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G. PULLAIAH COLLEGE OF ENGINEERING AND TECHNOLOGY

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Department of Mechanical Engineering

Bridge Course
On
Fluid Mechanics & Hydraulic Machinery

Mechanical Properties

Newton's laws of motion

Newton's laws of motion are three physical laws that together laid the foundation for classical-mechanics. They describe the relationship between a body and the forces acting upon it, and its motion in response to said forces. They have been expressed in several different ways over nearly three centuries, and can be summarized as follows:

1. **First law**: When viewed in an inertial reference frame, an object either is at rest or moves at a constant velocity, unless acted upon by an external force.
2. **Second law**: The acceleration of a body is directly proportional to, and in the same direction as, the net force acting on the body, and inversely proportional to its mass. Thus, $\mathbf{F} = m\mathbf{a}$, where $\mathbf{F}$ is the net force acting on the object, m is the mass of the object and $\mathbf{a}$ is the acceleration of the object.
3. **Third law**: When one body exerts a force on a second body, the second body simultaneously exerts a force equal in magnitude and opposite in direction to that of the first body.

Inertia

Inertia is the resistance of any physical object to any change in its motion

Conservation of momentum

Conservation of momentum is a fundamental law of physics which states that the momentum of a system is constant if there are no external forces acting on the system.

Conservation of energy

The law of conservation of energy states that the total energy of an isolated system cannot change—it is said to be *conserved* over time. Energy can be neither created nor destroyed, but can change form; for instance, chemical energy can be converted to kinetic energy.

Conservation of mass

The law of conservation of mass, or principle of mass conservation, states that for any system closed to all transfers of matter and energy (both of which have mass), the mass of the system must remain constant over time, as system mass cannot change quantity if it is not added or removed.

Conservation of Force

Conservation of Force is a force which refers to work done on an object , When it moves from a point A to a point B depends only on the points A & B and not on the path along which the object moves, the force is said to be a conservative force

Einstein’s mass energy relation: A physical system has a property called energy and a corresponding property called mass; the two properties are equivalent in that they are always both present in the same (i.e. constant) proportion to one another. The equivalence is described by the famous equation:

$$E = mc^2$$

Where E is energy, *m* is mass, and *c* is the speed of light

Torque

Torque is the tendency of a force to cause or change rotational motion of a body. Torque is calculated by multiplying Force and distance, so the SI units of torque are Nm.

Linear momentum

Linear momentum is a vector quantity or evaluation of an object's translational motion as derived by the product of its mass and its velocity. Linear momentum is denoted by the letter p and it is known simply as momentum.

$$P=mv$$

Angular momentum

The angular momentum of a rigid object is defined as the product of the moment of inertia and the angular velocity. It is analogous to linear momentum and is subject to the fundamental constraints of the conservation of angular momentum principle if there is no external torque on the object. Angular momentum is a vector quantity. It is derivable from the expression for the angular momentum of a particle.

$$L=I\omega$$

Viscosity

Viscosity is a measurement of how resistant a fluid is to attempts to move through it. A fluid with a low viscosity is said to be "thin," while a high viscosity fluid is said to be "thick." It is easier to move through a low viscosity fluid (like water) than a high viscosity fluid (like honey).

Surface tension

A property of liquids arising from unbalanced molecular cohesive forces at or near the surface, as a result of which the surface tends to contract and has properties resembling those of a stretched elastic membrane.

Definition of a Fluid

A fluid may be defined broadly as a substance which deforms continuously when subjected to shear stress. This fluid can be made to flow if it is acted upon by a source of energy. This can be made clear by assuming the fluid being consisted of layers parallel to each other and letting a force act upon one of the layers in a direction parallel to its plane. This force divided by the area of the layer is called shear stress. As long as this shear stress is applied the layer will continue to move relative to its neighboring layers.

If the neighboring layers offer no resistance to the movement of fluid, this fluid is said to be frictionless fluid or ideal fluid. (Practically speaking, ideal fluids do not exist in nature, but in many practical problems the resistance is either small or is not important, therefore can be ignored.)

A fluid is always a continuous medium and there cannot be voids in it. The properties of a fluid, e.g., density, may, however, vary from place to place in the fluid. In addition to shear force, fluid may also be subjected to compressive forces. These compressive forces tend to change the volume of the fluid and in turn its density. If the fluid yields to the effect of the compressive forces and changes its volume, it is compressible, otherwise it is incompressible.

