OMR 353- SENSORS

YEAR/SEM-IV/VII

UNITWISEHANDOUT

UNIT-I

SENSOR CLASSIFICATION, CHARACTERISTICS AND SIGNAL TYPES

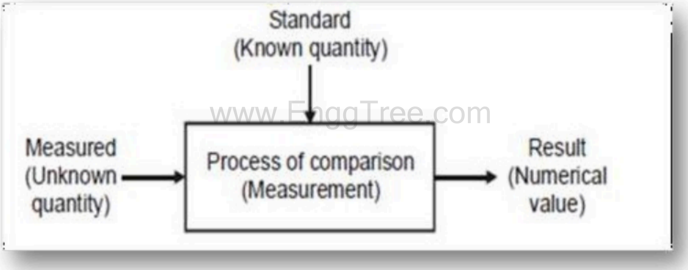
Basics of Measurement -Classification of error -Error analysis-Static and dynamic characteristics of transducers-Performance measures of sensors-Classification of sensors-Sensor calibration techniques Sensor output signal types-PWM and PPM

INTRODUCTION

Themeasurementofagivenquantityisessentiallyanactortheresultofcomparisonbetweenthe quantity (whose magnitude is unknown) and a predefined standard.

Sincetwoquantitiesarecompared,the resultisexpressedinnumericalvalues.

In fact, measurement is the process bywhich one can convert physical parameters to meaningful numbers.



Themeasuringprocess is onein which thepropertyof an object orsystem underconsideration is compared to an accepted standard unit, a standard defined for the particular property.

Sincetwoquantities,theamountofwhichisunknownandotherquantitywhoseamountisknown are compared, the result is expressed in terms of a numerical values.

Basic requirements:

1. The standard used for comparison purpose must be accurately defined and should be commonly accepted.

2. The apparatus used and the method adopted must be provable.

BASICS OF MEASUREMENT

Measurements is a vast field which embraces detection, acquisition control and analysis of data.

It involves the measurement of physical, electrical, mechanical, optical and chemical quantities and plays a very significant role in every branch of scientific research and engineering process which include control systems, process Instrumentation and data reduction.

There are two major function of all branch of engineering

Design of equipment and processes and

Proper operation control and maintenance of process.

METHODS OF MEASUREMENTS

The methods of measurements may be broadly classified into two categories.

(i) Direct methods

The unknown quantity (also called the measurand) is directly compared against a standard. The

result is expressed as a numerical number and a unit.

Direct methods are quite common for the measurement of physical quantities like length, mass and time.

(ii) Indirect methods

Measurements by direct methods are not always possible, feasible and practicable. These methods in most of the cases, are inaccurate because they involve human factors.

They are also less sensitive.

Hence direct methods are not preferred and are less commonly used.

A measurement system consists of a transducing element which converts the quantity to be measured into an analogous signal.

The analogous signal is then processed by some intermediate means and is then fed to the end devices which present the results of the measurements.

PRIMARY, SECONDARY AND TERTIARY MEASUREMENTS

Measurements may be classified as primary, secondary and tertiary based upon whether direct or indirect methods are used.

1. Primary Measurements

Aprimary measurementisonethatcanbemadebydirectobservationwithoutinvolvingany conversion (translation) of the measured quantity into length.

Typicalexamplesofprimarymeasurementsare:

Thematchingoftwo lengths suchaswhen determiningthe length ofan object withameterrod.

ii) Thematchingoof redhot met

iii) Thecountingof strokes of aclock chimeto measurethe time.

2.SecondaryMeasurement:

A secondary measurement involves only one translation (conversion) to be done on the quantity under measurement to convert it into a change of length.

Themeasurementquantitymaybepressureofgas,andtherefore,maynotbeobservable.

Therefore, a secondary measurement requires,

i) Aninstrumentwhichtranslatespressurechangesintolengthchanges.

ii) Alengthscaleorastandardwhichiscalibratedinlengthunitsequivalenttoknownchangesin pressure.

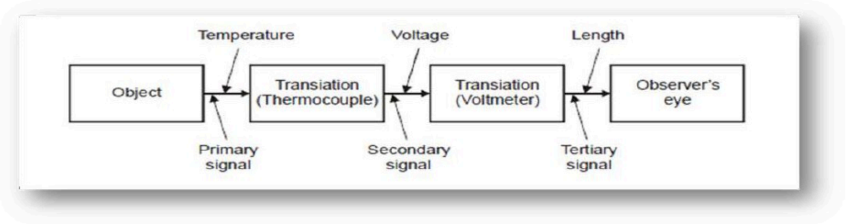
Therefore,inapressuregauze,theprimarysignal(pressure)istransmittedtoatranslatorandthe secondary signal (length) is transmitted to observer's eye.

3. TertiaryMeasurement

A tertiary measurement involves two translations. A typical example of such a measurement of temperature of an object by thermo couple.

Theprimarysignal(temperatureofobject)istransmittedtoatranslatorwhichgeneratesavoltage which is a function of the temperature. Therefore, first translation is temperature to voltage.

Thesecondarytranslationisthenvoltageintolength.Thetertiarysignal(lengthchange)is transmitted to the observer's brain.



Functions of Measurement System

1. IndicatingFunction:

Instrumentsandsystemsusedifferentkindsofmethodsforsupplyinginformationconcerningthe variable quantity under measurement.

Mostofthetimethisinformationisobtainedasadeflectionofapointerofameasuringinstrument.

Example:

The deflection of pointer of a speedometer indicates the speed of the automobile at that moment. A pressure gauge is used for indicating pressure.

2. Recordingfunction

Inmanycasestheinstrumentmakesawrittenrecord,usuallyonpaper,ofthevalueofthequantity under measurement against time or against some other variables. Thus the instrument performs a recording function.

Example:

A potentiometric type of recorder used for monitoring temperature records the instantaneous values of temperature on a strip chart recorder.

3.Controllingfunction

This is one of the most important functions especiallyin the field of industrial control processes. Inthiscase,theinformationisusedbytheinstrumentorthesystemtocontroltheoriginalmeasured quantity.

Theinstrumentswhosefunctionsaremainlyindicatingandrecordingespeciallytheseinstruments which are used for engineering analysis purpose.

Example:

Controllinginstruments arethermostats oftemperaturecontrol andfloats for liquid level control.

ApplicationsofMeasurementSystems:

1.Monitoringof processesand operation:

There are certain applications of measuring instruments that have essentially a monitoring function.Theysimplyindicatethevalueor conditionofparameterunderstudyandtheirreadings do not serve any control functions.

Example:

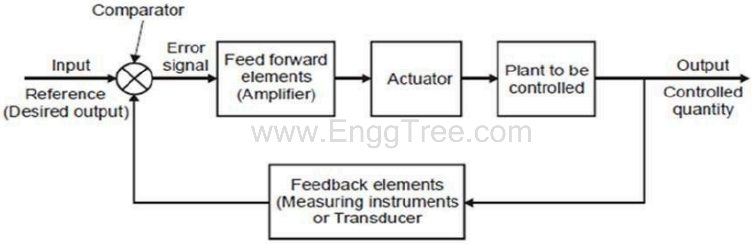
An ammeter or a voltmeter indicates the value of current or voltage being monitored (measured) at a particular instant.

Similarly, water and electric energy meters installed in homes keep track of commodity used so that later on its cost may be computed to be realized from the user.

2. Controlof processes andoperation:

A very useful application of instrument is in automatic control systems.

Therehasbeenaverystrongassociationbetweenmeasurementsandcontrol.



3.Experimental engineering analysis
Forsolutionofengineeringproblems,theoreticalandexperimentalmethodsareavailable. The relative affectability of the method depends upon the nature of the problem.

Experimentalengineeringanalysishas manyusesand somearelisted below.

i) Testingthevalidityof theoretical prediction

ii) Formulationsofgeneralizedempiricalrelationshipincaseswhereno proper theoretical backing exists.

iii) Determinationofsystemparameters,variablesandperformance indices.

iv) Fordevelopmentin importantspheresof studywherethereis sample scopeof study.

v) Solutionsofmathematicalrelationshipswiththehelpof analogies.

CLASSIFICATIONOFERRORS

Errorsinameasurementsystemcanbeclassifiedintofollowingcategories Gross

errors

Systematic errors

Instrumental error

Environmentalerror

Observational error

Random errors

1.GrossError

This class of errors mainly covers human mistakes in reading instruments, recording and calculating measurement results.

Thecausesof these errors areasfollows,

1. Misreadingof the instruments
2. Incorrectadjustments
3. Improperapplicationofthe instruments.

Grosserror canbeavoided byadoptingtwo means.

i) Greatcareshouldbetakeninreadingandrecordingthe data.

ii) Two,threeorevenmorereadingsshouldbetakenforthequantityundermeasurement.

2.Systematic errors

a.InstrumentalErrors

Theseerrorsariseduetothreemain reasons

(i) Duetoinherentshortcomingin theinstruments

These errors are inherent in instruments because of their mechanical structure. Theymaybe due toconstruction,calibrationoroperationoftheinstrumentsormeasuringdevices.Theseerrorsmay cause the instrument to read too low or too high.

Thepossibilityofsucherrorsasitisoftenpossibletoeliminatethem,oratleastreducethemtoa great extent by using the following methods.

a) The procedure of measurement must be carefullyplanned. Substitution methods or calibration against standard may be used for the purpose.

b) Correctionfactorsshouldbeappliedafterdeterminingtheinstrumentalerrors.

c) Theinstrument maybere-calibrated carefully.

(ii) Dueto misuseof the instruments

Theerrorscausedinmeasurementsareduetothefaultoftheoperatorthanthatoftheinstrument. A good instrument used in an unintelligent way may give erroneous results.

(iii) Dueto loadingeffects of instruments

Oneofthemostcommonerrorscommittedbybeginners,istheimproperuseofaninstrumentfor measurement work.

2. EnvironmentalErrors

Theseerrorsareduetoexternalconditiontothemeasuringdeviceincludingconditionsinthearea surrounding the instrument.

These maybe effects of temperature, pressure, humidity, dust, vibrations or of external magnetic orelectrostaticfields.Thecorrectivemeasureemployedtoeliminateortoreducetheseundesired effects are

Arrangementsshouldbemadetokeeptheconditionsasnearlyas

constant as possible.

Usingequipment which is immune to these effects.

Employingtechniqueswhicheliminatetheeffects ofthese disturbances

3. ObservationErrors

These are the errors introduced by the observer. There are many sources of observational errors such as parallax error while reading a meter, wrong scale selections, the habits of individual observers etc.,

To eliminate such observational errors, one should use the instruments with mirrors, knife edged pointers etc.,

Nowadays,theinstrumentswithdigitaldisplayofoutputwhichcompletelyeliminatestheerrors on account of human

Observationalorsensingpowersastheoutputisinformof digits.

4.RandomErrors

Randomerrorsaregenerallyunpredictableerrors, andtheyoccurevenwhenallsystematicerrors areaccountedforalthoughtheinstrumentisselectedproperlybasedonthenatureofmeasurement, pre-calibrationoftheinstrumentisproperlydonebeforethemeasurementandthereisanenvironmental control, random errors will be there.

However,theseerrorscanbeminimizedby takingmorenumberofreadingsandusingproper statistical methods for obtaining the best approximation of the true value.

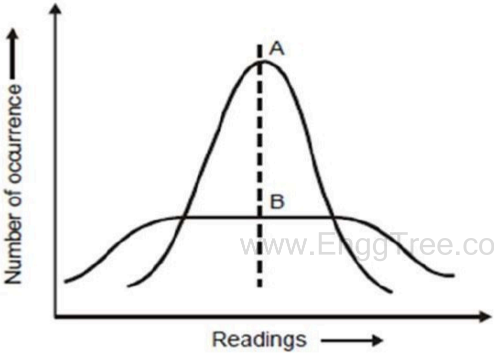
ERRORANALYSIS

Duetothepresenceoftherandomerrorsinanymeasurementsystems,theuncertaintyassociated with any measurement cannot be predetermined.

Onlythe probable value of theerroran bespecifiedusingstatistical erroranalysis.

1.ProbableError

Thedatacollectedfromanymeasurementcanbepictoriallyrepresentedbyahistogramforabetter visual appeal and quick understanding of information.



2. LimitedError

Generally the accuracy of a measuring instrumentisusually specified by itsmanufacturer asa percentage of the full scale readings.

But there is a possibility of getting the percentage error for various values of readings taken will be more than the percentage specified.

3. Oddsand Uncertainty

Thespecification oflimitingerrorisin itselfuncertain sincethe

manufacture themselves are not sure about the accuracy due to the presence of random errors in the measurement.

4. PropagationofErrors

If many number of instruments are to be used any measurement in order to compute a quantity, theoveralllimitingerrorshouldbecomputedfromtheindividuallimitingerrorsoftheinstruments.

STATICANDDYNAMIC CHARACTERISTICSOFTRANSDUCERS

1. Static Characteristic

Themainstaticcharacteristicsdiscussedhereare,

i) Accuracy

ii) Sensitivity

iii) Reproductively

iv) Drift

v) Static Error

vi) DeadZone

Thequalities(i),(ii)and(iii)aredesirable,whilequalities(iv),(v) and

(vi) are undesirable.

1. Accuracyand Precision

i) Accuracy

Itistheclosenesswithwhichaninstrumentreadingapproachesthetruevalueofthequantitybeing measured. Thus accuracy of a measurement means conformity to truth.

ii) Precision

It is a measure of the reproducibility of the measurements, i.e., given a fixed value of a quantity, precision is a measure of the degree of agreement within a group of measurements. The term ‘precise’ means clearly or sharply defined.

2. Sensitivity

Thesensitivityofanyinstrumentisstatedasanabilitytodetectchangesinthemeasuredquantity. Itcanbedefinedastheslopeofthecalibrationcurve,iftheinput/outputrelationshipislinear.The sensitivity of an instrument is also referred to the true quantity that is being measured.

$$\text{Sensitivity} = \frac{\text{Change in output unit}}{\text{Change in input unit}} = \frac{\Delta \theta_0}{\Delta \theta_i}$$

3. RepeatabilityandReproducibility:

Repeatabilitydescribesthecloseness ofoutput readings,whenthesameinput is appliedrepetitively overashortperiodoftimewiththesamemeasurementconditions,sameinstrumentandobserver, same location and same conditions of use maintained throughout.

Reproducibility describes the closeness of output readings for the same input when there are changesinthemethodofmeasurement,observer,measuringinstrument,location,conditionofuse and time of measurement.

4. Drift

All calibrations and specifications of an instrument are only valid under controlled conditions of temperature,pressureetc.,Thesestandardambientconditionsareusuallydefinedintheinstrument specifications. As variations occur in ambient temperature etc.,

Driftmaybeclassified intothreecategories

i) Zero Drift

If the whole calibration gradually shifts due to slippage, permanent set or due to undue warming up of electronic tube circuits, zero drift sets in.

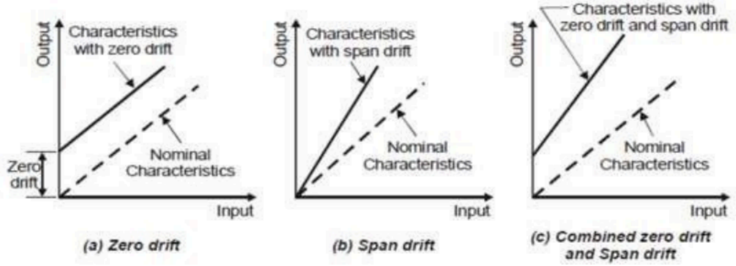
ii) SpanDriftorSensitivityDrift

Ifthereisproportionalchangeintheindicationallalongtheupwardscale, thedriftiscalledspan drift or sensitivity drift.

iii) Zonal Drift

Incasethedriftoccurs onlyoveraportion ofspanof aninstrument, itis calledzonal drift.

Therearemanyenvironmentalfactorswhichcausedrift.Theymaybestrayelectricandmagnetic fields, thermal emfs, change in temperature, mechanical vibrations, wear and tear and high mechanical stresses developed in some parts of the instruments and systems.



(a) Zero drift (b) Span drift (c) Combined zero drift and Span drift

5. StaticError

Staticerrorisdefinedasthedifferencebetweenthemeasuredvalueandthetruevalueof quantity then.

$\delta A = A_m - A_t$

$\delta A =$ Error

$A_m =$ Measured value of quantity

$A_t =$ True value of quantity

6. DeadZone

Deadzoneisdefinedasthelargestchangeofinputquantityforwhichthereisnooutputofthe instrument. The factors which produce dead zone are friction, backlash and hystersis in the instrument.

Dynamic Characteristics:

The dynamic characteristics of an instrument refers to performance of the instrument when it is subjected to time varying input. The performance criteria based upon the dynamic relation constitute the dynamic characteristics.

Thedynamiccharacteristicsofameasurementsystemare:

Speedof response

Itisdefinedastherapiditywithwhichameasurementsystemrespondstochangesinthemeasured quantity.

Measuringlog

It is the retardation or delay in the response of a measurement system to change in the measured quantity.

Themeasuringlagsareof two types,

i) Retardationtypeii)Timedelaytype

i) Retardation Type

In this case the response of the measurement system begins immediately after a change in measured quantity has occurred.

ii) TimeDelayType

In thiscasetheresponseofthemeasurementsystembeginsafteradeadtimeaftertheapplication of the input. Dead time simplyshift the response of the system along the time scale and causes a corresponding dynamic error.

Fidelity

It is defined as the degree to which a measurement system indicates changes in the measured quantity without any dynamic error.

Dynamicerror

Itis the differencebetween thetruevalueof quantity(under measurement)

changing with time and the value indicated by the measurement system. If no static error is assumed. It is also called measurement error.

PERFORMANCEMEASURESOFSENSORS

TypesofInput

Thetypeofinput, which canbeanyphysicalquantity, isgenerallydeterminedin advance.

1. OperatingRange

Choiceof transducer dependsupon theusefulrangeof input quantity.

2. Loading Effect

Thetransducer,thatisselectedforaparticularapplicationshouldideallyexactnoforce,poweror energy from the quantity under measurement in order that is measured accurately.

3. ResponseofTransducertoEnvironmental Influences

It should not be subjected to any disturbances like stray electromagnetic and electrostatic fields, mechanical shocks and vibrations temperature changes, pressure and humidity changes, changes in supply voltage and improper mechanical mountings.

4. Accuracyand Repeatability

Highaccuracyensuresthatfrequentcalibrationisnotrequiredanderrorsareless.Repeatabilityis more important than accuracy.

