantity or the variable which is being measured makes its first contact with the primary sensing element of a measurement system. The measurement is thus first detected by primary sensor or detector. The measurement is then immediately converted into an analogous electrical signal. This is done by a transducer. Though a transducer in general, is defined as a device which converts energy from one form to another. But in measurement systems, this definition is limited in scope. A transducer is defined as a device which converts a physical quantity into an electrical quantity. The output of the sensor and detector element employed for measuring a quantity could be in different analogous form. This output is then converted into an electrical signal by a transducer. This is true of most of the cases but is not true for all. In many cases, the physical quantity is directly converted into an electrical quantity by a detector transducer. The first stage of a measurement system is known as a detector transducer stage.

2.2.2 Variable conversion element

The output signal of the variable sensing element may be any kind. It could be a mechanical or electrical signal. It may be a deflection of elastic member or some electrical parameter, such as, voltage, frequency etc. Sometimes, the output from the sensor is not suited to the measurement system. For the instrument to perform the desired function, it may be necessary to convert this output signal from the sensor to some other suitable form while preserving the information content of the original signal. For example, suppose the output from the sensing element is in the form of very small displacement which is difficult to measure mechanically, it is converted in to corresponding electrical signal with the help of transducer called stain gauge for further processing. Also if the output at one stage is analogue form and the next stage of the system accepts input signal only in digital form. In such cases, we will have to use as Analogue /Digital converter.

In many instruments variable conversion element is not required. Some instruments/measuring systems may require more than one element.

2.2.3 Variable manipulation element

Variable manipulation means a change in numerical value of the signal. The function of a variable manipulation element is to manipulate the signal presented to this element while preserving the original nature of the signal. For example, a voltage amplifier acts as a variable manipulation element. The amplifier accepts a small voltage signal as input and produces an output signal which is also

voltage but of greater magnitude. The variable manipulation element could be either placed after the variable conversion element or it may precede the variable conversion element.

2.2.4 Signal conditioning element

The output signal of transducers contains information which is further processed by the system. Many transducers develop usually a voltage or some other kind of electrical signal and quite often the signal developed is of very low voltages, may be of the order of mV and some even V. This signal could be contaminated by unwanted signals like noise due to an extraneous source which may interfere with the original output signal. Another problem is that the signal could also be distorted by processing equipment itself. If the signal after being sensed contains unwanted contamination or distortion, there is a need to remove the interfering noise / sources before its transmission to next stage. Otherwise we may get highly distorted results which are far from its true value.

The solution to these problems is to prevent or remove the signal contamination or distortion. The operations performed on the signal, to remove the signal contamination or distortion, is called Signal Conditioning. The term signal conditioning includes many other functions in addition to variable conversion and variable manipulation. Many signal conditioning processes may be linear, such as, amplification, attenuation, integration, differentiation, addition and subtraction. Some may be non-linear processes, such as, modulation, filtering, clipping, etc. The signal conditioning processes are performed on the signal to bring it to the desired form for further transmission to next stage in the system. The element that performs this function in any instrument or instrumentation system is known as Signal Conditioning Element.

2.2.5 Data transmission element

There are several situations where the elements of an instrument are actually physically separated. In such situations it becomes necessary to transmit data from one element to another. The element that performs this function is called a Data Transmission Element. For example satellites or the air planes are physically separated from the control stations at earth. For guiding the movements of satellites or the air planes control stations send the radio by a complicated telemetry systems. The signal conditioning and transmission stage is commonly known as Intermediate Stage.

2.2.6 Data presentation element

The function of data presentation element is to convey the information about the quantity under measurement to the personnel handling the instrument or the system for monitoring, control, or analysis purposes. The information conveyed must be in a convenient form. In case data is to be monitored, visual display devices are needed. These devices may be analogue or digital indicating instruments like ammeters, voltmeters, etc. In case the data is to be recorded, recorders like magnetic tapes, high speed camera and T.V. equipment; storage type C.R.T., printers, analogue and digital computers may be used. For control and analysis purpose computers and the control elements are used. The final stage in a measurement system is known as terminating stage.

Figure below presents the block diagram of functional elements of a generalized measuring system / instrument. One must understand the difference between functional elements and the physical elements of measuring system. Functional element indicates only the function to be performed. Physical elements are the actual components or parts of the system. One physical element can perform

more than one function. Similarly one function could be performed by more than one physical element. This is more suitably illustrated in the example of a measuring instrument described below.

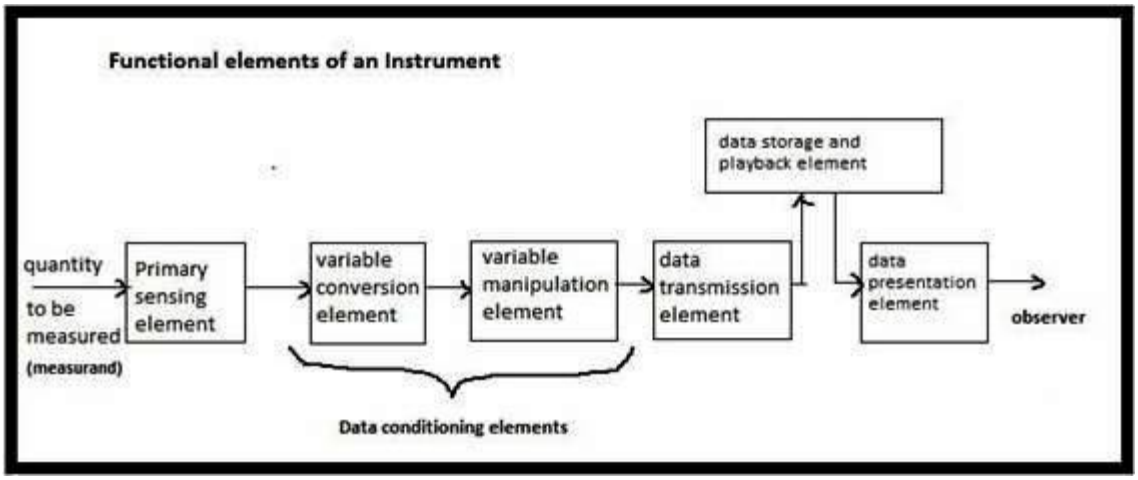


Fig. 1.2 Block diagram of functional elements of a measurement system / instrument

2.3 Functional Elements of a Bourdon Pressure Gauge

As an example of a measurement system, consider the simple Bourdon tube pressure gauge as shown in Fig. 1.2. This gauge offers a good example of a measurement system. In this case, the Bourdon tube acts as the primary sensing element and a variable conversion element. It senses the input quantity (pressure in this case). On account of the pressure the closed end of the Bourdon tube is displaced. Thus, the pressure is converted into a small displacement. The closed end of the Bourdon tube is connected through mechanical linkage to a sector-pinion gearing arrangement. The gearing arrangement amplifies the small displacement and makes the pointer to rotate through a large angle. The mechanical linkage thus acts as a data transmission element while the gearing arrangement acts as a data manipulation element. The dial scale on the gauge body plays the function of data presentation element and conveys the information about the quantity being measured. The information conveyed by this device is in analogue form.

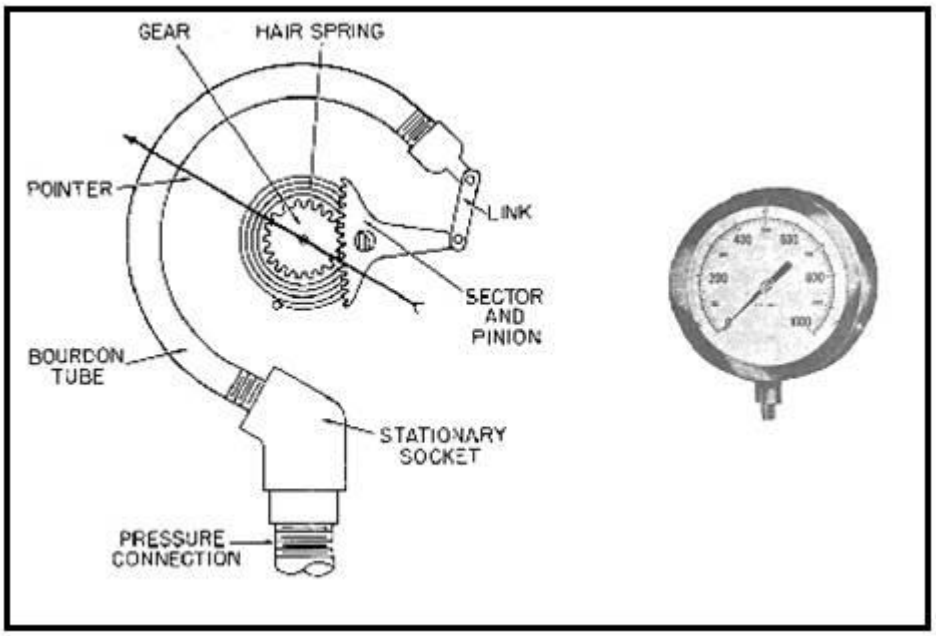


Fig. 1.2 Bourdon Pressure gauge, the pressure measuring instrument

CLASSIFICATION OF INSTRUMENTS

3.1 Introduction

In the physical science, process engineering and product quality assurance, measurement is the activity of obtaining and comparing physical quantities of real-world objects and events. Established standard objects and events are used as units, and the process of measurement gives a number relating the item under study and the referenced unit of measurement. Measurement generally involves using an instrument as a physical means of determining a quantity or variable. The instrument serves as an extension of human faculties and enables the man to determine the value of an unknown quantity which unaided human faculties cannot measure. An instrument may be defined as a device for determining the value or magnitude of a quantity or variable. Measuring instruments, and formal test methods which define the instrument's use, are the means by which the variables and the relations between variables are obtained

The instruments may be classified as follows:

i) Mechanical, electrical and electronic instruments
ii) Absolute and secondary instruments
iii) Manual and automatic instruments
iv) Analogue and digital instruments
v) Self operated and power operated instruments
vi) Self contained and remote indicating instruments

3.2 Mechanical, Electric and Electronic Instruments

3.2.1 Mechanical instruments

The first instruments were mechanical in nature and the principles on which these instruments worked are even in vogue today. The earliest scientific instruments used the same three essential elements as

our modern instruments do. These elements are a detector, an intermediate transfer device and an indicator, recorder or a storage device.

These instruments are very reliable for static and stable conditions. There is a large number of possibilities of mechanical instruments. It could be calipers, micrometers, scales, measuring tapes, lasers, etc. for measuring distances, a pressure gauge for measuring pressure, strain gauges for measure how much a part is stretched or compressed when a load is applied, tachometer for measuring the rotational speed, multimeter for measuring electrical voltages and currents.

However, the mechanical instruments suffer from a disadvantage that they are unable to respond rapidly to measurements of dynamic and transient conditions. These instruments have several moving parts that are rigid, heavy and bulky and consequently have a large mass. The mass presents inertia problems and hence these instruments cannot follow the rapid changes which are involved in dynamic measurements. Another disadvantage of mechanical instruments is that most of them are a potential source of noise and cause pollution of silence.

Mechanical instruments are simple in design and application. They are more durable and relatively cheaper. No external power source is required for the operation of mechanical instruments. They are quite reliable and accurate for measurements under stable conditions.

3.2.2 Electrical instruments

Electrical methods of indicating and transmitting the output are faster than the respective mechanical methods. However, an electrical system normally depends upon a mechanical pointer movement as an indicating device. Thus owing to the inertial of mechanical movements these instruments have a limited time and frequency response. For example, some electrical recorders can give full scale response in 0.2 seconds; while the majority of industrial recorders have response time of 0.5 to 24 seconds. Some of the galvanometers can follow 50 Hz variations, but as per present day requirements of fast measurements these are also considered to be slow.

Electrical instruments are light and compact. Amplification produced is greater than that produced by mechanical means. They provide greater flexibility and are lighter in construction. These instruments consume less power and hence cause lesser load on the system.

3.2.3 Electronic instruments

Majority of the modern scientific and industrial measurements require very rapid responses. The mechanical and electrical instruments and systems cannot fulfil these requirements. There is a requirement of decreasing the response time and also the detection of dynamic changes in certain parameters. The monitoring time could be of the order of milli seconds (ms) and many a times, micro seconds (s). This has led to the design of todays electronic instruments and their associated circuitry. These instruments involved vacuum tubes or semi-conductor devices. The present day practice is to use semi-conductor devices owing to their many advantages over their vacuum tube counterparts. Since in electronic devices the only movement involved is that of electrons and the inertia of electrons being very small, the response time of these devices is extremely small. For example, a C.R.O. is capable of following dynamic and transient changes of the order of a few nano seconds (10^{-9} s).

Electronically controlled power supplies are used to provide stable voltages for studies in the field of chemical reactions and nuclear instrumentation. Electronic instruments are steadily becoming more

reliable on account of improvements in design and manufacturing processes of semi-conductor devices. Another advantage of using electronic devices is that very weak signals can be detected by using pre-amplifiers and amplifiers. The foremost importance of the electronic instruments is the power amplification provided by the electronic amplifiers. Additional power may be fed into the system to provide an increased power output beyond that of the input. This has been only possible through the use of electronic amplifiers, which have no important mechanical counterpart. This is particularly important where the data presentation devices use stylus type recorders, galvanometers, cathode ray oscilloscopes and magnetic tape recorders.

It is a fact that hydraulic and pneumatic systems may be used for power amplification of signals. However, their use is limited to slow acting control applications like servo-systems, chemical processes and power systems. Electronic instruments find extensive use in detection of electro-magnetically produced signals such as radio, video, and microwave. Electrical and electronic instruments are particularly useful in the intermediate signal modifying stage. Electronic instruments are light compact and have a high degree of reliability. Their power consumption is very low.

Electronic instruments make it possible to build analogue and digital computers without which the modern developments in science and technological are virtually impossible. Computers require a very fast time response and it is only possible with use of electronic instruments. The mathematical processing of signal, such as, summation, differentiating and integrating is possible with electronic measurements. With these instruments non contact or remote measurements are also possible.

3.3 Absolute/primary and Secondary Instruments

Electrical measurements of different parameters like current, voltage, power, energy, etc. are most essential in any industry. These are among the oldest of all measurements. The various electrical instruments may be broadly divided into two categories:

1) Absolute instruments
2) Secondary instruments

3.3.1 Absolute/primary instruments

Absolute/primary instruments are those which give the value of electrical quantity to be measured in terms of the constants of the instruments and their deflection only e.g. tangent galvanometer. These instruments are rarely used except in standard laboratories, especially for calibration of secondary instruments.

3.3.2 Secondary instruments

Secondary instruments are those in which the values of electrical quantity to be measured can be determined from the deflection of the instruments only when they have been pre-calibrated by comparison with an absolute instrument. Without calibration, the deflection of such instruments is meaningless.

Working with absolute instruments for routine work is time consuming since every time a measurement is made, it takes a lot of time to compute the magnitude of the quantity under measurement. It is the secondary instruments which are most generally used in everyday work, the use of the absolute instruments being merely confined within laboratories as standardizing

instruments. A voltmeter, a glass thermometer and a pressure gauge are typical examples of secondary instruments.

Secondary type of measuring instruments has been classified in the following categories:

3.3.2.1 Indicating instruments

Indicating instruments are those which indicate the instantaneous value of the variables being measured, at the time at which it is being measured. Their indications are given by pointers moving over calibrated dials or scales, e.g., ammeter, voltmeter and wattmeter. This movement of pointer or the deflection is not constant but depends on the quantity it measures. As the needle deflects and indicates the amount of current, voltage or any quantity, these are called deflection type of instruments.

3.3.2.2 Recording instruments

Recording instruments are those which give a continuous record of variations of the measured variable over a selected period of time. The moving system of the instrument carries an inked pen which rests tightly on a graph chart. These instruments will go on recording on a graph sheet fixed on the instrument all the variations of the quantity in the time it is connected in the circuit. Normally these recordings will be for one day and the recorded sheets are kept as a record of variation of the quantity with time.

3.2.2.3 Integrating instruments

These are the instruments which will add up the quantity as the time passes or in other words will give a total account of quantity spent in a given time for which it is connected in a circuit. For example, an electric meter measure and register, by a set of dials and pointers, either the total quantity of electricity (in ampere-hours) or the total amount of electrical energy (in watt-hours or kilowatt-hours) supplied to a circuit over a period of time and are known as ampere-hour meters, watt hour meters, energy meters, etc. Another example is house hold water meter. Deflecting type instruments are again classified as follows:

a) Depending upon working principle, such as, moving coil, moving iron, dynamometer, electrostatic type, induction type
b) Depending upon the quantity it measures, such as, voltmeter, ammeter, ohm meter, power factor meter, energy meter etc.
c) Depending upon the shape of the instruments, such as, portable, panel board type with flush mounting or surface mounting.

Deflection is normally with in 90^o, but circular scale instruments are also available which give about 250^o deflection. All the deflecting instruments are marked on scale to indicate its working principle by symbols.

3.4 Manual and Automatic Instruments

Manual require the services of an operator, where as in automatic instruments the operator is not required. For example, measurement of rotational speed by a hand operated tachometer an operator is required to make the contact of the instrument with the rotating shaft. For measurement of temperature by a resistance thermometer by Wheat stone bridge in its circuit an operator is required

to indicate the temperature being measured. Where as, in measurement of temperature by mercury-in-glass thermometer, no operator is required.

3.5 Self Operated and Power Operated Instruments

A self operated instrument does not require any external power source for its operation. In such instruments the output energy is supplied by the input signal e.g. a dial indicator or mercury-in-glass type thermometer.

In power operated instruments some auxiliary power source is required for its operation. This external power source could be electricity, compressed air etc. In such cases the input signal supplies only the insignificant portion of the output power e.g. an electro-mechanical measurement system.

3.6 Self Contained and Remote Indicating Instruments

A self contained instrument has all the physical elements in one assembly e.g. an analog ammeter or a mercury-in-glass thermometer etc. Whereas, in a remote indicating instrument has primary sensory element and the secondary indicating element are located at two different locations linked by transmitting element. These locations could be long distance apart. In modern instrumentation technology such type of arrangement is quite necessary and vogue.

3.7 Contact Type and Non-Contact Type Instruments

In contact type instruments the sensing element of the instrument contacts the control medium for the measurements, for example mercury-in- glass thermometer. Where as in non-contact type instruments the sensor does not contact the control medium. The non-contact type measurement includes optical, radioactive or radiation measurements. Such as, radiation or optical pyrometer, non-touch tachometer etc.

1.4.2 Standards

The term standard is used to denote universally accepted specifications for devices. Components or processes which ensure conformity and interchangeability throughout a particular industry.

A standard provides a reference for assigning a numerical value to a measured quantity. Each basic measurable quantity has associated with it an ultimate standard. Working standards, those used in conjunction with the various measurement making instruments.

The national institute of standards and technology (NIST) formerly called National Bureau of Standards (NBS), it was established by an act of congress in 1901, and the need for such body had been noted by the founders of the constitution. In order to maintain accuracy, standards in a vast industrial complex must be traceable to a single source, which may be national standards.

The following is the generalization of echelons of standards in the national measurement system.

1. Calibration standards
2. Metrology standards
3. National standards

1. **Calibration standards:** Working standards of industrial or governmental laboratories.
2. **Metrology standards:** Reference standards of industrial or Governmental laboratories.
3. **National standards:** It includes prototype and natural phenomenon of SI (Systems International), the world wide system of weight and measures standards. Application of precise measurement has increased so much, that a single national laboratory to perform directly all the calibrations and standardization required by a large country with high technical development. It has led to the establishment of a considerable number of standardizing laboratories in industry and in various other areas. A standard provides a reference or datum for assigning a numerical value to a measured quantity.

4.4.3 Classification of Standards

To maintain accuracy and interchangeability it is necessary that Standards to be traceable to a single source, usually the National Standards of the country, which are further linked to International Standards. The accuracy of National Standards is transferred to working standards through a chain of intermediate standards in a manner given below.

•National Standards

•National Reference Standards

•Working Standards

•Plant Laboratory Reference Standards

•Plant Laboratory Working Standards

•Shop Floor Standards

Evidently, there is degradation of accuracy in passing from the defining standards to the shop floor standards. The accuracy of particular standard depends on a combination of the number of times it has been compared with a standard in a higher echelon, the frequency of such comparisons, the care with which it was done, and the stability of the particular standards itself.

1.4.4 Accuracy of Measurements

The purpose of measurement is to determine the true dimensions of a part. But no measurement can be made absolutely accurate. There is always some error. The amount of error depends upon the following factors:

- The accuracy and design of the measuring instrument
- The skill of the operator
- Method adopted for measurement
- Temperature variations
- Elastic deformation of the part or instrument etc.

Thus, the true dimension of the part cannot be determined but can only by approximate. The agreement of the measured value with the true value of the measured quantity is called accuracy. If the measurement of dimensions of a part approximates very closely to the true value of that dimension, it is said to be accurate. Thus the term accuracy denotes the closeness of the measured value with the true value. The difference between the measured value and the true value is the error of measurement. The lesser the error, more is the accuracy.

1.4.5 Precision

The terms precision and accuracy are used in connection with the performance of the instrument. Precision is the repeatability of the measuring process. It refers to the group of measurements for the same characteristics taken under identical conditions.

It indicates to what extent the identically performed measurements agree with each other. If the instrument is not precise it will give different (widely varying) results for the same dimension when measured again and again. The set of observations will scatter about the mean.

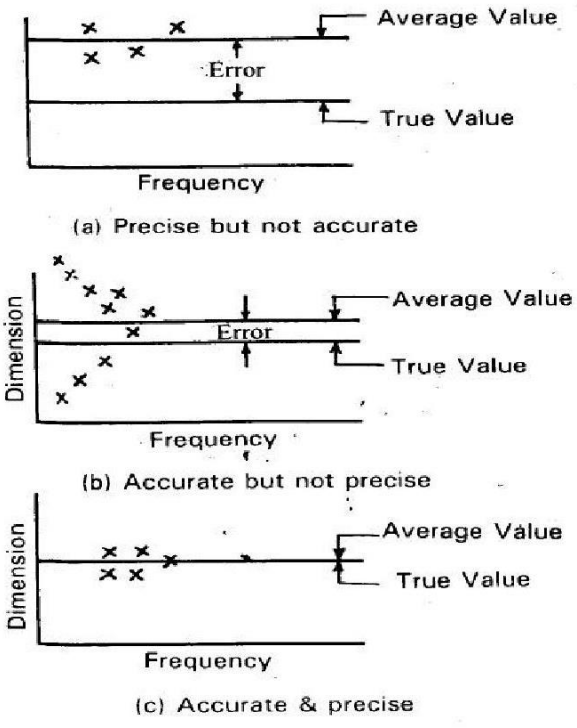
The scatter of these measurements is designated as σ, the standard deviation. It is used as an index of precision. The less the scattering more precise is the instrument. Thus, lower, the value of σ, the more precise is the instrument.

1.4.6 Accuracy

Accuracy is the degree to which the measured value of the quality characteristic agrees with the true value. The difference between the true value and the measured value is known as error of measurement. It is practically difficult to measure exactly the true value and therefore a set of observations is made whose mean value is taken as the true value of the quality measured.

1.4.7 Distinction between Precision and Accuracy

Accuracy is very often confused with precision though much different. The distinction between the precision and accuracy will become clear by the following example. Several measurements are made on a component by different types of instruments (A, B and C respectively) and the results are plotted. In any set of measurements, the individual measurements are scattered about the mean,



and the precision signifies how well the various measurements performed by same instrument on the same quality characteristic agree with each other.

The difference between the mean of set of readings on the same quality characteristic and the true value is called as error. Less the error more accurate is the instrument. Figure shows that the instrument A is precise since the results of number of measurements are close to the average value. However, there is a large difference (error) between the true value and the average value hence it is not accurate. The readings taken by the instruments are scattered much from the average value and hence it is not precise but accurate as there is a small difference between the average value and true value.

1.4.8 Factors affecting the accuracy of the Measuring System

The basic components of an accuracy evaluation are the five elements of a measuring system such as:

- Factors affecting the calibration standards.
- Factors affecting the work piece.
- Factors affecting the inherent characteristics of the instrument.
- Factors affecting the person, who carries out the measurements,
- Factors affecting the environment.

1. **Factors affecting the Standard**: It may be affected by:

   -Coefficient of thermal expansion

   -Calibration interval

   -Stability with time

   -Elastic properties

   -Geometric compatibility

2. **Factors affecting the Work piece**: These are: -Cleanliness

   -Surface finish, waviness, scratch, surface defects etc., -Hidden geometry

   -Elastic properties,-adequate datum on the work piece -Arrangement of supporting work piece

   -Thermal equalization etc.

3. **Factors affecting the inherent characteristics of Instrument**: -Adequate amplification for accuracy objective

   -Scale error

-Effect of friction, backlash, hysteresis, zero drift error

-Deformation in handling or use, when heavy work pieces are measured -Calibration errors

-Mechanical parts (slides, guide ways or moving elements) -Repeatability and readability

-Contact geometry for both work piece and standard.

4. Factors affecting person:

-Training, skill

-Sense of precision appreciation

-Ability to select measuring instruments and standards -Sensible appreciation of measuring cost

-Attitude towards personal accuracy achievements

-Planning measurement techniques for minimum cost, consistent with precision requirements etc.

5. **Factors affecting Environment**:

-Temperature, humidity etc.

-Clean surrounding and minimum vibration enhance precision -Adequate illumination

-Temperature equalization between standard, work piece, andinstrument -Thermal expansion effects due to heat radiation from lights

-Heating elements, sunlight and people

-Manual handling may also introduce thermal expansion.

Higher accuracy can be achieved only if, ail the sources of error due to the above five elements in the measuring system are analyzed and steps taken to eliminate them. The above analysis of five basic metrology elements can be composed into the acronym SWIPE, for convenient reference where,

S – STANDARD W – WORKPIECE I – INSTRUMENT

P – PERSON E – ENVIRONMENT

1.5 SENSITIVITY

Sensitivity may be defined as the rate of displacement of the indicating device of an instrument, with respect to the measured quantity. In other words, sensitivity of an instrument is the ratio of the scale

spacing to the scale division value.

