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Short Descriptions of Measurements and Instrumentation

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INTRODUCTION

Measurement is the numerical quantitation of the attributes of an object or event. Measurement may be a cornerstone of trade, science, technology, and quantitative research in many disciplines. Earlier, many measurement systems existed for the varied fields of human existence to facilitate comparisons in these fields. Often these were achieved by local agreements between trading partners or collaborators. The developments progressed towards unifying, widely accepted standards that resulted in the modern International System of Units (SI). This system reduces all physical measurements to a mathematical combination of seven base units. The science of measurement is chased within the field of metrology and other engineering applications. This paper provides a brief explanation of different measurement methods with their units.

1. TEMPERATURE MEASUREMENT

Temperature is a measure of hotness or coldness, and it has a great roll in engineering and process industries. Many machine component has a specific operating temperature rage, beyond that the components leads to fail or the performance becomes less. The unit of temperature is ^{o}C and the temperature of the body can be measured based on different principles and summarized as follows.

1.1. THERMOELECTRIC EFFECT SENSORS

Works based on the principle of when two bodies or thermocouples (like base-metal alloys of nisil (Ni/Mn/Al/Si), chromel (Ni/Cr) and others are coming in contact, they induced an e.m.f. due to temperature difference. The output of this kind of measurement is volte (V) and then we can get the corresponding temperature from thermocouple table.

1.2. VARYING RESISTANCE DEVICES

Works based on the principle of when the temperature of body is varying, then the resistance of the material to flow current will also vary. The output of this device is resistance of the body at a given temperature (the unit is Ohm,Ω). The measurement can be done using either resistance temperature devices or thermistors and then we can find the temperature on resistance-temperature table.

1.3. SEMICONDUCTOR DEVICE

This is another means of temperature measurement and it is cheap that makes it advantageous to use them over the others. The transistor circuit can configure in different ways based on the interested outputs (could be voltage or current).

1.4. RADIATION THERMOMETERS

Works based on the principle of every object can emit electromagnetic radiation when their temperature is greater than absolute zero temperature. The output of this device is a wavelength (μm) and then we can convert it in to temperature based on the radiation energy emission at different temperature figure.

1.5. THERMOGRAPHY

Works based on the scanning of an object using infrared radiation detector. The scanned image will show the temperature distribution over the object. This equipment is employed to measure a temperature form -20 ^{o}C to 1500^{o}C.

1.6. THERMAL EXPANSION METHODS

Works based on the dimension change of any substances when they exposed to the various temperature values. The materials could be liquid such as mercury and this kind of substances exhibit expansion and show the temperature, in addition to this bimetallic stripes also used, and when they subjected to temperature change they will bend, in these way the measurement can be taken and the unit is changing in length (mm).

1.7. QUARTZ THERMOMETERS

The temperature sensing element consists of quartz crystal enclosed within a probe. It works based on the principle of the resonant frequency of the material will change when the temperature varies. The measuring unit is frequency (rad/s).

1.8. FIBER-OPTIC TEMPERATURE SENSORS

This used in a situation that is hard to reach locations and high accuracy of measurement is required. It uses either intrinsic or extrinsic sensors. The output is the length change of fiber (mm).

1.9. ACOUSTIC THERMOMETERS

Works based on the principles of the velocity of sound will vary with different temperatures. The output is velocity (m/s).

$$\upsilon = \sqrt{\alpha RT/_{M}}$$

$$where\ \alpha\ \&\ R - are\ gas\ constants,$$
$$M - is\ molecular\ weigth\ of\ the\ gas$$

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1.10. COLOUR INDICATORS

Works based on the colour of the object will change when they exposed to various temperature. They employed to measure a range between 50 to 1250 ºC. This is a complicated temperature measurement method.

1.11. CHANGE OF STATE OF MATERIALS

This kind of measurement is used in ceramics industry and known as seger cons or pyro metric cones. The main parts of this devices are fused oxide and glass materials in the form of cone shape and this fused oxide will show the temperature change with in a rage of 6000 – 2000ºC.