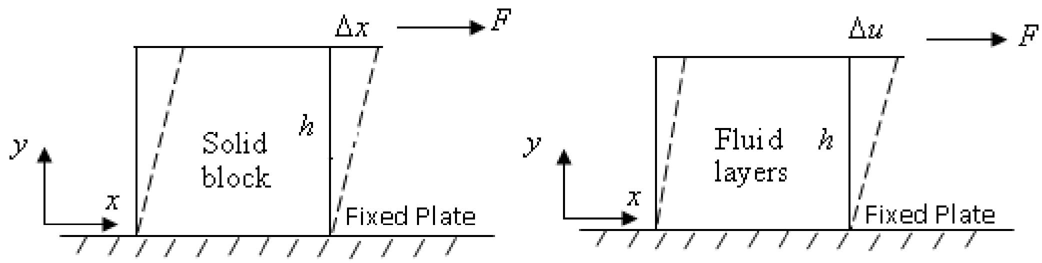
Mechanics

Mechanics is the oldest physical science that deals with both stationery and moving boundaries under the influence of forces. The branch of the mechanics that deals with bodies at rest is called statics while the branch that deals with bodies in motion is called dynamics.

Fluid Mechanics

Fluid Mechanics is the science that deals with behavior of fluids at rest (fluid statics) or in motion (fluid dynamics) and the interaction of fluids with solids or other fluids at the boundaries.

A substance in liquid / gas phase is referred as ‘fluid’. Distinction between a solid & a fluid is made on the basis of substance’s ability to resist an applied shear (tangential) stress that tends to change its shape. A solid can resist an applied shear by deforming its shape whereas a fluid deforms continuously under the influence of shear stress, no matter how small is its shape. In solids, stress is proportional to strain, but in fluids, stress is proportional to ‘strain rate.’



Definition of Stress

Consider a small area δA on the surface of a body (Fig. 1.1). The force acting on this area is δF This force can be resolved into **two perpendicular components**

- The component of force acting normal to the area called **normal** force and is denoted by δF_n
- The component of force acting along the plane of area is called **tangential** force and is denoted by δF_t

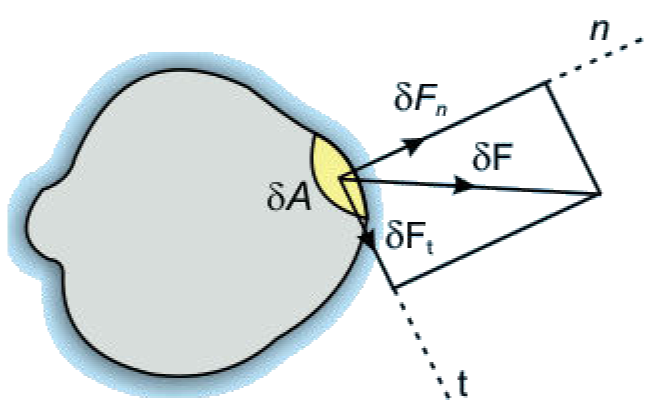


Fig 1.1 Normal and Tangential Forces on a surface

When they are expressed as force per unit area they are called as **normal stress** and **tangential stress** respectively**.** The tangential stress is also called shear stress

Dimension and Unit

A dimension is the measure by which a physical variable is expressed quantitatively and the unit is a particular way of attaching a number to the quantities of dimension. All the properties of fluid are assigned with certain unit and dimension. Some basic dimensions such as mass (M), length (L), time (T) and temperature (θ) are selected as Primary/Fundamental dimensions/unit. While others such as velocity, volume is expressed in terms of primary dimensions and is called as secondary/derived dimensions/unit. In this particular course, SI (Standard International) system of units and dimension will be followed to express the properties of fluid

Forces on Fluid Elements

Fluid Elements - Definition:

Fluid element can be defined as an infinitesimal region of the fluid continuum in isolation from its surroundings.

Two types of forces exist on fluid elements

- **Body Force**: distributed over the entire mass or volume of the element. It is usually expressed per unit mass of the element or medium upon which the forces act. Example: Gravitational Force, Electromagnetic force fields etc.
- **Surface Force**: Forces exerted on the fluid element by its surroundings through direct contact at the surface.
  Surface force has two components:
  - Normal Force: along the normal to the area
  - Shear Force: along the plane of the area.

The ratios of these forces and the elemental area in the limit of the area tending to zero are called the normal and shear stresses respectively.

1. **Pressure**: It is the normal force exerted by a fluid per unit area. More details will be available in the subsequent section (Lecture 02). In SI system the unit and dimension of pressure can be written as, N/m2
2. **Temperature**: It is the measure of hotness and coldness of a system. In thermodynamic sense, it is the measure of internal energy of a system. Many a times, the temperature is expressed in centigrade scale (°C) where the freezing and boiling point of water is taken as 0°C and 100°C, respectively. In SI system, the temperature is expressed in terms of absolute value in Kelvin scale (K = °C+ 273).