For example, if on a dial indicator, the scale spacing is 1.0 mm and the scale division value is 0.01 mm, then sensitivity is 100. It is also called as amplification factor or gearing ratio. If we now consider sensitivity over the full range of instrument reading with respect to measured quantities as shown in Figure the sensitivity at any value of y=dx/dy, where dx and dy are increments of x and y, taken over the full instrument scale, the sensitivity is the slope of the curve at any value of y.

The sensitivity may be constant or variable along the scale. In the first case we get linear transmission and in the second non-linear transmission.

Sensitivity refers to the ability of measuring device to detect small differences in a quantity being measured. High sensitivity instruments may lead to drifts due to thermal or other effects, and indications may be less repeatable or less precise than that of the instrument of lower sensitivity.

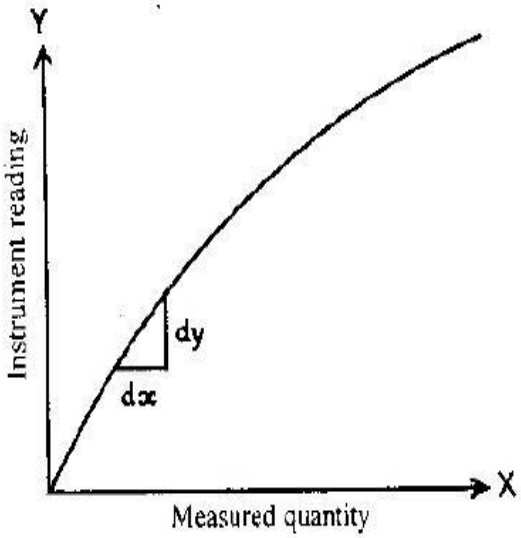


Fig 1.2 Sensitivity of Measurement

1.5.1 Readability

Readability refers to the case with which the readings of a measuring Instrument can be read. It is the susceptibility of a measuring device to have its indications converted into meaningful number. Fine and widely spaced graduation lines ordinarily improve the readability.

If the graduation lines are very finely spaced, the scale will be more readable by using the microscope; however, with the naked eye the readability will be poor. To make micrometers more readable they are provided with vernier scale. It can also be improved by using magnifying devices.

1.5.2 Calibration

The calibration of any measuring instrument is necessary to measure the quantity in terms of standard unit. It is the process of framing the scale of the instrument by applying some standardized signals. Calibration is a pre-measurement process, generally carried out by manufacturers.

It is carried out by making adjustments such that the read out device produces zero output for zero measured input. Similarly, it should display an output equivalent to the known measured input near the full scale input value.

The accuracy of the instrument depends upon the calibration. Constant use of instruments affects their accuracy. If the accuracy is to be maintained, the instruments must be checked and recalibrated

if necessary.

The schedule of such calibration depends upon the severity of use, environmental conditions, accuracy of measurement required etc. As far as possible calibration should be performed under environmental conditions which are vary close to the conditions under which actual measurements are carried out. If the output of a measuring system is linear and repeatable, it can be easily calibrated.

1.5.3 Repeatability

It is the ability of the measuring instrument to repeat the same results for the measurements for the same quantity, when the measurement are carried out-by the same observer,-with the same instrument,-under the same conditions,-without any change in location,-without change in the method of measurement-and the measurements are carried out in short intervals of time. It may be expressed quantitatively in terms of dispersion of the results.

1.5.4 Reproducibility

Reproducibility is the consistency of pattern of variation in measurement i.e. closeness of the agreement between the results of measurements of the same quantity, when individual measurements are carried out:

-by different observers -
by different methods
-using different instruments
-under different conditions, locations, times etc.

1.6 ERRORS IN MEASUREMENTS

It is never possible to measure the true value of a dimension there is always some error. The error in measurement is the difference between the measured value and the true value of the measured dimension.

Error in measurement = Measured value - True value

The error in measurement may be expressed or evaluated either as an absolute error or as a relative error.

1.6.1 Absolute Error

True absolute error:

It is the algebraic difference between the result of measurement and the conventional true value of the quantity measured.

Apparent absolute error:

If the series of measurement are made then the algebraic difference between one of the results of measurement and the arithmetical mean is known as apparent absolute error.

Relative Error:

It is the quotient of the absolute error and the value of comparison use or calculation of that absolute error. This value of comparison may be the true value, the conventional true value or the arithmetic mean for series of measurement. The accuracy of measurement, and hence the error depends upon so many factors, such as:

-calibration standard -Work piece -Instrument

-Person -Environment etc

1.6.2 Types of Errors

1. Systematic Error

These errors include calibration errors, error due to variation in the atmospheric condition Variation in contact pressure etc. If properly analyzed, these errors can be determined and reduced or even eliminated hence also called controllable errors. All other systematic errors can be controlled in magnitude and sense except personal error.

These errors results from irregular procedure that is consistent in action. These errors are repetitive in nature and are of constant and similar form.

2. Random Error

These errors are caused due to variation in position of setting standard and work-piece errors. Due to displacement of level joints of instruments, due to backlash and friction, these error are induced. Specific cause, magnitude and sense of these errors cannot be determined from the knowledge of measuring system or condition of measurement. These errors are non-consistent and hence the name random errors.

3. Environmental Error

These errors are caused due to effect of surrounding temperature, pressure and humidity on the measuring instrument. External factors like nuclear radiation, vibrations and magnetic field also leads to error. Temperature plays an important role where high precision is required. e.g. while using slip gauges, due to handling the slip gauges may acquire human body temperature, whereas the work is at 20°C. A 300 mm length will go

in error by 5 microns which is quite a considerable error. To avoid errors of this kind, all metrology laboratories and standard rooms worldwide are maintained at 20°C.

1.7.3 Calibration

It is very much essential to calibrate the instrument so as to maintain its accuracy. In case when the measuring and the sensing system are different it is very difficult to calibrate the system as an whole, so in that case we have to take into account the error producing properties of each component.

Calibration is usually carried out by making adjustment such that when the instrument is having zero measured input then it should read out zero and when the instrument is measuring some dimension it should read it to its closest accurate value.

It is very much important that calibration of any measuring system should be performed under the environmental conditions that are much closer to that under which the actual measurements are usually to be taken

Calibration is the process of checking the dimension and tolerances of a gauge, or the accuracy of a measurement instrument by comparing it to the instrument/gauge that has been certified as a standard of known accuracy.

Calibration of an instrument is done over a period of time, which is decided depending upon the usage of the instrument or on the materials of the parts from which it is made. The dimensions and the tolerances of the instrument/gauge are checked so that we can come to whether the instrument can be used again by calibrating it or is it wear out or deteriorated above the limit value.

If it is so then it is thrown out or it is scrapped. If the gauge or the instrument is frequently used, then it will require more maintenance and frequent calibration. Calibration of instrument is done prior to its use and afterwards to verify that it is within the tolerance limit or not. Certification is given by making comparison between the instrument/gauge with the reference standard whose calibration is traceable to accepted National standard.

2.1 LINEAR MEASURING INSTRUMENTS

Linear measurement applies to measurement of lengths, diameter, heights and thickness including external and internal measurements. The line measuring instruments have series of accurately spaced lines marked on them e.g. Scale.

The dimensions to be measured are aligned with the graduations of the scale. Linear measuring instruments are designed either for line measurements or end measurements. In end measuring instruments, the measurement is taken between two end surfaces as in micrometers, slip gauges etc.

The instruments used for linear measurements can be classified as:

1. Direct measuring instruments
2. Indirect measuring instruments

The Direct measuring instruments are of two types:

1. Graduated
2. Non Graduated

The graduated instruments include rules, vernier calipers, vernier height gauges, vernier depth gauges, micrometers, dial indicators etc.

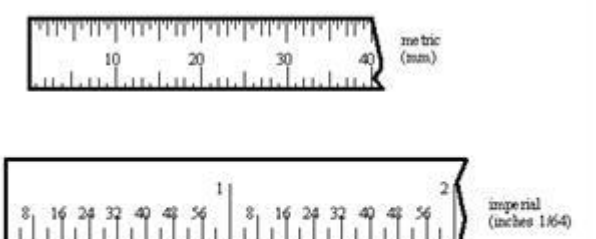
The non graduated instruments include calipers, trammels, telescopic gauges, surface gauges, straight edges, wire gauges, screw pitch gauges, radius gauges, thickness gauges, slip gauges etc.

They can also be classified as

1. Non precision instruments such as steel rule, calipers etc.,
2. Precision measuring instruments, such as vernier instruments, micrometers, dial gauges etc.

2.1.1 SCALES

- The most common tool for crude measurements is the scale (also known as **rules, or rulers**).
- Although plastic, wood and other materials are used for common scales, precision scales use tempered steel alloys, with graduations scribed onto the surface.
- These are limited by the human eye. Basically they are used to compare two dimensions.
- The metric scales use decimal divisions, and the imperial scales use fractional divisions.
- Some scales only use the fine scale divisions at one end of the scale. It is advised that the end of the scale not be used for measurement. This is because as they become worn with use, the end of the scale will no longer be at a `zero' position.
- Instead the internal divisions of the scale should be used. Parallax error can be a factor when making measurements with a scale.



2.1.2 CALIPERS

Caliper is an instrument used for measuring distance between or over surfaces comparing dimensions of work pieces with such standards as plug gauges, graduated rules etc. Calipers may be difficult to use, and they require that the operator follow a few basic rules, do not force them, they will bend easily, and invalidate measurements made. If measurements are made using calipers for comparison, one operator should make all of the measurements (this keeps the feel factor a minimal error source). These instruments are very useful when dealing with hard to reach locations that normal measuring instruments cannot reach. Obviously the added step in the measurement will significantly decrease the accuracy.

2.1.3 VERNIER CALIPERS

The vernier instruments generally used in workshop and engineering metrology have comparatively low accuracy. The line of measurement of such instruments does not coincide with the line of scale.

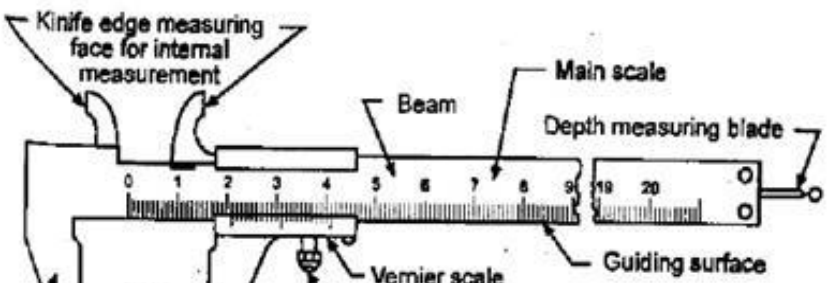
The accuracy therefore depends upon the straightness of the beam and the squareness of the sliding jaw with respect to the beam. To ensure the squareness, the sliding jaw must be clamped before taking the reading.

The zero error must also be taken into consideration. Instruments are now available with a measuring range up to one meter with a scale value of 0.1 or 0.2 mm.

Types of Vernier Calipers

According to Indian Standard IS: 3651-1974, three types of vernier calipers have been specified to make external and internal measurements and are shown in figures respectively. All the three types are made with one scale on the front of the beam for direct reading.

Type A: Vernier has jaws on both sides for external and internal measurements and a blade for depth measurement.



Type B: It is provided with jaws on one side for external and internal measurements.

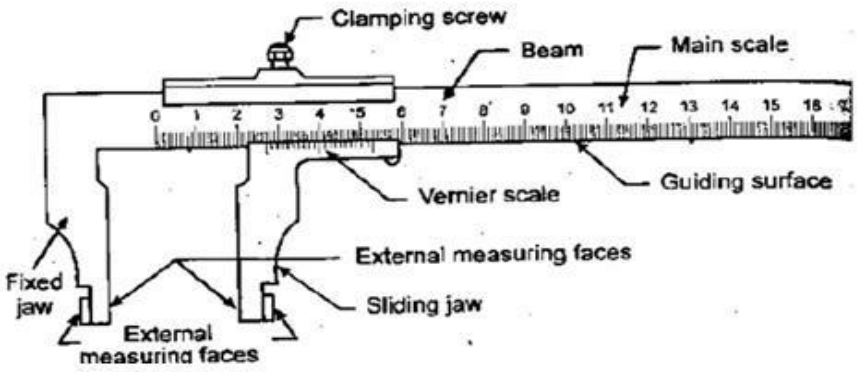


Fig 2.3 Vernier Caliper - Type B

Type C: It has jaws on both sides for making the measurement and for marking operations

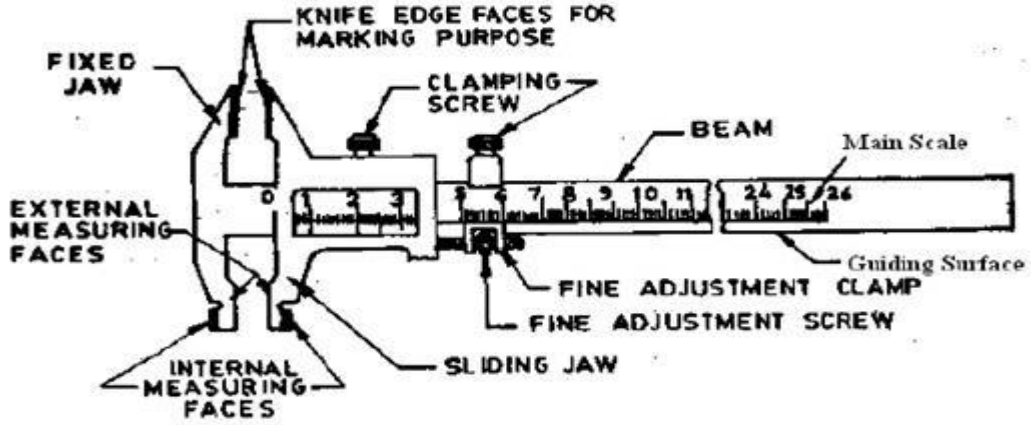


Fig 2.4 Vernier Caliper - Type C

Errors in Calipers

The degree of accuracy obtained in measurement greatly depends upon the condition of the jaws of the calipers and a special attention is needed before proceeding for the measurement. The accuracy and natural wear, and warping of Vernier caliper jaws should be tested frequently by closing them together tightly and setting them to 0-0 point of the main and Vernier scales.

2.1.4 MICROMETERS

There are two types in it.

(i) Outside micrometer — To measure external dimensions.

(ii) Inside micrometer — To measure internal dimensions.

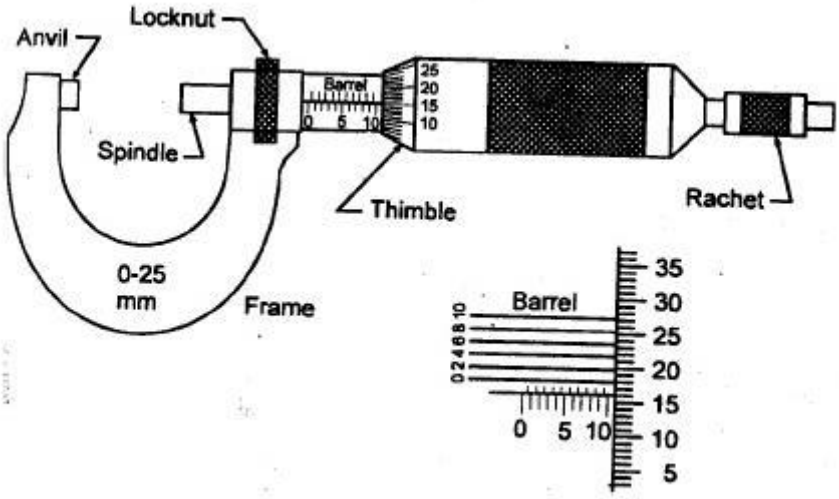


Fig 2.5 Micrometer

An outside micrometer is shown. It consists of two scales, main scale and thimble scale. While the pitch of barrel screw is 0.5 mm the thimble has graduation of 0.01 mm. The **least count** of this micrometer is 0.01 mm.

The micrometer requires the use of an accurate screw thread as a means of obtaining a measurement. The screw is attached to a spindle and is turned by movement of a thimble or ratchet at the end. The barrel, which is attached to the frame, acts as a nut to engage the screw threads, which are accurately made with a pitch of 0.05mm. Each revolution of the thimble advances the screw 0.05mm. On the barrel a datum line is graduated with two sets of division marks.

2.1.5 SLIP GAUGES

These may be used as reference standards for transferring the dimension of the unit of length from the primary standard to gauge blocks of lower accuracy and for the verification and graduation of measuring apparatus.

These are high carbon steel hardened, ground and lapped rectangular blocks, having cross sectional area 0f 30 mm and 10mm. Their opposite faces are flat, parallel and are accurately the stated distance apart. The opposite faces are of such a high degree of surface finish, that when the blocks are pressed together with a slight twist by hand, they will wring together.

They will remain firmly attached to each other. They are supplied in sets of 112 pieces down to 32 pieces. Due to properties of slip gauges, they are built up by, wringing into combination which gives size, varying by steps of 0.01 mm and the overall accuracy is of the order of 0.00025mm.

Slip gauges with three basic forms are commonly found, these are rectangular, square with center hole, and square without center hole.

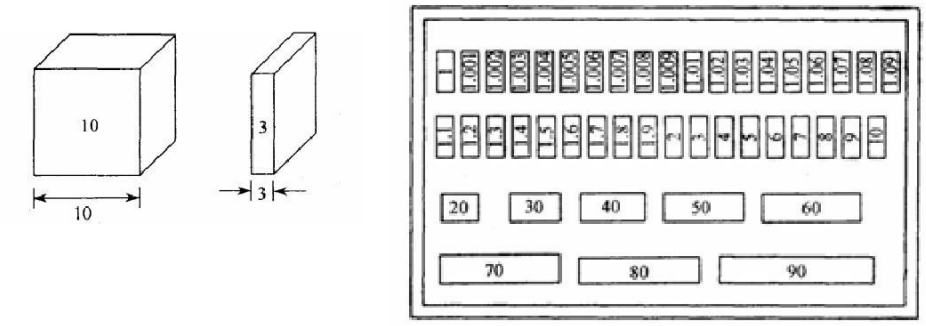


Fig 2.6 Slip Gauge

Wringing or Sliding is nothing but combining the faces of slip gauges one over the other. Due to adhesion property of slip gauges, they will stick together. This is because of very high degree of surface finish of the measuring faces.

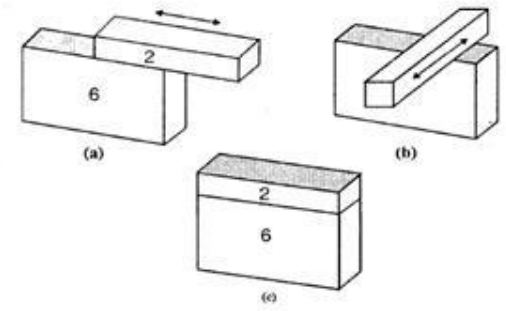


Fig 2.7 Wringing of slip gauge

Classification of Slip Gauges

Slip gauges are classified into various types according to their use as follows:

1) Grade 2

2) Grade 1

3) Grade 0

4) Grade 00

5) Calibration grade.

1.1.4 Grade 2:

It is a workshop grade slip gauges used for setting tools, cutters and checking dimensions roughly.

2) Grade 1:

The grade I is used for precise work in tool rooms.

3) Grade 0:

It is used as inspection grade of slip gauges mainly by inspection department.

4) Grade 00:

Grade 00 mainly used in high precision works in the form of error detection in instruments.

5) Calibration grade:

The actual size of the slip gauge is calibrated on a chart supplied by the manufactures.

Manufacture of Slip Gauges

The following additional operations are carried out to obtain the necessary qualities in slip gauges during manufacture.

i. First the approximate size of slip gauges is done by preliminary operations.

ii. The blocks are hardened and wear resistant by a special heat treatment process.

iii. To stabilize the whole life of blocks, seasoning process is done.

iv. The approximate required dimension is done by a final grinding process.

v. To get the exact size of slip gauges, lapping operation is done.

vi. Comparison is made with grand master sets.

Slip Gauges accessories

The application slip gauges can be increased by providing accessories to the slip gauges. The various accessories are

- Measuring jaw
- Scriber and Centre point.
- Holder and base

1. Measuring jaw:

It is available in two designs specially made for internal and external features.

2. Scriber and Centre point:

It is mainly formed for marking purpose.

3. Holder and base:

Holder is nothing but a holding device used to hold combination of slip gauges. Base in designed for mounting the holder rigidly on its top surface.

2.2 INTERFEROMETERS

They are optical instruments used for measuring flatness and determining the length of the slip gauges by direct reference to the wavelength of light. It overcomes the drawbacks of optical flats used in ordinary daylight. In these instruments the lay of the optical flat can be controlled and fringes can be oriented as per the requirement. An arrangement is made to view the fringes directly from the top and avoid any distortion due to incorrect viewing.

2.2.1 Optical Flat and Calibration

1. Optical flat are flat lenses, made from quartz, having a very accurate surface to transmit light.
2. They are used in interferometers, for testing plane surfaces.
3. The diameter of an optical flat varies from 50 to 250 nun and thickness varies from 12 to 25 mm.
4. Optical flats are made in a range of sizes and shapes.
5. The flats are available with a coated surface.
6. The coating is a thin film, usually titanium oxide, applied on the surface to reduce the light lost by reflection.
7. The coating is so thin that it does not affect the position of the fringe bands, but a coated flat. The supporting surface on which the optical flat measurements are made must provide a clean, rigid platform. Optical flats are cylindrical in form, with the working surface and are of two types are i) type A, ii) type B.

i) Type A:

It has only one surface flat and is used for testing flatness of precision measuring surfaces of flats, slip gauges and measuring tables. The tolerance on flat should be 0.05 µm for type A.

ii) Type B:

It has both surfaces flat and parallel to each other. They are used for testing measuring surfaces of micrometers, Measuring anvils and similar length of measuring devices for testing flatness and parallelism. For these instruments, their thickness and grades are important. The tolerances on flatness, parallelism and thickness should be 0.05 µm.

2 Interference Bands by Optical Flat

Optical flats arc blocks of glass finished to within 0.05 microns for flatness. When art optical flat is on a flat surface which is not perfectly flat then optical flat will not exactly coincide with it, but it will make an angle e with the surface as shown in Figure 2.8.

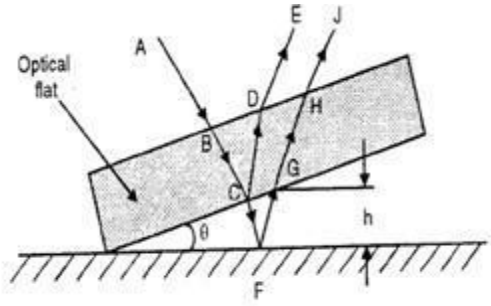


Fig 2.8 Optical Flat

2.3 LIMIT GAUGES

- A limit gauge is not a measuring gauge. Just they are used as inspecting gauges.
- The limit gauges are used in inspection by methods of attributes.
- This gives the information about the products which may be either within the prescribed limit or not.
- By using limit gauges report, the control charts of P and C charts are drawn to control invariance of the products.
- This procedure is mostly performed by the quality control department of each and every industry.
- Limit gauge are mainly used for checking for cylindrical holes of identical components with a large numbers in mass production.

2.3.1 Purpose of using limit gauges

- Components are manufactured as per the specified tolerance limits, upper limit and lower limit. The dimension of each component should be within this upper and lower limit.
- If the dimensions are outside these limits, the components will be rejected.
- If we use any measuring instruments to check these dimensions, the process will consume more time. Still we are not interested in knowing the amount of error in dimensions.
- It is just enough whether the size of the component is within the prescribed limits or not. For this purpose, we can make use of gauges known as limit gauges.

The common types are as follows:

Plug gauges.

Ring gauges.

Snap gauges.

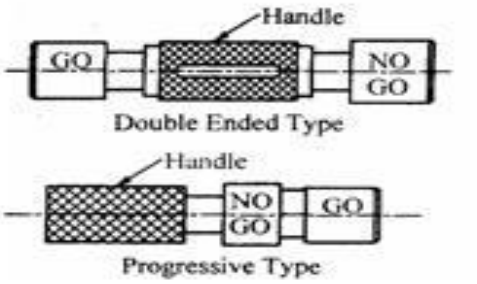


Fig 2.9 Plug Gauge

2.4 PLUG GAUGES

- The ends are hardened and accurately finished by grinding. One end is the GO end and the other end is NOGO end.
- Usually, the GO end will be equal to the lower limit size of the hole and the NOGO end will be equal to the upper limit size of the hole.
- If the size of the hole is within the limits, the GO end should go inside the hole and NOGO end should not go.
- If the GO end and does not go, the hole is under size and also if NOGO end goes, the hole is **over size**. Hence, the components are rejected in both the cases.

1. Double ended plug gauges

In this type, the GO end and NOGO end are arranged on both the ends of the plug. This type has the advantage of easy handling.

2. Progressive type of plug gauges

In this type both the GO end and NOGO end are arranged in the same side of the plug. We can use the plug gauge ends progressively one after the other while checking the hole. It saves time. Generally, the GO end is made larger than the NOGO end in plug gauges.

2.5 TAPER PLUG GAUGE

Taper plug gauges are used to check tapered holes. It has two check lines. One is a GO line and another is a NOGO line. During the checking of work, NOGO line remains outside the hole and GO line remains inside the hole.