Typeof ElectricalOutput

Thetypeofoutputwhichmaybeavailablefromthetransducersmaybeavailablefromthe transducers may be a voltage, current, impedance or a time function of these amplitudes.

1. Sensitivity

Thetransducersmustbe sensitiveenoughtoproducedetectableoutput.

2. OutputImpedance

Ideallythevalueofoutputimpedanceshouldbezeroifnoloadingeffectsarethereonthe subsequent stage.

3. UsefulOutput Range

Theoutputrangeofatransducerislimitedatthelowerendbynoisesignal. The upper

limit is set by the maximum useful input level.

4. Usageand Ruggedness

The ruggednessbothmechanicalandelectricalintensitiesofthetransducerversusitssizeand weight must be considered.

III.ElectricalAspects

Attention must bepaid to signal to noiseratios in casethetransducer is to beused in conjunction with amplifiers.

1. StabilityandReliability

Thetransducer shouldexhibita highdegreeofstabilityduringitsoperation andstoragelife.

CLASSIFICATIONOFSENSORS

1. DirectSensor

Asensorthatcanconvertanon-electricalstimulusintoanelectricalsignalwithintermediatestage. Example : Thermocouple (temperature to voltage)

2. IndirectSensor

Asensorthatmultipleconversionstepstotransformthemeasuredsignalintoanelectricalsignal. Based on physical law or convent distinguishing property:

Active and passive sensor

Contactandnoncontactsensor

Absolute and relative sensor

Analog and digital sensor

ActiveandPassive Sensor

1. ActiveSensor

Asensorthatrequiresexternalpowerto operate.

Example:

Carbonmicrophone,thermistor,straingauges,capacitiveandinductivesensors,etc.,

Theactivesensorisalsocalledasparametricsensor(outputisafunctionofaparameterlike resistance).

2. PassiveSensor

Itgeneratesitsownelectricsignaland doesnotrequireapower source.

Example:

Thermocouples,magneticmicrophones,piezoelectricsensors,photodiode. Also called as self generating sensors.

ContactandNonContactSensor

Contactsensorisasensorthatrequiresphysicalcontactwiththestimulus. Example : Strain gauges, temperature sensor

Noncontactsensordoesnotrequiresnophysicalcontact. Example: Most optical and magnetic sensors, infrared thermometer, etc.,

1.7.3Absoluteand RelativeSensors

1. AbsoluteSensors

Asensorthatreactstoastimulusonanabsolutescalesuchasthermistor,straingauge,etc., (thermistor always reads the absolute temperature).

2. RelativeSensors

Thestimulusissensedrelativetoafixedorvariablereference,forexamplethermocouplemeasures the temperature difference, pressure is often measured relative to atmospheric pressure.

Analog and DigitalSensors

Analogsensorshaveanoutputthatchangesoverarangeofvalueswhiledigitalsensorsarebinary and only have two states ON and OFF.

The anemometer is an example of an analogdevice. Since its rotatingspeed increases alongwith wind speed. Therefore, it can produce a range of value.

Anoccupancysensoris an exampleofadigital device, sinceit can onlydetect two states , empty room and occupied room.

Applicationof Sensors

1.Classificationbasedonbroadareaofdetectionlikeelectricsensors,magnetic,electromagnetic, acoustic, chemical, optical, heat, temperature, mechanical, radiation, biological, etc.,

2. Classification based on physical law like photoelectric, magneto electric, thermoelectric, photoconductive, photo magnetic, thermo magnetic, thermo-optic, electrochemical, magnetro resistive, photo elastic, etc.,

3. Classification based on specification like accuracy, sensitivity, stability, response time, hysteresis,frequencyresponse,input,resolution,linearity,hardness,costsize,weight,conduction material, temperature,etc.

SENSOR CALIBRATION

TechniquesofSensors

1. Whydoweneedto calibrate sensors?

Inordertoachievethebestpossibleaccuracyasensorshouldbecalibratedinthesystemwhereit will be used this is because.

i) No Sensoris Perfect

ii) Thesensor is onlyonecomponent in the measurement

2. Whatmakesagoodsensor?

Thetwomost importantcharacteristicsofasensor are:

i) Precision

Theideal sensor will alwaysproducethesame outputforthesame input.

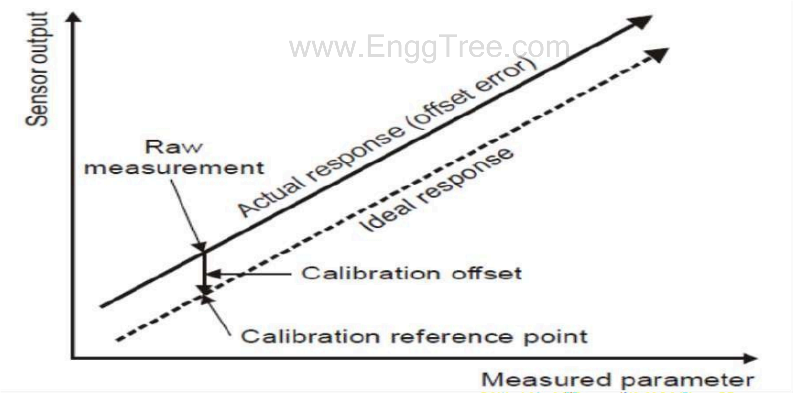
ii) Resolution

Agoodsensorwillbeableto reliablydetectsmallchangesinthemeasuredparameter.

Calibration Methods:

Thethreedifferenttypesofcalibrationare,

1.One pointcalibration



Onepointcalibrationcanbeusedtocorrectforsensoroffseterrorsinthe following

cases.

i) OnlyOneMeasurementPoint isNeeded

ii) TheSensorisKnowntobe Linear andHavetheCorrectSlopeover theDesiredMeasurement Range

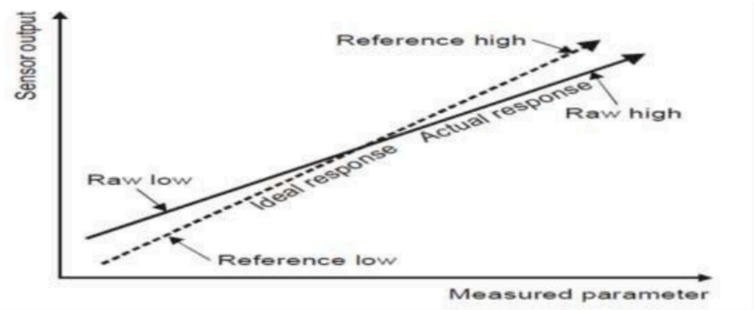
2. Twopointcalibration

Atwopoint calibrationisalittlemorecomplex.

Butitcanbe appliedto

eitherraworscaledsensor outputs.

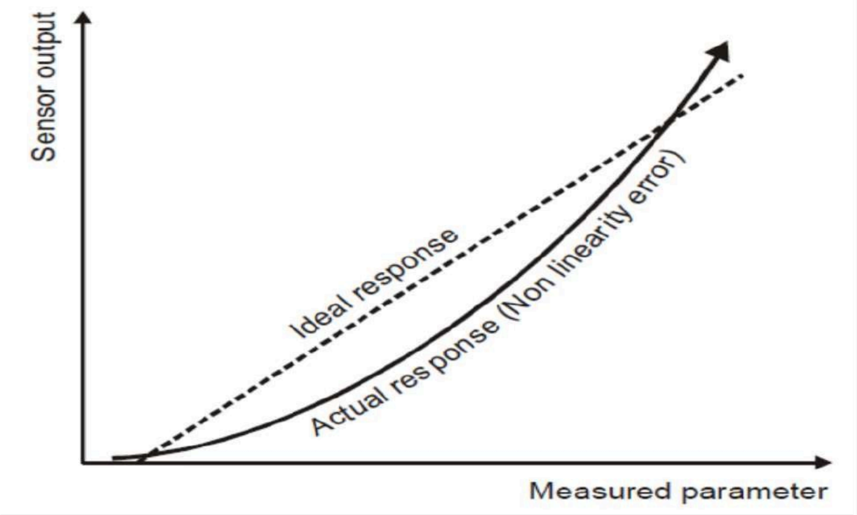
Atwopointcalibrationessentiallyre-scalestheoutputandiscapableofcorrectingbothslopeand offset errors.



Multipointcurvefitting:

Sensors that are non - linear over the measurement range require some curve-fitting to achieveaccurate measurements over the measurement range.

A common case requiring curve-fitting is thermocouples at extremely hot or cold temperatureswhilenearlylinearoverafairlywide range, theydodeviatesignificantlyatextremetemperature.



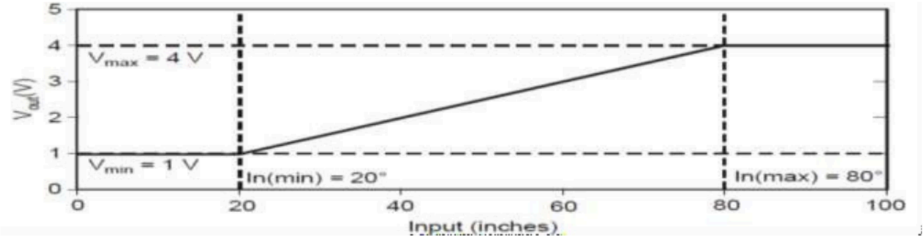
SENSOROUTPUTSIGNALTYPES

1.Analog Voltage

Sensor output an analog voltage proportional to some parameter which they are sensing. Figure below shows a typical analog transfer characteristics for a distance sensor.

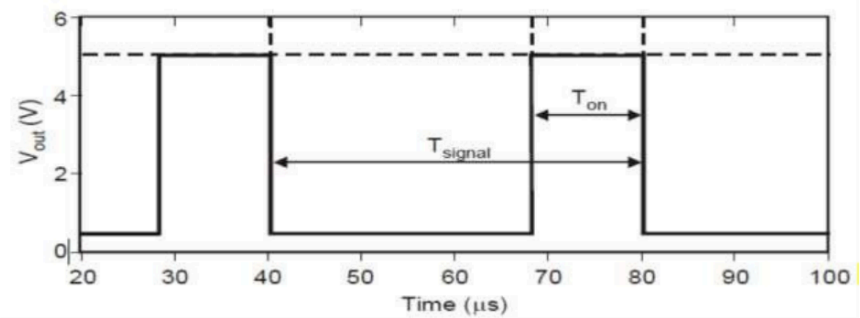
Analog signals are much more susceptible to noise than digital signals, so there are several measures that must be taken to ensure the date obtained from the sensor is accurate.

Themost commontechniquesfornoise reduction aredifferentialsignal transmissionandpassive low pass filtration. Since we are using a microcontroller, it may be convenient to applyan IIR or an FIR filter, coded in software.



2.PWM

PWMisapopulartechniquefortransmittingdigitaldatainembeddedsystem.AtypicalPWM waveformisshowninbelowFigureforadigitalsensorwithanNbitresolution,theontime(TON) can take 2N different values. A change in, 1 LSB is signified by a small change in the on time.



A PWM signal is much more immune to noise than an analog signal, but

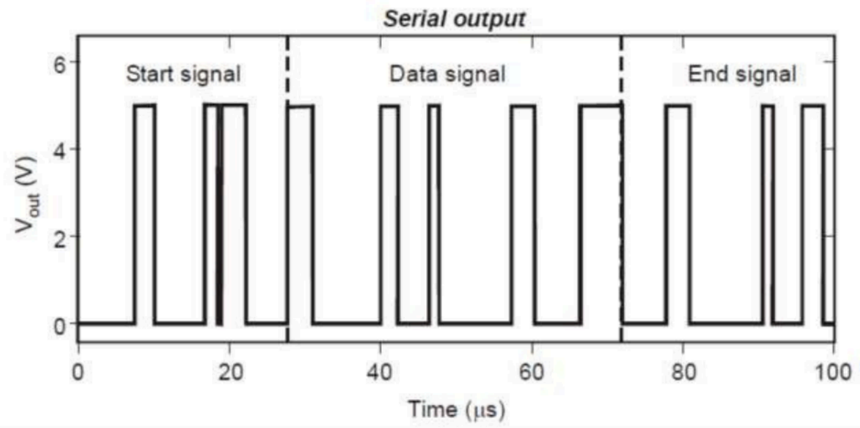
signalintegritycanstillbenefitfromdifferentialtransmission(asinUSB).

Thereis also a speed requirement :Anycircuitryin between the sensor

and the microcontroller must exhibit short settling time to preserve fast signal edges. If the rise time of a PWM signal is too slow, it may not be possible to use.

3. Serial Digital

Serialdigitalsignalsarethemostcomplicated.Thistypeofsignalrequiresthatthedevicessharing information are synced, and this is accomplished using one of many data packet protocols. An example is shown in below Figure.



ThisisthetypeofsignalusedforcommunicationbetweenthearduinoandacomputeroverUSB.

In order to communicate the two devices must agree on the serial transmission protocol and the symbol rate (band).

Being a digital signal, the noise margining is quite high, but signal integrity is still substantially improved with differential transmission.

Aswith PWM,anysignal conditioningcircuitrymust befastto pressurisingandfalling edges.

UNIT-II

DISPLACEMENT,PROXIMITYANDRANGINGSENSORS

Displacement Sensors – Brush Encoders-Potentiometers –Resolvers-Encoders- Optical, Magnetic and Inductive Encoders-Linear Variable Differential Transformer (LVDT)-Rotary Variable Differential Transformer(RVDT)-Syncro,Microsyn,Accelerometer-GPS,Bluetooth-RangeSensors-RF beacons, Ultrasonic Ranging, Reflective beacons, Laser Range Sensor (LIDAR)

MOTIONSENSORSINTRO

DUCTION

Thestudyof specificmeasuringdeviceswith motionmeasurements.

Based on two fundamental quantities in nature (length and time) and so many other quantities (suchasForce,PressureandTemperature,etc)areoftenmeasuredbytransducingthemtomotion and then measuring this resulting motion.

It is mainly concerned with electromechanical transducers which convert motion quantities into electrical quantities.

POTENTIOMETERS

Aresistivepotentiometer consistofaresistanceelementprovided withamovable contact.

The contact motion can be translation, rotation or a combination of the two (helical motion in a multiturn rotational device),thus allowing measurement of rotary and translatory displacements.

Translatorydeviceshavestrokesfromabout2to500mmandrotationalonesrangefromabout10 to as much as 60 full turns.

The cable-extension version allows very long travels (upto 40m) and convenient mounting in situations that might be awkward for other configuration.

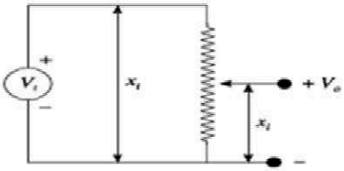
Such devices are also available using digital encoders in place of the potentiometer or with both a potentiometer and a tachometer generator, giving position and velocity data.

The resistance element is excited with either D.C or A.C voltage and the output voltage is a (ideally) linear function of the input displacement.

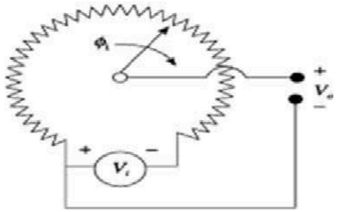
Resistanceelements incommon usemaybeclassified as

Wire–wound,conductiveplastic,depositedfilm,hybridorCernet. Potentiometer

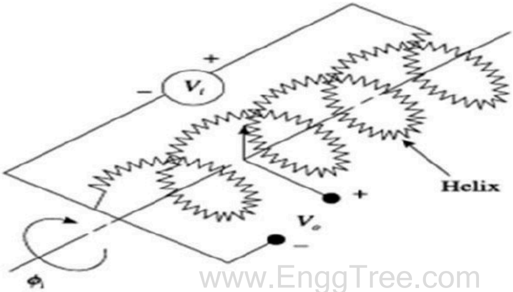
Displacement Transducer



(a) Linear potentiometer



(b) Rotary potentiometer



Multi-turn potentiometer.

Ifthedistributionofresistancewithrespecttotranslationalorangulartravelofthewiper(moving contact)islinear,theoutputvoltageeowillfaithfullyduplicatetheinputmotionxiorθi,ifthe terminals at eo are open circuit.

Thepotentiometeroutputvoltageistheinput,toameterorrecorderthatdrawssomecurrentfrom the potentiometer.

FromFig.3.4, analysisofthiscircuitgives,

$$\frac{e_0}{e_{ex}} = \frac{1}{1 \Big/ \left(\frac{\frac{x_i}{x_i+R_P}}{R_m}\right)\left(1-\frac{x_t}{x_i}\right)}$$

Theabove equationbecomesidealRP/Rm=0foranopencircuitconditions.

$$\frac{e_0}{e_{ex}} = \frac{x_i}{x_t}$$

Forno“loading”,theinput–outputcurveisastraightline.Inactualpractice,Rm≠αandequation 1 shows a non-linear between e0 and xi

Toachievegoodlinearity,fora‘meter’ofagivenresistanceRm,chooseapotentiometerof sufficiently low resistance relative to Rm .

IftheheatdissipationislimitedtoPwatts,theallowableexcitationvoltage isgivenbymax

$$e_{xx} = \sqrt{PR_p}$$

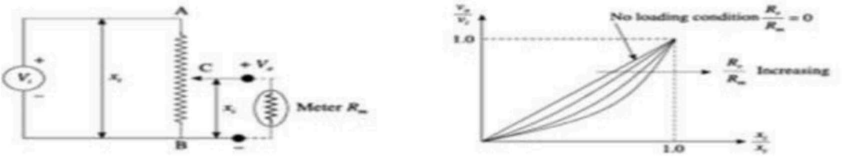
LOADINGEFFECTOFPOTENIOMETER

Ifthedistributionofresistancewithrespecttotranslationalorangulartravelofthewiper(moving contact) is linear, the output voltage eo will faithfully duplicate the input motion xi or i,□ ifthe terminals at eo are open circuit (no current drawn at the output).

Thepotentiometeroutputvoltageistheinput,toameterorrecorderthatdrawssomecurrentfrom the potentiometer.

Thus,amorerealisticcircuit isshown infigure below.