2. PRESSURE MEASUREMENT

Pressure can be defined as the force applied perpendicular to the surface of an object per unit area over which that force is distributed. Its measuring unit is bar or pascal. There are many instruments that used to measure press, and they are summarized as follows.

2.1. DIAPHRAGMS: works based on the principle of when there is a pressure change, then the diaphragms will displace from its initial positon and the intensity of the pressure is measured by the displacement range that makes during measurement. Its measuring unit is mm.

2.2. CAPACITIVE PRESSURE SENSOR: this is similar to diaphragm device, their difference is in capacitive pressure sensor the measuring taken considering the capacitance changes between the diaphragm and the metal plate that is close to it and the unit is farad (F).

2.3. FIBRE-OPTIC PRESSURE SENSORS: this is also a type of diaphragm device, but the measuring displacement in diaphragm and bourdon tube pressure sensors is by optoelectronic means.

2.4. BELLOWS: works based on the principles of when the bellows is subjected to certain unknown pressure then the bellows will produce a translational motion of the end of the bellows and can be measured by capacitive, inductive, or potentiometric transducer**.** This will measure an Absolut pressure up to 2.5 bar.

2.5. BOURDON TUBE**:** this used a special kind of shape elastic materials that displaced or deform with pressure. The shape of the material could be c –type, spiral type and helical type, and hence the output is deformation, then the unit is mm.

2.6. MANOMETERS: this is a passive instrument and the pressure is measured based on the height difference of the liquid. They use U-shaped tube or any other, whenever there is a pressure difference between the two ends of the tube the height will be different, and the measurement unit is mm.

2.7. RESONANT-WIRE DEVICES: involves a wire which is fixed at its two ends and covered up with some material and when the pressure is applied it will vibrate based on the intensity of the pressure. The vibration will amplify to see it clearly and converted to frequency. So the measurement of this devices is frequency (rad/s).

2.8. DEAD-WEIGHT GAUGE: they used the ceiled cylinder and piston, and inside the cylinder there is some kind of liquid. When there is a pressure change, the piston head is moving downwards to compress the fluid. The amount of the compressed distance (mm) is a measure of pressure.

2.9. SPECIAL MEASUREMENT DEVICES FOR LOW PRESSURES: a thermocouple gauge is used, so it uses find temperature pressure relationship. Used to measure a pressure that is below atmospheric pressure.

2.10. HIGH-PRESSURE MEASUREMENT (GREATER THAN 7000 BAR): used a special material to have the change the resistance of the wire when there is a pressure difference. The measurement unit is Ohm, (Ω).

2.11. INTELLIGENT PRESSURE TRANS-DUCERS: to increase the accuracy of the measurement they integrated the microprocessor to the pressure transducer.

3. FLOW MEASUREMENT

The flow measurement can be define as the quantification of bulk fluid movement. Flow can be measured in a variety of ways base on the kind of fluid.

3.1. MASS FLOW RATE: the measuring unit is g/s. There are many ways of measuring of mass flow.

3.1.1. CONVEYOR-BASED METHODS

Used to measure a solid mass flow rate and it has a load cell that enables to measure the mass of the material that distributed over the length of the conveyor. The mass flow rate is given by

$$Q = {}^{Mv}/_{L}\ , where\ M - mass\ of\ material, v - velocity\ and\ L - length.$$ Its unit is Kg/s.

3.1.2. CORIOLIS FLOWMETER

Employed to measure the fluid flow rate, it has a pair of vibrating tube. The vibration of the tube causes force on the particles in the flowing fluid, these force induced a motion of the fluid particles in the direction that is orthogonal to the direction of flow called Coriolis force. The deflection of the tube is a measure of fluid flow and its unit is mm.