They are various types taper plug gauges are available as shown in fig. Such as

2 Taper plug gauge — plain

3 Taper plug gauge — tanged.

4 Taper ring gauge plain

5 Taper ring gauge — tanged.

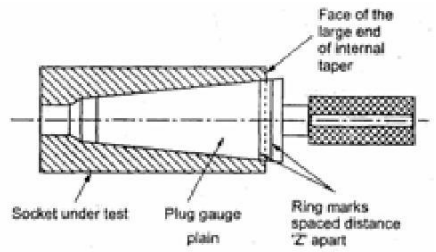


Fig 2.10 Taper Gauge

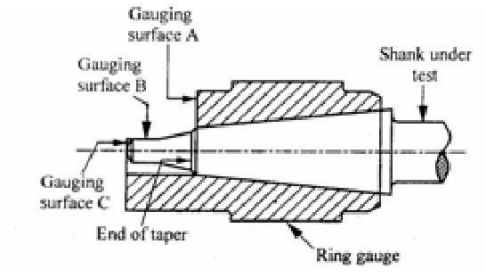


Fig 2.11 Taper ring Gauge plain

2.6 RING GAUGES

- Ring gauges are mainly used for checking the diameter of shafts having a central hole. The hole is accurately finished by grinding and lapping after taking hardening process.
- The periphery of the ring is knurled to give more grips while handling the gauges. We have to make two ring gauges separately to check the shaft such as GO ring gauge and NOGO ring gauge.
- But the hole of GO ring gauge is made to the upper limit size of the shaft and NOGO for the lower limit.
- While checking the shaft, the GO ring gauge will pass through the shaft and NOGO will not pass.

- To identify the NOGO ring gauges easily, a red mark or a small groove cut on its periphery.

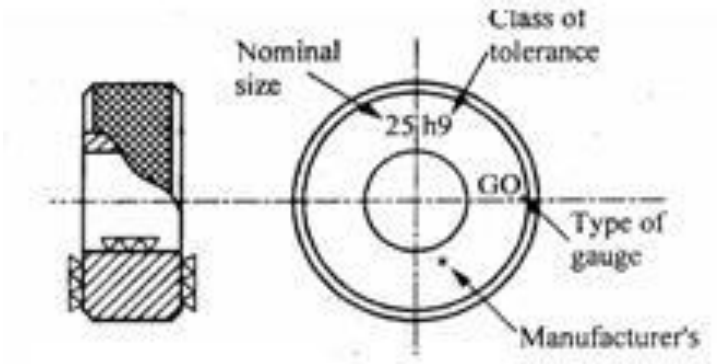


Fig 2.12 Ring Gauge

2.7 SNAP GAUGE

Snap gauges are used for checking external dimensions. They are also called as gap gauges. The different types of snap gauges are:

1. Double Ended Snap Gauge

This gauge is having two ends in the form of anvils. Here also, the GO anvil is made to lower limit and NOGO anvil is made to upper limit of the shaft. It is also known as solid snap gauges

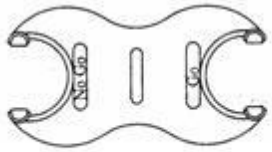


Fig 2.13 Double ended Snap Gauge

2. Progressive Snap Gauge

This type of snap gauge is also called caliper gauge. It is mainly used for checking large diameters up to 100mm. Both GO and NOGO anvils at the same end. The GO anvil should be at the front and NOGO anvil at the rear. So, the diameter of the shaft is checked progressively by these two ends. This type of gauge is made of horse shoe shaped frame with I section to reduce the weight of the snap gauges.

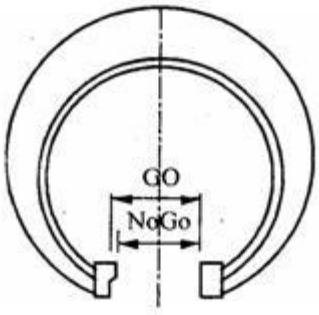


Fig 2.14 Progressive Snap Gauge

3. Adjustable Snap Gauge

Adjustable snap gauges are used for checking large size shafts made with horseshoe shaped frame of I

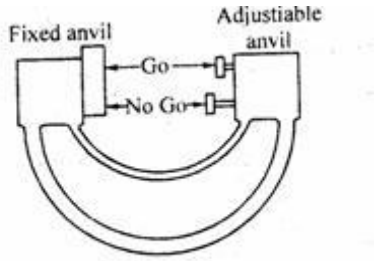


Fig 2.15 Adjustable Snap Gauge

section. It has one fixed anvil and two small adjustable anvils. The distance between the two anvils is adjusted by adjusting the adjustable anvils by means of setscrews. This adjustment can be made with the help of slip gauges for specified limits of size.

4. Combined Limit Gauges

A spherical projection is provided with GO and NOGO dimension marked in a single gauge. While using GO gauge the handle is parallel to axes of the hole and normal to axes for NOGO gauge.

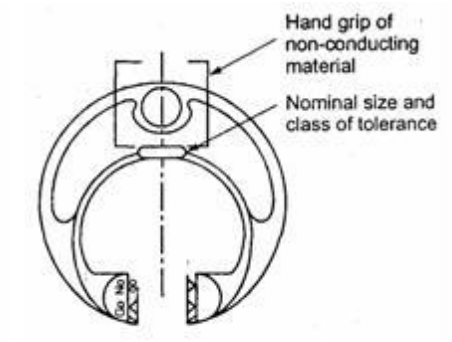


Fig 2.17 Position Gauge

5. Position Gauge

It is designed for checking the position of features in relation to another surface. Other types of gauges are also available such as contour gauges, receiver gauges, profile gauges etc.

2.8 TAYLOR' S PRINCIPLE

It states that GO gauge should check all related dimensions. Simultaneously NOGO gauge should check only one dimension at a time.

Maximum metal condition

It refers to the condition of hole or shaft when maximum material is left on i.e. high limit of shaft and low limit of hole.

Minimum metal condition

If refers to the condition of hole or shaft when minimum material is left on such as low limit of shaft and high limit of hole.

Applications of Limit Gauges

Thread gauges

Form gauges

Screw pitch gauges

Radius and fillet gauges

Feeler gauges

Plate gauge and Wire gauge

2.9 COMPARATORS

Comparators are one form of linear measurement device which is quick and more convenient for checking large number of identical dimensions. Comparators normally will not show the actual dimensions of the work piece. They will be shown only the deviation in size. i.e.

During the measurement a comparator is able to give the deviation of the dimension from the set dimension. This cannot be used as an absolute measuring device but can only compare two dimensions.

Comparators are designed in several types to meet various conditions. Comparators of every type incorporate some kind of magnifying device. The magnifying device magnifies how much dimension deviates, plus or minus, from the standard size.

The comparators are classified according to the principles used for obtaining magnification. The common types are:

1) Mechanical comparators

2) Electrical comparators

3) Optical comparators

4) Pneumatic comparators

5) MECHANICAL COMPARATORS

Mechanical comparator employs mechanical means for magnifying small deviations. The method of magnifying small movement of the indicator in all mechanical comparators are effected by means of levers, gear trains or a combination of these elements. Mechanical comparators are available having magnifications from 300 to 5000 to 1. These are mostly used for inspection of small parts machined to close limits.

1. Dial indicator

A dial indicator or dial gauge is used as a mechanical comparator. The essential parts of the instrument are like a small clock with a plunger projecting at the bottom as shown in

fig.

Very slight upward movement on the plunger moves it upward and the movement is indicated by the dial pointer. The dial is graduated into 100 divisions.

A full revolution of the pointer about this scale corresponds to 1mm travel of the plunger. Thus, a turn of the pointer b one scale division represents a plunger travel of 0.01mm.

Experimental setup

The whole setup consists of worktable, dial indicator and vertical post. The dial indicator is fitted to vertical post by on adjusting screw as shown in fig. The vertical post is fitted on the work table; the top surface of the worktable is finely finished. The dial gauge can be adjusted vertically and locked in position by a screw.

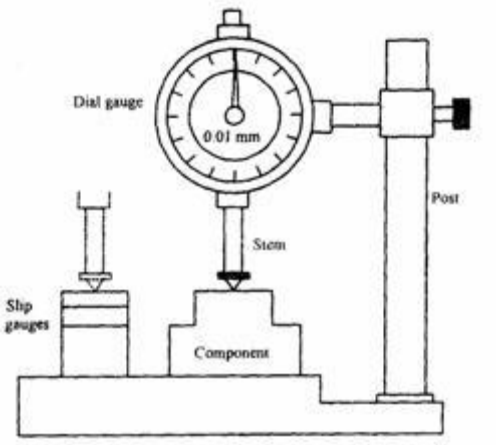


Fig 2.18 Dial Indicator

Procedure

Let us assume that the required height of the component is 32.5mm. Initially this height is built up with slip gauges. The slip gauge blocks are placed under the stem of the dial gauge. The pointer in the dial gauge is adjusted to zero. The slip gauges are removed.

Now the component to be checked is introduced under the stem of the dial gauge. If there is any deviation in the height of the component, it will be indicated by the pointer.

Mechanism

The stem has rack teeth. A set of gears engage with the rack. The pointer is connected to a small pinion. The small pinion is independently hinged. I.e. it is not connected to the stern. The vertical movement of the stem is transmitted to the pointer through a set of gears. A spring gives a constant downward pressure to the stem.

2. Read type mechanical comparator

In this type of comparator, the linear movement of the plunger is specified by means of read mechanism. The mechanism of this type is illustrated in fig. A spring-loaded pointer is pivoted. Initially, the comparator is set with the help of a known dimension eg. Set of slip gauges asshown in fig. Then the indicator reading is adjusted to zero. When the part to be measured is kept under the pointer, then the comparator displays the deviation of this dimension either in ± or— side of the set

dimension.

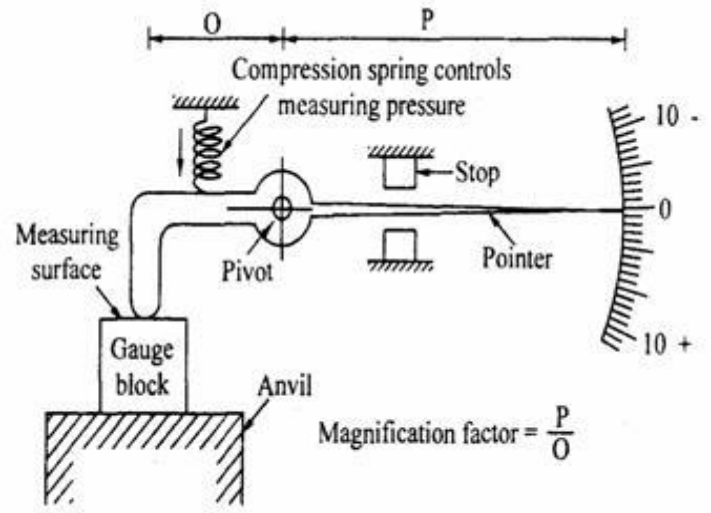


Fig 2.18 Read type Mechanical Comparator

Advantages

1) It is usually robust, compact and easy to handle.

2) There is no external supply such as electricity, air required.

3) It has very simple mechanism and is cheaper when compared to other types.

4) It is suitable for ordinary workshop and also easily portable.

Disadvantages

1. Accuracy of the comparator mainly depends on the accuracy of the rack and pinion arrangement. Any slackness will reduce accuracy.
2. It has more moving parts and hence friction is more and accuracy is less.
3. The range of the instrument is limited since pointer is moving over a fixed scale.

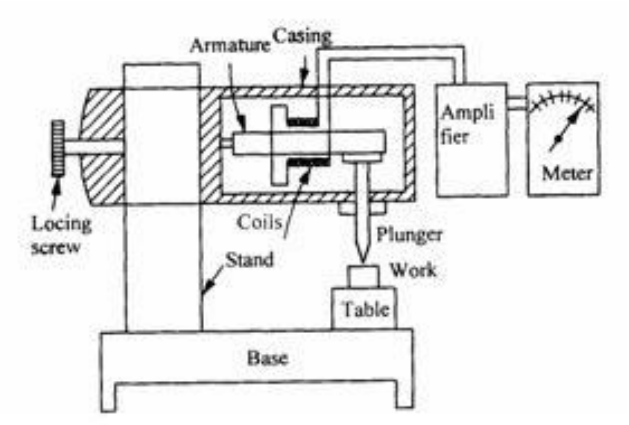
2.9.2 ELECTRICAL COMPARATOR:

An electrical comparator consists of the following three major part such as

1) Transducer

2) Display device as meter

3) Amplifier



Transducer

An iron armature is provided in between two coils held by a lea spring at one end. The other end is supported against a plunger. The two coils act as two arms of an A.C. wheat stone bridge circuit.

Amplifier

The amplifier is nothing but a device which amplifies the give input signal frequency into magnified output

Display device or meter

The amplified input signal is displayed on some terminal stage instruments. Here, the terminal instrument is a meter.

Working principle

If the armature is centrally located between the coils, the inductance of both coils will be equal but in opposite direction with the sign change. Due to this, the bridge circuit of A.C. wheat stone bridge is balanced. Therefore, the meter will read zero value. But practically, it is not possible.

In real cases, the armature may be lifted up or lowered down by the plunger during the measurement. This would upset the balance of the wheat stone bridge circuit. Due to this effect, the change in current or potential will be induced correspondingly. On that time, the meter will indicate some value as displacement. This indicated value may be either for larger or smaller components. As this induced current is too small, it should be suitably amplified before being displayed in the meter.

Checking of accuracy

To check the accuracy of a given specimen or work, first a standard specimen is placed under the plunger. After this, the resistance of wheat stone bridge is adjusted so that the scale reading shows zero. Then the specimen is removed. Now, the work is introduced under the plunger. If height variation of work presents, it will move the plunger up or down. The corresponding movement of the plunger is first amplified by the amplifier then it is transmitted to the meter to show the variations. The least count of this electrical comparator is **0.001mm (one micron).**

2.9.3 ELECTRONIC COMPARATOR

In electronic comparator, transducer induction or the principle of application of frequency modulation or radio oscillation is followed.

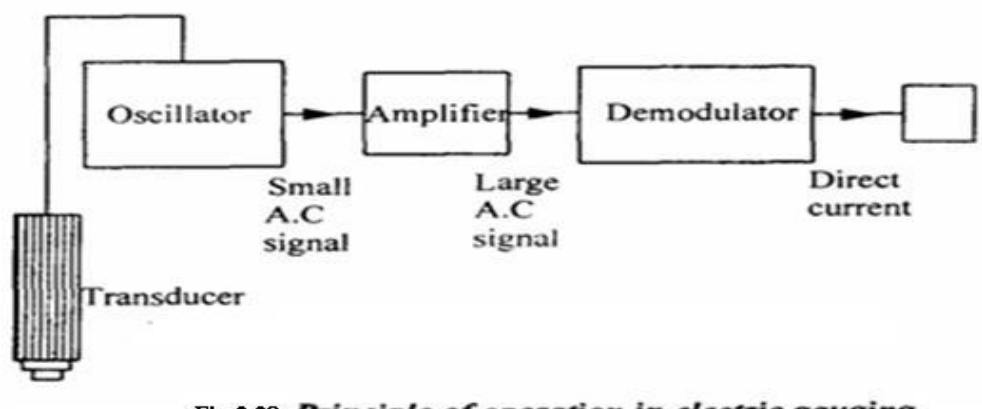


Fig 2.20 *Principle of operation in electric gauging*

Construction details

In the electronic comparator, the following components are set as follows:

i. Transducer

ii. Oscillator

iii. Amplifier

iv. Demodulator

v. Meter

(i) Transducer

It converts the movement of the plunger into an electrical signal. It is connected with oscillator.

(ii) Oscillator

The oscillator which receives electrical signal from the transducer and raises the amplitude of frequency wave by adding carrier frequency called as modulation.

(iii) Amplifier

An amplifier is connected in between oscillator and demodulator. The signal coming out of the oscillator is amplified into a required level.

(iv) Demodulator

Demodulator is nothing but a device which cuts off external carrier wave frequency. i.e. It converts the modulated wave into original wave as electrical signal.

(v) Meter

This is nothing but a display device from which the output can be obtained as a linear measurement.

2.9.3.1 Principle of operation

The work to be measured is placed under the plunger of the electronic comparator. Both work and comparator are made to rest on the surface plate. The linear movement of the plunger is converted into electrical signal by a suitable transducer.

Then it sent to an oscillator to modulate the electrical signal by adding carrier frequency of wave. After that the amplified signal is sent to demodulator in which the carrier waves are cut off. Finally, the demodulated signal is passed to the meter to convert the probe tip movement into linear measurement as an output signal. A separate electrical supply of D.C. is already given to actuate the meter.

2.9.3.2 Advantages of Electrical and Electronic comparator

1) It has less number of moving parts.
2) Magnification obtained is very high.

Two or more magnifications are provided in the same instrument to use various ranges.

The pointer is made very light so that it is more sensitive to vibration.

The instrument is very compact.

2.9.3.3 Disadvantages of Electrical and Electronic comparator

1) External agency is required to meter for actuation.
2) Variation of voltage or frequency may affect the accuracy of output.
3) Due to heating coils, the accuracy decreases.
4) It is more expensive than mechanical comparator.

2.10 SINE BAR

Sine bars are always used along with slip gauges as a device for the measurement of angles very precisely. They are used to

1) Measure angles very accurately.
2) Locate the work piece to a given angle with very high precision.

Generally, sine bars are made from high carbon, high chromium, and corrosion resistant steel. These materials are highly hardened, ground and stabilized.

In sine bars, two cylinders of equal diameter are attached at lie ends with its axes are mutually parallel to each other. They are also at equal distance from the upper surface of the sine bar mostly the distance between the axes of two cylinders is 100mm, 200mm or 300mm. The working surfaces of the rollers are finished to 0.2µm R value. The cylindrical holes are provided to reduce the weight of the sine bar.

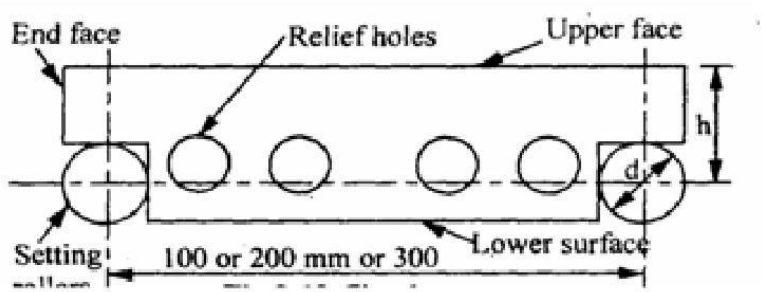


Fig 2.21 Sine Bar

2.10.1 Working principle of sine bar

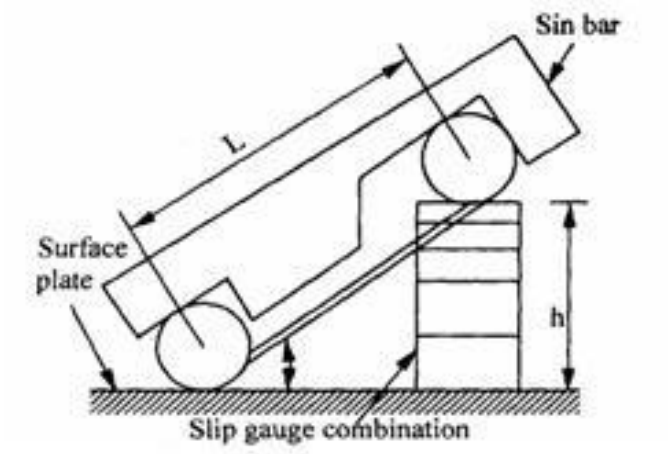


Fig 2.22 Principle of Sine bar

The working of sine bar is based on **trigonometry principle**. To measure the angle of a given specimen, one roller of the sine bar is placed on the surface plate and another one roller is placed over the surface of slip gauges. Now, ‘h be the height of the slip gauges and ‘L’ be the distance between roller centers, then the angle is calculated as

$$\text{Sin}\theta = \frac{h}{L}$$

$$\therefore \theta = Sin^{-1}(h/L)$$

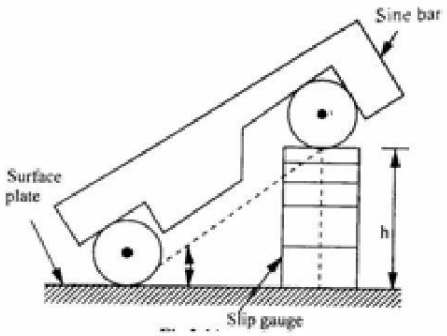


Fig 2.23 Work Location

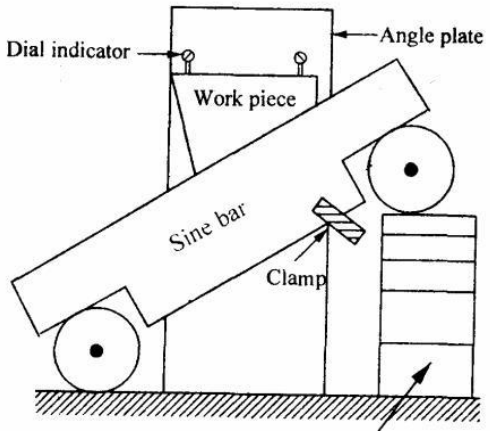
i. To set at a given angle θ, first '*h*' of slip gauge is calculated by the formula $Sin\theta = h/L$
ii. After calculating the height '*h*', the required height '*h*' is made by using suitable slip gauge combinations.
iii. After this, one of the rollers is placed on the top of the sine bar and the other one is placed on the top of the slip gauge combination.

2.10.2 Use of Sine Bar

Locating any' work to a given angle

1. Before checking the unknown angle of the specimen, first the angle (0) of given specimen is found approximately by bevel protractor.
2. Then the sine bar is set at angle of 0 and clamped on the angle plate.
3. Now, the work is placed on the sine bar and the dial indicator set at one end of the work is moved across the work piece and deviation is noted.
4. Slip gauges are adjusted so that the dial indicator reads zero throughout the work surface.

(ii) To check unknown angles:



Limitations of sine bars

1) Sine bars are fairly reliable for angles than 15°.

2) It is physically difficult to hold in position.

3) Slight errors in sine bar cause larger angular errors.

4) A difference of deformation occurs at the point of roller contact with the surface plate and to the gauge blocks.

5) The size of parts to be inspected by sine bar is limited.

Sources of error in sine bars

The different sources of errors are listed below:

1) Error in distance between roller centers.

2) Error in slip gauge combination.

3) Error in checking of parallelism.

4) Error in parallelism of roller axes with each other.

5) Error in flatness of the upper surface of sine bar.

2.11 BEVEL PROTRACTORS

Bevel protractors are nothing but angular measuring instruments.

Types of bevel protractors:

The different types of bevel protractors used are:

1) Vernier bevel protractor

2) Universal protractor

3) Optical protractor

2.11.1 VERNIER BEVEL PROTRACTOR:

Working principle

A vernier bevel protractor is attached with acute angle attachment. The body is designed its back is flat and no projections beyond its back. The base plate is attached to the main body and an adjustable blade is

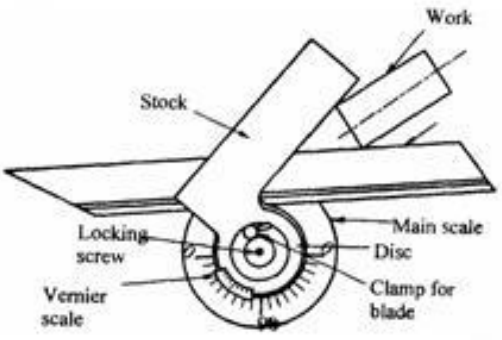


Fig 2.24 Vernier Bevel Protractor

attached to the circular plate containing Vernier scale. The main scale is graduated in degrees from 0° to 90° in both the directions. The adjustable can be made to rotate freely about the center of the main scale and it can be locked at any position.

For measuring acute angle, a special attachment is provided. The base plate is made fiat for measuring angles and can be moved throughout its length. The ends of the blade are beveled at angles of 45° and 60°. The main scale is graduated as one main scale division is 1° and Vernier is graduated

into 12 divisions on each side of zero. Therefore the least count is calculated as

$$Least\ count = \frac{One\ main\ scale\ division}{No.\ of\ divisions\ on\ vernier\ scale}$$

$$= \frac{1^{\circ}}{12}(\text{deg}rees)$$

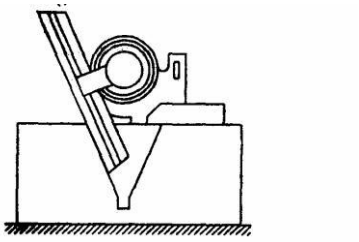
$$= \frac{1}{12} \times 60 = 5\,\text{min}\,utes$$

Thus, the bevel protractor can be used to measure to an accuracy of 5 minutes.

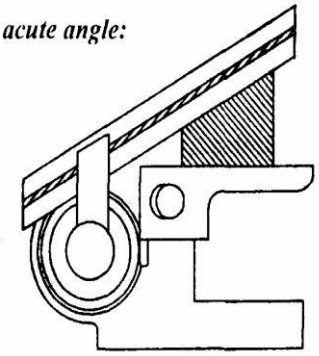
Applications of bevel protractor

The bevel protractor can be used in the following applications.

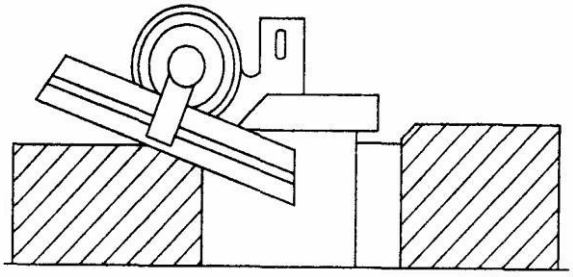
1. For checking a 'V' block:



2. For measuring acute angle:



3. For checking in inside beveled face of a ground surface.



2.12 AUTO- COLLIMATOR

Auto-collimator is an optical instrument used for the measurement of small angular differences, changes or deflection, plane surface inspection etc. For small angular measurements, autocollimator provides a very sensitive and accurate approach. An auto-collimator is essentially an infinity telescope and a collimator combined into one instrument.