Loading effect of potentiometer



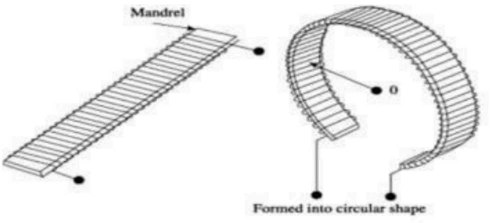
Wire–woundresistance shape

Togetsufficientlyhighresistancevaluesinsmall space,the wirewound

resistance element is widely used. The resistance wire is wound on a mandrel or card, which is then formed into a circle or helix, if a rotational device is desired

shown in figure below with such a construction, the variation of resistance is not a linear continuouschange,butactuallyproceedsinsmallstepsasthewipermoves fromoneturnofwire to the next.

Thisphenomenonresultsinafundamentallimitationontheresolutionintermsofresistancewire size.



RESOLVERS:

Uses:For conversionof angularpositionofashaftintocartesiaco-ordinates.

Theoutputofthetransducerisintheformoftwosignals,oneproportionaltothesineoftheangle and the other proportional to cosine of the angle.

Aresolverisverypreciseelectromagneticdevicecomprisingoftwostatorandtworotorwindings.

Construction:

The construction of a resolver is similar to that of a two phase, two pole wound rotor inductionmotor.

Thestatorwindingsareidenticalandarehousedinamagneticstructure,withtheaxisoftwo windings 90^0 to each other.

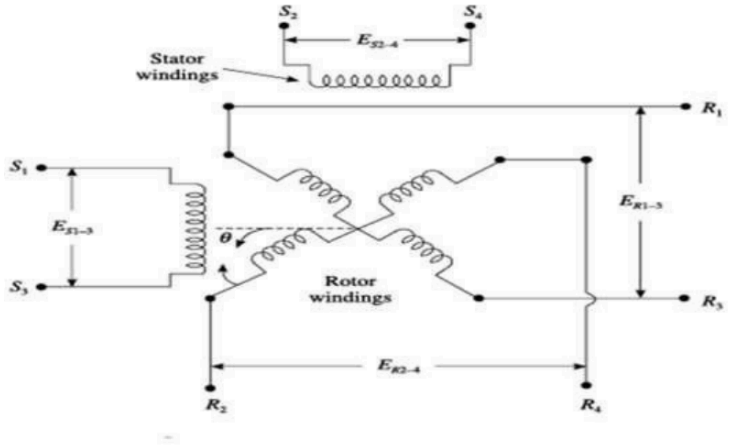
Similarly,thetworotorwindingsareplaced inamagneticstructureandaremutually perpendicular to each other.

WINDINGCONFIGURATIONOFRESOLVER

Statorwindingsaresuppliedwithanalternatingvoltagethatproducesanalternatingmagneticflux which induces voltages in the two rotor windings.

The output voltage of the rotor windingsis proportional to the stator voltage and the couplingbetween stator and rotor windings.

The way in which the windings are placed, the rotor output voltages are proportional to the sine and cosine of the rotor angle.



WhenoneofthestatorwindingsS1S3isexcitedbyanA.Csource,withtheotherstatorwindings S2S4 short circuited, the following output voltage are obtained from the rotor.

ER1-3 =ES 1-3 Cosθ---------------------------(1)

ER2-4=-ES1-3Sin θ---------------------------(2)

Whenthetwostatorwindingsareexcited,theoutputsareusunder ER 1-

3 = ES 1-3 Cosθ+ES 2-4 Sin θ------------------------------(3)

ER2-4 =ES 2-4Cosθ-ES 1-3 sin θ---------------------------(4)

Whenthetworotorwindingsareexcited,theoutputfromthestatorwindings ES 1-3

= ER1-3 Cosθ-ER 2-4 Sin θ--------------------------------(5)

ES2-4 =ER 2-4Cosθ+ER1-3 sin θ-------------------------(6)

whereθ=angular displacementofrotor

ClassificationofResolvers

I)Computing Resolvers:

Uses:

Forgeneratingsine,cosineandtangentfunctionsaswellasforsolvinggeometricrelationships.

II)Synchro resolvers:

Uses:

Fordata transmission

Itperformthesamefunctionsassynchrotransmitters,receiversandcontroltransformersbutwith a better accuracy.

APPLICATIONS:

Vector Resolution

VectorComposition

Vector angle and component resolution

Pulseamplitudecontrolandpulseresolution

Phase shifting

ClassificationofEncoders

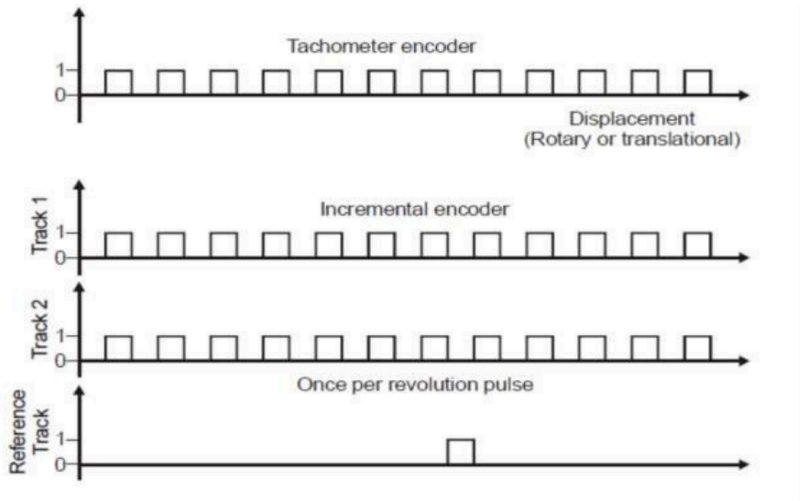
Tachometer Encoders

Hasonlyasingleoutput signalwhichconsists ofapulse for

Eachincrementofdisplacement.Ifthemotionwerealwaysinonedirection,adigitalcountercould accumulate these pulses to determine the displacement from a known starting point.

Any motion in the opposite direction would also produce identical pulses, which would produce errors.

Thisdigitaltransducerisusuallyusedformeasurementofspeed,ratherthanfordisplacementand in situations where the rotation never reverses.



INCREMENTALENCODERS

Theproblems caused byreversemotion in thecaseoftachometer encoder aresolvedbyusing an incremental encoder.

Theincrementalencoder usesatleasttwo/threesignalgenerating elements.

The two tracks the tachometer encoder uses only one track in the case incremental encoder aremechanically shifted by ¼ cycle relative to each other.

Thisallowsdetectionofmotionwhichsignalrisesfirstthusanupdownpulsecountercanbeused to substract pulses whenever the motion reverses.

Athirdoutput,whichproducesonepulseperrevolutionatadistinctpoint,issometimesprovided for Zero reference.

Advantageof Incrementalencoder:

Ableto rotatethrough asmanyrevolutions asthe application requires.

Anyfalsepulseresultingfromelectricnoisewillerrorsthatpersistevenwhenthenoisedisappears.

Thefailureofsystempoweralsocausestotalinformationaboutthepositiondatawhichcannotbe retrieved even after re-application of power.

ABSOLUTEENCODERS

Generallylimited tomeasurement ofasingle revolution.

Theyusemultipletracksandoutputs,whicharereadoutinparalleltoproducebinary representation of the angular shaft input position.

There is a one-to-one correspondence between binary output, position data are recovered whenpower is restored after an outage.

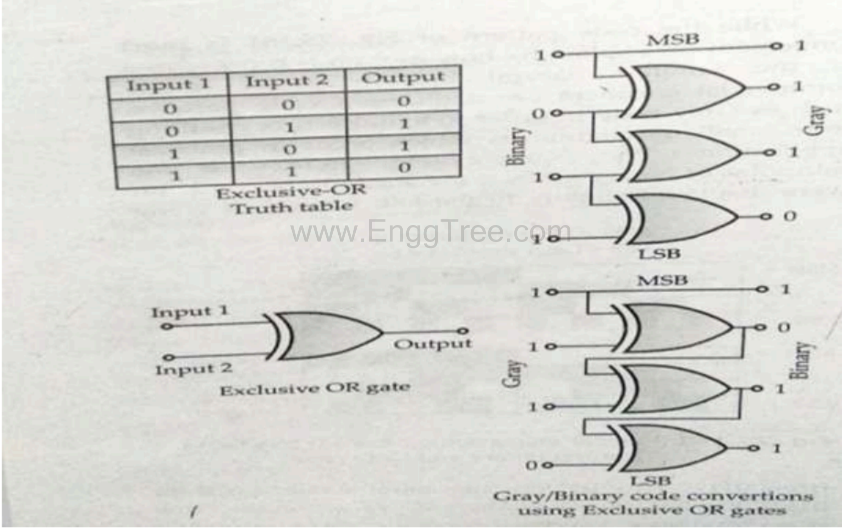
Thetransient electricnoisecauses onlytransient measurementerrors.

Generally limited to measurement of a single revolution. They use multiple tracks and outputs,whicharead outimparallelto producebinaryrepresentation ofthe angularshaftinput position.

Since there is a one-to-one correspondence between binary output, position data are recoveredwhen power is restored after an outage

LINEARDISPLACEMENTDIGITALTRANSDUCER GRAY/BINARY

CODE CONVERSIONS



Input 1	Input 2	Output
0	0	0
0	1	1
1	0	1
1	1	0

Exclusive-OR Truth table

Exclusive OR gate

Gray/Binary code convertions using Exclusive OR gates

OPTICAL

IncrementalEncoder:

Incrementalencoderscreatesaseriesofequallyspacedsignals

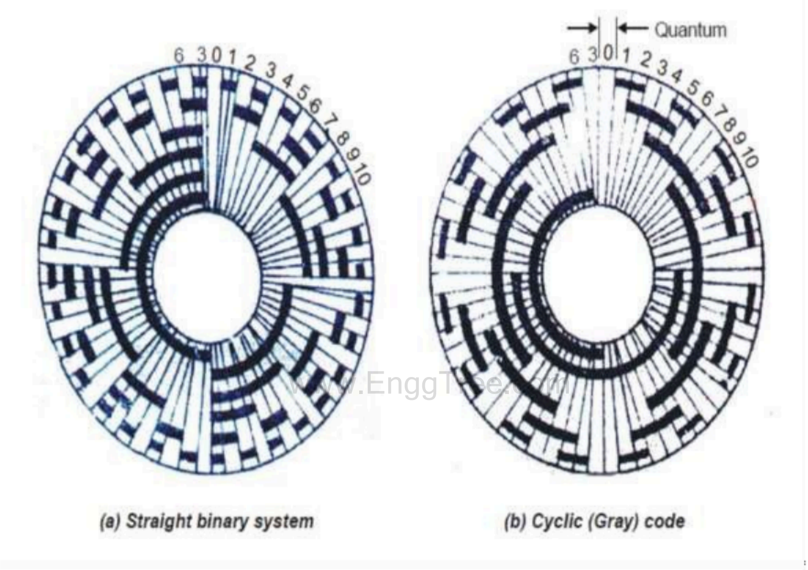
corresponding to the mechanical increment required.

Forexample,if wedivideashaft rotationinto 100parts, anencoderwould be selected to supply 1000 square wave cycles per revolution. By using a counter to count these cycoles, we can find out how much the shaft has rotated

Opticalencoders tendtofollow oneoftwo principlesofoperation;

They consist of either a system of coded tracks consisting of transparent and opaque section and associated lamps and photocells to detect the corresponding switchingsequence, or they rely on the use of more fringe techniques, capable of much higher resolution when used for incremental measurement

SHAFTENCODERS



(a) Straight binary system

(b) Cyclic (Gray) code

The absolute digitiser comprises an assembly consisting of a gray - coded

patternphotographicallyreproduceonaglassdiscmountedontheinputshaft.

Thecode consists oftenannulartrackseach withapattern ofopaqueand

transparentsections.Thecodereadingsystememploysafilamentlampandcollimatinglensfrom which light passes through the disc and a narrow radial slit, to be detected by ten photovoltaic cells.

Depending on the angular position of the shaft, certain cells receive light from the transparent portionsofthediscandenabletheoutputsfromalltencellstoreproducetheshaftpositiondirectly in parallel - gray - coded form.

The output which is noise free, is suitable for amplification and subsequent processing for use in digital servo systems, computers, data logging and visual displays.

MAGNETICENCODER

Incaseofmagneticencoders,theconductingportionsofthecontactingtypeencodersarereplaced by magnetic tape with magnetized portions and non conducting portions are represented by non-magnetized portions as shown in figure below.

Formagnetizingtheportionsacoatingofmagneticmaterialpowderis made.

The sensing section consists of toroidal cores, each provided with two coils, namely reading coil (R - coil) and Interrogate coil (I - coil).

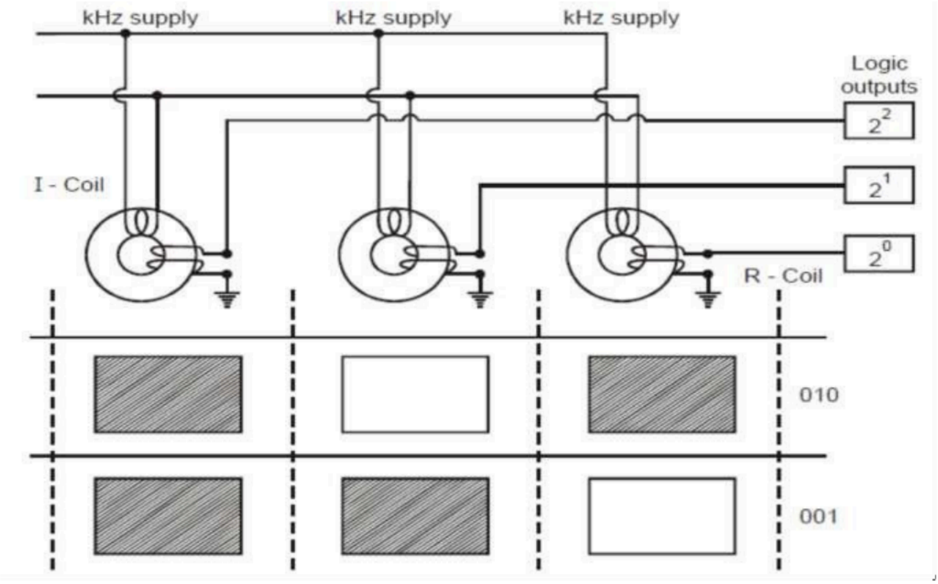
Thesesensingcoilsareplacedclosertothepatternofthemagneticencoder,butthereisnocontact with the encoder.

The detection of the magnetized portions saturates the toroidal core, and suitable output signal is generated.

Whentheinterrogatecoilisenergizedwithaconstantvoltagesignalof200KHz,thereadingcoil generates the output signals as a transformer action.

If the toroidal core is over the magnetized portion, the output signal from the R - Coil is low and when the core is over the non - magnetized portion, the output signal from the R - coil is high.

MAGNETICENCODER



Hence,basedonthepresenceandabsenceofthemagnetizedportions,theamplitudesoftheoutput voltages will vary.

If there is low level output voltage, it can be represented by binary logic - 0, and if there is high level output voltage, it can be represented by binary logic - 1.

Thiskindofmagneticencodersareveryresistanttodust,grease,moistureandothercontaminants commoninindustrialenvironemntsandtoshockandvibration.Henceitsapplicationsinindustries are high.

INDUCTIVE:

i) Changeofselfinductance

The self - inductance of a coil

$$L = \frac{N^2}{R}$$

where N = number of turns and

R = reluctance of the magnetic circuit

$$R = \frac{\ell}{\mu A}$$

$$\therefore \quad \text{Inductance } L = N^2 \mu \left(\frac{A}{L} \right) = N^2 \mu G$$

where, μ = Effective permeability of the medium

ii) Mutual Inductance

Themutualinductancebetweenthecoilscanbevariedbyvariationofself inductances or the coefficient of coupling.

$$M = K\sqrt{L_1 L_2}$$

where L_1 and L_2 = self - inductance of two coils

K = Co - efficient of coupling

However,themutualinductance can be converted into a self inductance by connecting the coils in series. The self - inductanceofsuchanarrangementvaries$L1+L2-2M$to$L1+L2+2M$withone of the coils being stationary while the other is movable. The self inductance of eachcoilisconstantbutthemutualinductancchangesdependinguponthe displacement of the movable coil.

iii) ProductionofEddyCurrents

These inductive transducers work on the principle that if a conducting plate is placed near a coil carrying alternating current, eddy currents are produced in the conducting plate.

Theconductingplateacts as ashort-circuited secondarywindingofa transformer.

Theeddycurrentsflowingintheplateproduceamagneticfieldoftheirownwhichactagainstthe magnetic field produced by the coil. This results in reduction of flux and thus the inductance of the coild is reduced.

Thenearer is theplate tothe coil,the higher aretheeddycurrentsand thushigheristhereductionintheinductanceofthecoil.Thustheinductance of the

coil alters with variation of distance between the plate and the coil.

TypesofInductiveTransducer

1.AirCoredCoils

Aircoredcoiltransducerscanbeoperatedatahighercarrierfrequencybecauseofabsenceofeddy current losses in air cores.

Theinductanceofaircoredcoilsisindependentofthecurrentcarriedbythecoilasthe permeability of air is constant and does not depend upon the current carried by the coil.

Hence aircoredcoiltranducercanbeusedformeasurementofdisplacementvariationsoccurring at fairly high frequencies.

2. IronCored Coils

The greatest disadvantage of iron cored coils transducers is that their inductance is not constant but depends upon the value of the current carried by the coil.

Also,athighfrequencies,theeddycurrentlosstendstobehighandtherefore iron

cored coil transducers cannot be used beyond a particular frequency.

The frequency of supply voltage should not exceed 20 KHz for iron core transducer to keep the core losses to acceptable values.