3.1.3. THERMAL MASS FLOW MEASUREMENT

Employed to measure gas flow rate, the principle of operation is to direct the flowing of material past a heated element. It can be measured either by measuring temperature rise (unit is degree centigrade) or by measuring the heart power consumption (watt).

3.1.4. JOINT MEASUREMENT OF VOLUME FLOW RATE AND FLUID DENSITY: is a cheapest measurement device and operated based on the Coriolis flowmeter principle.

3.2. VOLUME FLOW RATE: the measuring unit is m^3/s, and the following devices are used to measure volume flow.

3.2.1. DIFFERENTIAL PRESSURE (OBSTRU-CTION-TYPE) METERS: involves the insertion of some devices that can have different shape and arrangements inside the fluid carrying pipe. The devices that place inside pipe is used to obstruct the fluid flow and could be orifice plate, venture tube, flow nozzle and dull flow tubes. The measuring unit is $mm^3/_s$.

3.2.2. VARIABLE AREA FLOWMETERS (ROTAMETERS): has two main components such as float devices and the tube which has a variable area. When the tube is flow the float device will float on a height that depends on the flow rate. The measuring unit is millimeter (mm).

3.2.3. POSITIVE DISPLACEMENT FLOW-METERS: use a rotary piston, the slotted cylindrical piston rotate inside the chambered. When the piston moves round the chamber such that its outer surface maintains contact with the inner surface of the chamber at this time the piston slot slides up and down. The movement of piston is a measure of the volume flow rate.

3.2.4. TURBINE METERS: this use a multi bladed wheel on the shaft that rotates inside the fluid carrying pipe. On the surface of the pipe there is a ferromagnetic material is mounted and when the baled is come close to this ferrous material it will induce an electromotive force. The rotational speed of the blead is proportional to the fluid flow rate, and its measuring unit is volte (V).

3.2.5. ELECTROMAGNETIC FLOWMETERS: used to measure only an electrically conductive fluid. The electrodes will pass laterally through the tube and at 90dgree there is a magnetic field coil, and when the fluid is flowing a voltage will be induced that is proportional to the fluid flow. Its measuring unit is volte (V).

3.2.6. VORTEX-SHEDDING FLOWMETERS: work based on the natural phenomenon of vortex shedding and it has no a moving parts, that is created by placing a streamlined obstacle in the fluid carrying pipe. The shedding frequency of is proportional to the fluid flow.

3.2.7. ULTRASONIC FLOWMETERS: quite similar with magnetic flowmeter so it's limited to measure only a conductive fluid. The measure is either based on Doppler shift or on transmit time. The measuring unit could be either m/s or s.

4. LEVEL MEASUREMENT

Level measurement describes the nature of information within the values assigned to variables. The level measurement can take in many different methods. The following are some methods that employed for level measurement.

4.1. DIPSTICKS: is a cheapest device consists of scaled labeled metal bar which shows the level of the fluid. The measure of level is height that covered by the fluid, and its unit is mm.

4.2. FLOAT SYSTEMS: this has a cylinder and a piston and a scale with the pointes. The end of the piston road is connected by the spring on the closed end of the cylinder and also the pointer wire is connected on the piston road. When the level of the fluid is changed the pointer moves proportional to the level then the level is shown on the scale.

4.3. PRESSURE-MEASURING DEVICES (HYD-ROSTATIC SYSTEMS): works based on the principle of the hydrostatic pressure due to a liquid is proportional to the depth. Then the level is measured corresponding to the depth. Its measuring unit is mm.

4.4. CAPACITIVE DEVICES: is used to measure both the level of solids and liquids. The level can be measured based on the capacitance. The measuring unit is farad (F).

4.5. ULTRASONIC LEVEL GAUGE: is a non-contacting measuring devices. It uses an ultra sound emitter, the ultra sound will release to the direction of interested level measuring and then the time that take to return the sound back to the emitter is a measure of level. The measuring unit is seconds (s).