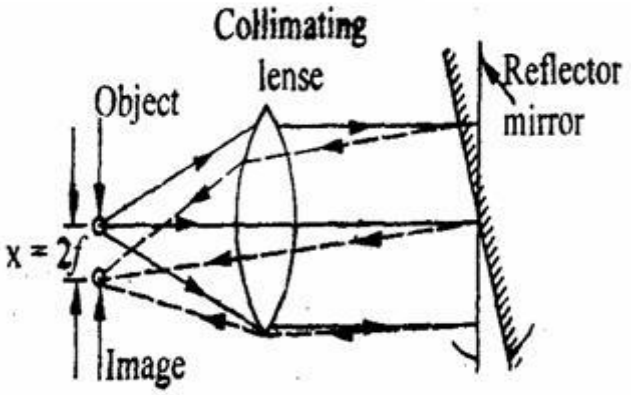


Fig 2.25 Auto-Collimator

Basic principle

If a light source is placed in the flows of a collimating lens, it is projected as a parallel beam of light. If this beam is made to strike a plane reflector, kept normal to the optical axis, it is reflected back along its own path and is brought to the same focus. The reflector is tilted through a small angle

'0'. Then the parallel beam is deflected twice the angle and is brought to focus in the same plane as the light source.

The distance of focus from the object is given by

$$x = 2\theta \, . f$$

Where, f = Focal length of the lens

θ = Fitted angle of reflecting mirror.

2.12.1 WORKING OF AUTO-COLLIMATOR:

There are three main parts in auto-collimator.

1. Micrometer microscope.

2. Lighting unit and

3. Collimating lens.

Figure shows a line diagram of a modern auto-collimator. A target graticule is positioned perpendicular to the optical axis. When the target graticule is illuminated by a lamp, rays of light diverging from the intersection point reach the objective lens via beam splitter. From objective, the

light rays are projected as a parallel rays to the reflector.

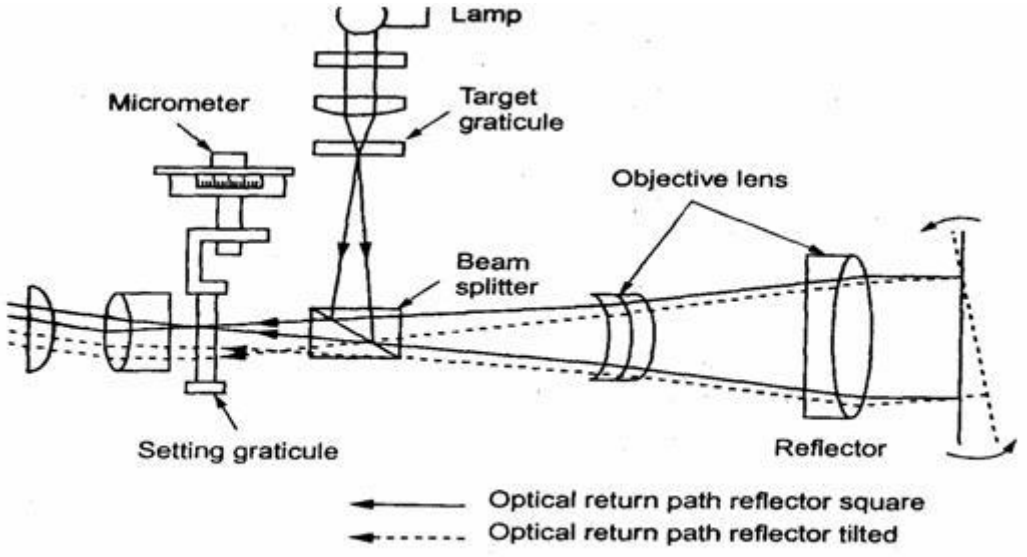


Fig 2.26 Line diagram of an injected graticule auto-collimator

A flat reflector placed in front of the objective and exactly normal to the optical axis reflects the parallel rays of light back along their original paths. They are then brought to the target graticule and exactly coincide with its intersection.

A portion of the returned light passes through the beam splitter and is visible through the eyepiece. If the reflector is tilted through a small angle, the reflected beam will be changed its path at twice the angle. It can also be brought to target graticule but linearly displaced from the actual target by the amount 2θ x f. linear displacement of the graticule image in the plane tilted angle of eyepiece is directly proportional to the reflector. This can be measured by optical micrometer.

The photoelectric auto- collimator is particularly suitable for calibrating polygons, for checking angular indexing and for checking small linear displacements.

2.12.2 APPLICATIONS OF AUTO-COLLIMATOR

Auto-collimators are used for

1) Measuring the difference in height of length standards.
2) Checking the flatness and straightness of surfaces.
3) Checking square ness of two surfaces.
4) Precise angular indexing in conjunction with polygons.
5) Checking alignment or parallelism.

6) Comparative measurement using master angles.

7) Measurement of small linear dimensions.

8) For machine tool adjustment testing.

2.13 ANGLE DEKKOR

This is also a type of auto-collimator. There is an illuminated scale in the focal plane of the collimating lens. This illuminated scale is projected as a parallel beam by the collimating lens which after striking a reflector below the instrument is refocused by the lens in the filed of view of the eyepiece. In the field of view of microscope, there is another datum scale fixed across the center of screen.

The reflected image of the illuminated scale is received at right angle to the fixed scale as shown in fig. Thus the changes in angular position of the reflector in two planes are indicated by changes in the point of intersection of the two scales. One division on the scale is calibrated to read 1 minute.

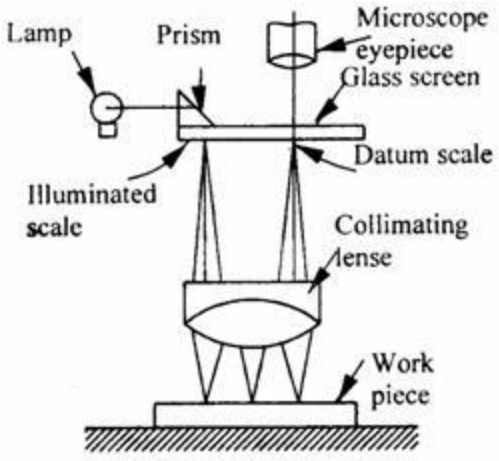


Fig 2.27 Angle Dekkor

2.13.1 Uses of Angle Dekkor

(i) Measuring angle of a component

Angle dekkor is capable of measuring small variations in angular setting i.e. determining angular tilt. Angle dekkor is used in combination with angle gauge. First the angle gauge combination is set up to the nearest known angle of the component. Now the angle dekkor is set to zero reading on the illuminated scale. The angle gauge build up is then removed and replaced by the component under test. Usually a straight edge being used to ensure that there is no change in lateral positions. The new position of the reflected scale with respect to the fixed scale gives the angular tilt of the component from the set angle.

(ii) Checking the slope angle of a V-block

Figure shows the set up for checking the sloping angle of V block. Initially, a polished reflector or slip gauge is attached in close contact with the work surface. By using angle gauge zero reading is obtained in the angle dekkor. Then the angle may be calculated by comparing the reading obtained from the angle dekkor and angle gauge.

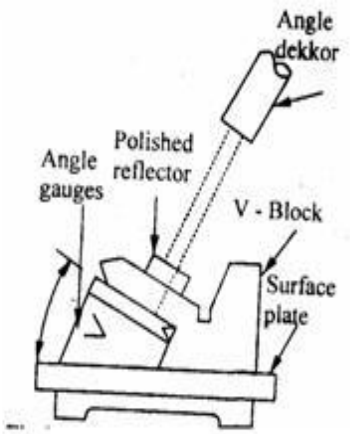


Fig 2.28 Checking of V-Slope Angle Dekkor

(iii) To measure the angle of cone or Taper gauge

Initially, the angle dekkor is set for the nominal angle of cone by using angle gauge or sine bar. The cone is then placed in position with its base resting on the surface plate. A slip gauge or reflector is attached on the cone since no reflection can be obtained from the curved surface. Any deviation from the set angle will be noted by the angle dekkor in the eyepiece and indicated by the shifting of the image of illuminated scale.

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SCHOOL OF MECHANICAL ENGINEERING

DEPARTMENT OF AUTOMOBILE ENGINEERING

UNIT – V - TEMPERATURE, FLOW AND ADVANCED MEASUREMENT TECHNIOUES – SAUA1201

5.1 MEASUREMENT OF FORCE

The mechanical quantity which changes or tends to change the motion or shape of a body to which it is applied is called force. Force is a basic engineering parameter, the measurement of which can be done in many ways as follows:

- Direct methods
- Indirect methods

Direct methods It involves a direct comparison with a known gravitational force on a standard mass, say by a balance.

Indirect methods It involves the measurement of effect of force on a body, such as acceleration of a body of known mass subjected to force.

Devices to measure Force

- Scale and balances
  a. Equal arm balance
  b. Unequal arm balance
  c. Pendulum scale
- Elastic force meter (Proving ring)
- Load cells
  a. Strain gauge load cell
  b. Hydraulic load cell
  c. Pneumatic load cell

5.1.1 Scale and balances

a. Equal arm balance

An equal arm balance works on the principle of moment comparison. The beam of the equal arm balance is in equilibrium position.

when, Clockwise rotating moment = Anti-clockwise rotating moment

$$M_2L_2 = M_1L_1$$

That is, the unknown force is balanced against the known gravitational force.

Description

The main parts of the arrangement are a follows:

- A beam whose centre is pivoted and rests on the fulcrum of a knife edge. Either side of the beam is equal in length with respect to the fulcrum
- A pointer is attached to the center of the beam. This pointer will point vertically downwards when the beam is in equilibrium.
  A Provision to place masses at either end of the beam.

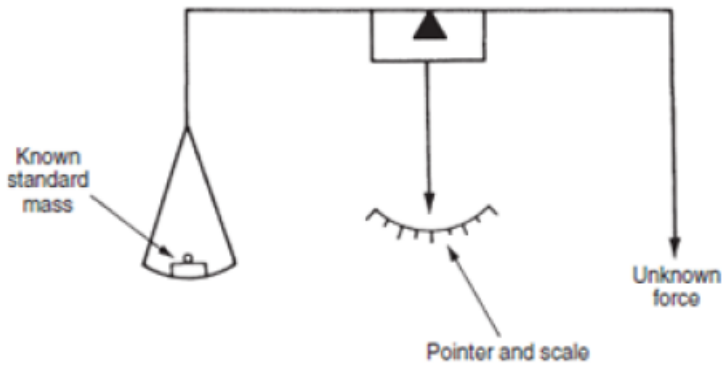


Fig: Equal Arm Balance

Operation

- A known standard mass (m1) is placed at one end of the beam and an unknown mass (m2) is placed at its other end.
- Equilibrium condition exists when, clockwise rotating moment = Anti- clockwise rotating moment Moreover at a given location, the earth's attraction will act equally on both the masses (m1 and m2) and hence at equilibrium condition. W1=W2. That is, the unknown force (weight) will be equal to the known force (weight).

b. Unequal arm balance

An unequal arm balance works on the principle of moment comparison. The beam of the unequal arm balance is in equilibrium position.

when, Clockwise rotating moment = Anti-clockwise rotating moment

$$F \times L2 = Fx \times L1$$

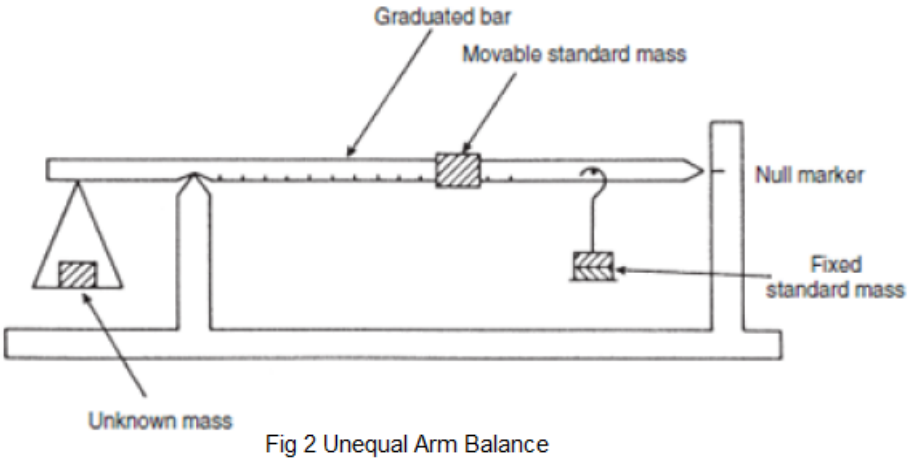


Fig 2 Unequal Arm Balance

Description

The main parts of the arrangements are as follows:

- A graduated beam pivoted to a knife edge "Y"
- A leveling pointer is attached to the beam
- A known mass "m" is attached to the right side of the beam. This creates an unknown force "F". This mass "m" can slide on the right side of the beam.
- Provisions are made to apply an unknown force "Fx" on the left side of the beam.

Operation

- An unknown force "Fx" is applied on the left side of the beam through knife edge "Z" as shown
- Now the position of mass "m" on the right side of the beam is adjusted until the leveling pointer reads null balance position. When the leveling pointer is in null balance position, the beam is in equilibrium.

Clock wise rotating moment = Anti-clock wise rotating moment

$$Fx.L1 = F.\ L2$$

$$Fx = Mg.L2/L1$$

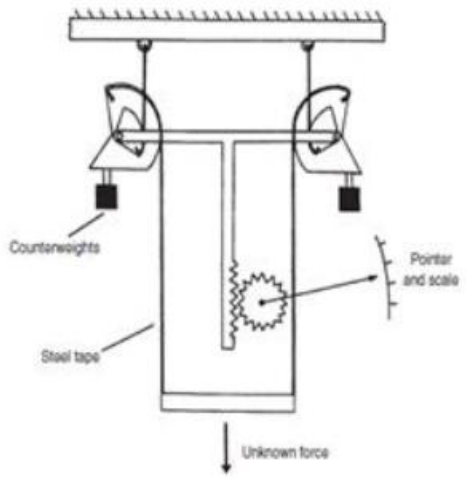
- Thus the unknown force “Fx” is proportional to the distance “L2” of the mass “m” from the knife edge “Y”
- The right hand side of the beam which is graduated is calibrated to get a direct measure of “Fx”

c. Pendulum Scale(Multi-lever Type)

It is a moment comparison device. The unknown force is converted to torque which is then balanced by the torque of a fixed standard mass arranged as a pendulum.

Description

- The scale’s frames carry support ribbons. These support ribbons are attached to the sectors. The loading ribbons are attached to the sectors and the load rod a shown. The load rod is inturn attached to the weighing platform.
- The two sectors are connected on either side of an equalizer beam. The sectors carry counter weighs. To the center of the equalizer beam is attached a rack and pinion arrangement.
- A pointer is attached to the pinion which sweeps over a weight (force) calibrated scale.



Operation

- The unknown force is applied to the load rod. Due to this force, the loading tapes are pulled downwards. Hence the loading tapes rotate the sectors.
- As the sectors rotate about the pivots, it moves the counter weights outwards, This movements increases the counter weight effective moment until the torque produced by the force applied to the load rod and the moment produced by the counter weight balance each other, thereby establishing an equilibrium.
- During the process of establishing equilibrium, the equalizer beam would be displaced downwards. As the rack is attached to the equalizer beam, the rack also is displaced downwards rotating the pinion.
- As the pointer is attached to the pinion, the rotation of the pinion makes the pointer to assume a new position on the scale. The scale is calibrated to read the weight directly. Thus the force applied on the load rod is measured.

5.1.2 Elastic force meter (Proving Ring)

When a steel ring is subjected to a force across its diameter, it deflects. This deflection is proportional to the applied force when calibrated. Description A steel ring attached with external bosses to apply force. A precision micrometer with one of its ends mounted on a vibrating reed.

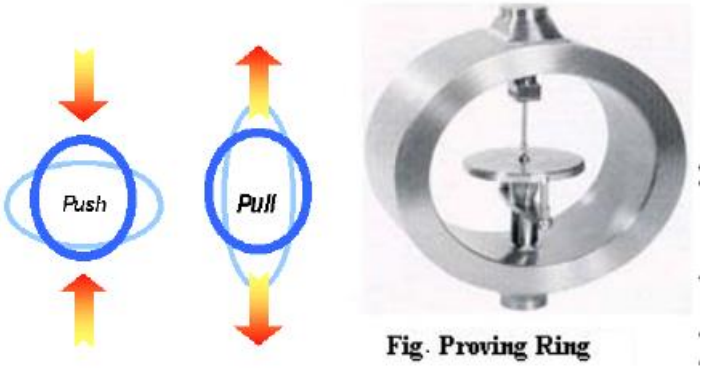


Fig. Proving Ring

Operation

- The force to be measured is applied to the external bosses of the proving ring. Due to the applied force, the ring changes in diameter. This deflection of the ring is proportional to the applied force.
- At this stage, the reed is plucked to obtain a vibrating motion. When the reed is vibrating, the micrometer wheel is turned until the micrometer contact moves forward and makes a noticeable damping of the vibrating reed.
- Now the micrometer reading is noted which is a measure of deflection of the ring. The device is calibrated to get a measure of force in terms of deflection of the proving ring.

5.1.3 Load cells

a. Strain gauge load cell

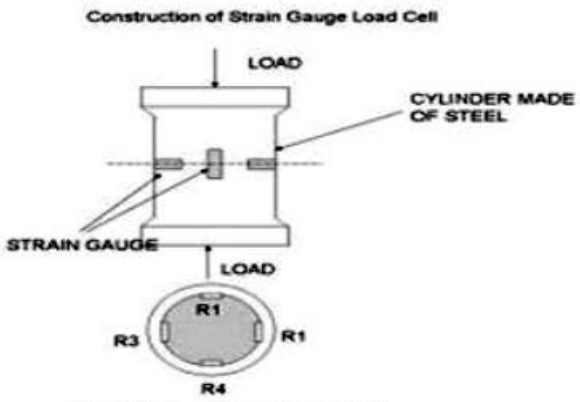


Fig. Strain Gauge Load Cell

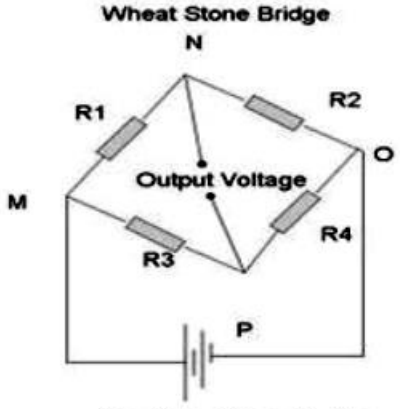


Fig. Wheat Stone Bridge

- When a steel cylinder is subjected to a force, it tends to change in dimension. On this cylinder if strain gauges are bonded, the strain gauge also is stretched or compressed, causing a change in its length and diameter.
- This change in dimension of the strain gauge causes its resistance to change. This change in resistance of the strain gauge becomes a measure of the applied force.

Description

- A cylinder made of steel on which four identical strain gauges are mounted.
- Out of the four strain gauges, two of them (R1 and R4) are mounted along the direction of the applied load(Vertical gauges)
- The other two strain gauges (R2 and R3 horizontal gauges) are mounted circumferentially at right angles to gauges R1 and R4.
- The four gauges are connected to the four limbs of wheat stone bridge. Operation

- When there is no load on the steel cylinder, all the four gauges will have the same resistance. As the terminals N and P are at the same potential, the wheat stone bridge is balanced and hence the output voltage will be zero.
- Now the force to be measured is applied on the steel cylinder. Due to this, the vertical gauges R1 and R4 will under go compression and hence there will be a decrease in resistance. At the same time, the horizontal gauges R2 and R3 will undergo tension and there will be an increase in resistance. Thus when strained, the resistance of the various gauges change.
- Now the terminals N and P will be at different potential and the change in output voltage due to the applied load becomes a measure of the applied load when calibrated.

b. Hydraulic Load Cell

- When a force is applied on liquid medium contained in a confined space, the pressure of the liquid increases. This increase in pressure of the liquid is proportional to the applied force. Hence a measure of the increase in pressure of the liquid becomes a measure of the applied force when calibrated.
- The force to be measure is applied to the piston
- The applied force moves the piston down wards and deflects the diaphragm and this deflection of the diaphragm increase the pressure in the liquid medium.
- This increase in pressure of the liquid medium is proportional to the applied force. This increase in pressure is measured by the pressure gauge which is connected to the liquid medium.
- The pressure is calibrated in force units and hence the indication in the pressure gauge becomes a measure of the force applied on the piston.

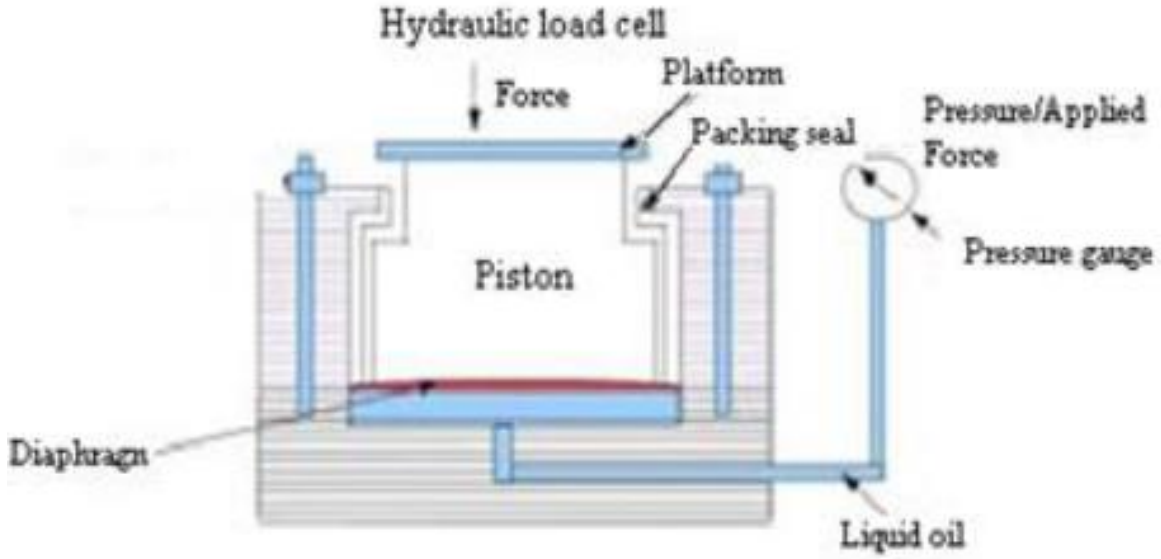


Fig. Hydraulic Load Cell

c. Pneumatic load cells

- If a force is applied to one side of a diaphragm and an air pressure is applied to the other side, some particular value of pressure will be necessary to exactly balance the force. This pressure is proportional to the applied force.

- The force to be measured is applied to the top side of the diaphragm. Due to this force, the diaphragm deflects and causes the flapper to shut-off the nozzle opening.
- Air supply is provided at the bottom of the diaphragm. As the flapper closes the nozzle opening, a back pressure results underneath the diaphragm.
- This back pressure acts on the diaphragm producing an upward force. Air pressure is regulated until the diaphragm returns to the pre-loaded position which is indicated by air which comes out of the nozzle.
- At this stage, the corresponding pressure indicated by the pressure gauge becomes a measure of the applied force when calibrated.

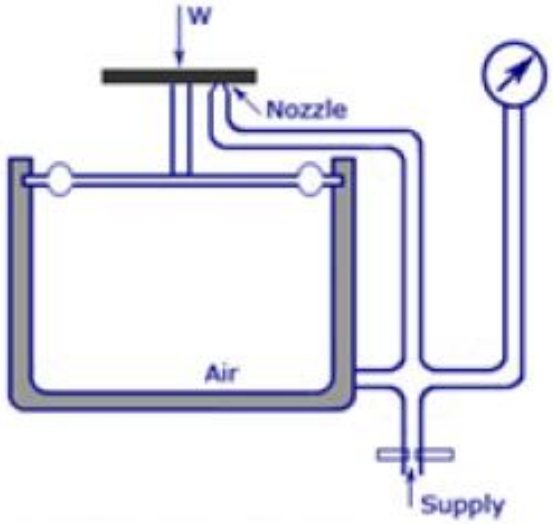


Fig. Pneumatic Load Cell

5.2 TORQUE MEASUREMENT

- Measurement of applied torques is of fundamental importance in all rotating bodies to ensure that the design of the rotating element is adequate to prevent failure under shear stresses.
- Torque measurement is also a necessary part of measuring the power transmitted by rotating shafts.
- The four methods of measuring torque consist of
    1. Measuring the strain produced in a rotating body due to an applied torque
    2. An optical method
    3. Measuring the reaction force in cradled shaft bearings
    4. Using equipment known as the Prony brake.

5.2.1 Measurement of Induced Strain

Measuring the strain induced in a shaft due to an applied torque has been the most common method used for torque measurement in recent years. The method involves bonding four strain gauges onto a shaft as shown in Figure, where the strain gauges are arranged in a d.c. bridge circuit. The output from the bridge circuit is a function of the strain in the shaft and hence of the torque applied.

It is very important that positioning of the strain gauges on the shaft is precise, and the difficulty in achieving this makes the instrument relatively expensive. This technique is ideal for measuring the stalled torque in a shaft before rotation commences.

However, a problem is encountered in the case of rotating shafts because a suitable method then has to be found for making the electrical connections to the strain gauges. One solution to this

problem found in many commercial instruments is to use a system of slip rings and brushes for this, although this increases the cost of the instrument still further.

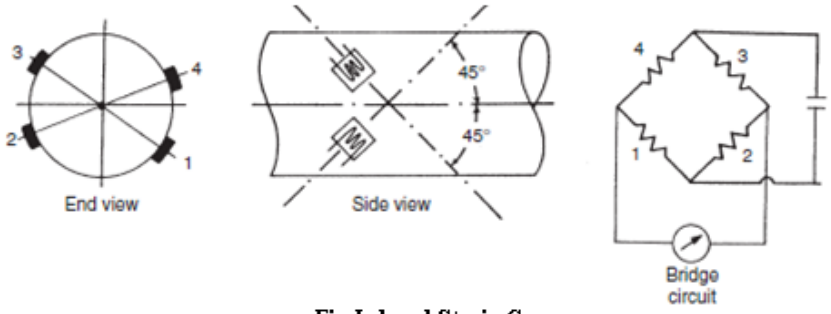


Fig. Induced Strain Gauge

5.2.2. Optical Torque Measurement

Optical techniques for torque measurement have become available recently with the development of laser diodes and fiber-optic light transmission systems. One such system is shown in Figure. Two black-and-white striped wheels are mounted at either end of the rotating shaft and are in alignment when no torque is applied to the shaft.