CAPACITIVETRANSDUCERS

$$\text{Capacitance } C = \frac{\varepsilon A}{d} = \frac{\varepsilon_r \varepsilon_o A}{d}$$

Where A = Overlapping are of plates ; m^2

d = Distance between two plates ; m

$\varepsilon = \varepsilon_r \varepsilon_o$ = Permitivity of medium ; $\frac{F}{m}$

ε_r = Relative permitivity

ε_o = Permitivity of free space

$= 8.85 \times 10^{-12}$ F/m

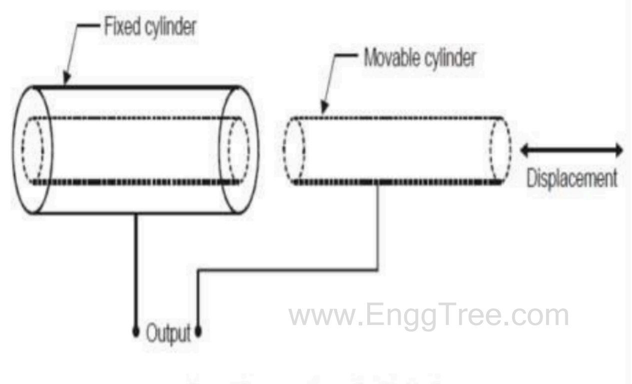
➨The capacitance transducer works on the principle of change of capacitance which maybe caused by

- ChangeinoverlappingareaA
- Changeinthedistancedbetweenthe plates
- Changeindielectric constant

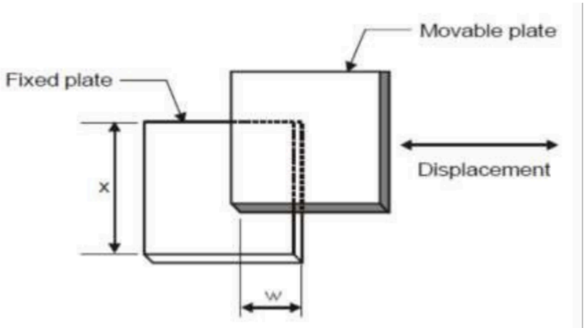
➨Thesechangesarecausedbyphysicalvariableslikedisplacement,forceandpressurein mostofthecases.

➨The change in capacitance maybe caused bychange in dielectric constant as is the case in measurement of liquid or gas levels.

TransducerusingChangein Areaof Plates

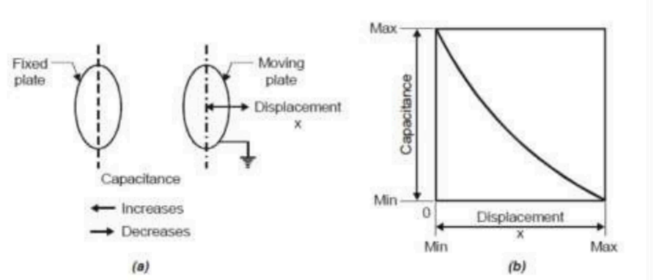


(a) Capacitive transducer of cylindrical type



(b) Parallel plate capacitive transducer

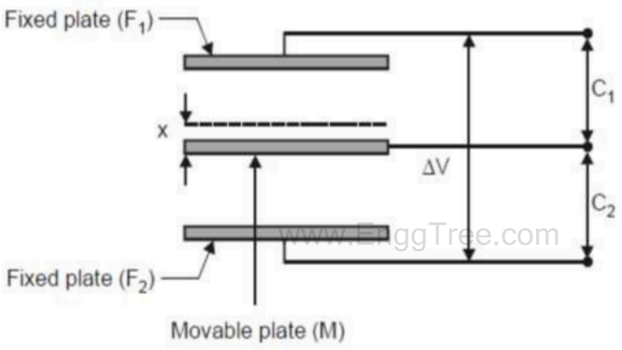
TransducersUsingChangeinDistanceBetweenPlates

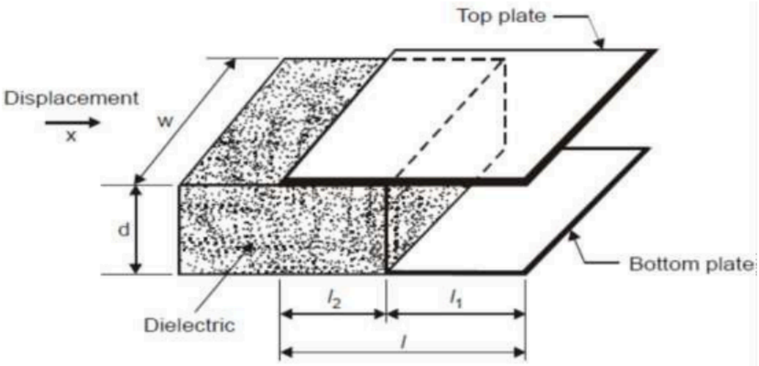


(a) (b)

Capacitive Transducer using the Principle of Change of Capacitance with Change of Distance between Plates

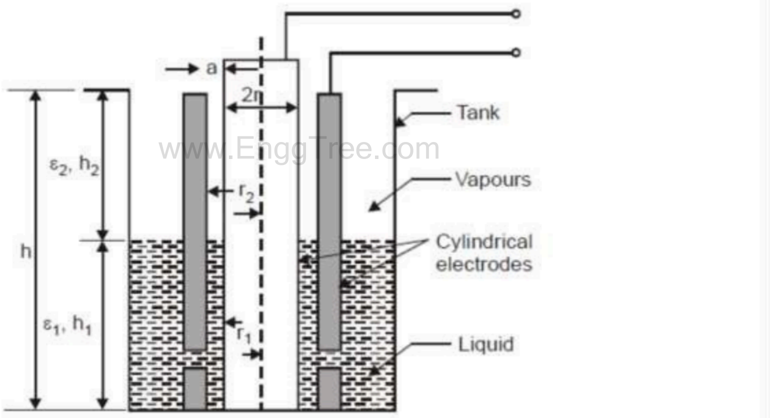
DifferentialArrangementofCapacitiveTransducer





Capacitive Transducer using Principle of Change in Dielectric Constant for Measurement of Displacement

VariationofDielectric ConstantforMeasurementofLiquidLevel



Capacitive Transducer for Measurement of Level of a non -conducting Liquid

LINEARVARIABLEDIFFERENTIALTRANSFORMER(LVDT)

The most widely used inductive transducer to translate the linear motion into electrical signal is the linear variable differential transformer (LVDT).

The transformerconsistof a single primary windingPand two secondary windings S1 and S2wound on a cylindrical former.

The secondary windings have equal number of turns and are identically placed on either side of the primary winding.

Theprimarywindingisconnectedtoanalternatingcurrentsource. A

movable soft iron core is placed insider the former.

Thedisplacementto be measuredis appliedtothearmattachedto thesoftiron core.

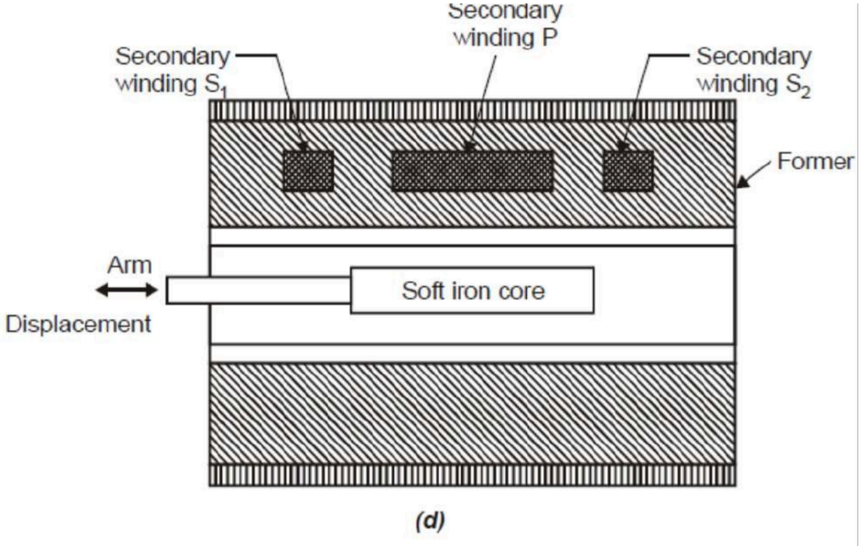
In order to overcome the problem of eddycurrent losses in the core, nickel - iron alloyis used as core material and is slotted longitudinally.

Operations:

The output voltage of secondary winding S1 is ES1 and that of secondary winding S2 is ES2. In ordertoconverttheoutputvoltagefromS1andS2intoasinglevoltagesignal,thetwosecondary S1 and S2 are connected in series are shown in figure 2.20. Thus the output voltage of the transducer is the difference of the two voltages.

Differentialoutput voltage

Eo =ES1 – ES2



Linear Variable Differential Transformer (LVDT)

Case1:

Whenthecoreisatitsnormal(NULL)position,thefluxlinkingwithboththesecondarywindings are equal and hence equal emfs are induced in them. Thus at null position ES1 = ES2. Since the outputvoltageofthetransduceristhedifferenceofthetwovoltages,theoutputvoltageEoiszero at null position.

Case2:

Now if the core moved to the left of the null position, more flux links withwinding S1 and less with winding S2.Hence output voltage ES2 of the secondary winding S1 andmore than ES2. The magnitudeofoutputvotageisEo=ES1–ES2andtheoutputvoltageisinphasewiththeprimary voltage.

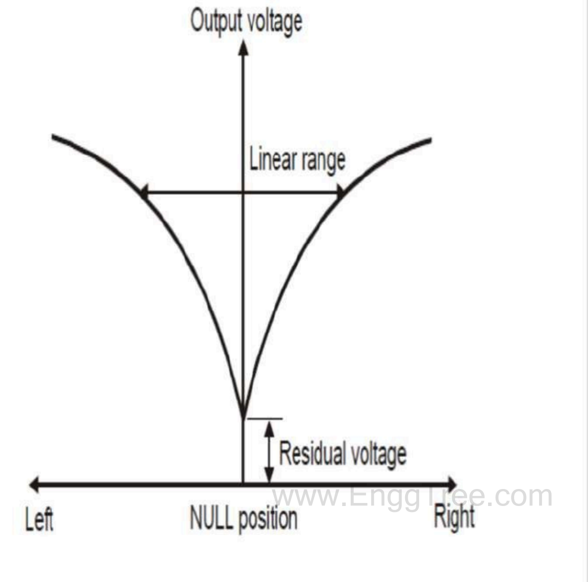
Case3:

Nowifthecoreismovedtotherightofthenullposition,thefluxlinkingwithwindingS2becomes largerthanthatlinkingwithwindingS1.ThisresultinES2becominglargerthanES1.Theoutput voltage in this case is Eo = ES2 – ES1and is 180° out of phase with the primary voltage.

Inpractice,outputvoltageisnotzero

at null position, but some residual voltage exists at output terminals of LVDT but it is usually less than 1% of maximum value of output voltage in linear range as shown in figure.Other causes of residual voltage are stray magnetic fields and temperature effects.

However, with improved technological methods and with the use of better ac sources, the residual voltage can be reduced to almost a negligible value.



Displacement Vs Differential Output Voltage Characteristics

Advantages of LVDT:

High Range

Immunity from External Effects

High Input and High Sensitivity

Ruggedness

Low Hysteresis

Low Power Consumption

Disadvantage of LVDT

1. Large displacements are required for differential output.

2. Theyaresensitive tostraymagneticfield.

3. Manyatime, thetransducer performanceis affected byvibration.

4. The receiving instrument must be selected to operate on AC signals or a demodulator network must be used if a DC output is required.

5. The dynamic response is limited mechanically by the mass of the core and electrically by the frequency of applied voltage.

The frequency of the carrier should be at least ten times the highest frequency component to be measured.

6. Temperatureaffectstheperformanceofthetransducer.

Applications

LVDTsareusedtomeasure

1.Displacement

2. Force,

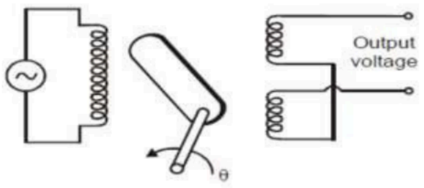
3. Weight

4. Pressure,

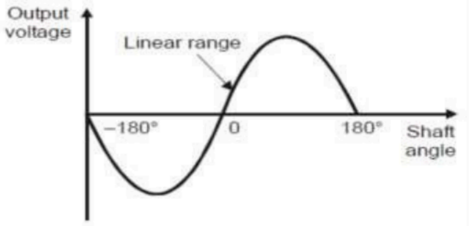
5. Position.

ROTARYVARIABLEDIFFERENTIALTRANSFORMER(RVDT)

RVDTisusedtosensetheangulardisplacementanditissimilartotheLVDTexceptthatitscore is cam shaped and may be rotated between the windings by means of shaft are shown in figure.



(a) Arrangement of RVDT



(b) Output voltage waveform of transducer

Operations:

The operation of a RVDT is similar to that of LVDT. At the null position of the core, the output voltages of secondary winding S1 and S2 are equal and in opposition.

Therefore, thenet output is zero.Anyangulardisplacement from the null position will result in a differential voltage output. The greater this angular displacement, the greater will be the differential output. Hence the response of the transducer is linear.

Clockwise rotation produces an increasing voltage of a secondary winding of one phase while counterclock - wise rotation produces an increasing voltageof opposite phase.

Hencetheamountofangulardisplacementanditsdirectionmaybeascertainedfromthemagnitude and phase of the output voltage of the transducer.

SYNCHRO:

A synchro is an electromagnetic transducer which is commonly used to convert the angular position of a shaft into an electrical signal.

Althoughthename,‘synchro’isuniversallyusedintheinstrumentationfiled,tradenamessuchas selsyns, microsysns and autosysn are used for these instruments.

Synchro consists of two major parts such as stator and rotor. The output emf voltage induced in the stator coil is due to variation in the angular motion of the rotor when it is excited with ac voltage.

Construction

Synchroisasingleassemblycomprisingbothstatorandrotor.Theyare made up

of silicon or steel material of high grade.

Instator,three coilsofidenticaltype arearrangedinamannerthattheir

axesaremutuallyat120°apart.Thesethreewindingsareuniformlydistributed in their

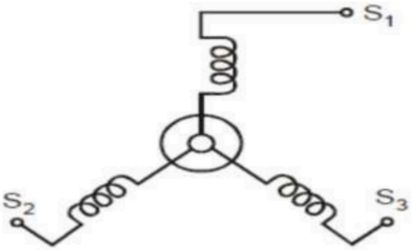
slots provided by the stator.

Therotoris provided with awindingthroughwhich an acexcitation is

given.Therearetwopopulartypesofrotorshapessuchasdumpbellshapedrotorandcylindrical shaped rotor. Figure 2.23 shows various shaped rotor types, and figure below shows the arrangement of stator assembly.

(i) Dump bell shaped rotor *(ii) Cylindrical shaped*

(a) Different shapes of rotor



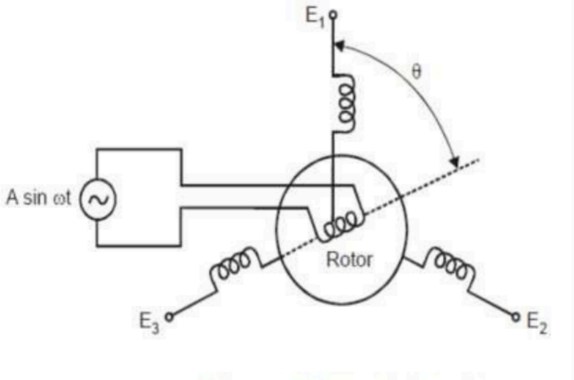
(b) Arrangement of stator

Working Principle:

Thereisasinglewindingintherotorwhichisexcitedwithanacvoltage. Due to

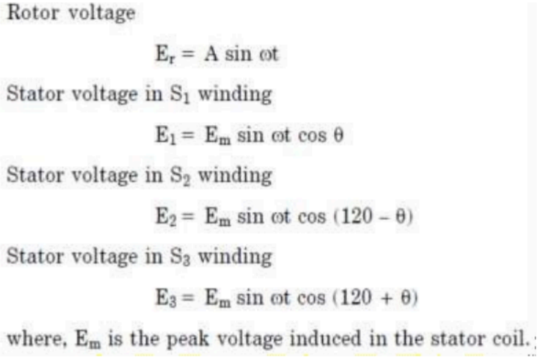
this, there will be flux generation in stator path.

Wheneverthereisanangulardisplacementintherotorwinding,therewillbevariationintheflux which will further induce emf in all the three windings in stator assembly.



Schematic Diagram of Synchro

Expressionofvoltagefor rotorandstator windings



Rotor voltage

$$E_r = A \sin \omega t$$

Stator voltage in S_1 winding

$$E_1 = E_m \sin \omega t \cos \theta$$

Stator voltage in S_2 winding

$$E_2 = E_m \sin \omega t \cos (120 - \theta)$$

Stator voltage in S_3 winding

$$E_3 = E_m \sin \omega t \cos (120 + \theta)$$

where, E_m is the peak voltage induced in the stator coil.

MICROSYN:

Microsynisanother nameofthevariablereluctancetransducer.

Therearetwo majorpartssuch asaferromagnetic rotorand astatorassembly.

Inthestator,fourcoilsa,b,canddareconnectedtogetherwiththatthevoltageinducedincoilsa and c should be same as the voltages induced in coils b and d at NULL position of the ferromagnetic rotor.

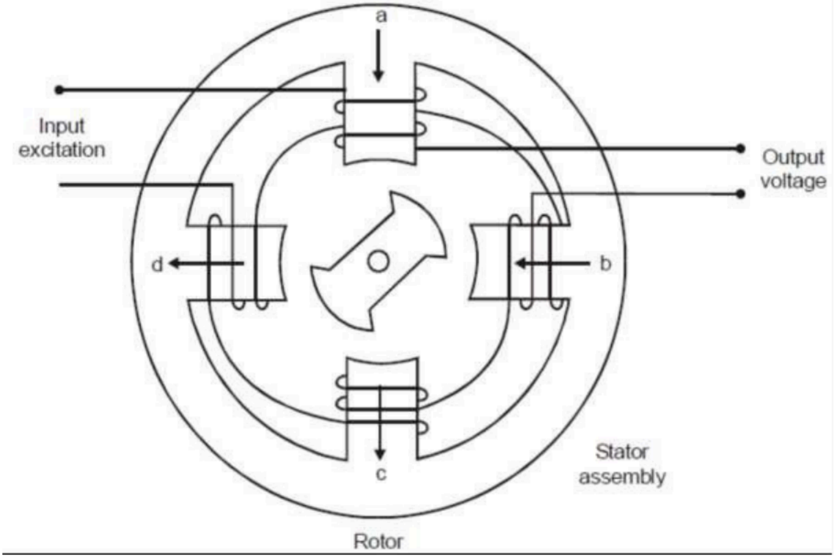
Basedontherotationoftherotorinclockwisedirectionstherewillbeincreased reluctanceinthe coils a and c and decreased reluctance in the coils b and d which gives a net output voltage (Eo).

Iftherotationincounterclockwisedirectionsitproducessamekindofeffectincoilsbanddwith 180° phase shift.