Units and scales of Pressure Measurement

Pascal (N/m^2) is the unit of pressure.

Pressure is usually expressed with reference to either absolute zero pressure (a complete vacuum)or local atmospheric pressure.

- The absolute pressure: It is the difference between the value of the pressure and the absolute zeropressure.

$$p_{abs} = p - 0 = p$$

- Gauge pressure: It is the difference between the value of the pressure and the local atmospheric pressure(p_{atm})

$$p_{gauge} = p - p_{atm}$$

- Vacuum Pressure: If $p<p_{atm}$ then the gauge pressure becomes negative and is called the vacuum pressure. But one should always remember that hydrostatic pressure is always compressive in nature

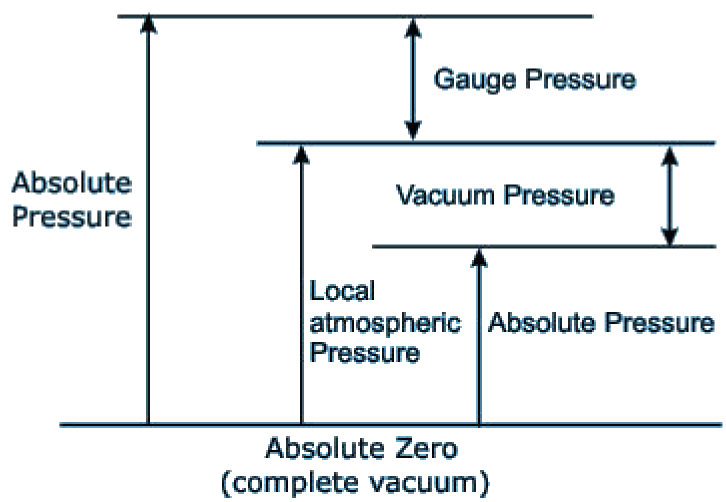


Fig 4.1 the Scale of Pressure

At sea-level, the international standard atmosphere has been chosen as P_{atm} = 101.32 kN/m^2

Scalar and Vector Fields

Scalar: Scalar is a quantity which can be expressed by a single number representing its **magnitude.**
Example: mass, density and temperature.

Scalar Field

If at every point in a region, a scalar function has a defined value, the region is called a scalar field.

Example: Temperature distribution in a rod.

Vector: Vector is a quantity which is specified by both magnitude and direction. Example: Force, Velocity and Displacement.

Vector Field

If at every point in a region, a vector function has a defined value, the region is called a vector field. Example: velocity field of a flowing fluid.

Flow Field

The region in which the flow parameters i.e. velocity, pressure etc. are defined at each and every point at any instant of time is called a flow field.

Thus a flow field would be specified by the velocities at different points in the region at different times.

Hydraulic machines

Hydraulic machines are machinery and tools that use liquid fluid power to do simple work. Heavy equipment is a common example.

In this type of machine, hydraulic fluid is transmitted throughout the machine to various hydraulic motors and hydraulic cylinders and becomes pressurized according to the resistance present. The fluid is controlled directly or automatically by control valves and distributed through hoses and tubes.

The popularity of hydraulic machinery is due to the very large amount of power that can be transferred through small tubes and flexible hoses, and the high power density and wide array of actuators that can make use of this power.

Hydraulic machinery is operated by the use of hydraulics, where a liquid is the powering medium.

A fundamental feature of hydraulic systems is the ability to apply force or torque multiplication in an easy way, independent of the distance between the input and output, without the need for mechanical gears or levers, either by altering the effective areas in two connected cylinders or the effective displacement (cc/rev) between a pump and motor. In normal cases, hydraulic ratios are combined with a mechanical force or torque ratio for optimum machine designs such as boom movements and trackdrives for an excavator.

Advantages of hydraulic power transmission

- Some of the major advantages of hydraulic power transmission are as follows:
- Great efficiency and economy due to low friction losses and high system reliability (efficiency is approx. 70 to 80 percent)
- Freedom of location of input and output power converters such as prime movers, pumps, and actuators.
- Safety and overload protection by means of relief valves.
- Emergency power stored in an accumulator.
- Infinitely variable control of output force, output torque, output speed, and actuator position.
- Extremely high output forces and force multiplication by means of the "hydraulic lever".
- Low inertia and ease of shock absorption during actuator motion, reversal, start, and stop.
- Hydraulic systems are self-lubricating and power can be diverted to alternative actuators.