Light from a laser diode light source is directed by a pair of fiber-optic cables onto the wheels. The rotation of the wheels causes pulses of reflected light, which are transmitted back to a receiver by a second pair of fiber-optic cables. Under zero torque conditions, the two pulse trains of reflected light are in phase with each other. If torque is now applied to the shaft, the reflected light is modulated.

Measurement by the receiver of the phase difference between the reflected pulse trains therefore allows the magnitude of torque in the shaft to be calculated. The cost of such instruments is relatively low, and an additional advantage in many applications is their small physical size.

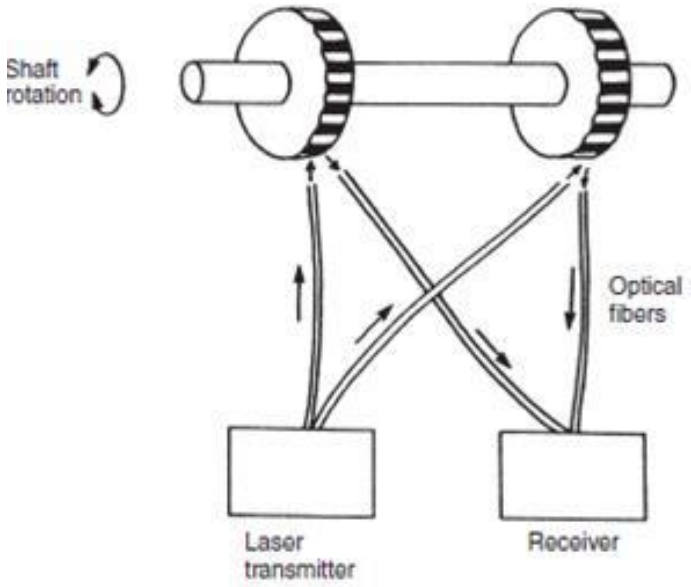


Fig. Optical Torqu Measurement

5.2.3. Reaction Forces in Shaft Bearings

Any system involving torque transmission through a shaft contains both a power source and a power absorber where the power is dissipated. The magnitude of the transmitted torque can be measured by cradling either the power source or the power absorber end of the shaft in bearings, and then measuring the reaction force, F, and the arm length, L, as shown in Figure.

The torque is then calculated as the simple product, FL. Pendulum scales are used very commonly for measuring the reaction force. Inherent errors in the method are bearing friction and windage torques. This technique is no longer in common use.

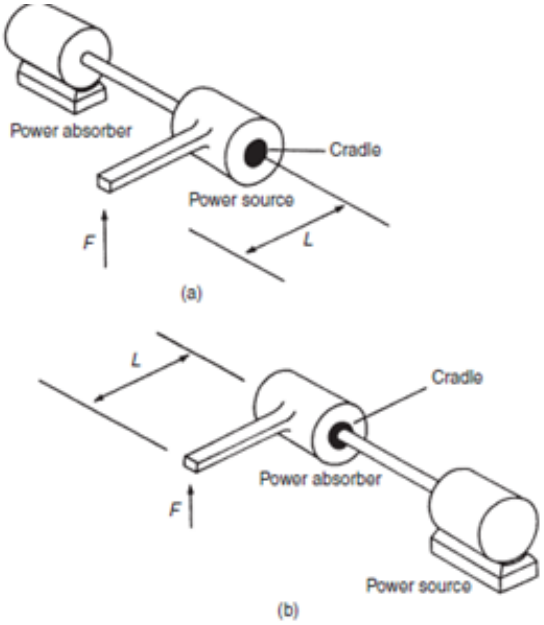


Fig .Measuring Reaction forces in cradled shaft bearing

5.2.4. Prony Brake

The Prony brake is another torque- measuring system that is now uncommon. It is used to measure the torque in a rotating shaft and consists of a rope wound round the shaft, as illustrated in Figure. One end of the rope is attached to a spring balance and the other end carries a load in the form of a standard mass, m.

If the measured force in the spring balance is Fs, then the effective force, Fe, exerted by the rope on the shaft is given by

$$Fe = mg - Fs$$

If the radius of the shaft is Rs and that of the rope is Rr, then the effective radius, Re, of the rope and drum with respect to the axis of rotation of the shaft is given by

$$Re = Rs + Rr$$

The torque in the shaft, T, can then be calculated as

$$T= FeRe$$

While this is a well-known method of measuring shaft torque, a lot of heat is generated because of friction between the rope and shaft, and water cooling is usually necessary.

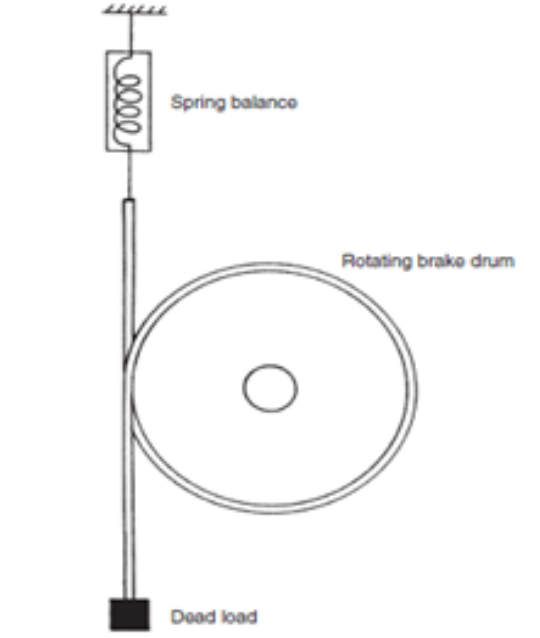


Fig. Prony Brake

5.3 MEASUREMENT OF POWER

Torque is exerted along a rotating shaft. By measuring this torque which is exerted along a rotating shaft, the shaft power can be determined. For torque measurement dynamometers are used.

$T = F.r$ $P = 2\pi NT$

Where,

T – Torque,

F – Force at a known radius r,

P – Power

Types of dynamometers

- Absorption dynamometers
- Driving dynamometers
- Transmission dynamometers

5.3.1 Absorption dynamometers

The dynamometer absorbs the mechanical energy when torque is measured. It dissipates mechanical energy (heat due to friction) when torque is measured. Therefore, dynamometers are used to measure torque/power of power sources like engine and motors.

5.3.2 Mechanical Dynamometers

In prony brake, mechanical energy is converted into heat through dry friction between the wooden brake blocks and the flywheel (pulley) of the machine. One block carries a lever arm. An arrangement is provided to tighten the rope which is connected to the arm. Rope is tightened so as to increase the frictional resistance between the blocks and the pulley. Power dissipated, $P = 2\pi NT/60$ The capacity of proney brake is limited due to wear of wooden blocks, friction coefficient varies. So, it is unsuitable for large powers when it is used for long periods.

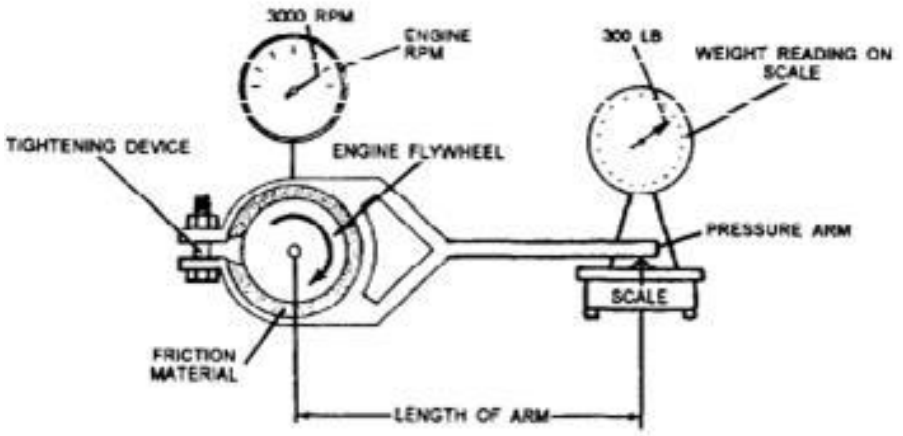


Fig. Mechanical Dynamometer

5.3.3 Eddy Current Dynamometer

Basically an electrical dynamometer of absorption type, used to measure power from a source such as engine or a motor. When a conducting material moves through a magnetic flux field, voltage is generated, which causes current to flow. If the conductor is a wire forming, a part of a complete circuit current will be caused to flow through that circuit and with some form of commutating device a form of A.C or D.C generator may result. An eddy current dynamometer is shown above.

It consists of a metal disc or wheel which is rotated in the flux of a magnetic field. The field if produced by field elements or coils is excited by an external source and attached to the dynamometer housing which is mounted in trunnion bearings. As the disc turns, eddy currents are generated. Its reaction with the magnetic field tends to rotate the complete housing in the trunnion bearings. Water cooling is employed.

5.3.4 Hydraulic or Fluid Friction Dynamometer

A rotating disk that is fixed to the driving shaft, Semi-elliptical grooves are provided on the disc through which a stream of water flows. There is a casting which is stationary and the disc rotates in this casing. When the driving shaft rotates, water flow is in a helical path in the chamber. Due to vortices and eddy-currents setup in the water, the casting tends to rotate in the same direction as that of the driving shafts. By varying the amount of water, the braking action is provided. Braking can also be provided by varying the distance between the rotating disk and the casting. The absorbing element is constrained by a force-measuring device placed at the end of the arm of radius r

5.4 FLOW MEASUREMENTS

The flow rate of a fluid flowing in a pipe under pressure is measured for a variety of applications, such as monitoring of pipe flow rate and control of industrial processes. Differential pressure flow meters, consisting of orifice, flow nozzle, and venturi meters, are widely used for pipe flow measurement and are the topic of this course.

All three of these meters use a constriction in the path of the pipe flow and measure the difference in pressure between the undisturbed flow and the flow through the constriction. That pressure difference can then be used to calculate the flow rate. Flow meter is a device that measures the rate of flow or quantity of a moving fluid in an open or closed conduit. Flow measuring devices are generally classified into four groups. They are

1. Mechanical type flow meters

Fixed restriction variable head type flow meters using different sensors like orifice plate, venturi tube, flow nozzle, pitot tube, dall tube, quantity meters like positive displacement meters, mass flow meters etc. fall under mechanical type flow meters.

2. Inferential type flow meters

Variable area flow meters (Rotameters), turbine flow meter, target flow meters etc.

3. Electrical type flow meters

Electromagnetic flow meter, Ultrasonic flow meter, Laser doppler Anemometers etc. fall under electrical type flow meter.

4. Other flow meters

Purge flow regulators, Flow meters for Solids flow measurement, Cross- correlation flow meter, Vortex shedding flow meters, flow switches etc.

5.4.1 Orifice Flow Meter

An Orifice flow meter is the most common head type flow measuring device. An orifice plate is inserted in the pipeline and the differential pressure across it is measured.

Principle of Operation

The orifice plate inserted in the pipeline causes an increase in flow velocity and a corresponding decrease in pressure. The flow pattern shows an effective decrease in cross section beyond the orifice plate, with a maximum velocity and minimum pressure at the venacontracta.

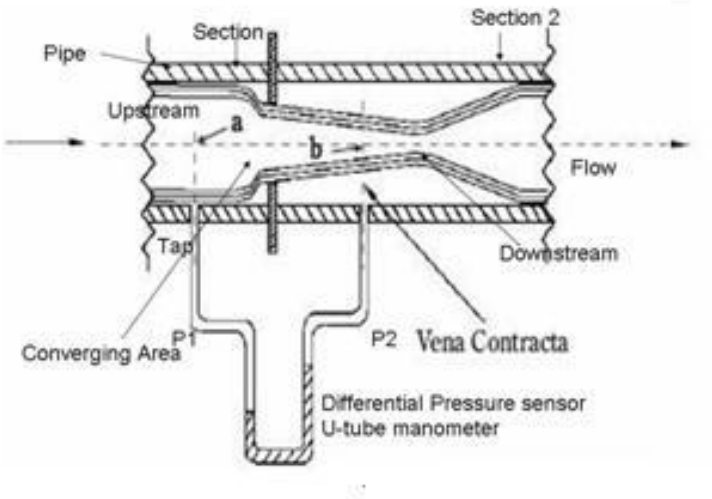
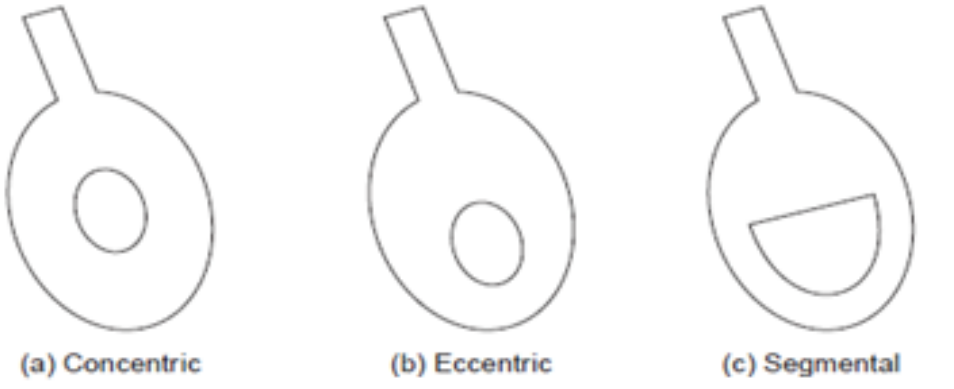


Fig. Orifice Meter

The flow pattern and the sharp leading edge of the orifice plate which produces it are of major importance. The sharp edge results in an almost pure line contact between the plate and the effective flow, with the negligible fluid-to-metal friction drag at the boundary.

Types of Orifice Plates The simplest form of orifice plate consists of a thin metal sheet, having in it a square edged or a sharp edged or round edged circular hole. There are three types of orifice plates namely

a. Concentric, b.Eccentric and c. Segmental type.



The concentric type is used for clean fluids. In metering dirty fluids, slurries and fluids containing solids, eccentric or segmental type is used in such a way that its lower edge coincides with the inside bottom of the pipe. This allows the solids to flow through without any obstruction. The orifice plate is inserted into the main pipeline between adjacent flanges, the outside diameters of the plate being turned to fit within the flange bolts. The flanges are either screwed or welded to the pipes.

Applications

- The concentric orifice plate is used to measure flow rates of pure fluids and has a wide applicability as it has been standardized
- The eccentric and segmental orifice plates are used to measure flow rates of fluids containing suspended materials such as solids, oil mixed with water and wet steam.

Advantages

- It is very cheap and easy method to measure flow rate
- It has predictable characteristics and occupies less space
- Can be used to measure flow rates in large pipes

Limitations

- The vena-contracta length depends on the roughness of the inner wall of the pipe and sharpness of the orifice plate. In certain case it becomes difficult to tap the minimum pressure due the above factor
- Pressure recovery at downstream is poor, that is, overall loss varies from 40 to 90% of the differential pressure.
- In the upstream straightening vanes are a must to obtain laminar flow conditions.
- The orifice plate gets corroded and due to this after sometime, inaccuracy occurs. The coefficient of discharge is low.

5.4.2 Venturi Meter

Venturi tubes are differential pressure producers, based on Bernoulli's Theorem. General performance and calculations are similar to those for orifice plates. In these devices, there is a continuous contact between the fluid flow and the surface of the primary device. It consists of a cylindrical inlet section equal to the pipe diameter, a converging conical section in which the cross sectional area decreases causing the velocity to increase with a corresponding increase in the velocity head and a decrease in the pressure head; a cylindrical throat section where the velocity is constant so that the decreased pressure head can be measured and a diverging recovery cone where the velocity decreases and almost all of the original pressure head is recovered. The unrecovered pressure head is commonly called as head loss.

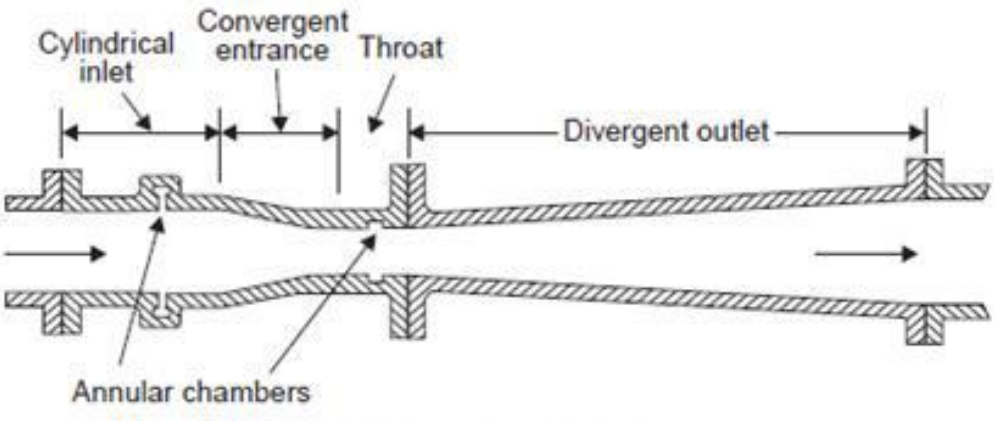


Fig. Long form Venturi

$$\frac{p_1}{\rho} + \frac{{v_1}^2}{2} = \frac{p_2}{\rho} + \frac{{v_2}^2}{2}$$

where

p is pressure (N/m^2)
v is velocity (m/s)
ρ is the density of the liquid (kg/m^3).

$$\therefore \dot{Q} = \frac{a_1 a_2}{\sqrt{\left({a_1}^2 - {a_2}^2\right)}} \sqrt{\frac{2}{\rho}\left(p_1 - p_2\right)}\ \text{m}^3/\text{s}$$

$$\dot{Q} = a_2 \sqrt{\frac{2\left(p_1 - p_2\right)}{\rho\left(1 - \beta^4\right)}}$$

β is the ratio : $\dfrac{\text{throat diameter}}{\text{pipe diameter}}$

Limitations

This flow meter is limited to use on clean, non- corrosive liquids and gases, because it is impossible to clean out or flush out the pressure taps if they clog up with dirt or debris.

5.4.3 Short Form Venturi Tubes

In an effort to reduce costs and laying length, manufactures developed a second generation, or short-form venturi tubes shown in Figure.

There were two major differences in this design. The internal annular chamber was replaced by a single pressure tap or in some cases an external pressure averaging chamber, and the recovery cone angle was increased from 7 degrees to 21 degrees. The short form venture tubes can be manufactured from cast iron or welded from a variety of materials compatible with the application.

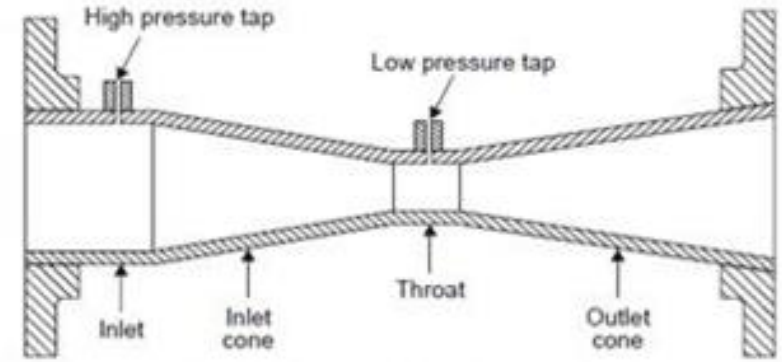


Fig .Short-form Venturi Tube

The pressure taps are located one-quarter to one-half pipe diameter upstream of the inlet cone and at the middle of the throat section. A piezometer ring is sometimes used for differential pressure measurement. This consists of several holes in the plane of the tap locations. Each set of holes is connected together in an annular ring to give an average pressure. Venturis with piezometer connections are unsuitable for use with purge systems used for slurries and dirty fluids since the purging fluid tends to short circuit to the nearest tap holes. Piezometer connections are normally used only on very large tubes or where the most accurate average pressure is desired to compensate for variations in the hydraulic profile of the flowing fluid. Therefore, when it is necessary to meter dirty fluids and use piezometer taps, sealed sensors which mount flush with the pipe and throat inside wall should be used. Single pressure tap venturis can be purged in the normal manner when used with dirty fluids. Because the venturi tube has no sudden changes in contour, no sharp corners, and no projections, it is often used to measure slurries and dirty fluids which tend to build up on or clog of the primary devices.

5.4.3 Flow Nozzle

Flange Type Flow Nozzle

The Flow nozzle is a smooth, convergent section that discharges the flow parallel to the axis of the downstream pipe. The downstream end of a nozzle approximates a short tube and has the diameter of the venacontracta of an orifice of equal capacity. Thus the diameter ratio for a nozzle is smaller or its flow coefficient is larger. Pressure recovery is better than that of an orifice. Figure shows a flow nozzle of flange type.

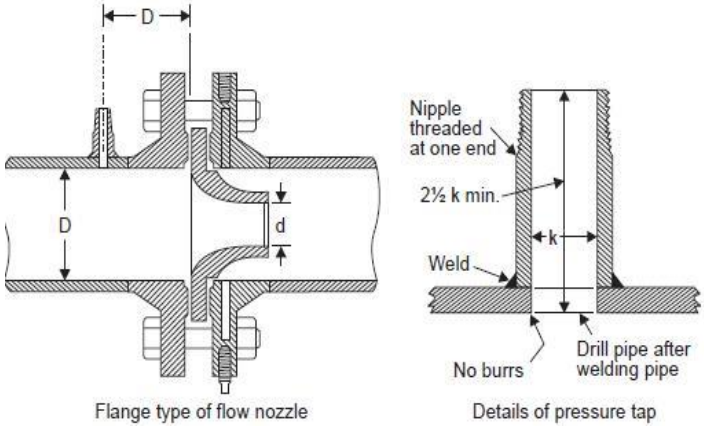


Fig. Flow Nozzle

Advantages

1. Permanent pressure loss lower than that for an orifice plate.

2. It is suitable for fluids containing solids that settle.

3. It is widely accepted for high pressure and temperature steam flow.

Disadvantages

1. Cost is higher than orifice plate.

2. It is limited to moderate pipe sizes, it requires more maintenance.

5.4.4 Pitot tube

An obstruction type primary element used mainly for fluid velocity measurement is the Pitot tube.

Principle

Consider Figure which shows flow around a solid body. When a solid body is held centrally and stationary in a pipeline with a fluid streaming down, due to the presence of the body, the fluid while approaching the object starts losing its velocity till directly in front of the body, where the velocity is zero. This point is known as the stagnation point. As the kinetic head is lost by the fluid, it gains a static head. By measuring the difference of pressure between that at normal flow line and that at the stagnation point the velocity is found out. This principle is used in pitot tube sensors.

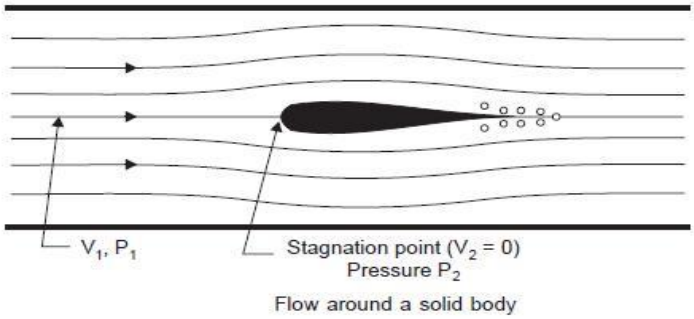


Fig. Flow through solid body

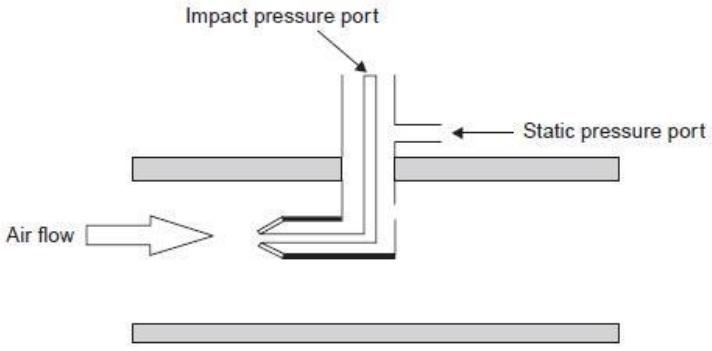


Fig. Pitot tube

A common industrial type of pitot tube consists of a cylindrical probe inserted into the air stream, as shown in Figure. Fluid flow velocity at the upstream face of the probe is reduced

substantially to zero. Velocity head is converted to impact pressure, which is sensed through a small hole in the upstream face of the probe. A corresponding small hole in the side of the probe senses static pressure. A pressure instrument measures the differential pressure, which is proportional to the square of the stream velocity in the vicinity of the impact pressure sensing hole. The velocity equation for the pitot tube is given by,

$$v = Cp\sqrt{2gh}$$

Advantages

1. No pressure loss.
2. It is relatively simple.
3. It is readily adapted for flow measurements made in very large pipes or ducts

Disadvantages

1. Poor accuracy.
2. Not suitable for dirty or sticky fluids and fluids containing solid particles.
3. Sensitive to upstream disturbances.

5.4.5 Rotameter

The orifice meter, Venturimeter and flow nozzle work on the principle of constant area variable pressure drop. Here the area of obstruction is constant, and the pressure drop changes with flow rate. On the other hand Rotameter works as a constant pressure drop variable area meter. It can be only be used in a vertical pipeline. Its accuracy is also less (2%) compared to other types of flow meters. But the major advantages of rotameter are, it is simple in construction, ready to install and the flow rate can be directly seen on a calibrated scale, without the help of any other device, e.g. differential pressure sensor etc. Moreover, it is useful for a wide range of variation of flow rates (10:1).

The basic construction of a rotameter is shown in figure. It consists of a vertical pipe, tapered downward. The flow passes from the bottom to the top. There is cylindrical type metallic float inside the tube. The fluid flows upward through the gap between the tube and the float. As the float moves up or down there is a change in the gap, as a result changing the area of the orifice. In fact, the float settles down at a position, where the pressure drop across the orifice will create an upward thrust that will balance the downward force due to the gravity. The position of the float is calibrated with the flow rate.