Withthehelpofmicrosyns,itispossibletodetectverysmallmotionwhichprovidesoutputsignal for even 0.01° of changes in angles.

Microsynshavethesensitivityashighasfivevoltperdegreerotations.

VariableReluctanceTransducer:



ACCELEROMETERS:

Anaccelerometerisanelectromechanicaldevicethatmeasuresacceleration forces.

These forces may be static, like the constant force of gravity pulling at our feet, or they could be dynamic - caused by moving or vibrating the accelerometer.

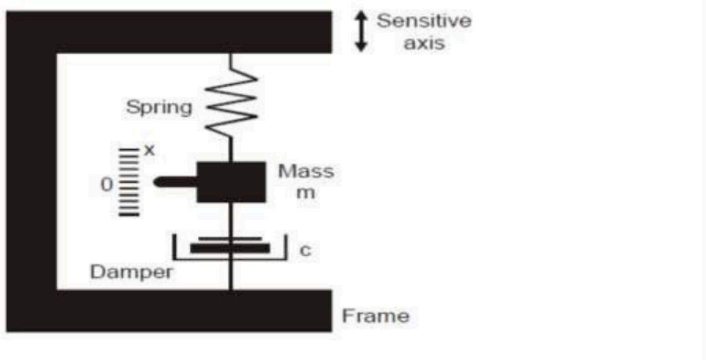
The accelerometers measure the inertia force generated when a mass is affected by change in velocity.

This force may change the tension of a string or cause a deflection of beam or may even change the vibrating frequency of a mass.

The Accelerometers are composed of three main elements: a mass, asuspension mechanism that positionsthemassandasensingelementthatreturnsaobservationproportionaltotheacceleration of the mass.

Some devices include an additional servo loop that generates an opposite force to improve the linearity of the sensor.

Manyoftheaccelerometersarcbasedonthependulumprinciple.Theyarebuiltwithaproofmass, a spring hinge and a sensing device.



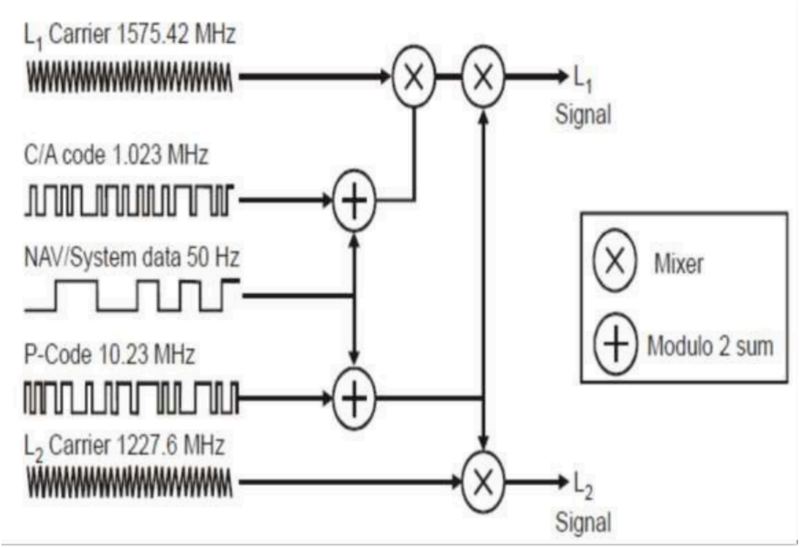
Basic components of a one degree of freedom accelerometer

GPS(GLOBALPOSITIONINGSYSTEM):

The Global PositioningSystem (GPS) is a space-based navigations system that provides location and time information in all weather conditions, anywhere on or near the earth where there is an unobstructed line of sight to four or more GPS satellites.

GPSis"spacebasedsatellitenavigationsystem"whichcanshowtheexactpositiononornearthe Earth surface, anytime, anywhere, in any weather condition.

The GPS system provides critical capabilities to military, civil and commercial users around the world.



Advantagesand Disadvantages:

The principle advantage of using GPS over land based beacons is that the GPS signal is readily available which reduces the deployment cost and time of the system.

Further, a GPS system is less susceptible to damage since the satellites, the beacons of the GPS, are maintained by international reputed organizations.

GPSis extremelyeffectiveforoutdoorground-based and flyingrobots.

Adisadvantageofthistechniqueisthatthestationaryreceivermustbeinstalled,itslocationmust bemeasuredverycarefully,andofcoursethemovingrobotmustbewithinkilometersofthisstatic unit in order to benefit from the DGPS technique.

SystemDescription

1. TheSpaceSegment:Consistsofsatellitesandtransmitted signals.

SpecialFeaturesoftheSpace Segment:

The Operational GPS Constellation consists of minimum 24 satellites, each in its own orbit, approximately about 20,200 km. above the Earth, in 12 hours (nearly 11hrs 58 min). There are often more than 24 operational satellites as new ones are launched to replace older satellites.

Thesatelliteorbitsrepeatalmostthesamegroundtrack(astheearthturnsbeneaththem)onceeach day. The orbit altitude is such that the satellites repeat the same track and configuration over any point approximately each 24 hours (4 minutes earlier each day).

2. TheControlSegment:

Consists of ground stations (located around the world) that make sure the satellites are working properly.

Control Segments formerly consists of 5 tracking stations situated at Hawaii, Ascension Island, Diego Garcia, Kwajalein and the Master Control facility is located at Schriever Air force Base(Formerly Falcon AFB) in Colorado Springs.

Newly added control stations after 2005 are Washington DC England, Ecuador, Argentina, Bahrain and Australia.

TheseMonitorstationsmeasuresignalsfromtheSVs,whichareincorporatedintoorbitalmodels for each satellites.

Master stations collect the data about the satellites of this system continuously from the other tracking stations.

MCS process the tracking data for computation of satellite ephemerides (or co- ordinate) and satellite clock parameters.

TheMaster controlstationuploadsephemerisand clockdatatoSVs.

3. TheUser Segment

Consistsof receivers,which wecan hold inourhandormountin our car.

TheGPSusersegmentconsistsoftheGPSreceiversandtheusercommunity.GPSreceivers convert SV signals into position, velocity and time estimates.

Foursatellitesarerequiredtocomputethefourdimensionsof X,Y,Z(Position)andTime. GPS

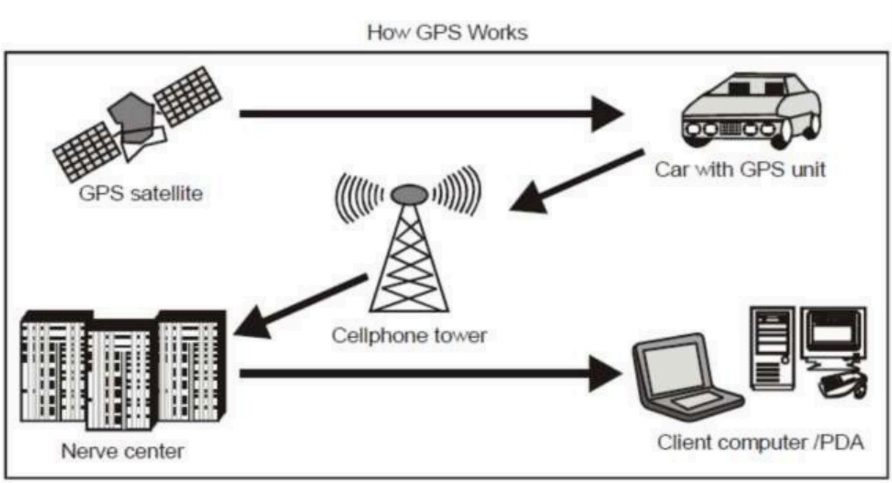
receivers are used for navigation, positioning, time dissemination andother research.

Navigationinthreedimensionsis theprimaryfunctionofGPS.

Navigation receivers are made for aircraft, ships, and ground vehicles and for hand carrying byindividuals.

Precise positioning is possible using GPS receivers at reference locations providing corrections and relative positioning, geodetic control and plate tectonic studies are example.

GPS user segment



Applicationsof GPS:

1. RoadTraffic Congestion
2. Tectonics
3. GPS and Terrorism
4. GPSof Mining
5. GPS and Tours
6. Navigation
7. Disaster Relief
8. GPS-EquiRadioSondesandDropsondes
9. FleetTracking
10. CellularTelephony
11. Robotics

BLUETOOTH

Bluetoothis astandardized protocol forsending and receivingdatavia2.4GHzwireless link.

It's a secure protocol and it's perfect for short-range, lowpower, low-cost, wireless transmissions between electronic devices.

WorkingofBluetooth

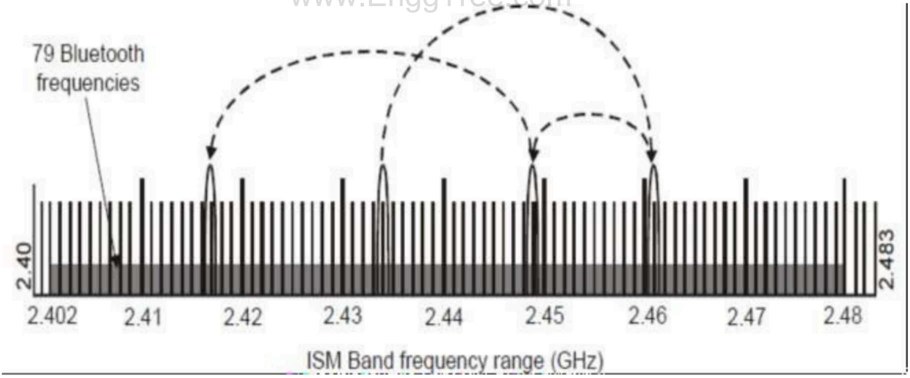
The Bluetooth protocol operates at 2.4 GHzin the same unlicensed ISM frequency band where RF protocols like ZigBee and WiFi also exist.

Thereisa standardizedsetof rulesandspecifications thatdifferentiatesit fromother protocols.

If you have a few hours to kill and want to learn every nook and cranny of Bluetooth, check out the published specifications, otherwise here's a quick overview of what makes Bluetooth special.

BWT-enableddevicesoperateintheunrestricted2.4-gigahertz(GHz)Industrial,Science,Medical (ISM) band. The ISM band ranges between 2.400

GHzand2.483GHz.BWT-enableddevicesuseseventy-nine1-megahertzfrequencies(from 2.402 to 2.480 GHz) in the ISM band.



ConnectionProcess:

1. Inquiry

IftwoBluetoothdevicesknowabsolutelynothingabouteachother,onemustrunaninquirytotry to discover the other. One device sends out the inquiry request, and anydevice listening for such a request will respond with its address, and possibly its name and other information.

2. Paging(Connecting)

Paging is the process of forming a connection between two Bluetooth devices. Before this connection can be initiated, each device needs to know the address of the other (found in the inquiry process).

3.Connection

After a device has completed the pagingprocess, it enters the connection state. While connected, a device can either be actively participating or it can be put into a low power sleep mode.

Active Mode: This is the regular connected mode, where the device is actively transmitting orreceiving data.

SniffMode: Thisisapower-savingmode,wherethedeviceislessactive.It'llsleepandonlylisten for transmissions at a set interval (e.g. every 100 ms).

Hold Mode: Hold mode is a temporary, power-saving mode where a device sleeps for a defined period and then returns back to active mode when that interval has passed. The master can command a slave device to hold.

Park Mode: Park is the deepest of sleep modes. A master can command a slave to "park", andthat slave will become inactive until the master tells it to wake back up.

4. BondingandPairing

WhentwoBluetoothdevicesshareaspecialaffinityforeachother,theycanbebondedtogether. Bonded devices automatically establish a connection whenever they're close enough.

5. PowerClasses

The transmit power, and therefore range, of a Bluetooth module is defined by its power class. There are three defined classes of power: Some modules are only able to operate in one power class, while others can vary their transmit power.

6. Bluetooth Profiles

Bluetooth standard to more clearly define what kind of data a Bluetooth module is transmitting. While Bluetooth specifications define how the technology works, profiles define how it's used.

RANGESENSORS

Commonlyusedrangesensors inrobotics:

1.Tactileand Proximitysensors

2. UltrasonicSensors

3. IRRangeSensors
4. LaserRangeFinders
5. Vision Systems

Eachvariesincomplexity, size,weight,expense, accuracy, etc..

Thedetectionrangeis definedasthemaximum distancethatthesensor canreadreliablyfrom.

RFBEACON (RADIOFREQUENCY BEACON-1MTO 100 M)

Aradiobeaconisatransmitterataknownlocation,whichtransmitsacontinuousorperiodicradio signal with limited information content on a specified radio frequency.

Occasionally the beacon function is combined with some other transmission, like telemetry data or meteorological information.

TheMillibotlocalizationsystemisbasedontrilateration,i.e.,determinationofthepositionbased on distance measurements to known landmarks or beacons.

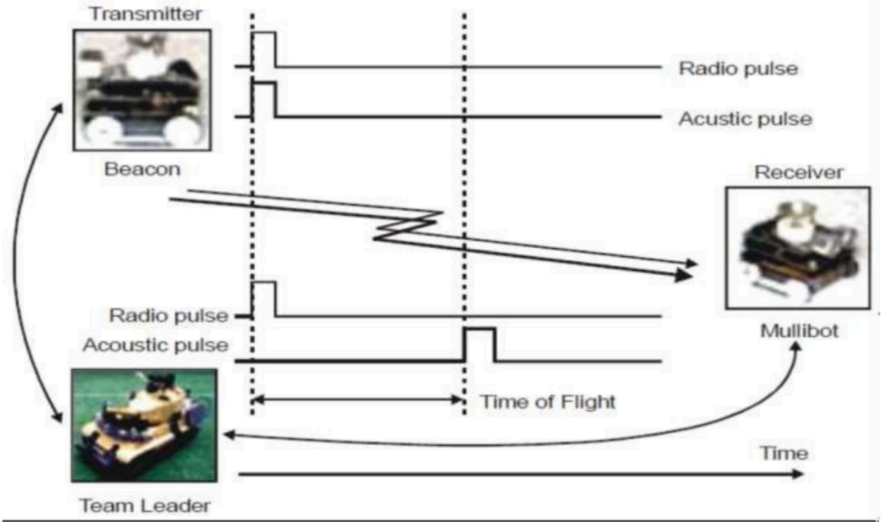
GPSisanexampleofatrilaterationsystem;thepositionofaGPSunitonearth iscalculatedfrom distancemeasurements to satellites in space.

Similarly, the Millibotlocalization system determines the position ofeach robotbased on distance measurements to stationary robots withknown positions.

Thelocalizationsystemusesultrasoundpulsestomeasurethedistancesbetweenrobots.

Periodically,eachbeaconsimultaneouslyemitsaradiofrequency(RF)pulseandanultrasonic pulse.

Radio FrequencyBeacon



Applications of Radio beacons

1. Airandseanavigation,

2. Propagationresearch,

3. Roboticmapping,

4. Radio-frequencyidentification(RFID)/NearFieldCommunication

(NFC) and

5. Indoorguidance,aswithreal-timelocatingsystems(RTLS)likeSyledis or

simultaneous localization and mapping (SLAM).

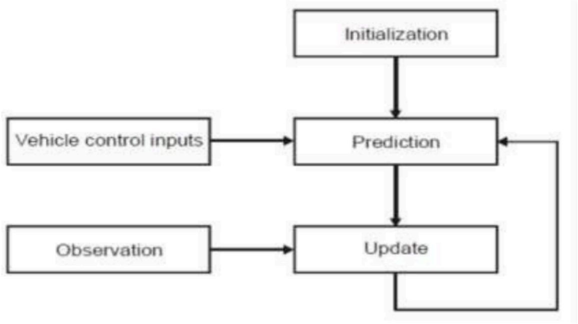
REFLECTIVEBEACONS

BeaconbasedLocalization

Beaconnavigationsystemsarethemostcommonnavigationaidsonshipsandaircraftsaswellas oncommercialmobilerobotsystems.Activebeaconscanbedetectedreliablyandprovideaccurate positioning information with minimal processing.

As a result, this approach allows high sampling rates and yields high reliability, but it does also incurhighcostininstallationandmaintenance.Mostofthebeaconbasedlocalizationsystemsrely on a set of beacons placed at known positions in the environment. The mobile robot vehicle is equipped with a sensor(s) that can observe the beacons and the navigational system uses these observationsandknowledgeof thebeaconpositionsto locatetherobot vehicle.

1.Estimation Process



2. Trilateration

Trilaterationisamethodtodeterminethepositionofanobjectbasedonsimultaneousrange measurements from three stations located at known sites.

Intrilaterationnavigationsystems,thereareusuallythreeormoretransmittersmountedatknown locations in the environment and one receiver on board the robot.

3.Triangulation

Itisthemostwidespreadmethodused tolocalizeamobilerobot vehicle.

Inthisconfigurationtherearethreeormore active transmittersmountedatknownlocations

ULTRASONICSENSORS

Thesensor sendsasonicpulse signal, whichis reflected bytheobject to bedetected.

Thetime,whichthepulsesignalrequiresfromthesensortotheobjectandback,ismeasuredand evaluated.

Thedistanceiscalculated fromthetimeand thepulse speed.

Ultrasonicsensorsaresuitableforuseindifficultindustrialenvironments.

Disturbances such as dust, soiling or fog do not influence measurements.

Mutuallyinterferinglightinfluencesortemperaturefluctuationsarenot aproblem either.

ClassificationofUltrasonicSensors:

1. Short-Range Distance

Sensors(Displacement)Precisioninthemillimetrer

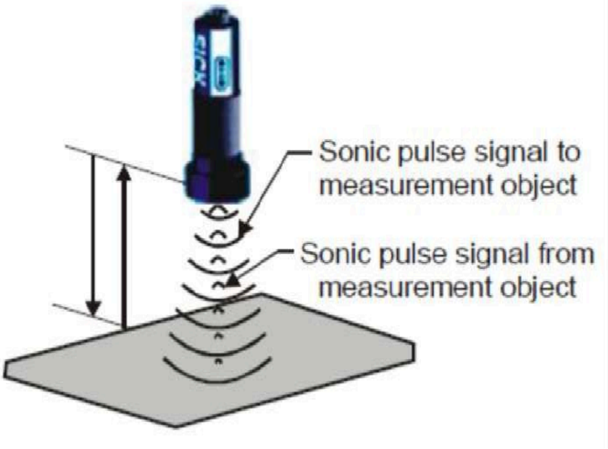
ange

2. Mid-RangeDistanceSensors

Thesolution for measuringranges from 13mm to 24 m

3. Long-RangeDistance Sensors

Developed for maximum ranges from 200 mm to 1,200 m



Advantages&Disadvantagesofultrasonicrangesensors

Advantages of ultrasonic range sensors

1. Reliablewithgood precision
2. Notas proneto outside interference
3. Good maximumrange
4. Inexpensive

Disadvantages

1. Sensitivetosmoothness&angletoobstacles
2. Poor resolution
3. Pronetoself-interferencefromechos
4. Cannotdetectobstaclestooclose

LIGHTDETECTIONANDRANGING (LIDAR)

LaserRangeFindersare perhapsthemostaccuratesensorsformeasuringdistances.