4.6. RADAR (MICROWAVE) METHODS: this is also a non-contact measurement. This use a micro wave to measure the level. Phase difference will show the level. So the measuring unit is rad.

4.7. RADIATION METHODS: an expensive device and contain radiation source and detector system. The radiation level shows the level and it converted to an output signal.

4.8. OTHER TECHNIQUES: there are also some other techniques that used to measure the level.

4.8.1. VIBRATING LEVEL SENSOR: work based On the principle of vibration of the two piezoelectric oscillators.

4.8.2. HOT-WIRE ELEMENTS/CARBON RESIS-TOR ELEMENTS:
The hot wire- elements or carbon resistors are placed at regular intervals along a vertical line. When the level at some position the wire will become cooled or loss its heat due to conduction between the fluid and the wire. The measuring unit is degree centigrade.

4.8.3. LASER METHODS: the reflective level sensor. It uses light to measure the level of the liquid.

5. MASS (WEIGHT) MEASUREMENT

Mass refers to the intrinsic property of all material objects to resist changes in their momentum. Weight, on the other hand, refers to the downward force produced when a mass (unit is Kg.) is in a gravitational field. There are several methods that used to measure mass or weight of the object.

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5.1. ELECTRONIC LOAD CELL (ELE-CTRONIC BALANCE): when the load or the mass is placed on some elastic material the material will deform. The amount of deformation is the measure of mass, the measuring unit is mm.

5.2. PNEUMATIC/HYDRAULIC LOAD CEL-LS: involves some internally a little grooved block, on one end of this grooved block is connected with the pressure meter and the other end is a hole to allow the air to in and out. The when the mass is placed the top of the block the pressure meter read the pressure force due to the load and the measuring unit is bar.

5.3. INTELLIGENT LOAD CELLS: is integrated the pervious devices with the microprocessor to the standard cell.

5.4. MASS-BALANCE (WEIGHING) INSTRU-MENTS: work based on the comparing the gravitational force on the measured mass with the gravitational force on another body of known mass. This is done with the help of pointer and scale balance system.

5.5. SPRING BALANCE: work based on the principle of deflection of the spring. When the load or mass is attached to the spring the spring start to elongated proportional to the weight of the mass. The measuring unit is mm.

6. FORCE MEASUREMENT

Forces can be described as a push or pull on an object. They can be due to phenomena such as gravity, magnetism, or anything that might cause a mass to accelerate and the measuring unit is N. There are two main devices that used to measure the force.

6.1. USE OF ACCELEROMETERS: based on the principle of newton second law. If the acceleration of the known mass is known, then the force can be known. The measuring unit is m/s^2.

6.2. VIBRATING WIRE SENSOR: when the material vibrates through a permanent magnetic field they intercept the magnetic fields. Then the frequency of the interruption is a measure of force that applied of the material and the measuring unit is rad/s.

7. TORQUE MEASUREMENT

When the force is acting on the object at some distance from the fixed position, then the object will have subjected to a twisting force with a given arm length. There are a number of methods that used to measure torque and its unit is (Nm).

7.1. REACTION FORCES IN SHAFT BEARINGS: if the magnitude of the transmitted torque can be measured by cradling either the power source or the power absorber end of the shaft in bearing, then the torque is a product of reaction force and arm length. The measuring unit is Nm.

7.2. PRONY BRAKE: this used to measure the torque of rotating shaft that contains a shaft, rope and a dead weight. The rotating drum break will displace the spring and then the effective load can be calculated as the sum of dead weight and the load on the spring, then we can find the torque. The measuring unit is Nm.

7.3. MEASUREMENT OF INDUCED STRAIN: this system has a four strain gages that are attached on the surface of shaft. The output is a function of strain, and this can be converted to capacitance using transducers.

7.4. OPTICAL TORQUE MEASUREMENT: The two black and white striped wheels are mounted on the end of the shaft. The light form the laser transmitter will release to those wheels and then the light will back to the receiver, the phase difference is the measure of torque.