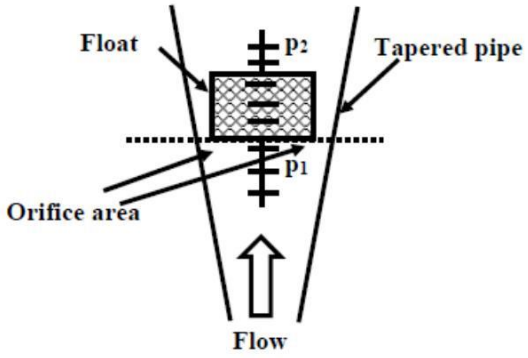


Fig. Rotameter

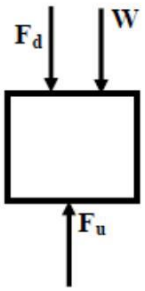


Fig. Force acting on float

γ_1= Specific weight of the float

γ_2= specific weight of the fluid

v= volume of the float A_f= Area of the float.

A_t= Area of the tube at equilibrium (corresponding to the dotted line)

$$Q = \frac{C_d A_2}{\sqrt{1-(\frac{A_2}{A_1})^2}} \sqrt{\frac{2g}{\gamma_2}(p_1 - p_2)}$$

F_d = Downward thrust on the float F_u = Upward thrust on the float

The major source of error in rotameter is due to the variation of density of the fluid. Besides, the presence of viscous force may also provide an additional force to the float.

Applications

- Can be used to measure flow rates of corrosive fluids
- Particularly useful to measure low flow rates

Advantages

- Flow conditions are visible
- Flow rate is a linear function(uniform flow scales)
- Can be used to measure flow rates of liquids, gases and vapour
- By changing the float, tapered tube or both, the capacity of the rotameter can be changed.

Limitations

- They should be installed vertically
- They cannot be used for measurements in moving objects
- The float will not be visible when coloured fluids are used, that is, when opaque fluid are used.
- For high pressure and temperature fluid flow measurements, they are expensive
- They cannot be used for fluids containing high percentage of solids in suspension.

5.5 TEMPERATURE MEASUREMENT

Temperature is one of the most measured physical parameters in science and technology; typically for process thermal monitoring and control. There are many ways to measure temperature, using various principles.

Four of the most common are:

- Mechanical (liquid-in-glass thermometers, bimetallic strips, etc.)
- Thermojunctive (thermocouples)
- Thermoresistive (RTDs and thermistors)
- Radiative (infrared and optical pyrometers)

Mechanical Temperature Measuring Devices

A change in temperature causes some kind of mechanical motion, typically due to the fact that most materials expand with a rise in temperature. Mechanical thermometers can be constructed that use liquids, solids, or even gases as the temperature-sensitive material. The mechanical motion is read on a physical scale to infer the temperature.

5.5.1 Bimetallic strip thermometer

- Two dissimilar metals are bonded together into what is called a bimetallic strip, as sketched to the right.
- Suppose metal A has a smaller coefficient of thermal expansion than does metal B. As temperature increases, metal B expands more than does metal A, causing the bimetallic strip to curl upwards as sketched.
- One common application of bimetallic strips is in home thermostats, where a bimetallic strip is used as the arm of a switch between electrical contacts. As the room temperature changes, the bimetallic strip bends as discussed above. When the bimetallic strip bends far enough, it makes contact with electrical leads that turn the heat or air conditioning on or off.
- Another application is in circuit breakers High temperature indicates over-current, which shuts off the circuit.
- Another common application is for use as ven, wood burner, or gas grill thermometers. These thermometers consist of a bimetallic strip wound up in a spiral, attached to a dial that is calibrated into a temperature scale.

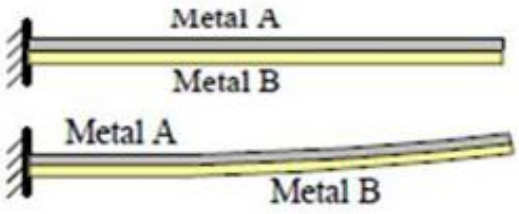


Fig .Bimetallic Strip

5.5.2 Pressure thermometer

- A pressure thermometer, while still considered mechanical, operates by the expansion of a gas instead of a liquid or solid. There are also pressure thermometers that use a liquid instead of a gas
- Suppose the gas inside the bulb and tube can be considered an ideal gas. The ideal gas law is PV = mRT, where P is the pressure, V is the volume of the gas, m is the mass of the gas, R is the gas constant for the specific gas (not the universal gas constant),and T is the absolute temperature of the gas.
- Specific gas constant R is a constant. The bulb and tube are of constant volume, so V is a constant. Also, the mass m of gas in the sealed bulb and tube must be constant (conservation of mass).
- A pressure thermometer therefore measures temperature indirectly by measuring pressure.
- The gage is a pressure gage, but is typically calibrated in units of temperature instead.
- A common application of this type of thermometer is measurement of outside temperature from the inside of a building. The bulb is placed outside, with the tube running through the wall into the inside.
- The gauge is on the inside. As *T* increases outside, the bulb temperature causes a corresponding increase in pressure, which is read as a temperature increase on the gauge.

$$e_0 = C_1(T_1 - T_2) + C_2(T_1^2 - T_2^2)\,\mu v$$

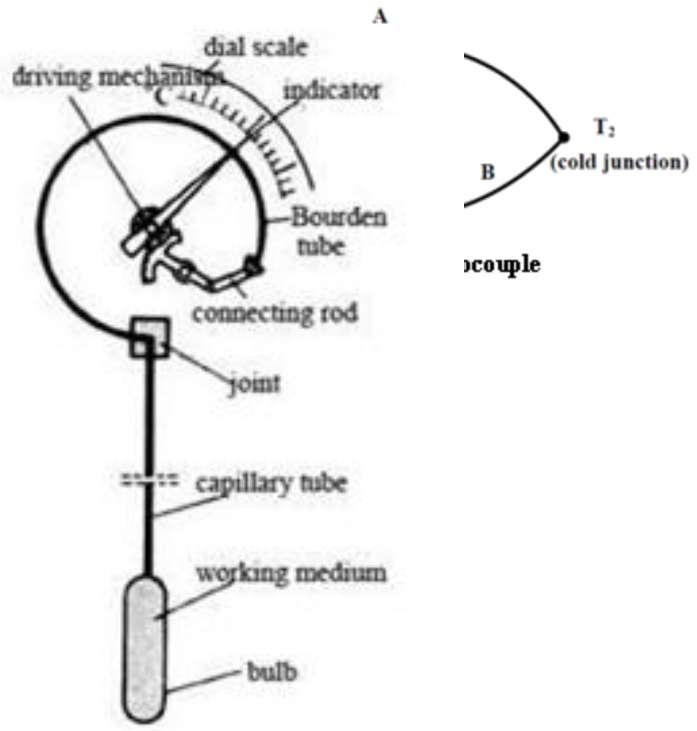


Fig.Pressure Thermometer

5.5.3 Thermocouples (Thermo-junctive temperature measuring devices)

Thomas Johan Seeback discovered in 1821 that thermal energy can produce electric current. 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, the actual 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 two effects: Peltier effect and Thomson effect. A typical thermocouple junction is shown in fig. 5. The emf generated can be approximately expressed by the relationship: Where, T_1 and T_2 are hot and cold junction temperatures in K. C_1 and C_2 are constants depending upon the materials. 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:

They are rugged and readings are consistent

(i) They can measure over a wide range of temperature

(ii) 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).

5.5.4. Thermocouple Materials

Table-1 Thermocouple materials and Characteristics

Type	Positive lead	Negative lead	Temperature range	Temperature coeff.variation μv/°C	Most linear range and sensitivity in the range
R	Platinum-Rhodium (87% Pt, 13% Rh)	Platinum	0-1500°C	5.25-14.1	1100-1500°C 13.6-14.1 μv/°C
S	Platinum-Rhodium (90% Pt, 10% Rh)	Platinum	0-1500°C	5.4-12.2	1100-1500 °C 13.6-14.1 μv/°C
K	Chromel (90%Ni, 10% Cr)	Alumel ($Ni_{94}Al_2$ Mn_3Si)	-200-1300°C	15.2-42.6	0-1000 °C 38-42.9 μv/°C
E	Chromel	Constantan (57%Cu, 43%Ni)	-200-1000°C	25.1-80.8	300-800 °C 77.9-80.8 μv/°C
T	Copper	Constantan	-200-350°C	15.8-61.8	nonlinear
J	Iron	Constantan	-150-750°C	21.8-64.6	100-500 °C 54.4-55.9

Theoretically, any pair of dissimilar materials can be used as a thermocouple. But in practice, only few materials have found applications for temperature measurement. The choice of materials is influenced by several factors, namely, sensitivity, stability in calibration, inertness in the operating atmosphere and reproducibility (i.e. the thermocouple can be replaced by a similar one without any recalibration).

Table-I shows the common types of thermocouples, their types, composition, range, sensitivity etc. The upper range of the thermocouple is normally dependent on the atmosphere where it has been put. For example, the upper range of Chromel/ Alumel thermocouple can be increased in oxidizing atmosphere, while the upper range of Iron/ Constantan thermocouple can be increased in reducing atmosphere.

Laws of Thermocouple

The Peltier and Thompson effects explain the basic principles of thermoelectric emf generation. But they are not sufficient for providing a suitable measuring technique at actual measuring situations. For this purpose, we have three laws of thermoelectric circuits that provide us useful practical tips for measurement of temperature. These laws are known as law of homogeneous circuit, law of intermediate metals and law of intermediate temperatures. These laws can be explained using figure

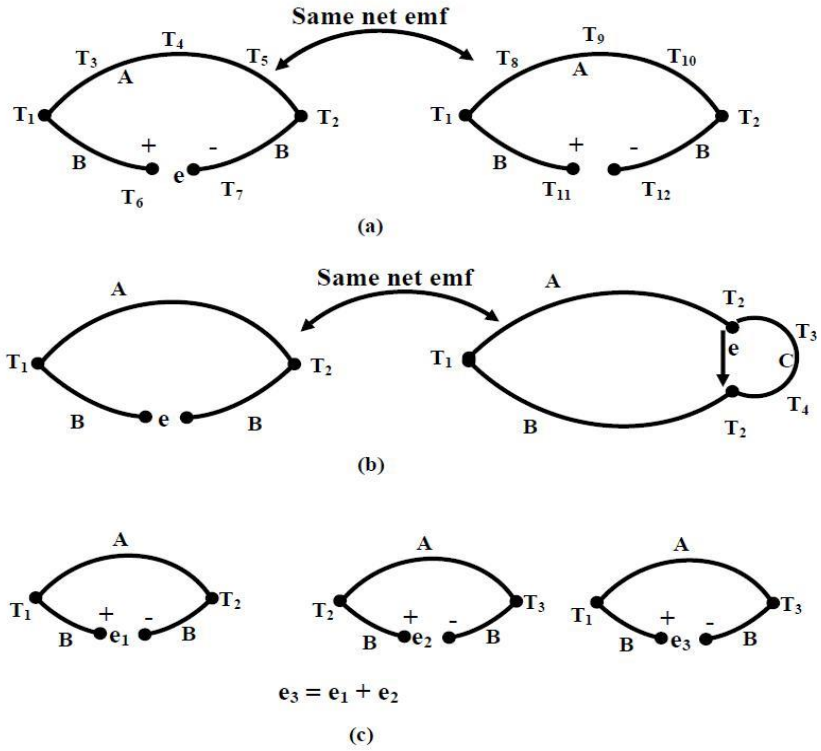
The first law can be explained using figure

(a). It says that the net thermo-emf generated is dependent on the materials and the temperatures of two junctions only, not on any intermediate temperature.

According to the second law, if a third material is introduced at any point (thus forming two additional junctions) it will not have any effect, if these two additional junctions remain at the same temperatures (figure b). This law makes it possible to insert a measuring device without altering the thermo-emf.

The third law is related to the calibration of the thermocouple. It says, if a thermocouple produces emf e_1, when its junctions are at T_1 and T_2, and e_2 when its junctions are at T_2 and T_3; then it will generate emf e_1+e_2 when the junction temperatures are at T_1 and T_3 (figure c).

The third law is particularly important from the point of view of reference junction compensation. The calibration chart of a thermocouple is prepared taking the cold or reference junction temperature as 0 C. But in actual measuring situation, seldom the reference junction temperature is kept at that temperature, it is normally kept at ambient temperature. The third law helps us to compute the actual temperature using the calibration chart.



5.5.5 Thermo Resistive Temperature Measuring Devices

Principle of operation

- A change in temperature causes the electrical resistance of a material to change.
- The resistance change is measured to infer the temperature change.
- There are two types of thermoresistive measuring devices: resistance temperature detectors and thermistors, both of which are described here.

Resistance temperature detectors

A resistance temperature detector (abbreviated RTD) is basically either a long, small diameter metal wire (usually platinum) wound in a coil or an etched grid on a substrate, much like a strain gauge.

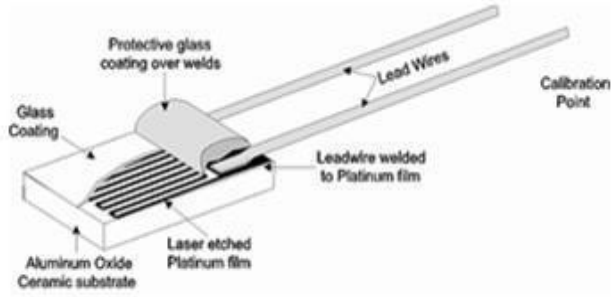
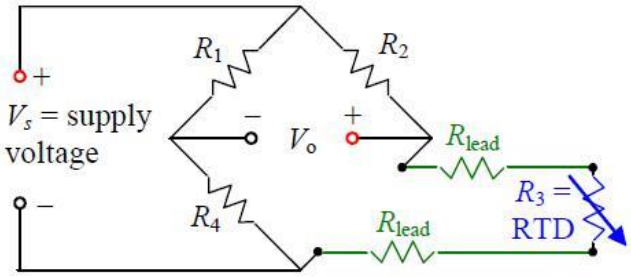


Fig 5.28 RTD

The resistance of an RTD increases with increasing temperature, just as the resistance of a strain gage increases with increasing strain. The resistance of the most common RTD is 100 Ω at 0ºC.



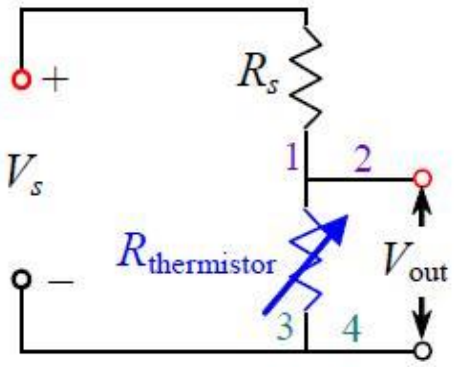
If the temperature changes are large, or if precision is not critical, the RTD resistance can be measured directly to obtain the temperature. If the temperature changes are small, and/or high precision is needed, an electrical circuit is built to measure a change in resistance of the RTD, which is then used to calculate a change in temperature. One simple circuit is the quarter bridge Wheatstone bridge circuit, here called a two-wire RTD bridge circuit

R_{lead} represents the resistance of one of the wires (called lead wires) that run from the bridge to the RTD itself. Lead resistance is of little concern in strain gage circuits because R_{lead} remains constant at all times, and we can simply adjust one of the other resistors to zero the bridge.

For RTD circuits, however, some portions of the lead wires are exposed to changing temperatures. Since the resistance of metal wire changes with temperature, R_{lead} changes with T and this can cause errors in the measurement. This error can be non-trivial changes in lead resistance may be misinterpreted as changes in RTD resistance, and therefore give a false temperature measurement

5.5.6 T**hermistors**

A thermistor is similar to an RTD, but a semiconductor material is used instead of a metal. A thermistor is a solid state device. Resistance thermometry may be performed using thermistors. Thermistors are many times more sensitive than RTD's and hence are useful over limited ranges of temperature. They are small pieces of ceramic material made by sintering mixtures of metallic oxides of Manganese, Nickel, Cobalt, Copper and Iron etc.



Resistance of a thermistor decreases non-linearly with temperature. Thermistors are extremely sensitive but over a narrow range of temperatures. A thermistor has larger sensitivity than does an RTD, but the resistance change with temperature is nonlinear, and therefore temperature must be calibrated with respect to resistance. Unlike RTDs, the resistance of a thermistor decreases with increasing temperature. The upper temperature limit of thermistors is typically lower than that of RTD. However, thermistors have greater sensitivity and are typically more accurate than RTDs or thermocouples. A simple voltage divider, where V_s is the supply voltage and R_s is a fixed (supply) resistor. R_s and V_s can be adjusted to obtain a desired range of output voltage V_{out} for a given range of temperature. If the proper value of R_s is used, the output voltage is nearly (but not exactly) linear with temperature. Some thermistors have 3 or 4 lead wires for convenience in wiring – two wires are connected to one side and two to the other side of the thermistor (labeled 1, 2 and 3, 4 above).

5. ADVANCES IN METROLOGY

5.1 PRECISION INSTRUMENT BASED ON LASER

Laser stands for **Light Amplification by Stimulated Emission of Radiation.** Laser instrument is a device to produce powerful, monochromatic, collimated beam of light in which the **waves are coherent**. Laser development is for production of clear coherent light. The advantage of coherent light is that whole of the energy appears to be emanating from a very small point. The beam can be focused easily into either a parallel beam or onto a very small point by use of lenses A major impact on optical measurement has been made by development in elector optics, providing automation, greater acuity of setting and faster response time. Radiation sources have developed in a number of areas; the most important developments are light emitting diodes and lasers. The laser is used extensively for interferometry particularly the He- Ne gas type. The laser distance measuring interferometer has become an industry standard. This produces 1 to 2mm diameter beam of red light power of 1MW and focused at a point of very high intensity. The beam begins to expand at a rate of 1mm/m. The laser beam is visible and it can be observed easily. This is used for very accurate measurements of the order of 0.lμm are 100m.

5.1.1 Laser Metrology

Metrology lasers are low power instruments. Most are helium-neon type. Wave output laser that emit visible or infrared light. He-Ne lasers produce light at a wavelength of 0.6μm that is in phase, coherent and a thousand times more intense than any other monochromatic source. Laser systems have wide dynamic range, low optical cross talk and high contrast. Laser fined application in dimensional measurements and surface inspection because of the properties of laser light. These are useful where precision, accuracy, rapid non-contact gauging of soft, delicate or hot moving points.

5.1.2 Use of Laser

- **Laser Telemetric system**

Laser telemetric system is a non-contact gauge that measures with a collimated laser beam. It measures at the rate of 150 scans per second. It basically consists of three components, a transmitter, a receiver and processor electronics. The transmitter module produces a collimated parallel scanning laser beam moving at a high constant, linear speed. The scanning beam appears a red line. The receiver module collects and photoelically senses the laser light transmitted past the object being measured. The processor electronics takes the received signals to convert them 10 a convenient form and displays the dimension being gauged. The transmitter contains a low power helium-neon gas laser and its power supply, a specially designed collimating lens, a synchronous motor, a multi faceted reflector prism, a synchronous pulse photo detector and a protective replaceable window. The high speed of scanning permits on line gauging and thus it is possible to detect changes in dimensions when components are moving on a continuous product such as in rolling process moving at very high speed. There is no need of waiting or product to cool for taking measurements. This system can also be applied on production machines and control then with closed feedback loops. Since the output of this system is available in digital form, it can run a process controller limit alarms can be provided and output can be taken on digital printer.

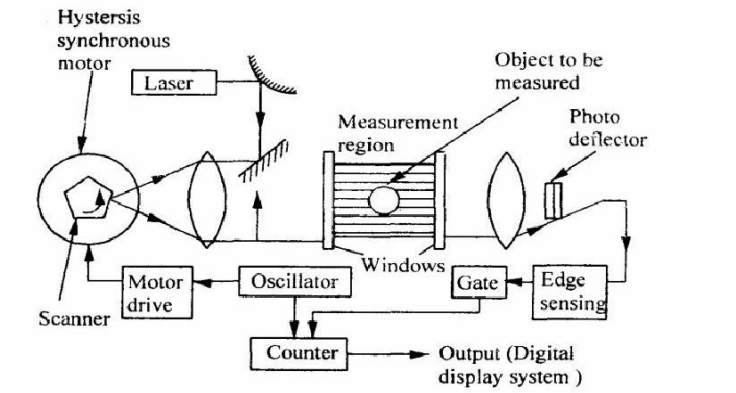
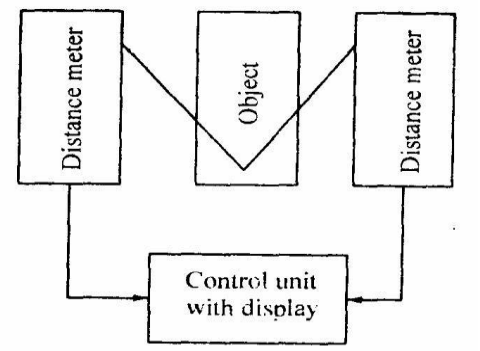


Fig 5.1 Laser Telemetric System

- **Laser and LED based distance measuring instruments**

These can measure distances from I to 2in with accuracy of the order of 0. 1 to 1% of the measuring range When the light emitted by laser or LED hits an object, scatter and some of this scattered light is seen by a position sensitive detector or diode array. If the distance between the measuring head and the object changes. The angle at which the light enters the detector will also change.

The angle of deviation is calibrated in terms of distance and output is provided as 0-2OmA. Such instruments are very reliable because there are no moving parts their response time is milliseconds. The measuring system uses two distance meters placed at equal distance on either side of the object and a control unit to measure the thickness of an object. The distance meter is focused at the centre of the object.



- **Scanning Laser gauge**

Fig shows a schematic diagram of a scanning laser gauge. It consist of transmitter, receives and processor electronics. A thin band of scanning laser light is made to pass through a linear scanner lens to render it parallel beam. ‘The object placed in a parallel beam, casts a time dependent shadow. Signal from the light entering the photocell (receiver) arc proc by a microprocessor to provide display of the dimension represented by the time difference between the shadow edges. It can provide results to an accuracy of0.25 for 10—50mm diameter objects. It can be used for objects 0.05mm to 450mm diameter; and offers repeatability of 0.1μm

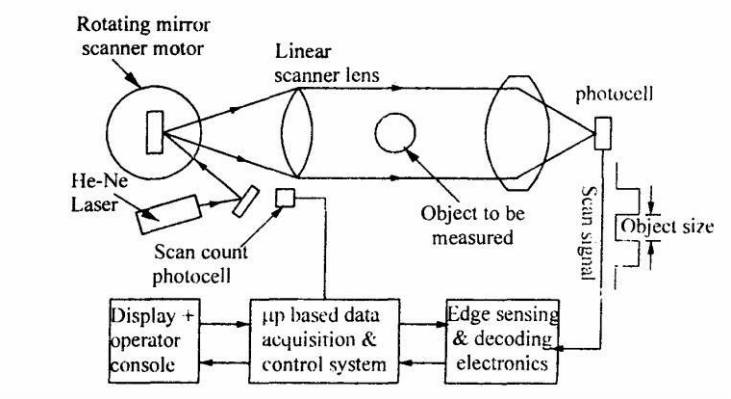


Fig 5.2 Scanning Laser Gauge

- **Photo diode away imaging**

The system comprises of laser source, imaging optics. Photo-diode array. Signal processor and display unit. For large parts, two arrays in which one for each edge are used. Accuracies as high as 0.05 μm have been achieved.

- **Diffraction pattern technique**

These are used to measure small gaps and small diameter parts. A parallel coherent laser beam is diffracted by a small part and a lens on a linear diode array focuses the resultant pattern. Its use is restricted to small wires. The measurement accuracy is more for smaller parts. The distance between the alternating light and dark hands in the diffraction pattern is a (tired function of the wile diameter, wavelength of laser beam and the focal length of the lens.

- **Two- frequency laser interferometer**

Fig. shows schematic arrangement. This consists of two frequency laser head, beam directing and splitting optics, measurement optics, receivers, and wavelength compensators and electronics. It is ideally suited for measuring linear positioning straightness in two planes, pitch and yaw.

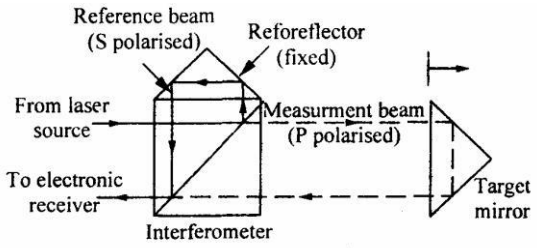


Fig 5.3 Two-frequency laser interferometer

The two-frequency laser head provides one frequency with P-polarization and another frequency with S-polarization. The laser beam is split at the polarizing beam splitter into its two separate frequencies. The measuring beam is directed through the interferometer to reflect off a target mirror or retro reflector attached to the object to be measured. The reference beam is reflected from fixed retro reflector. The measurement beam on its return path recombines with the reference beam and is directed to the electronic receiver.

- **Gauging wide diameter from the diffraction pattern formed in a laser**

Figure shows a method of measuring the diameter of thin wire using the interference fringes resulting from diffraction of the light by the wire in the laser beam. A measure of the diameter can be obtained by moving the photo detector until the output is restored to its original value. Variation in wire diameter as small as 0.2% over wire diameter from 0.005 to 0.2mm can be measured.