Light distanceand ranging (LIDAR) systems usethetimetaken bythelight to flyback and forth to an object in an effort to measure the distance to this target.

BuildingaLIDARsystemcanbemadewitheitherahigh-speedanalogto-digitalconverter(ADC) or a time-to-digital converter (TDC).

Lidarsystemsuseoneof threetechniques:

a) PulsedModulation

b) AmplitudeModulationContinuousWave(AMCW)

c) FrequencyModulation Continuous Wave (FMCW)

ComponentsofaLiDARsystem

Laserscanner

High-precisionclock

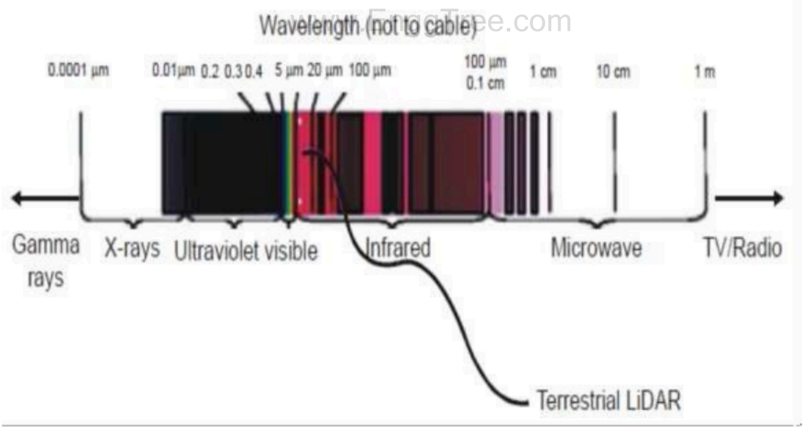
GPS

IMU-Inertialnavigationmeasurementunit

Data storage and management systemsGPS

ground station

ElectromagneticSpectrum



Working ofLaser
High-voltageelectricitycausesaquartzflashtubetoemitanintenseburstoflight,excitingsome of the atoms in a cylindrical ruby crystal to higher energy levels.

Ataspecific energylevel,someatomsemitparticles oflightcalled photons.

At first the photonsareemitted in all directions.Photons from one atom stimulate emission ofphotons from other atoms and the light intensity is rapidly amplified.

Applications

1. FactoryAutomation Optical ProximitySensor
2. FactoryAutomationOptical LevelSensor
3. FactoryAutomation VolumeScanners
4. Drones

UNIT-III

FORCE,MAGNETICANDHEADING SENSORS

Strain Gage – Types, Working, Advantage, Limitation, and Applications: Load Measurement – Force and Torque Measurement - Magnetic Sensors – Types, Principle, Advantage, Limitation, and Applications - Magneto Resistive – Hall Effect, Eddy Current Sensor - Heading Sensors – Compass, Gyroscope and Inclinometers.

PiezoresistiveEffect

If a metal conductor is stretched or compressed, its resistance changes on account of the fact that bothlengthanddiameterofconductorchange.Alsothereisachangeinthevalueofresistivityof the conductor when it is strained and this property is called piezoresistive effect.

Therefore,resistancestraingaugesarealsoknown aspiezoresistive gauges.

Uses:

1. Usedformeasurementofstrainand associatedstressinexperimental stress analysis.
2. Manydetectorsandtransducersnotablytheloadcells,torquemeters,diaphragmtypespressure gauges, temperature sensors, accelerometers and flow meters, employstrain gauges as secondary transducers.

Theoryof Strain Gauges

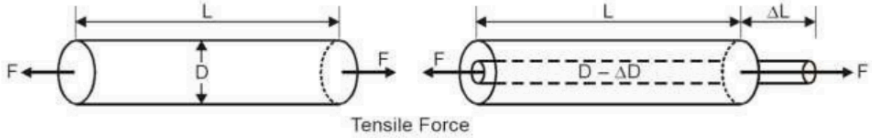


Figure 3.1: Change in Dimensions of a Strain Gauge Element when Subjected to a Tensile Force

Thechangeinthevalueofresistancebystrainingthegaugemaybepartlyexplainedbythenormal dimensional behaviour of elastic material.

If astripofelasticmaterialissubjectedto tension.

Sincetheresistanceofthegaugeaconductorisproportionaltoislengthandinverselyproportional to its area of cross section, the resistance of the gauge increases with positive strain.

The change in the value resistance of strained conductor is more than what can be accounted for an increase in resistance due to dimensional changes. The extra change in the value of resistance is conductor when strained.

This propertyis known is piezoresistiveeffect

Let us consider a strain gauge made of circular wise. The wire has two dimensions; Length = L, area = A, Diameter = D before being strained. The material of the wire has resistivity ρ.

$$\therefore \quad \text{Resistance of unstrained gauge, } R = \frac{\rho L}{A}$$

Letatensilestress S beappliedto thewire.This producesapositivestrain

Let ΔL = Change in length

ΔA = Change in area

ΔD = Change in diameter and

ΔR = Change in resistance

In order to find how ΔR depends upon the material physical quantities, the expression for R is differentiated with respect to stress S.

$$\frac{dR}{dS} = \frac{\rho}{A}\frac{\partial L}{\partial S} - \frac{\rho L}{A^2}\frac{\partial L}{\partial S} + \frac{L}{A}\frac{\partial \rho}{\partial S} \qquad \text{... (3.1)}$$

Dividing equaiton 1 throughout resistance R= $\frac{\rho L}{A}$, we have

$$\frac{1}{R}\frac{dR}{dS} = \frac{1}{L}\frac{\partial L}{\partial S} - \frac{1}{A}\frac{\partial A}{\partial S} + \frac{1}{\rho}\frac{\partial \rho}{\partial S} \qquad \text{... (3.2)}$$

It is evident from equation 2, that the per unit change in resistance is due to

1. Per unit change in length $= \frac{\Delta L}{L}$
2. Per unit change in area $= \frac{\Delta A}{A}$ and
3. Per unit change in resistivity $= \frac{\Delta \rho}{\rho}$

Area, $A = \frac{\pi}{4} D^2 \qquad \therefore \frac{\partial A}{\partial S} = 2\frac{\pi}{4} D \frac{\partial D}{\partial S}$ ... (3.3)

$$\frac{1}{A}\frac{dA}{dS} = \frac{\left(2\,\pi/4\right) D}{\left(\pi/4\right) D^2}\quad \frac{\partial D}{\partial S} = \frac{2}{D}\frac{\partial D}{\partial S} \qquad \text{... (3.4)}$$

∴ Equation 3.3 can be written as

$$\frac{1}{R}\frac{dR}{dS} = \frac{1}{L}\frac{\partial L}{\partial S} - \frac{2}{D}\frac{\partial D}{\partial S} + \frac{1}{\rho}\frac{\partial \rho}{\partial S} \qquad \text{... (3.5)}$$

Poisson's ratio

$$\nu = \frac{\text{lateral strain}}{\text{Longitudinal strain}} = \frac{-\partial D/D}{\partial L/L} \qquad \text{... (3.6)}$$

$$\frac{\partial D}{D} = -\nu \times \frac{\partial L}{L}$$

$$\frac{1}{R}\frac{dR}{dS} = \frac{1}{L}\frac{\partial L}{\partial S} + \nu\frac{2}{L}\frac{\partial L}{\partial S} + \frac{1}{\rho}\frac{\partial \rho}{\partial S} \qquad \text{... (3.7)}$$

For small variations, the above relationship can be written as

$$\frac{\Delta R}{R} = \frac{\Delta L}{L} + 2\nu\frac{\Delta L}{L} + \frac{\Delta \rho}{\rho} \qquad \text{... (3.8)}$$

The gauge factor is defined as the ratio of per unit change in resistance to per unit change in length

$$\text{Gauge factor,} \quad G_f = \frac{\frac{\Delta R}{R}}{\frac{\Delta L}{L}} \qquad \text{... (3.9)}$$

$$\frac{\Delta R}{R} = G_f\frac{\Delta L}{L} = Gf \times \varepsilon \qquad \text{... (3.10)}$$

where ε = strain = $\frac{\Delta L}{L}$

The gauge factor can be written as

$$= 1 + 2\nu + \frac{\Delta\rho/\rho}{\varepsilon} \qquad \text{... (3.11)}$$

$$= \underbrace{1}_{\substack{\text{Resistance}\\ \text{change due}\\ \text{to change of}\\ \text{length}}} \quad \underbrace{+\,2\nu}_{\substack{\text{Resistance}\\ \text{change due}\\ \text{to change in}\\ \text{area}}} \quad + \underbrace{\frac{\Delta\rho/\rho}{\varepsilon}}_{\substack{\text{Resistance}\\ \text{change due}\\ \text{to piezo -}\\ \text{resistive effect}}}$$

$$G_f = \frac{\Delta R/R}{\Delta L/L} = 1 + 2\nu + \frac{\Delta\rho/\rho}{\Delta L/L}$$

Typesof Strain Gauges:

1. Unbondedmetalstraingauges
2. Bondedmetalwirestraingauges
3. Bondedmetal foilstraingauges
4. Vacuumdepositedthinmetalfilmstraingauges
5. Sputterdepositedthinmetalstraingauges
6. Bondedsemiconductorstraingauges
7. Diffusedmetalstrain gauges

ApplicationsofStraingauges

Experimentalstressanalysisofmachinesandstructures.

Constructionofforce,torque,pressure,flowandaccelerationtransducers.

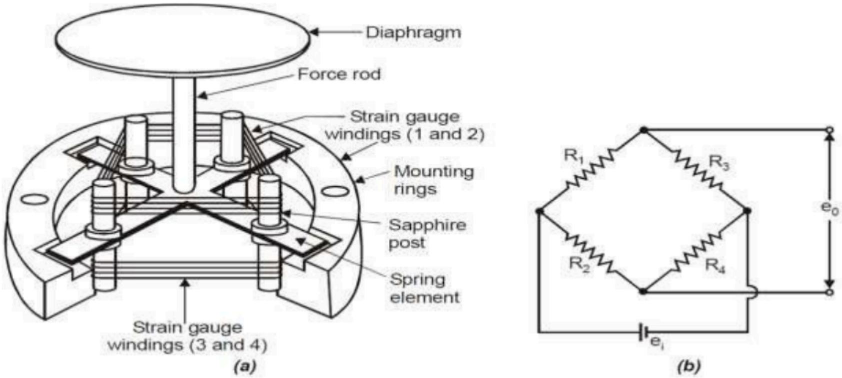
1.UnbondedMetalStrain Gauges

Thisgaugeconsistsofawirestretchedbetweentwopointsinaninsulatingmediumsuchasair. The wires may be made of various copper nickel, chrome nickel or nickel iron alloys.

Theyareabout0.003mm indiameter,haveagaugefactorof2to4andsustainofforceof2mN. The length of wire is 25mm or less.

Theflexureelementisconnectedviaarodisdiaphragmwhichisusedforsensingofpressure. The wires are tensioned to avoid buckling when they experience a compressive force.

Setupof aUnbondedStrain Gauge andMeasurement withaWheatstoneBridge



The unbounded metal wire gauges, used almost exclusively in transducer applications emply preloaded resistance wires connected in a wheatstone bridge.

At initial preload, the strains and resistances of the four arms are nominally equal with the result the output voltage of the bridge, e_0.

Application ofpressure produces asmall displacement which is about 0.004 mm (full scale), the displacement increases tension in two wires and decreases it in the other two, therebydecreasing the resistance of the remaining two wires. This causes an unbalance of the bridge producing an outputvoltagewhichisproportionaltotheinputdisplacementandhencetotheappliedpressures.

Electric resistance of each armis 12W to 1000W, theinput voltageto the bridge is 5 to 10 Vand the full scale output of the bridge is typically about 20 mV to 50 mV.

2.BondedMetalWireStrain Gauges

A resistance wire strain gauge consists of a grid of fine resistance wire of about 0.025 mm in diameterorless.Thefridiscementedtocarrierwhichmaybeathinsheetofpaper,athinsheetof bakelite or a sheet of teflon.

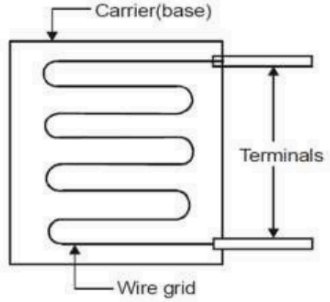
The wire is covered on top with a thin sheet of material so as to prevent it from any mechanical damage. The spreading of wire permits a uniform distribution of stress over the grid.

Thecarrierisbondedwithanadhesivematerialtothespecimenunderstudy.Thispermitsagood transfer of strain from carrier to grid of wires.

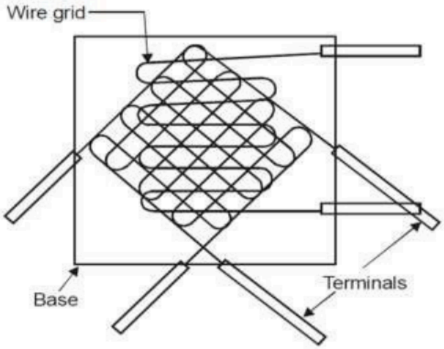
Thewirescannotbuckleastheyareembeddedinamatrixofcementandhencefaithfullyboththe tensile and compressive strains of the specimen.

Since,thematerialsandthewiresizesusedforbondedwirestraingaugesarethesameasusedfor unbondedwirestraingauges,thegaugefactorsandresistances,forbotharecomparable.themost commonly used forms of strain gauges.

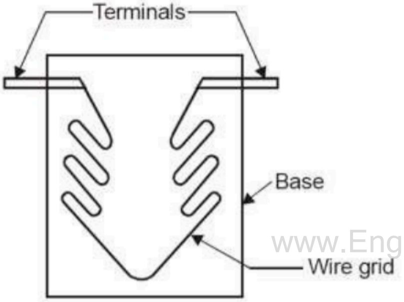
ResistanceWireStrain Gauge



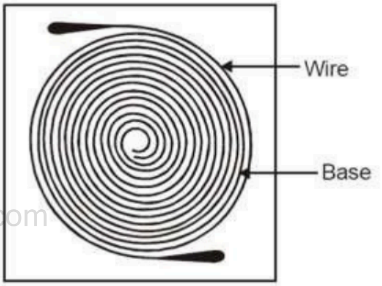
(a) Linear strain gauge



(b) Rosette



(c) Torque gauge



(d) Helical gauge

4.BondedMetalFoilStrainGauges:

Thisclass of straingaugesis onlyan extension of thebonded metal wirestrain gauges.

Thebondedmetalwirestraingaugeshavebeencompletelysupersededbybondedmetalfoilstrain gauges.

Metal foil strain gauges and are used today for most general purpose stress analysis application and for many transducers.

Foiltypegaugeshavemuchgreaterheatdissipationcapacityascomparedwithwirewoundstrain gauges on account of their greater surface area for the same volume.

Theycan beused for higheroperatingtemperaturerange.

Alsothelargesurfacearealead tobetter bonding.

The sensing elements of foil gauges are formed from sheets less than 0.005 mm thick by photo - etching processes, which allow greater flexibility with regard to shape.

Forexample,thethreelinear grid gaugesaredesignedwithfatendsturns.

This local increase in area reduces the transverse sensitivity which is a spurious input since thegauge is designed to measure the strain component along the length of grid elements.

Tocalculate whateffectanappliedstresshason a metalstraingauge.

Hooke’s law gives a relationship between stress and strain for linear stress -strain curve in terms of modulus of elasticity of the material under stress.

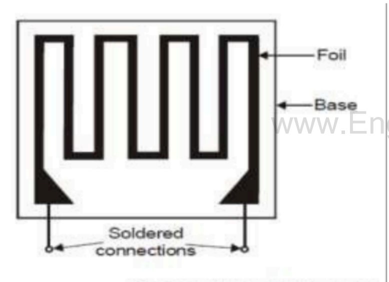
Hooke’slawas

Strain=S/E

whereG,SandEarerespectivelythestrain,stressandmodulusofelasticity. Units for

stress and modulus of elasticity are N/m2.

Thechangeinthevalue of resistanceis quitesmall.



Bonded Metal Foil Gauges

5.EvaporationDepositedThinMetalStrainGauges:

Evaporationdepositedthinfilmmetalstraingaugesaremostlyusedforthefabricationoftransducers. They are of sputter deposited variety.

Bothprocessesbeginwithasuitableelasticmetalelement.Theelasticmetalelementconvertsthe physical quantity into a strain.

Exampleofapressuretransducer,athin,circular metaldiaphragmis formed.

Both the evaporation and sputtering processes from all the strain gauge elements directly on the strain surface, they are not separately attached as in the case of bonded strain gauges.

In the evaporation process, the diaphragm is placed in a vacuum chamber with some insulating material.

Heat is applied until insulating material vapourises and then condenses, forming a thin dielectric film on the diaphragm.

Suitably shaped templates are placed over the diaphragm and the evaporation and condensation processes are repeated with the metallic gauge material forming the desired strain gauge pattern on top of the insulating substrate.

In the sputteringprocess, a thin dielectric layer is deposited in vacuum over the entirediaphragm surface.

Thedetailedmechanismofdepositionis,however,entirelydifferentfromtheevaporationmethod.

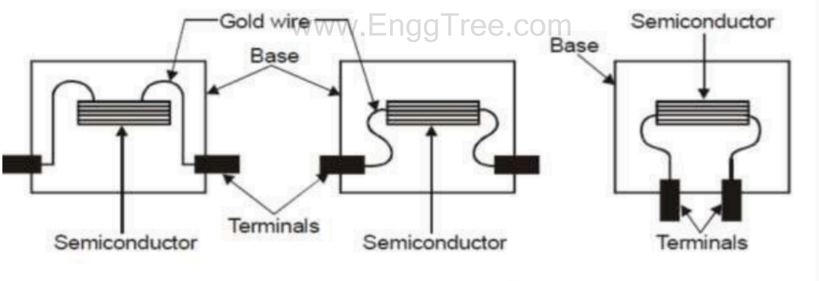
The complete layer of metallic gauge is sputtered on the tope of the dielectric material without using any substrate.