8. TRANSLATIONAL MOTION TRANS-DUCERS

The motion of the object can be can be rotational, translational or both translational and rotational. In this section we going to see the measuring device that employed for rotational motion measurements.

8.1. DISPLACEMENT: the measuring unit is m. Based on the distance rage the measurement equipment may classify short rang and long rage distance measurements.

8.1.1. MEASUREMENT OF SHORT DISPL-ACEMENT

8.1.1.1. THE RESISTIVE POTENTIOMETER: this is the beast known displacement – measuring device that contains a resistance element with a movable contact. The displacement is measure as a function of voltage. The measuring unit is volte (V).

8.1.1.2. LINEAR VARIABLE DIFFERENTIAL TRANSFORMER (LVDT): the object whose translational displacement to be measured is physically attached to the central iron core of the transformer. The output is voltage; the measuring unit is volte (V).

8.1.1.3. VARIABLE CAPACITANCE TRANSDU-CERS: this device contain a concentric hollow metal cylinders, when the smallest diameter cylinder is moving through the larger cylinder the capacitance will vary, this is because the gap between the cylinders is varies based on the displacement. The measuring unit is farad (F).

8.1.1.4. VARIABLE INDUCTANCE TRANSDU-CERS: a coiled element and the object that going to be measured its displacement are the main component of this device. The object will move through the coil, then the displacement will have measured as a function of inductance, the unit is henry (H).

8.1.1.5. STRAIN GAUGES: this used to measure displacements with in devices like diaphragm based pressure sensors rather than as a primary sensor in their own right for direct displacement measurement. The measuring unit is displacement (mm).

8.1.1.6. PIEZOELECTRIC TRANSDUCERS: the measurement of displacement is based on the amount of induced e.m.f. this is a very sensitive measurement devices thousands times better than strain gauge.

8.1.1.7. NOZZLE FLAPPER: this will translate the displacement in to pressure change. Nozzle flapper is a main component to measure the displacement of the object, when the object is close to the nozzle flapper the pressure on the pressure gauge will change, the measuring unit is Pa.

8.1.1.8. OTHER METHODS OF MEASURING SMALL DISPLACEMENTS: apart from the measuring device that lists above, there are many other measuring methods. Linear inductosyn, Translation of linear displacements into rotary motion, Integration of output from velocity transducers and accelerometers, Laser interferometer, Fotonic sensor, Evanescent-field fibre-optic sensors, Non-contacting optical sensor.

8.1.2. MEASUREMENT OF LARGE DISPLACEMENTS (RANGE SENSORS)
The larger translational displacements can be measured using range sensors. The devices that used to measure larger displacements are listed down as follows.

✓ *Rotary potentiometer and spring-loaded drum:* consists a steel wire, pulley, rotary potentiometer and spring loaded drum. The steel wire is attached with the object and the wire pass through the pulley and the rotation is measured by rotary potentiometer.

✓ *Range sensors:* has energy source, an energy detector and electronic means of time of flight of the energy between the source and detector. Time is the measure of this displacement measurement. The measuring unit is seconds.

✓ *Proximity sensors:* the output is binary in nature that express weather the body is or is not close to the boundary. Similar with range sensors.

8.2. VELOCITY: the measuring unit is m/s. There are three main equipment's that used to measure velocity.

✓ *Differentiation of displacement measurements:* to use this method a low noise instrument such as a d.c. excited carbon film potentiometer or laser interferometer should be chosen.

✓ *Integration of the output of an accelerometer:* where an accelerometer is already including a system, integration of its output can be performed to yield a velocity signal.

✓ *Conversion to rotational velocity:* this enables any of the rotational velocity measuring instruments.

8.3. ACCELERATION: is measured using accelerometer, it has a known mass, spring, damper and a casing that can covered the whole body. When there is acceleration the mass will start vibrate and its unit is m/s^2.