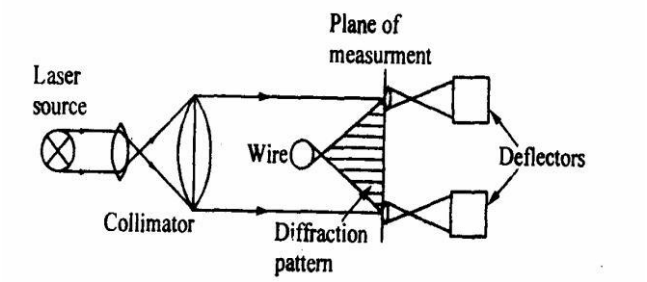


Fig 5.4 Diffraction Pattern

Figure shows the length measurement by fringe counting. The laser output, which may be incoherent illumines three slits at a time in the first plane which form interference fringes. The movement can be determined by a detector. The total number of slits in the first plane is governed by the length over which measurement is required

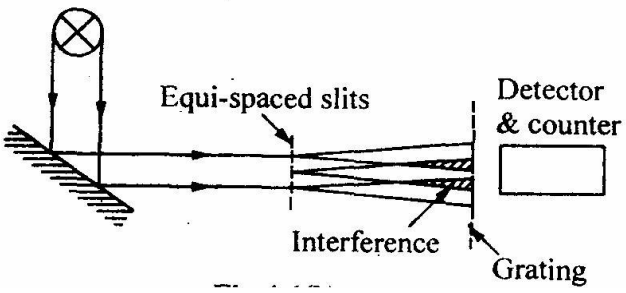


Fig 5.5 Fringe counting

The spacing between the slits and distance of the slit to the plane of the grating depend on the wavelength of the light used.

5.1.3 Principle of Laser

The photon emitted during stimulated emission has the same energy, phase and frequency as the incident photon. This principle states that the photon comes in contact with another atom or molecule in the higher energy level E2 then it will cause the atom to return to ground state energy level E1 by releasing another photon. The sequence of triggered identical photon from stimulated atom is known as stimulated emission. This multiplication of photon through stimulated emission leads to coherent, powerful, monochromatic, collimated beam of light emission. This light emission is called laser.

5.2 LASER INTERFEROMETRY

Brief Description of components

(i) Two frequency Laser source

It is generally He-Ne type that generates stable coherent light beam of two frequencies, one polarized vertically and another horizontally relative to the plane of the mounting feet. Laser oscillates at two slightly different frequencies by a cylindrical permanent magnet around the cavity. The two components of frequencies are distinguishable by their opposite circular polarization. Beam containing both frequencies passes through a quarter wave and half wave plates which change the circular polarizations to linear perpendicular polarizations, one vertical and other horizontal. Thus the laser can be rotated by 90°about the beam axis without affecting transducer performance. If the laser source is deviated from one of the four optimum positions, the photo receiver will decrease. At 45° deviation the signal will decrease to zero.

(ii) Optical elements

a) Beam splitter

Sketch shows the beam splitters to divide laser output along different axes. These divide the laser beam into separate beams. To avoid attenuation it is essential that the beam splitters must be oriented so that the reflected beam forms a right angle with the transmitted beam. So that these two beams: are coplanar with one of the polarisation vectors of the input form.

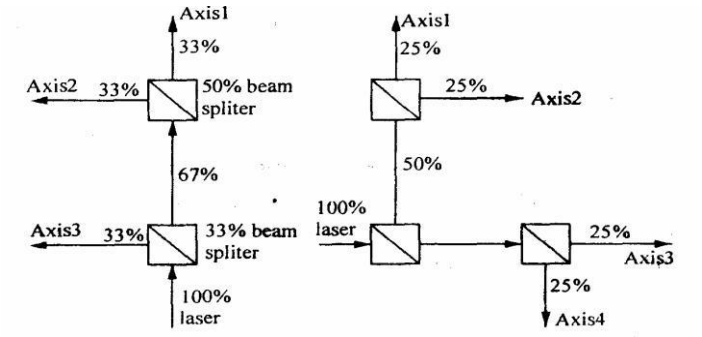


Fig 5.6 Beam Splitter

b) Beam benders

These are used to deflect the light beam around corners on its path from the laser to each axis. These are actually just flat mirrors but having absolutely flat and very high reflectivity. Normally these are restricted to 90° beam deflections to avoid disturbing the polarizing vectors.

c) Retro reflectors

These can be plane mirrors, roof prism or cube corners. Cube corners are three mutually perpendicular plane mirrors and the reflected beam is always parallel to the incidental beam. Each ACLI transducers need two retro reflectors. All ACLI measurements are made by sensing differential motion between two retro reflectors relative to an interferometer. Plane mirror used as retro reflectors with the plane mirror interferometer must be flat to within 0.06 micron per cm.

(iii) Laser head's measurement receiver

During a measurement the laser beam is directed through optics in the measurement path and then returned to the laser head is measurement receiver which will detect part of the returning beam and a doppler shifted frequency component.

(iv) Measurement display

It contains a microcomputer to compute and display results. The signals from receiver and measurement receiver located in the laser head are counted in two separatepulse converter and subtracted. Calculations are made and the computed value is displayed. Other input signals for correction are temperature, co-efficient of expansion, air velocity etc., which can be displayed.

(v) Various version of ACLI

a) Standard Interferometer

- Least expensive.
- Retro reflector for this instrument is a cube corner.
- Displacement is measured between the interferometer and cube corner.

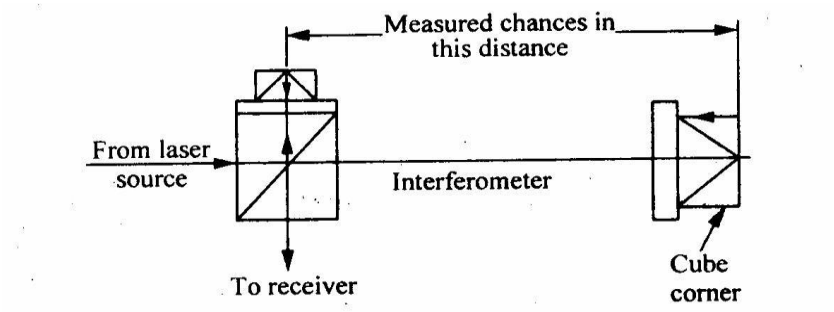


Fig 5.7 Standard Interferometer

Signal beams Interferometer

Beam traveling between the interferometer and the retro reflector.

Its operation same as standard interferometer.

The interferometer and retro reflector for this system are smaller than the standard system.

Long range optical path

Wear and tear.

5.3 LASER INTERFEROMETER

It is possible to maintain the quality of interference fringes over longer distance when lamp is replaced by a laser source. Laser interferometer uses AC laser as the light source and the measurements to be made over longer distance. Laser is a monochromatic optical energy, which can be collimated into a directional beam AC. Laser interferometer (ACLI) has the following advantages.

- High repeatability
- High accuracy
- Long range optical path
- Easy installations

- Wear and tear

Schematic arrangement of laser interferometer is shown in fig. Two-frequency zeeman laser generates light of two slightly different frequencies with opposite circular polarisation. These beams get split up by beam splitter B One part travels towards B and from there to external cube corner here the displacement is to the measured.

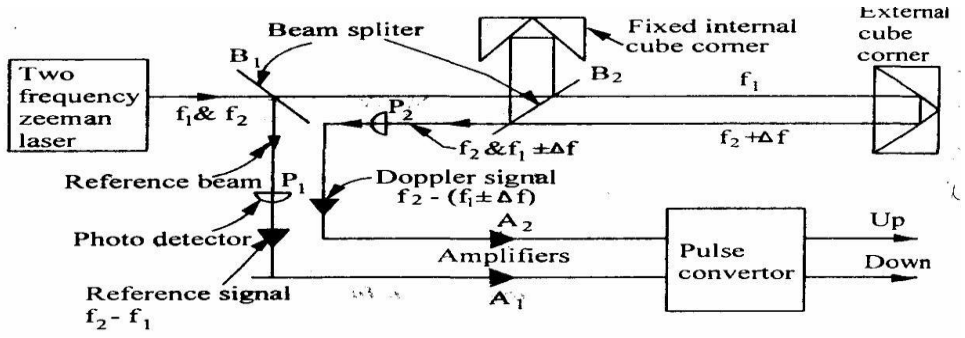


Fig 5.8 Laser Interferometer

This interferometer uses cube corner reflectors which reflect light parallel to its angle of incidence. Beam splitter B2 optically separates the frequency J which alone is sent to the movable cube corner reflector. The second frequency from B2 is sent to a fixed reflector which then rejoins f1 at the beam splitter B2 to produce alternate light and dark interference flicker at about 2 Mega cycles per second. Now if the movable reflector moves, then the returning beam frequency Doppler-shifted slightly up or down by Δf.

Thus the light beams moving towards photo detector P2 have frequencies f2 and (f1 ±

Δf1) and P2 changes these frequencies into electrical signal. Photo detector P2 receive signal from beam splitter B2 and changes the reference beam frequencies f1 and f2 into

electrical signal. An AC amplifier A separates frequency. Difference signal f2 – f1 and A2 separates frequency difference signal. The pulse converter extracts i. one cycle per half wavelength of motion. The up-down pulses are counted electronically and displayed in analog or digital form.

5.3.1 Michelson Interferometer

Michelson interferometer consists of a monochromatic light source a beam splitter and two mirrors. The schematic arrangement of Michelson interferometer is shown in fig. The monochromatic light falls on a beam splitter, which splits the light into two rays of equal intensity at right angles. One ray is transmitted to mirror M1 and other is reflected through beam splitter to mirror M2,.

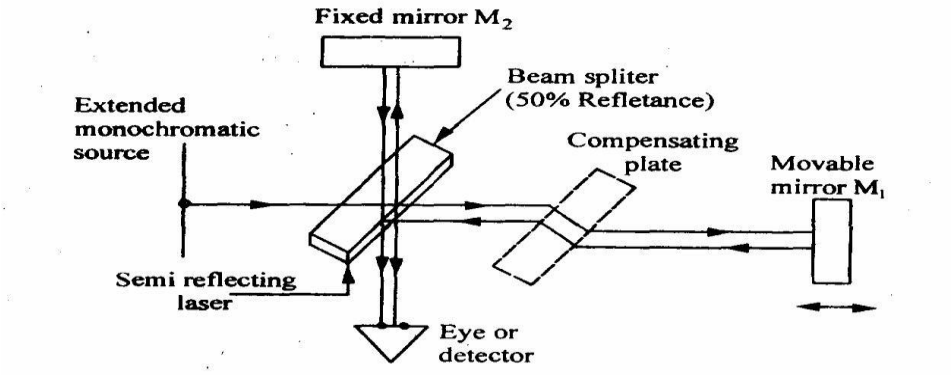


Fig 5.9 Michelson Interferometer

From both these mirrors, the rays are reflected back and these return at the semireflecting surface from where they are transmitted to the eye. Mirror M2 is fixed and mirror M1 is movable. If both the mirrors are at same distance from beam splitter, then light will arrive in phase and observer will see bright spot due to constructive interference. If movable mirror shifts by quarter wavelength, then beam will return to observer 1800 out of phase and darkness will be observed due to destructive interferenceEach half-wave length of mirror travel produces a change in the measured optical path of one wavelength and the reflected beam from the moving mirror shifts through 360° phase change. When the reference beam reflected from the fixed mirror and the beam reflected from the moving mirror rejoin at the beam splitter, they alternately reinforce and cancel each other as the mirror moves. Each cycle of intensity at the eye represents l/2 of mirror travel. When white light source is used then a compensator plate is introduced in each of the path of mirror M1 So that exactly the same amount of glass is introduced in each of the path.

To improve the Michelson interferometer

(i) Use of laser the measurements can be made over longer distances and highly accurate measurements when compared to other monochromatic sources.

(ii) Mirrors are replaced by cube-corner reflector which reflects light parallel to its angle of incidence.

(iii) Photocells are employed which convert light intensity variation in voltage pulses to give the amount and direction of position change.

5.3.2 Dual Frequency Laser Interferometer

This instrument is used to measure displacement, high-precision measurements of length, angle, speeds and refractive indices as well as derived static and dynamic quantities. This system can be used for both incremental displacement and angle measurements. Due to large counting range it is possible to attain a resolution of 2mm in 10m measuring range. Means are also provided to compensate for the influence of ambient temperature, material temperature, atmospheric pressure and humidity fluctuation

5.3.3 Twyman-Green Interferometer

The Twyman-Green interferometer is used as a polarizing interferometer with variable amplitude balancing between sample and reference waves. For an exact measurement of the test surface, the instrument error can be determined by an absolute measurement. This error is compensated by storing the same in microprocessor system and subtracting from the measurement of the test surface.

It has following advantages

- It permits testing of surface with wide varying reflectivity.
- It avoids undesirable feedback of light reflected of the tested surface and the instrument optics.
- It enables utilization of the maximum available energy.
- Polarization permits phase variation to be effected with the necessary precision.

5.3.4 Laser Viewers

The profile of complex components like turbine blades can be checked by the use of optical techniques. It is based on use of laser and CCTV. A section of the blade, around its edge is delineated by two flat beam of laser light. This part of the edge is viewed at a narrow angle by the TV camera or beam splitter

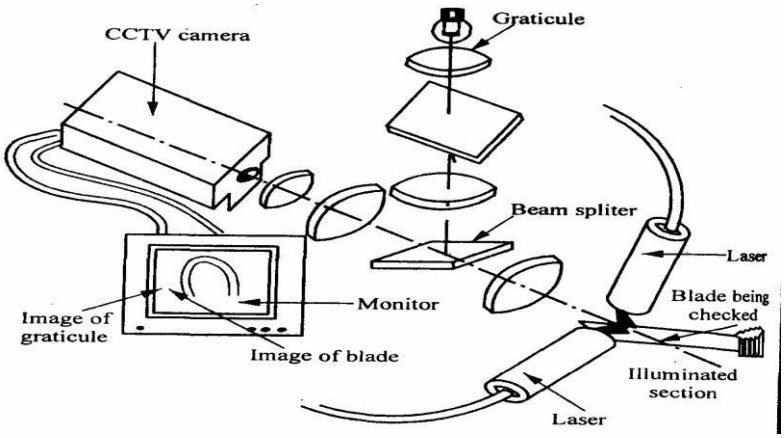


Fig 5.10 Laser Viewers

Both blade and graticule are displayed as magnified images on the monitor, the graticule position being adjustable so that its image can be superimposed on the profile image. The graticule is effectively viewed at the same angle as the blade. So, distortion due to viewing angle affects both blade and graticule. This means that the graticule images are direct 1:1.

5.4 INTERFEROMETRIC MEASUREMENT OF ANGLE

With laser interferometer it is possible to measure length to accuracy of 1 part in 106 on a routine basis. With the help of two retro reflectors placed at a fixed distance and a length measuring laser interferometer the change in angle can be measured to an accuracy of 0.1 second. The device uses sine Principle. The line joining the poles the retro-reflectors makes the hypotenuse of the right triangle. The change in the path difference of the reflected beam represents the side of the triangle opposite to the angle being measured. Such laser interferometer can be used to measure an angle up to ± 10 degrees with a resolution of 0. 1 second. The principle of operation is shown in fig.

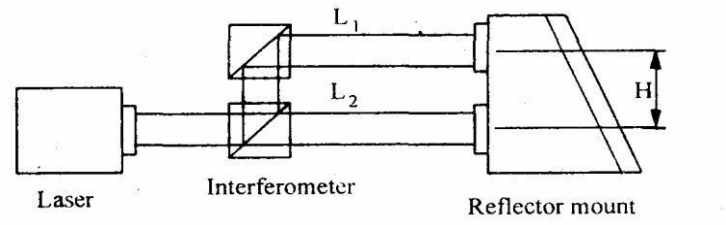


Fig 5.11 Interferometric Angle Measurement

5.4.1 Laser Equipment for Alignment Testing

This testing is particularly suitable in aircraft production, shipbuilding etc. Where a number of components, spaced long distance apart, have to be checked to a predetermine straight line. Other uses of laser equipment are testing of flatness of machined surfaces, checking square ness with the help of optical square etc. These consist of laser tube will produces a cylindrical beam of laser about 10mm diameter and an auto reflector with a high degree of accuracy. Laser tube consists of helium-

neon plasma tube in a heat aluminum cylindrical housing. The laser beam comes out of the housing from its centre and parallel to the housing within 10” of arc and alignment stability is the order of 0.2” of arc per hour. Auto reflector consists of detector head and read out unit. Number of photocell are arranged to compare laser beam in each half horizontally and vertically. This is housed on a shard which has two adjustments to translate the detector in its two orthogonal measuring directions perpendicular to the laser beam. The devices detect the alignment of flat surfaces perpendicular to a reference line of sight.

5.5 MACHINE TOOL TESTING

The accuracy of manufactured parts depends on the accuracy of machine tools. The quality of work piece depends on Rigidity and stiffness of machine tool and its components. Alignment of various components in relation to one another Quality and accuracy of driving mechanism and control devices.

It can be classified into

- Static tests
- Dynamic tests.

- **Static tests**

If the alignment of the components of the machine tool are checked under static conditions then the test are called static test.

- **Dynamic tests**

If the alignment tests are carried out under dynamic loading condition. The accuracy of machine tools which cut metal by removing chips is tested by two types of test namely.

- Geometrical tests
- Practical tests

- **Geometrical tests**

In this test, dimensions of components, position of components and displacement of component relative to one another is checked.

- **Practical tests**

In these test, test pieces are machined in the machines. The test pieces must be appropriate to the fundamental purpose for which the machine has been designed.

5.5.1 Purpose of Machine Tool Testing

The dimensions of any work piece, its surface finishes and geometry depends on the accuracy of machine tool for its manufacture. In mass production the various components produced should be of high accuracy to be assembled on a non-sensitive basis. The increasing demand for accurately machined components has led to improvement of geometric accuracy of machine tools. For this purpose various checks on different components of the machine tool are carried out.

5.5.2 Type of Geometrical Checks on Machine Tools.

Different types of geometrical tests conducted on machine tools are as follows:

1. Straightness.
2. Flatness.

3. Parallelism, equi-distance and coincidence.
4. Rectilinear movements or squareness of straight line and plane.
5. Rotations.

Main spindle is to be tested for

Out of round.

Eccentricity

Radial-throw of an axis.

Run out

Periodical axial slip

Camming

5.5.3 Various tests conducted on any Machine Tools

- Test for level of installation of machine tool in horizontal and vertical planes.
- Test for flatness of machine bed and for straightness and parallelism of bed ways on bearing surface.
- Test for perpendicularity of guide ways to other guide ways.
- Test for true running of the main spindle and its axial movements.
- Test for parallelism of spindle axis to guide ways or bearing surfaces.
- Test for line of movement of various members like spindle and table cross slides etc.

5.5.4 Use of Laser for Alignment Testing

- The alignment tests can be carried out over greater distances and to a greater degree of accuracy using laser equipment.
- Laser equipment produces real straight line, whereas an alignment telescope provides an imaginary line that cannot be seen in space.
- This is important when it is necessary to check number of components to a predetermined straight line. Particularly if they are spaced relatively long distances apart, as in aircraft production and in shipbuilding.
- Laser equipment can also be used for checking flatness of machined surface by direct displacement. By using are optical square in conjunction with laser equipment squareness can be checked with reference to the laser base line.

5.6 CO-ORDINATE MEASURING MACHINES

Measuring machines are used for measurement of length over the outer surfaces of a length bar or any other long member. The member may be either rounded or flat and parallel. It is more useful and advantageous than vernier calipers, micrometer, screw gauges etc. the measuring machines are generally universal character and can be used for works of varied nature. The co-ordinate measuring machine is used for contact inspection of parts. When used for computer-integrated manufacturing these machines are controlled by computer numerical control. General software is provided for reverse engineering complex shaped objects. The component is digitized using CNC, CMM and it is then converted into a computer model which gives the two surface of the component. These advances

include for automatic work part alignment on the table. Savings in inspection 5 to 10 percent of the time is required on a CMM compared to manual inspection methods.

5.6.1 Types of Measuring Machines

Length bar measuring machine.

Newall measuring machine.

Universal measuring machine.

Co-ordinate measuring machine.

Computer controlled co-ordinate measuring machine.

5.6.2 Constructions of CMM

Co-ordinate measuring machines are very useful for three dimensional measurements. These machines have movements in X-Y-Z co-ordinate, controlled and measured easily by using touch probes. These measurements can be made by positioning the probe by hand, or automatically in more expensive machines. Reasonable accuracies are 5 micro in. or 1 micrometer. The method these machines work on is measurement of the position of the probe using linear position sensors. These are based on moiré fringe patterns (also used in other systems). Transducer is provided in tilt directions for giving digital display and senses positive and negative direction.

5.6.3 Types of CMM

(i) Cantilever type

The cantilever type is very easy to load and unload, but mechanical error takes place because of sag or deflection in Y-axis.

(ii) Bridge type

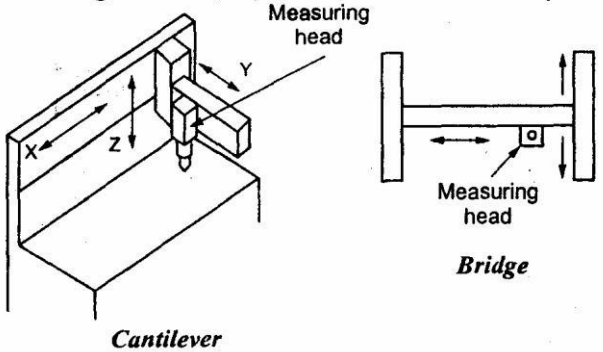
Bridge type is more difficult to load but less sensitive to mechanical errors.

(iii) Horizontal boring Mill type

This is best suited for large heavy work pieces.

(iv) Vertical boring mill type: -

Vertical boring mill is highly accurate but slower to operate.



(Measuring head movement in plane perpendicular to paper)

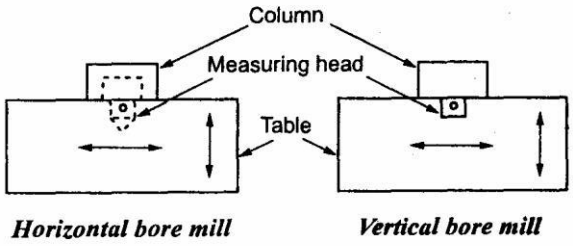


Fig 5.12 Types of CMM

Working Principle

CMM is used for measuring the distance between two holes. The work piece is clamped to the worktable and aligned for three measuring slides x, y and z. The measuring head provides a taper probe tip which is seated in first datum hole and the position of probe digital read out is set to zero. The probe is then moved to successive holes, the read out represent the co-ordinate part print hole location with respect to the datum hole. Automatic recording and data processing units are provided to carry out complex geometric and statistical analysis. Special co-ordinate measuring machines are provided both linear and rotary axes. This can measure various features of parts like cone, cylinder and hemisphere. The prime advantage of co-ordinate measuring machine is the quicker inspection and accurate measurements.

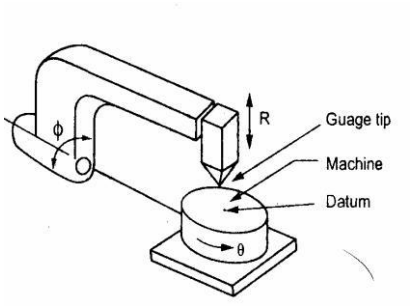


Fig 5.13 Schematic Diagram

5.6.4 Causes of Errors in CMM

1 The table and probes are in imperfect alignment. The probes may have a degree of run out and move up and down in the Z-axis may cause perpendicularity errors. So CMM should be calibrated with master plates before using the machine.

2 Dimensional errors of a CMM is influenced by

Straightness and perpendicularity of the guide ways.

Scale division and adjustment.

Probe length.

Probe system calibration, repeatability, zero point setting and reversal error.

Error due to digitization.

Environment

3 Other errors can be controlled by the manufacture and minimized by the measuring software. The length of the probe should be minimum to reduce deflection.

4 The weight of the work piece may change the geometry of the guide ways and therefore, the work piece must not exceed maximum weight.

5 Variation in temperature of CMM, specimen and measuring lab influence the uncertainly of measurements.

6 Translation errors occur from error in the scale division and error in straightness perpendicular to the corresponding axis direction.

7 Perpendicularity error occurs if three axes are not orthogonal.

5.6.5 Calibration of Three Co-Ordinate Measuring Machine

The optical set up for the V calibration is shown in figure

The laser head is mounted on the tripod stand and its height is adjusted corresponding to the working table of CMM. The interferometer contains a polarized beam splitter which reflects F1 component of the laser beam and the F2 Component parts through. The retro reflector is a polished trihedral glass prism. It reflects the laser beam back along a line parallel to the original beam by twice the distance. For distance measurement the F1 and F2 beams that leave the laser head are aimed at the interferometer which splits F1 and F2 via polarizing beaming splitter. Component F1 becomes the fixed distance path and F2 is sent to a target which reflects it back to the interferometer.

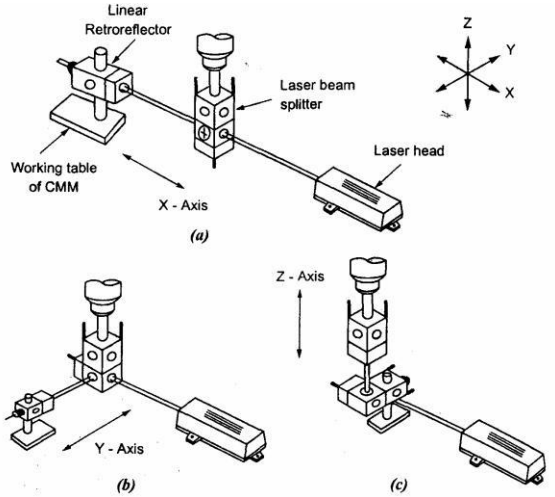


Fig 5.14 Optical setup

Relative motion between the interferometer and the remote retro reflector causes a Dopper shift in the returned frequency. Therefore the laser head sees a frequency difference given by F1-F2 ± ΔF2. The F1-F2 ± ΔF2 signal that is returned from the external interferometer is compared in the measurement display unit to the reference signal. The difference ΔF2 is related to the velocity. The longitudinal micrometer microscope of CMM is set at zero and the laser display unit is also set at zero. The CMM microscope is then set at the following points and the display units are noted.1 to 10mm, every mm and 10 to 200mm, in steps of 10mm. The accuracy of linear measurements is affected by changes in air temperature, pressure and humidity.

5.6.6 Performance of CMM

- Geometrical accuracies such as positioning accuracy, Straightness and Squareness.

Total measuring accuracy in terms of axial length measuring accuracy. Volumetric length measuring accuracy and length measuring repeatability. i.e., Coordinate measuring machine has to be tested as complete system.

Since environmental effects have great influence for the accuracy testing, including thermal parameters, vibrations and relative humidity are required.