Turbines:

Hydro-power is one of the major cheap source of power available on earth, and hence it widely used for generation of electric power worldwide. Water stored in the dam contains potential energy. The water flows through the turbine, so that power is generated by impact of water or reaction of water flow. The turbine drives a generator which delivers electrical power. Thus turbines are of great importance.

Turbines are basically of two types, impulse turbines and reaction turbines. In impulse turbines, water coming from high head acquires high velocity. The high velocity water jet strikes the buckets of the turbine runner and comes it to rotate by impact. In reaction turbine, total head of water is partly converted into velocity head as it approaches turbine runner and it fills the runner and pressure of water gradually changes as it flows through runner. In impulse turbine, the turbine used nowadays is pelton wheel turbine.

The Pelton wheel turbine consists of runner mounted over the main shaft. Runner consists of buckets fitted to the disc. The buckets have a shape of double ellipsoidal cups. The runner is encased in a casing provided with a Perspex window for visualization. A nozzle fitted in the side of casing directs the water jet over the ‘Splitter’ or centre ridge of the buckets. A spear operates inside the nozzle to control the water flow. On the other side of the shaft, a rope brake is mounted for loading the turbine.

Francis turbine is a reaction type of hydraulic turbine, used in reservoir of medium height to convert hydraulic energy into mechanical and electrical energy. Francis turbine is radial inward flow reaction turbine. This has the advantage of centrifugal forces acting against the flow, thus reducing the tendency of the turbine to over speed. Francis turbines are best suited for medium heads. The specific speed ranges from 25 to 300.

PumpS:

Centrifugal pump is a Rota dynamic machine. This develops dynamic pressure of liquid by virtue of rotation for pumping of liquid to a higher height. In centrifugal pump, liquid in the impeller of the pump is made to rotate by external force, so that it is thrown away from the center of rotation. As constant supply of liquid is made available at the center, liquid can be pumped to higher level. Two or more impellers are connected either in series or parallel is called as multi stage centrifugal pump.

Mathematical formulae

Common integrals

i) Integrals of Trigonometric Functions

1. $\int \mathrm{Sin}\, x dx = -\mathrm{Cos}\, x + C$
2. $\int \mathrm{Cos}\, x dx = \mathrm{Sin}\, x + C$
3. $\int Tan\ x dx = \log|\sec x| + C$
4. $\int \mathrm{Sec}\, x dx = \log|\sec x + \tan x| + C$
5. $\int Cotx\ dx = \log|\mathrm{Sin}\, x| + C$
6. $\int Cosec\ x\ dx =$
7. $\int Tan^2\, x dx = Tanx - x + C$
8. $\int Sec^2\, x\ dx = Tanx + C$

ii) Integrals of Exponential and Logarithmic Functions

1. $\int \log x dx = x \log x - x + C$
2. $\int e^x\, dx = e^x + C$
3. $\int a^x dx = \frac{a^x}{\log a} + C$

iii) The roots of the quadratic equation, $ax^2 + bx + c = 0\ are$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

Common derivatives

1. $(c.f(x))'$=c.$f(x)'$

2.$(f \pm g)' = f' \pm g'$

3.$(f.g)' = f'.g + f.g'$

4.$\left(\frac{f}{g}\right)' = \frac{f'.g - f.g\prime}{g2}$

5.$\left(f\left(g(x)\right)\right)' = f'\left(g(x)\right).g'(x)$

6.$\frac{d}{dx}(c) = 0$

7. $\frac{d}{dx}(x) = 1$

8. $\frac{d}{dx}(x^n) = nx^{n-1}$

9. $\frac{d}{dx}(sinx) = cosx$

10. $\frac{d}{dx}(cosx) = -sinx$

11. $\frac{d}{dx}(tanx) = sec^2x$

12. $\frac{d}{dx}(secx) = secx.tanx$

13. $\frac{d}{dx}(cosecx) = -cosecx.cotx$

14. $\frac{d}{dx}(cotx) = -cosec^2x$

15. $\frac{d}{dx}(sin^{-1}x) = \frac{1}{\sqrt{1-x^2}}$

16. $\frac{d}{dx}(cos^{-1}x) = \frac{-1}{\sqrt{1-x^2}}$

17. $\frac{d}{dx}(tan^{-1}x) = \frac{1}{1+x^2}$

18. $\frac{d}{dx}(a^x) = a^x.loga$

19. $\frac{d}{dx}(e^x) = e^x$

20. $\frac{d}{dx}(logx) = \frac{1}{x}$