Thediaphragmsarenowremovedfromthevacuumchamberandmicro-imagingtechniquesusing photo masking materials are used to form the gauge pattern.

Thediaphragmsarethen returnedtothevacuum chamber.

Sputteretchingtechniquesareusedtoremoveallunmaskedmetallayer,leavingbehindthedesired gauge pattern.

6.SemiconductorStrainGauges



Semi - Conductor Strain Gauge

Tohaveahighsensitivity, ahighvalueofgaugefactorisdesirable.

Ahighgaugefactormeansarelativelyhigherchangeinresistancewhichcanbeeasily measured

with a good degree of accuracy.

Semiconductor strain gauges are used where a very high gauge factor and a small envelope arerequired.

Theresistanceofthesemi-conductorschanges withchangeinapplied strain.

Unlike in the case of metallic gauges where the change in resistance is mainly due to change in dimensionswhenstrained,thesemi -conductorstraingaugesdependfortheiractionuponpiezo-resistive effect.

i.e.,thechangein thevalueoftheresistancedueto changein resistivity.

Semi-conductingmaterialssuchassiliconandgermaniumareusedasresistive materials

for semiconductor strain gauges.

Atypicalstraingaugeconsistsofstrainsensitivecrystalmaterialandleads thatareoverlappedin a protective matrix.

The production of these gauges employs conventional semi – conductor technology using semi - conducting wafers or filaments which have a thickness of 0.5mm.

Gold leads are generally employed for making the contacts. Some of the typical semi conductor straingaugesareshowninfigure3.6.Thesestraingaugescanbefabricatedalongwithintegrated circuit (IC) operational amplifier which can act as pressure sensitive transducers.

7.Diffused StrainGauges

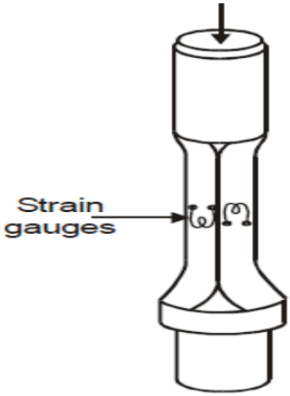
Thediffusedstraingaugesareprimarilyusedintransducers.thediffusionprocessusedinIC manufacture is employed.

Inpressuretransducers,forexample,thediaphragmwouldbeofsiliconratherthanmetalandthe straingaugeeffectwouldberealizedbydepositingimpuritiesinthediaphragmtoformanintrinsic strain gauge.

Thistypeofconstructionmayallowlowermanufacturingcostsinsomedesignsasalargenumber of diaphragms can be made on a single silicon wafer.

LOADCELL

Loadcellsutilizeanelasticmemberastheprimary transducerandstraingaugesassecondary transducers.



Load Cell

Principle

- A load cell is a transducer that is used to create an electrical signal whose magnitude is directly proportional to the force being measured.
- A load cell usually consists of four strain gauges in a Wheatstone bridge. The change in resistance of the strain gauge can be utilized to measure strain accurately when connected to an appropriate measuring circuit configuration. The electrical signal output is typically very small in the order of a few millivolts. It is amplified by an instrumentation amplifier before sending it to the measurement system.

MAGNETICSENSORS

Magnetizationservesastrongimpactinchangingthepropertiesof certainmaterials.

Magnetizationchangesorproduceeffectswhich aremechanicalorelectricalinnature andwhich are measurable.

Also,opticalenergymayproducechangesinmagnetizationcharacteristicsofthematerials. Not all

such changes are easilytransducible, perhaps not at this stage of the state of theart.

- MagneticSensorTypes
- Magneticfield sensors
- Magneto-elasticsensors
- Magneticelastic sensors
- Torque/ forcesensors
- Magnetoresistivesensors
- Halleffectsensorsormagneto galvanic sensors
- Distance orproximitysensors

- Wiegandandpulse wiresensors
- Superconductingquantuminterferencedevices(SQUIDS)
- Magnetostriction

1. MagneticField Sensors

Developedfollowing‘Δyeffect’whichineffectisobservedasthechangeinYoung’smodulus with magnetization. The sensors are often termed as Acoustic Delay Line Components(ADLC).

2. Magneto-Elastic Sensors

Based on the fact that in a longitudinal field, torsion given in a ferromagnetic rod changes its magenetization. This is known as ‘matteucci effect’.

3. MagneticElasticSensors

Produced using ‘villari effect’ in which a tensile or compressive stress changes magnetization or affects magnetization in some way.

4. Torque/ForceSensors

‘Widemanneffect’isusedtodevelopthetorque/forcesensors.Insuchsensors,torsionisproduced in a ferromagnetic rod carrying a current when subjected to a longitudinal field.

5. MagnetoResistiveSensors

Becomingincreasinglypopulararedevelopedonthebasisof‘Thomsoneffect’whichisbasically a change in resistance of specified materials with magnetic field impressed.

6. HallEffectSensorsorMagneto Galvanic Sensors

The common and widely used type magnetic sensors. These operate on the fact that a crystal carryingacurrentwhensubjectedtoamagneticfieldperpendiculartothedirectionofthecurrent, produces a transverse voltage.

7. Distanceor ProximitySensors

Developed based on ‘skin effect’ in which eddy current forces the current flowing through the interior of a material to move to its surface level.

8. WiegandandPulseWire Sensors

A specific type of material when subjected to pulse voltage under stress shows switching effect whichoccursduetobarkhausenjump.Thisisutilizedtoproducesuchsensors.Theeffectiscalled ‘sixtus - tonks effect’ after the experimenter who demonstrated the effect.

9. SuperconductingQuantumInterferenceDevices(SQUIDS)

It is used for varying application areas, are based on the superconducting state specifically, ‘flux quantization and joseph on effect’. These types of sensors have a resolution of the order of a few femto tesla (ft).

10. Magnetostriction

Usedincombinationwithpiezoelectricelementsforfieldmeasurement.Thiseffectisalsoknown as ‘joule effect’ in which magnetization changes the shape of a ferromagnetic material body.

Principle

The∆Yeffectisanoutcomeofmagneto striction.Changeindimensionduetomagneto strictionina material is actually caused by rotation of the magnetization.

Ademagnetizedferromagneticmaterial,whenundergoesamechanicalstress,developstwotypes of stresses in it, namely,

1.Theplainmechanicalelasticstrain,εsand

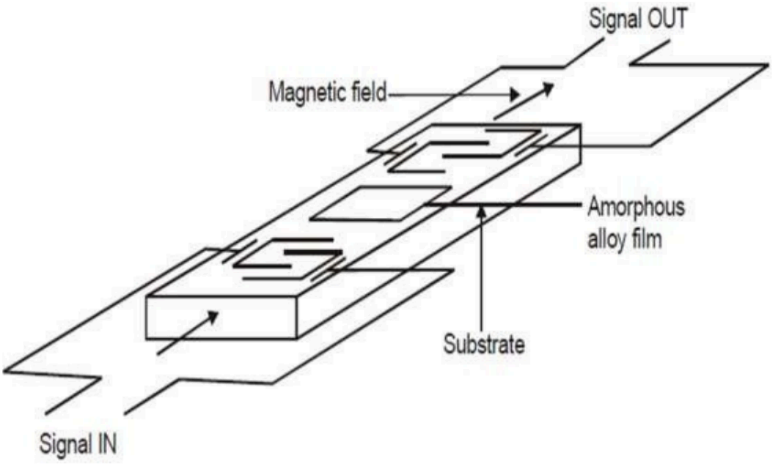
2.Themagneto elasticstrain εm.

Which is the result of reorientation of magnetic domains bythe applied stress Sa, thus giving the Young’s modulus of the demagnetized material as,

$$Y_{dm} = \frac{Sa}{\varepsilon_s + \varepsilon_m}$$

For a saturated sample no magneto elastic strain is produced because no further reorientation is possible and hence, the Young’s modulus is,

$$\frac{\Delta Y}{Y_{dm}} = \frac{Y_{sm} - Y_{dm}}{Y_{dm}} = \frac{\varepsilon_m}{\varepsilon_s} \qquad Y_{sm} = \frac{Sa}{\varepsilon_s}$$



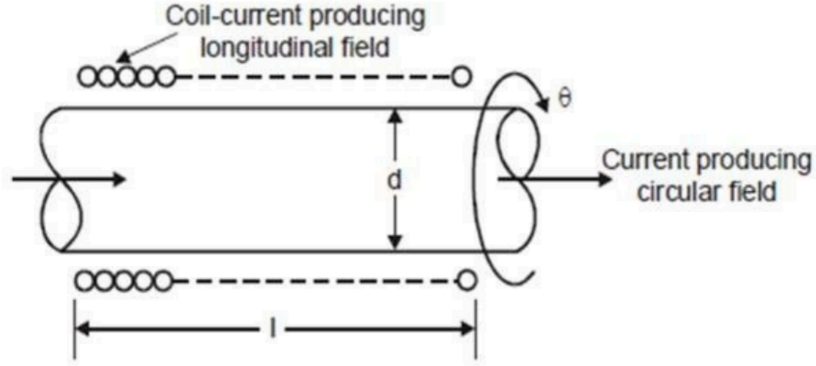
Thesoundvelocityisgivenbytherelation

$$v = \sqrt{\frac{Y}{\rho}}$$

Thechangein velocityΔv, inthefilm isgivenby,

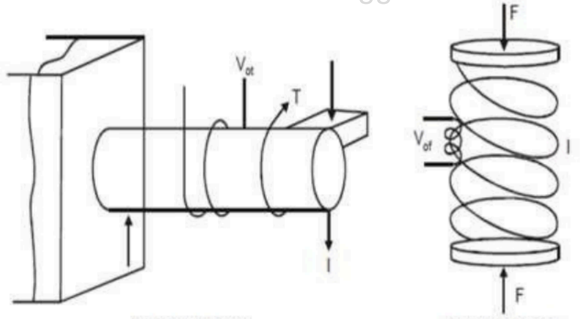
$$\frac{\Delta v}{v} = \sqrt{\frac{\Delta Y}{Y}}$$

$$\theta = (\lambda_1 - \lambda_t) \frac{41}{a} \frac{H_1 H_r}{H_1^2 + H_r^2}$$



1. WidemannEffect

Widemanneffectisused tomaketorque/forcesensors.



(a) Torque sensor (b) Force sensor

TheWidemann effecthas twoinverse effects

i) When a ferromagnetic rod which is circularly magnetized, is twised a longitudinal magneticfield is produced in it and

ii) Whensucharodwithlongitudinalmagnetizationistwisted,a

Circularmagnetic fieldisproducedinitwhich,essentiallyisthe

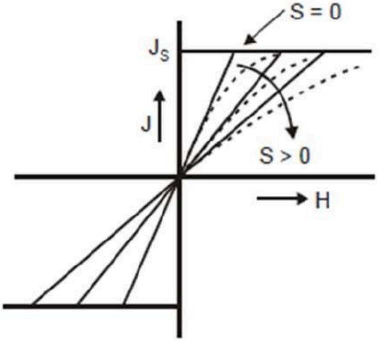
Matteucci effect.

Themagneto-mechanicalcouplingfactorKssisdefinedastheratiooftheelasticstressenergyto the total stored energy such that,

$$K_{SS} = \frac{E_s}{E_s + E_m + E_{cr} + E_{ua} + E_N}$$

$$K_{SS} = \frac{E_s}{E_s + E_m}$$

Figureshowsthetheoreticalandpracticalcurvesforsoftalloystripmaterialwithtensileload.



VillariEffect:

BasedontheVillarieffect,threebasictypes ofmagnetoelasticsensorsmaybedesigned namely,

i) Thetypeinwhichmechanicalloadinginunidirectionalsoastoproducecompressionortension and this changes the inductance or permeability with the specimen having predefined magnetic flux path as in choke or coil type design.

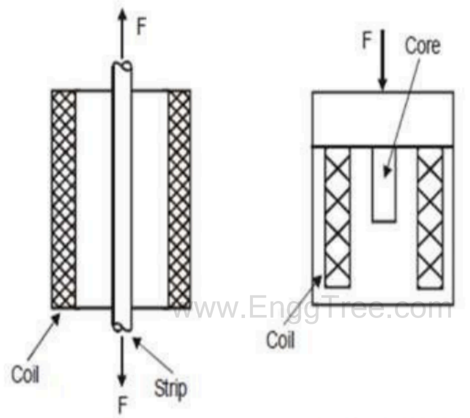
ii) Oneinwhichmechanicalloadingchangestheflux intwodirectionsorinaplaneasincircular rings or laminated cores and

iii) Thethirdinwhichloadingchangesthefluxspatiallythatis 3-

dimensionally in torque transducer for shafts.

Inductancevariation sensors

(a)Stripand (b)Potcore sensors



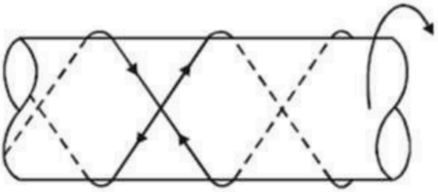
(a) Strip (b) Pot core sensors

The most important are the torque sensors. If the shaft material does not have the requisite magnetic properties such as magnetotriction, an additional magnetic coating on the shaft surface produces the desired mechanical stress on this surface that is to be measured.

Inasolidorhollowcylindricalshafts,stressdevelopedintwoprincipalorthogonaldirections,one compressive and the other tensile, each at an angle of ± 45°with the shaft axis in a screw like fashion around the shaft.

ForahollowshaftofinnerandouterdiametersDiandDo,theangleoftorsionΦ,thelengthofthe shaft l, torque produced is given

$$\pi = \frac{C\pi\phi}{321}\left(D_o^4 - D_i^4\right)$$



The maximum stress on the surface of the shaft is

$$S_m = \frac{16\,D_o\,T}{\pi\left(D_o^4 - D_i^4\right)}$$

and the maximum strain ε_m is

$$\varepsilon_m = \frac{S_m}{Y}(1+\nu) = \frac{16\,D_o\,(1+\nu)}{\pi\left(D_o^4 - D_i^4\right)Y}\,T$$

Where;ν=Poissonratio

Two types of designs are (a) Yoke coil type and (b) The cylindrical coil type (which are mounted coaxially with respect to the shaft.

MAGNETORESISTIVE SENSOR

AnisotropicMagnetoresistiveEffect:

Magneto-resistive effects are observed in metals specially in ferromagnetic types and in such cases,itisknownasanisotropicmagneto-resistiveeffect(or)geometricalmagneto-resistiveeffect for short samples in semiconductors.

1.AnisotropicMagnetoresistiveSensing

Magnetoresistiveeffectcanbeanalyzedtakingintoaccountthecomplexferromagneticbehaviour.

Howeverforsensingpurposes,knowledgeoftherelationsbetweenthedirectionofmagnetization and resistivity is sufficient as also between the magnetization - direction and external fields.

If the angle between the direction of internal magnetization M and that of current in the sample I is Φ, then the resistivity is given by,

$$\rho\ (\phi) = \rho\alpha + (\rho\beta - \rho\alpha)\cos^2\phi$$

$\rho\alpha$ is the value ρ for $= \phi\ 90^\circ$ and

$\rho\beta$ is the value ρ for $= \phi\ 0^\circ$

Thequantity(ρß-ρα)/ραspecifiestheMagnetoresistiveeffectoritscoefficientwhich,ingeneral is positive and quite large.

P(Φ) is not scalar and should produce and electric field Ea perpendicular to the external field Eb to generate a current density Jb, Ea is in the J-M plane which is the plane of the ferromagnetic material, but perperndicular to J so that

$$E_a = J_b\,\Delta\rho\sin\phi\cos\phi$$

where $\Delta\rho = \rho\beta - \rho\alpha$

If now, a bar of length l, width w and thickness t is considered with current I flowing along the length, From equation (1), the ressitance of the bar is

$$R(\phi) = \frac{\rho_\alpha l}{Wt} + \left(\frac{\Delta\rho l}{Wt}\right)\cos^2\phi$$

$$= R + \Delta R\cos^2\phi$$

and the voltage dro V_b is

$$V_b = \frac{\rho_\alpha I l}{Wt} + \left(\frac{\Delta\rho I l}{Wt}\right)\cos^2\phi$$

$$V_b = \frac{\Delta\rho I}{t}\sin\phi\cos\phi$$

TheeffectthatproducesEaiscalledtheplanarhall effect.

Va is planar hall voltage which is dependent on the sign of Φ while the magnetoresistive voltage Vb does not depend on the sign of Φ .

If theswingratio l/W>>1, theratio ofthe instantaneous partofVb and Vaortheswing ratio l/W is much larger.

ThismakesVbi>>Vaisothatplanarhallvoltage isimportantissmalllengthsamplesonly.

Under the influence of an external field H, magnetization M rotates which can be calculated by evaluatingtheenergydensityϵintermsofangleψbetweenMandtheaxisoflowestenergycalled the easy axis.

2. SemiconductorMagneto-resistors

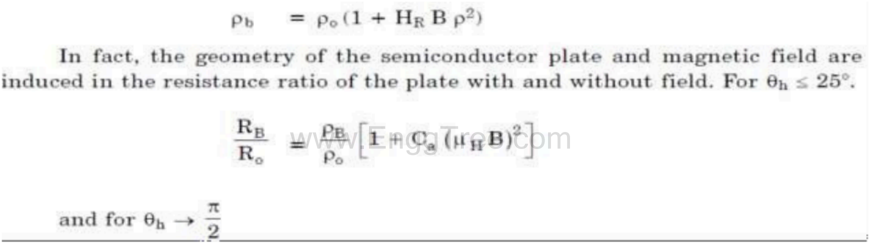
Whenasemiconductormaterialisexposedtomagnetic field,itsresistance increases.

It is subsequently seen that Lorentz force acts perpendicular to the velocity V of a free charge carrierandthemagneticinductionBandthechargecarriereventuallycollideswithlatticetolose its velocity.

This is attributed to the Hall angle **θ**h between the electrical field Ex and the direction of the current.

This change in the direction of the current or its rotation increases the path length of the current flow as mentioned earlier but is observed as an increase in the resistance of the material.