5.7 APPLICATIONS

Co-ordinate measuring machines find applications in automobile, machine tool, electronics, space and many other large companies.

These machines are best suited for the test and inspection of test equipment, gauges and tools.

For aircraft and space vehicles, hundred percent inspections is carried out by using CMM.

CMM can be used for determining dimensional accuracy of the components.

These are ideal for determination of shape and position, maximum metal condition, linkage of results etc. which cannot do in conventional machines.

CMM can also be used for sorting tasks to achieve optimum pairing of components within tolerance limits.

CMMs are also best for ensuring economic viability of NC machines by reducing their downtime for inspection results. They also help in reducing cost, rework cost at the appropriate time with a suitable CMM.

5.7.1 Advantages

- The inspection rate is increased.
- Accuracy is more.
- Operators error can be minimized.
- Skill requirements of the operator is reduced.
- Reduced inspection fixturing and maintenance cost.
- Reduction in calculating and recording time.
- Reduction in set up time.
- No need of separate go / no go gauges for each feature.
- Reduction of scrap and good part rejection.
- Reduction in off line analysis time.
- Simplification of inspection procedures, possibility of reduction of total inspection time through use of statistical and data analysis techniques.

5.7.2 Disadvantages

- The lable and probe may not be in perfect alignment.
- The probe may have run out.
- The probe moving in Z-axis may have some perpendicular errors.
- Probe while moving in X and Y direction may not be square to each other.
- There may be errors in digital system.

5.8 COMPUTER CONTROLLED CO-ORDINATE MEASURING MACHINE

- The measurements, inspection of parts for dimension form, surface characteristics and position of geometrical elements are done at the same time.
- Mechanical system can be divided into four basic types. The selection will be depends on the application.
    1. Column type.

2. Bridge type.

3. Cantilever type.

4. Gantry type.

All these machines use probes which may be trigger type or measuring type. This is connected to the spindle in Z direction. The main features of this system are shown in figure

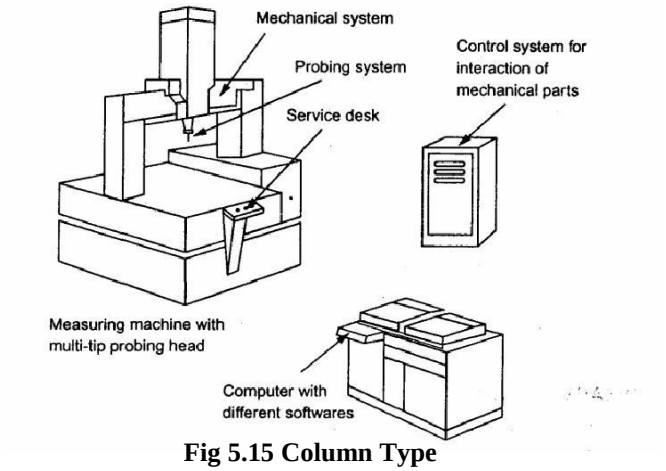


Fig 5.15 Column Type

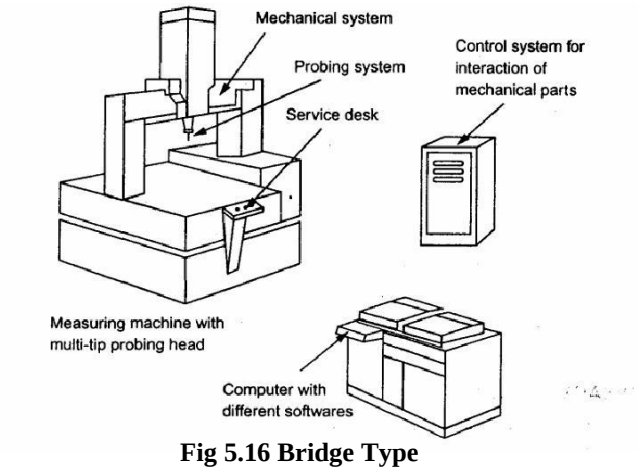
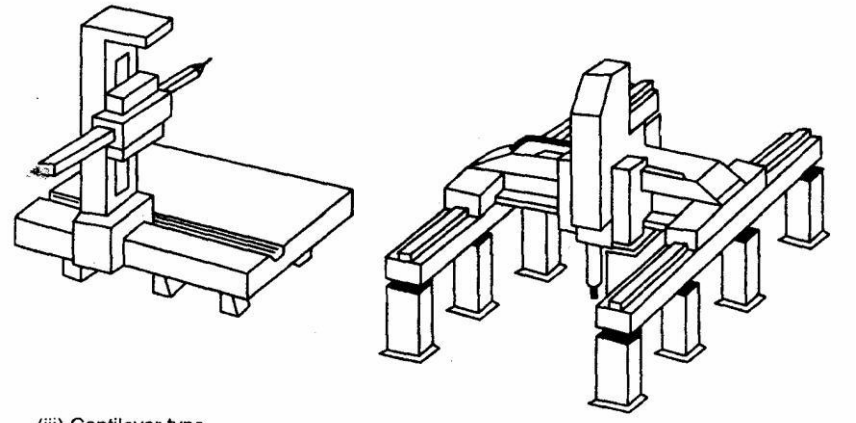


Fig 5.16 Bridge Type



5.8.1 Trigger type probe system

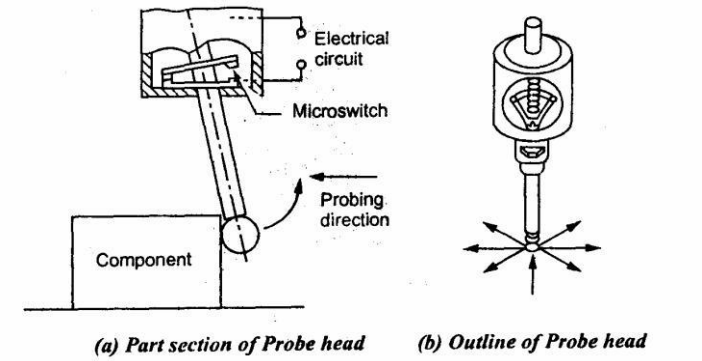


Fig 5.17 Trigger Type Probe System

2.10.3 The buckling mechanism is a three point hearing the contacts which are arranged at 1200 around the circumference. These contacts act as electrical micro switches.

2.10.4 When being touched in any probing direction one or f contacts is lifted off and the current is broken, thus generating a pulse, when the circuit is opened, the co-ordinate positions are read and stored.

2.10.5 After probing the spring ensures the perfect zero position of the three-point bearing. The probing force is determined by the pre stressed force of the spring with this probe system data acquisition is always dynamic and therefore the measuring time is shorter than in static principle.

5.8.2 Measuring type probe system

- It is a very small co-ordinate measuring machine in which the buckling mechanism consists of parallel guide ways when probing the spring parallelogram are deflected from their initial position.
- Since the entire system is free from, torsion, friction, the displacement can be measured

  easily.

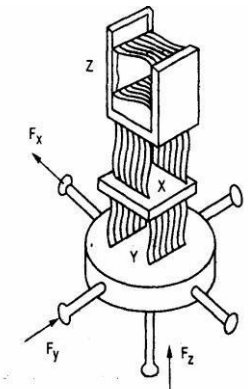
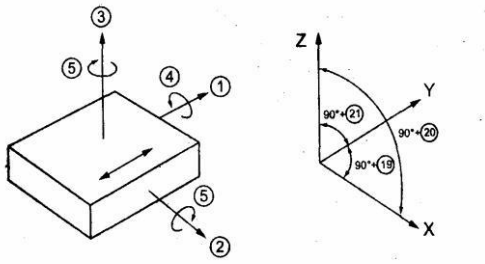


Fig 5.18 Buckling Mechanism

- The mathematical model of the mechanical system is shown in figure. If the components of the CMM are assumed as rigid bodies, the deviations of a carriage can be described by three displacement deviations.
- Parallel to the axes 1, 2 and 3 and by three rotational deviations about the axes 4, 5 and 6.Similarly deviations 7-12 occur for carriage and 13-18 occur for Z carriage and the three squareness deviations 19, 20 and 21 are to be measured and to be treated in the mathematical model.



- Moving the probe stylus in the Y direction the co-ordinate system L is not a straight line but a curved one due to errors in the guide.
- If moving on measure line L further corrections are required in X, Y and Z coordinates due to the offsets X and Z from curve L resulting from the pitch angle 5, the roll angle 4 and the yaw angle 6.
- Similarly the deviations of all three carriages and the squareness errors can be taken into account.
- The effect of error correction can be tested by means of calibrated step gauges.

The following test items are carried out for CMM.

(i)Measurement accuracy

a. Axial length measuring accuracy
b.Volumetric length measuring accuracy

(ii)Axial motion accuracy

a. Linear displacement accuracy

b. Straightness

c. Perpendicularity

d. Pitch, Yaw and roll.

The axial length measuring accuracy is tested at the lowest position of the Z-axis. The lengths tested are approximately 1/10, 1/5, 2/5, 3/5 and 4/5 of the measuring range of each axis of CMM. Tile test is repeated five times for each measuring length and results plotted and value of measuring accuracy is derived.

5.9 CNC-CMM

Construction

The main features of CNC-CMM are shown in figure has stationary granite measuring table, Length measuring system. Air bearings; control unit and software are the important parts of CNC & CMM.

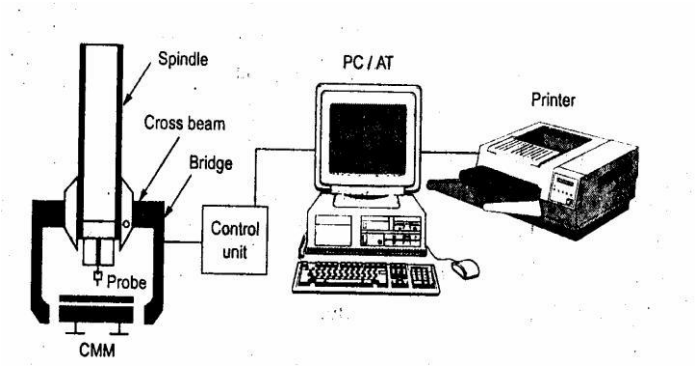


Fig 5.19 CNC - CMM

2.12 Stationary granite measuring table

Granite table provides a stable reference plane for locating parts to be measured. It is provided with a grid of threaded holes defining clamping locations and facilitating part mounting. As the table has a high load carrying capacity and is accessible from three sides. It can be easily integrated into the material flow system of CIM.

- **Length measuring system**

A 3- axis CMM is provided with digital incremental length measuring system for each axis.

- **Air Bearing**

The Bridge cross beam and spindle of the CMM are supported on air bearings.

- **Control unit**

The control unit allows manual measurement and programme. It is a microprocessor control.

- **Software**

The CMM, the computer and the software represent one system; the efficiency and cost effectiveness depend on the software.

5.9.1 Features of CMM Software

Measurement of diameter, center distance, length.

Measurement of plane and spatial carvers.

Minimum CNC programme.

Data communications.

Digital input and output command.

Programme for the measurement of spur, helical, bevel' and hypoid gears.

Interface to CAD software.

A new software for reverse engineering complex shaped objects. The component is digitized using CNC CMM. The digitized data is converted into a computer model which is the true surface of the component. Recent advances include the automatic work part alignment and to orient the coordinate system. Savings in inspection time by using CMM is 5 to 10% compared to manual inspection method.

5.10 COMPUTER AIDED INSPECTION USING ROBOTS

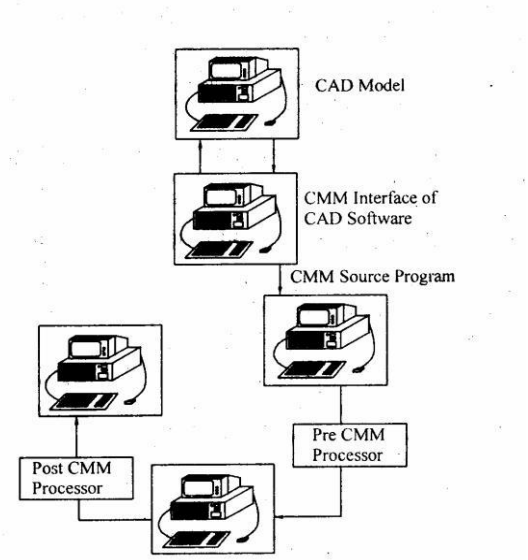
Robots can be used to carry out inspection or testing operation for mechanical dimension physical characteristics and product performance. Checking robot, programmable robot, and co-ordinate robot are some of the types given to a multi axis measuring machines. These machines automatically perform all the basic routines of a CNC co ordinate measuring machine but at a faster rate than that of CMM. They are not as accurate as p as CMM but they can check up to accuracies of 5micrometers. The co-ordinate robot can take successive readings at high speed and evaluate the results using a computer graphics based real time statistical analysis system.

5.10.1 Integration of CAD/CAM with Inspection System

A product is designed, manufactured and inspected in one automatic process. One of the critical factors is in manufacturing equality assurance. The co-ordinate measuring machine assists in the equality assurance function. The productivity can be improved by interfacing with CAD/CAM system. This eliminates the labour, reduces preparation time and increases availability of CMM for inspection. Generally the CAD/CAM-CMM interface consists of a number of modules as given

(1) CMM interface

This interface allows to interact with the CAD/CAM database to generate a source file that can be converted to a CMM control data file. During source file creation, CMM probe path motions are simulated and displayed on the CAD/CAM workstation for visual verification. A set of CMM command allow the CMM interface to take advantage of most of the CMM functional capabilities. These command statement include set up, part datumcontrol, feature construction,



geometric relations, tolerance, output control and feature measurements like measurements of lines, points, arcs, circles, splines, conics, planes, analytic surfaces.

(2) Pre- processor

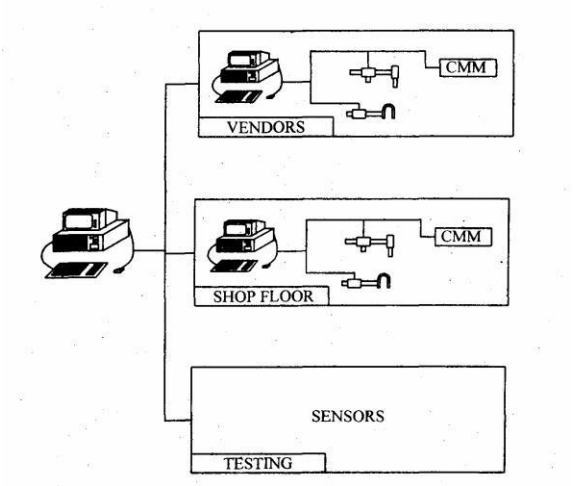
The pre-CMM processor converts the language source file generated by CMM interface into the language of the specified co ordinate measuring machine.

(3) Post-CMM processor

This creates wire frame surface model from the CMM-ASCII output file commands are inserted into the ASCJI-CMM output file to control the creation of CAD/CAM which include points, lines, arcs, circles, conics, splines and analytic surfaces.

5.10.2 Flexible Inspection System

The block diagram of flexible inspection system is shown in figure. This system has been developed and the inspection done at several places in industry. This system helps product performance to improve inspection and increase productivity. FIS is the Real time processor to handle part dimensional data and as a multi programming system to perform manufacturing process control. The input devices used with this system are CMM's;



Microprocessor based gauges and other inspection devices. The terminal provides interactive communication with personal computers where the programmes are stored. The data from CMMs and other terminals are fed into the main computer for analysis and feedback control. The equality control data and inspection data from each station are fed through the terminals to the main computer.

The data will be communicated through telephone lines. Flexible inspection system involves more than one inspection station. The objective of the flexible inspection system is to have off time multi station automated dimensional verification system to increase the production rate and less inspection time and to maintain the inspection accuracy and data processing integrity.

5.10.3 Machine Vision

A Vision system can be defined as a system for automatic acquisition and analysis of images to obtain desired data for interpreting or controlling an activity. It is a technique which allows a sensor to view a scene and derive a numerical or logical decision without further human intervention. Machine vision can be defined as a means of simulating the image recognition and analysis capabilities of the human system with electronic and electro mechanical techniques. Machine vision system are now a days used to provide accurate and in expensive 100% inspection of work pieces. These are used for functions like gauging of dimensions, identification of shapes, measurement of distances, determining orientation of parts, quantifying motion-detecting surface shading etc. It is best suited for high production. These systems function without fatigue. This is suited for inspecting

the masks used in the production of micro-electronic devices. Standoff distance up to one meter is possible.

5.10.4 Vision System

The schematic diagram of a typical vision system is shown. This system involves image acquisition; image processing Acquisition requires appropriate lighting. The camera and store digital image processing involves manipulating the digital image to simplify and reduce number of data points. Measurements can be carried out at any angle along the three reference axes x y and z without contacting the part. The measured values are then compared with the specified tolerance which stores in the memory of the computer.

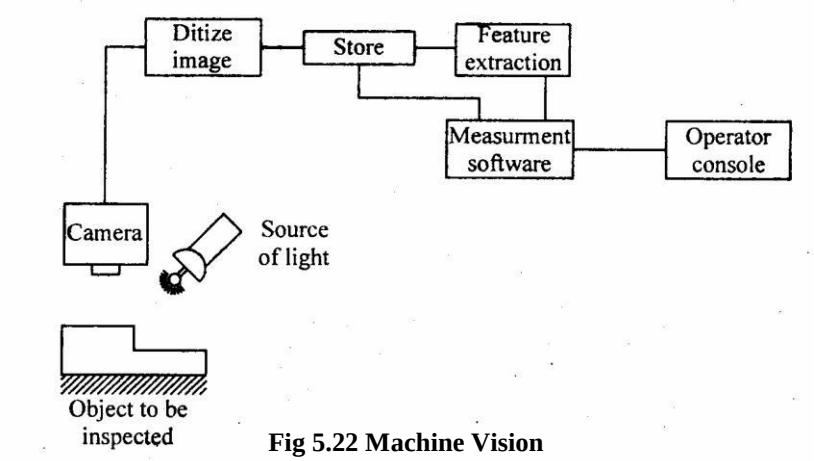


Fig 5.22 Machine Vision

The main advantage of vision system is reduction of tooling and fixture costs, elimination of need for precise part location for handling robots and integrated automation of dimensional verification and defect detection.

Principle

Four types of machine vision system and the schematic arrangement is shown

(i) Image formation.

(ii) Processing of image in a form suitable for analysis by computer.

(iii) Defining and analyzing the characteristic of image.

(iv) Interpretation of image and decision-making.

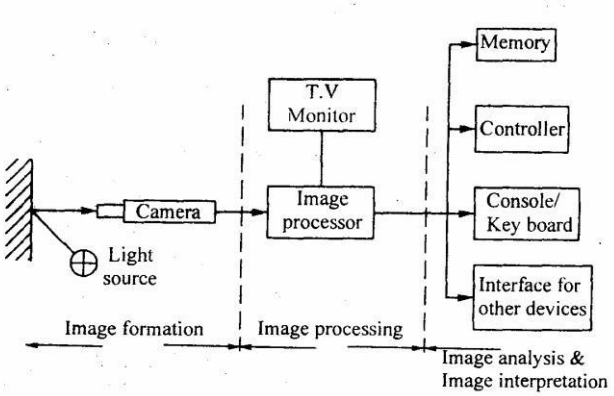


Fig 5.23 Schematic arrangement of Machine Vision

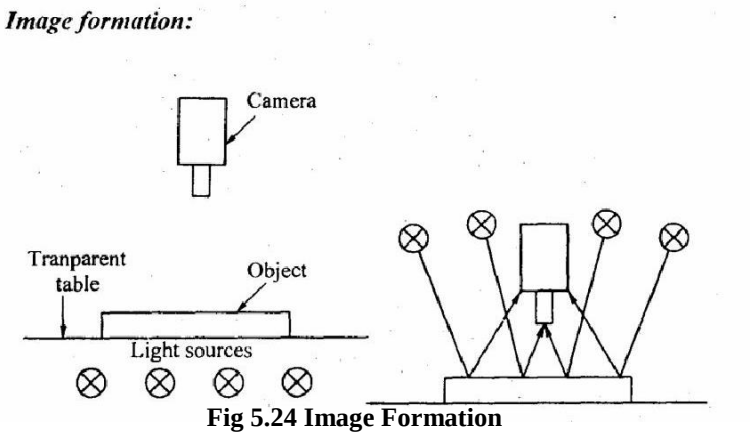


Fig 5.24 Image Formation

For formation of image suitable light source is required. It consists of incandescent light, fluorescent tube, fiber optic bundle, and arc lamp. Laser beam is used for triangulation system for measuring distance. Ultraviolet light is used to reduce glare or increase contrast. Proper illumination back lighting, front lighting, structured light is required. Back lighting is used to obtain maximum image contrast. The surface of the object is to be inspected by using front lighting. For inspecting three-dimensional feature structured lighting is required. An image sensor vidicon camera, CCD camera is used to generate the electronic signal representing the image. The image sensor collects light from the scene through a lens, using photosensitive target, converts into electronic signal.

Vidicon camera

Image is formed by focusing the incoming light through a series of lenses onto the photoconductive faceplate of the vidicon tube. The electron beam scans the photoconductive surface and produces an analog voltage proportional to the variation in light intensity for each scan line of the original scene.

Solid-state camera

The image sensors change coupled device (CCD) contain matrix of small array, photosensitive elements accurately spaced and fabricated on silicon chips using

integrated circuit technology. Each detector converts in to analog signal corresponding to light intensity through the camera lens.

Image processor

A camera may form an image 30 times per sec at 33 m sec intervals. At each time interval the entire image frozen by an image processor for processing. An analog to digital converter is used to convert analog voltage of each detector in to digital value. If voltage level for each pixel is given by either 0 or I depending on threshold value. It is called binary system on the other hand grey scale system assigns upto 256 different values depending on intensity to each pixel. Grey scale system requires higher degree of image refinement, huge storage processing capability. For analysis 256 x 256 pixels image array up to 256 different pixel values will require 65000-8 bit storage locations at a speed of 30 images per second. Techniques windowing and image restoration are involved.

Windowing

Processing is the desired area of interest and ignores non-interested part of image.

Image restoration

Preparation of image during the pre-processing by removing the degrade. Blurring of lines, poor contrast between images and presence of noise are the degrading.

The quality may be improved

2.14 By improving the contrast by brightness addition.

2.15 By increasing the relative contrast between high and low intensity elements.

2.16 By Fourier domain processing.

2.17 Other techniques to reduce edge detection and run length encoding.

Image Analysis

Digital image of the object formed is analyzed in the central processing Unit of the system. Three important tasks performed by machine vision system are measuring the distance of an object from a vision system camera, determining object orientation and defining object position. The distance of an object from a vision system camera can be determined by **triangulation technique.** The object orientation can he determined by the methods of **equivalent ellipse**. The image can be interpreted by two-dimensional image. For complex three-dimensional objects boundary locations are determined and the image is segmented into distinct region.

Image Interpretation

This involves identification of on object. In binary system, the image is segmented on the basis of white and black pixels. The complex images can he interpreted by grey scale technique and algorithms. The most common image interpretation is template matching.

5.10.5 Function of Machine Vision

- Lighting and presentation of object to evaluated.
- It has great compact on repeatability, reliability and accuracy.
- I.ighting source and projection should be chosen and give sharp contrast.
- Images sensor compressor TV camera may he vidicon or solid state.
- For simple processing, analog comparator and a computer controller to convert the video information to a binary image is used.
- Data compactor employs a high speed away processor to provide high speed processing of the input image data.
- System control computer communicates with the operator and make decision about the part being inspected.
- The output and peripheral devices operate the control of the system. The output enables the vision system to either control a process or provide caution and orientation information two a robot, etc.
- These operate under the control of the system control of computer.

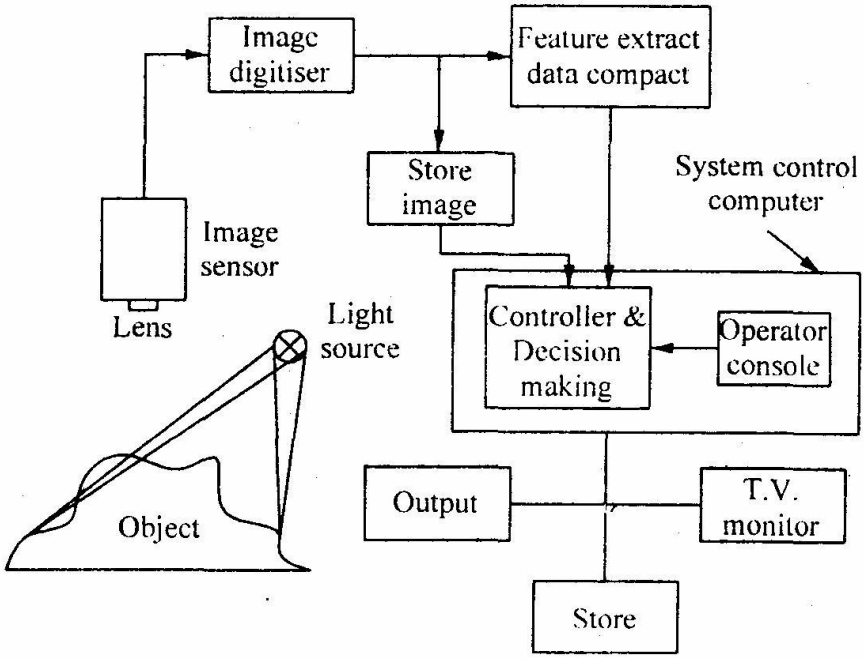


Fig 5.25 Functions of Machine Vision

5.10.6 Applications

- Machine vision can he used to replace human vision fur welding. Machining and maintained relationship between tool and work piece and assembly of parts to analyze the parts.
- This is frequently used for printed circuit board inspection to ensure minimum conduction width and spacing between conductors. These are used for weld seam tracking, robot guideness and control, inspection of microelectronic devices and tooling, on line inspection in machining operation, assemblies monitoring high-speed packaging equipment etc.
- It gives recognition of an object from its image. These are designed to have strong geometric feature interpretation capabilities and pa handling equipment.