8.4. VIBRATION: it can be measured in terms of displacement, velocity and acceleration, but acceleration is the best measuring device of vibration. Vibration can be measured based on the frequency and amplitude, but commonly frequency (rad/s), is used to express it.

9. ROTATIONAL DISPLACEMENT

The rotational displacement measurement is applicable in many engineering components. The measuring unit is rad.

9.1. CIRCULAR AND HELICAL POTENTIO-METERS: the cheapest and quit similar with the translational motion potentiometer device, except that truck is bent round in to a circular shape.

9.2. ROTATIONAL DIFFERENTIAL TRANSF-ORMER: uses a transformer to measure the rotational motion.

9.3. INCREMENTAL SHAFT ENCODERS**:** this gives a digital output, the measures the instantaneous angular position of the shaft relative to some arbitrary datum point. The light source will release a light and the light sensor will sense the sight as on and off. In this way the rotational displacement is measure.

9.4. CODED-DISC SHAFT ENCODERS: unlike the incremental shaft encoder that gives a digital output in the form of pulses that have to be counted, the digital shaft encoder has an output in the form of binary number of several digits that provides an absolute measurement of shat position.

9.5. THE RESOLVER: known as a synchro-resolver, is an electromechanically device that gives an analogue output by transformer action. It has a two stator windings, which are mounted are right angles to one another and rotor, which can have either one or two windings, and the measuring unit is volte (V).

9.6. THE SYNCHRO: this is similar with the resolver, but they have three stator windings. The measuring unit is volte (V).

9.7. THE INDUCTION POTENTIOMETER: this is also similar with resolver and synchros, but it has only one stator winding.

9.8. THE ROTARY INDUCTOSYN: It has a two circular discs that arranged radially. The larger versions give a measurement resolution of up to 0.05 seconds of arc. The measuring unit is seconds.

9.9. GYROSCOPES: this measures both absolute angular displacement and absolute angular velocity. It can use mechanical gyroscopes, free gyroscopes, rate integration gyroscope and optical gyroscopes.

10. ROTATIONAL VELOCITY

10.1. DIGITAL TACHOMETERS: is the non-contact measuring devices, is working based on the generator working principles. The measurement resolution is governed by the number of marks around the circumference of the disc.

10.2. STROBOSCOPIC METHODS: it operates on the physical principle to digital tachometers except that the pulses involved consist of flashes of light generated electronically and whose frequency is adjustable so that it can be matched with the frequency of occurrence of some feature on the rotating body being measured.

10.3. ANALOGUE TACHOMETERS: is a less accurate device, it exists in various forms, like d.c. tachometer, a.c. tachometer and drag-cup tachometer.

10.4. MECHANICAL FLY BALL: is also known as a centrifugal tachometer, there is a spring the connected with the flay ball, when the shaft is rotate the flay ball moves up due to the centrifugal force, this time the spring will deformed and the pointes will show the rotational velocity on the scale.

10.5. THE RATE GYROSCOPE: it has an almost identical construction to the rate integration gyroscope. The angular speed is measured based on the static sensitivity of the instrument.

10.6. FIBER-OPTIC GYROSCOPE: involves beam splitter, interferometer and optic- fiber coil**,** the incident light from the light source is separated by the beam splitter in to a pair of beams. The splinted light moves oppositely towards the open end of optic-fiber coil.

10.7. DIFFERENTIATION OF ANGULAR DISPLACEMENT MEASUREMENTS: this is another method of measuring the angular velocity by differentiating the angular displacement. The unit is rad/s^2.

10.8. INTEGRATION OF THE OUTPUT FROM AN ACCELEROMETER: this is also another method of angular velocity measurement from angular acceleration by integrating it.

11. MEASUREMENT OF ROTATIONAL ACCELERATION

This works with a very similar principles of translational motion accelerometer. It consists rotatable mass mounted inside the housing that is attached to the accelerometer and its unit is rad/s^2.

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