Whenthefieldisweak,thechangeinresistivityisproportionaltothesquareofthecomponentof the field perpendicular to the current vector,



$$\rho_b = \rho_o(1 + H_R B \rho^2)$$

In fact, the geometry of the semiconductor plate and magnetic field are induced in the resistance ratio of the plate with and without field. For $\theta_h \le 25°$.

$$\frac{R_B}{R_o} = \frac{\rho_B}{\rho_o}\left[1 + C_a(\mu_H B)^2\right]$$

and for $\theta_h \rightarrow \frac{\pi}{2}$

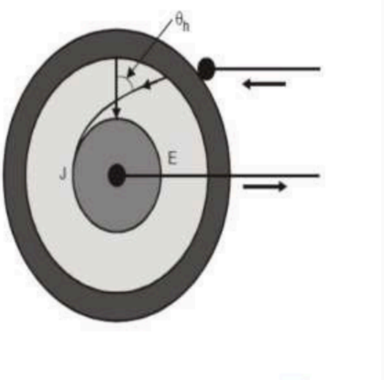
$$\frac{R_B}{R_0} = \frac{\rho_B}{\rho_0}\left[C_b + C_c \mu_H B\right]$$

3.EffectofGeometry:

Inanisotropicmaterialshapedasasquareplatesubjectedtoamagneticfieldperpendiculartothe plate surface and current supplying electrodes mounted on the width side, hall angle **θ**h is significant only in the regions close to the electrode.

Andinthecentralpart,thecurrentpathsarealmostparalleltothelengthedgeswherethehallfield tends to reduce the magneto-resistive effect.

To acertain extent,countered byreducingthe l/Wratio.



Design of Magnetoresistor with Radial E

4.EffectofMaterial:

Hallmobilitydependentonthematerial.Itshouldbelarger,however,forbettermeasurement.

OfthefourpossiblebasematerialsGaAs,InAS,SiandInSb,thelastonehasthehighermobility ofabout7.7×104cm2/V–1/S–1whichis1.5timeslargerthanthatofInAs,30timeslargerthan that of Si and nearly 10 times larger than Ga AS.

However,temperaturecoefficientofresistanceisalsohigherinInSb,being –2×10–2/°C. For the other materials, the values are as follows,

$$\begin{aligned} \alpha_{\text{Ga AS}} &= 8 \times 10^{-4}\,/^\circ\text{C} \\ \alpha_{\text{In AS}} &= 10^{-3}\,/^\circ\text{C} \quad \text{and} \\ \alpha_{\text{Si}} &= 5 \times 10^{-3}\,/^\circ\text{C} \end{aligned}$$

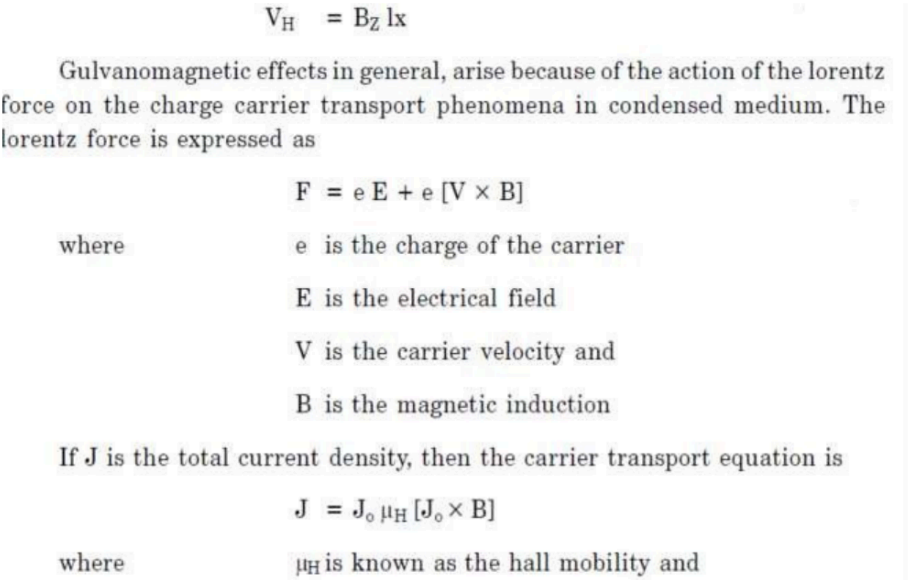
HALLEFFECTSENSOR

Themost importantofthemagneticsensor arethe halleffectsensors.Hall effectsensorsarealso galvano-magnetic effect sensors.

Hall Effect

Whenacurrentissentthroughaverylongstripofextrinsichomogeneoussemiconductorinthex (long)directionandacrosstheplanexyperpendiculartoit,amagneticfieldisappliedtoproduce afluxdensityBZ,thenanelectricfieldEyinthedirectionofyisproducedwhichiscalledthehall effect.

With electrodes across the strip in the ‘y’ direction, a voltage VH called the hall voltage can be collected which approximately given by



$$V_H = B_Z\, lx$$

Gulvanomagnetic effects in general, arise because of the action of the lorentz force on the charge carrier transport phenomena in condensed medium. The lorentz force is expressed as

$$F = e\,E + e\,[V \times B]$$

where e is the charge of the carrier

E is the electrical field

V is the carrier velocity and

B is the magnetic induction

If J is the total current density, then the carrier transport equation is

$$J = J_o\, \mu_H\, [J_o \times B]$$

where μ_H is known as the hall mobility and

Amagneticfieldalsoaffectstheelectricalfieldpotentialandcarrierconcentrationandhenceitsi not justified to write J = Jo for B = 0 as is apparent from equation 3.

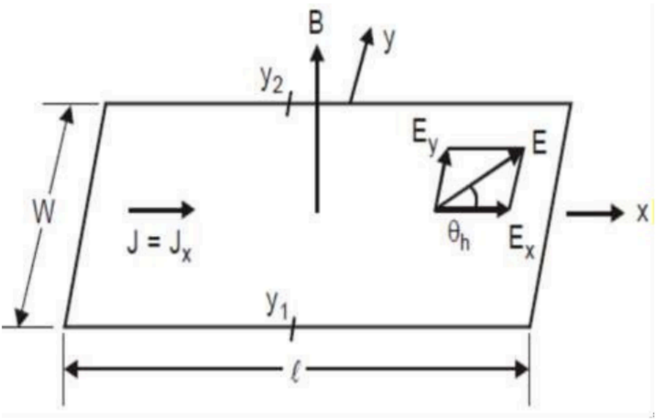
If$\sigma$is theconductivityand D,thediffusion, co efficient Jo in general,

$$Jo = \sigma E - eD\, \ddot{\nabla} n$$

whichtakesaccountofthedriftanddiffusionandtransversetransportcausedbythemagneticfield is taken care of by the second term in above equation.

HallmobilityµH,istheproductofthedriftmobilityofthecarrierµandthehallscatteringfactor rwhichisgivenbytheappropriaterationoftherelaxationtimeaveragesofthecarriersovertheir energy distribution.

BasicSchemeofa Hall Device



$$r = \frac{(\tau^2)}{(\tau)^2}$$

and $\mu_H = r\mu$

r = 1 for degenerate semiconductors or metals

r = 1.93 for scattering with ionized impurities while

r = 1.8 for accoustic phonons

EyistheHallfieldoftenrepresentedasEHandthisfieldwouldproduceavoltageacrossthewidth of the strip. This transverse voltage called the hall voltage, VH is given by

$$V_H = \int_{y_2}^{y_1} E_H \, dy = -\mu H B_z E_x W$$

Another parameters that sometimes acquires importance in the discussion of hall sensors is the hall angle and is given by figure 3.35

$$\tan\theta_h = \frac{E_y}{E_x} = -\mu_H B_z$$

The hall effect has varying intensity in different materials. The materials for this effect are characterized by hall co efficient which is defined as,

$$h_c = \frac{E_H}{J \times B}$$

$$\text{from equation } R(H) = R \pm \Delta R - \Delta R \left(\frac{H_y}{H_o}\right)^2$$

$$h_c = \frac{E_y}{J_x \times B_z} = \frac{\mu_H E_x}{J_x}$$

For a special case of zero carrier concentration gradient for homogeneous material ($J_x = \sigma E_x$ and conductivity σ is given by eμn), the hall coefficient is

$$h_c = \frac{r}{e_n}$$

The hall voltage can be expressed in terms of the hall cofficient h_c using equation 3.57 and 3.60 as

$$V_H = -h_c J_x B_z W$$

EDDYCURRENTSENSORS

Bothinductanceandeddycurrentsensorsfollowthe Faraday'slawofinductionwhichismathematically states as,

$$\oint E\,dl = -\frac{d}{dt}\iint_A B \times dA$$

The voltage induced in closed turns of a coil is proportional to the time rate of change of flux linkage with it.

Theessentialdifference betweenthetwo,howeveristhattheinductancesensorsusetheeffectof voltage induction whereas the eddy current types use the current induced due to alternating magnetic field.

Both these variations are, perhaps, industrially, the most useful onesas theyareeasilyadapted to measure displacement, rpm, proximity, force, weight, acceleration, torque, pressure and so on.

Avoltageinproportion toa variableto bemeasured, canbeinducedin anumberofways such as

i) Byvaryingthecouplingbetween the twocoils,

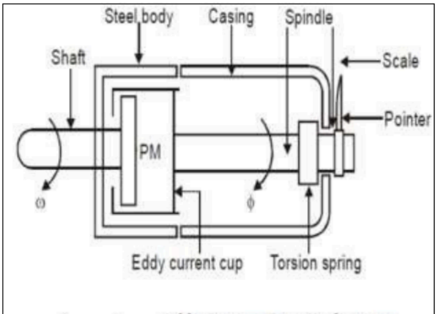
ii) Bychanginginductanceof two coils when asoft magneticcoreis displaceinsidethem,

iii) Byvaryingmagnetic fluxlinkagewhenanair gapisvariedorwhenthe directionofmagnetic polarization is changed.

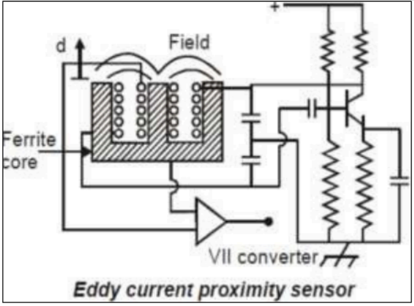
Twotypesofsensors

i) Theeddycurrenttachometerand

ii) Theeddycurrentproximitysensorsteelbody



Eddy Current Type Tachometer.



Eddy current proximity sensor

HEADINGSENSORS(INTERIAL SENSORS)

Headingsensorscanbeproprioceptive(Gyroscope,inclinometerorcompass).Allow,together with appropriate velocity information, to integrate movements to a position estimate.

Itis usedto determinetheorientationof therobotinrelation toafixed frame/inclination.

Interialsensorsareaclassofsensorsthatmeasurethederivativesoftherobotposition variables.Thisclassofsensorsincludesheadingsensorsaswellasgyroscopesandaccelerometers.

Headingsensorsmeasurethehorizontalorverticalanglereferredtoagivendiscretion.

Inclinometers, compass, gyrocompasses belongs to this group.

Itprovidesanestimateof thepositionifusedtogetherwithspeedmeasurements.

Theaboveprocedureis alsocalleddeadreckoningandisa characteristicof marine navigation.

Compass

The compass has been around since at least 200 BC. The chinese suspended a piece of natural magnetite from a silk thread and used it to guide a chariot over land. Absolute measure for orientation based on earth magnetic field. It is known since the ancient time.

Theyareaffectedbytheearthmagneticfield(absolutemeasurement)

Physical measurements are

Mechanical (magnetic needle, hall effect, magnetostrictive effect, piezoelectric. Piezoelectric resonatorshavebeenusedasstandardclocksinrecentelectronicstechniquesbecauseoftheirsharp resonance profiles.

We propose a magnetic field sensor consisting of a piezoelectric resonator and magnetostrictive magnetic layers.

Itisverifiedthatitsresonancefrequencychangesinamagneticfieldwithsensitivityhighenough to detect terrestrial magnetic field.

So,itisusefulasanelectroniccompassthatisingreatdemandfromthemobiletelecommunication technology.

Advantages

It can be readily downsized maintaining a high S/N because it detects an external field through change of the resonance frequency rather than the analogue output.

Limitations

☐ Theearthmagneticfieldisratherweak

☐ Themeasurementiseasilydisturbedbynearmetallicobjects. is

It ☐ rarely used for indoor navigation

PRINCIPLE

Theprincipleof adigitalcompassisbasedonmeasuringthedirectionofEarth'smagnetic field.

Many cost effective digital compasses are built with hall effect sensors, which are based on the principlethatelectricpotentialchangesinasemiconductorwhenitisexposedtoamagnetic field.

E.g.,AllegroA132Xfamilyhalleffectsensors,wherethepresenceofasouthpolemagneticfield perpendicular to the IC package face increases the output voltage from its neutral value, proportional to the magnetic field applied depending on the sensitivity of the device.

Asinglehalleffectsensor measuresflux inone dimension.

Tomeasurethetwoaxesofmagneticfields, twoofthesesensorsareplacedat90° angles.

The resolution obtained with hall effect sensors is low and prone to errors, particularly due to interfering magnetic fields.

Tomeasuremagneticfield,foursensorsareconnectedinabridgeconfigurationwitheachresistor oriented to maximize the sensitivity and minimize the temperature effects.

The values of the resistors will change when they are exposed to a magnetic field and the bridge will beimbalanced, thus generatingan output voltageproportional to the magneticfield strength.

Digitalcompassesdevelopedwiththistechnologyarereliable,andtheyhavegoodresolutionand fast response. Nevertheless, they are also sensitive to interfering magnetic fields.

Therefore,usingtheminmanmadeenvironmentsrequirescaution.

Examples :Devantech's CMPSO3 magnetic compass which uses the philips,KMZ51 magnetic fieldsensorandthehoneywellHMR300digitalcompassmodulethatprovidesheading,pitchand roll outputs for navigation.

PHOTOGRAPHICVIEWOFCOMPASS

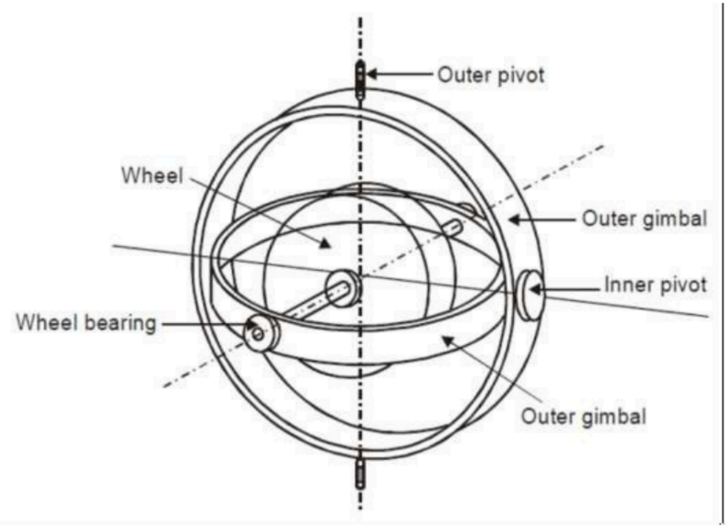
2. Gyroscope:

MEMSgyroscopesdetectrotationalrateaboutthe X,YandZ(orroll),pitchandyaw)axes.

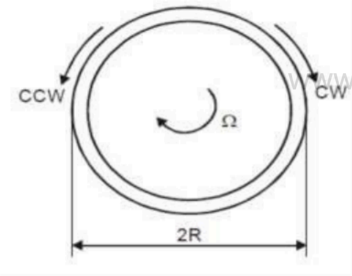
When the gyroscope is rotated about any of these axes, the corioli's effect causes a deflection, whichisdetected,demodulatedandfilteredtoproduceavoltagethatisproportionaltotheangular rate.

Analog Device's ADISI6485 is example of a MEMS – based gyroscope, which provides three axes gyroscope readings in digital form via serial parallel interface (SPI) bus.

MECHANICALGYROSCOPE



ELECTRICALGYROSCOPE



OPTICALGYROSCOPE

Single axis optical gyro

3-axis optical gyro

3.Inclinometers

Inclinometer are instruments for measuring angle of tilt, elevation or depression of an object with respect to local gravity vector. Inclinometers measure both inclines (positive slopes, as seen by an observer looking upwards) and declines (negative slops as seen by an observer looking downward).

Sensor technologies for inclinometers include accelerometer, capacitive, gas bubble in the liquid and pendulum.

UNIT-IV

UNIT-IV

OPTICAL,PRESSUREANDTEMPERATURESENSORS

Photo Conductive Cell, Photo Voltaic, Photo Resistive, LDR – Fiber Optic Sensors Pressure – Diaphragm Bellows - Piezoelectric - Piezo-resistive - Acoustic, Temperature – IC, Thermistor, RTD, Thermocouple – Non Contact Sensor – Chemical Sensors - MEMS Sensors - Smart Sensors.

PHOTOCONDUCTIVECELL

Electricconductioninsemiconductormaterialsoccurswhenfreechargecar

riers e.g., electrons are available in the material when an electric field

is applied.

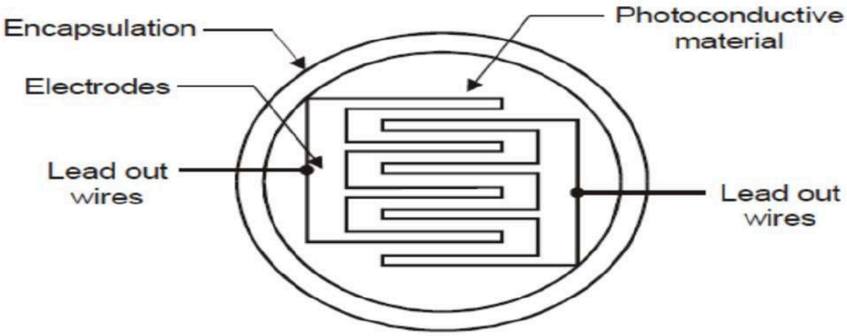
Incertainsemiconductors,lightenergy falling onthemisofthecorrectorderofmagnitudeto release charge carriers which increase flow of current produced by an applied voltage.

Theincreaseofcurrentwithincreaseinlightintensitywiththeappliedvoltageremainingconstant means that the resistance of semiconductors decreases with increase in light intensity.

Therefore,thesesemiconductorsarecalledphotoconductivecellsorphotoresistorsorlight dependent resistor (LDR), since incident light effectively varies their resistance.

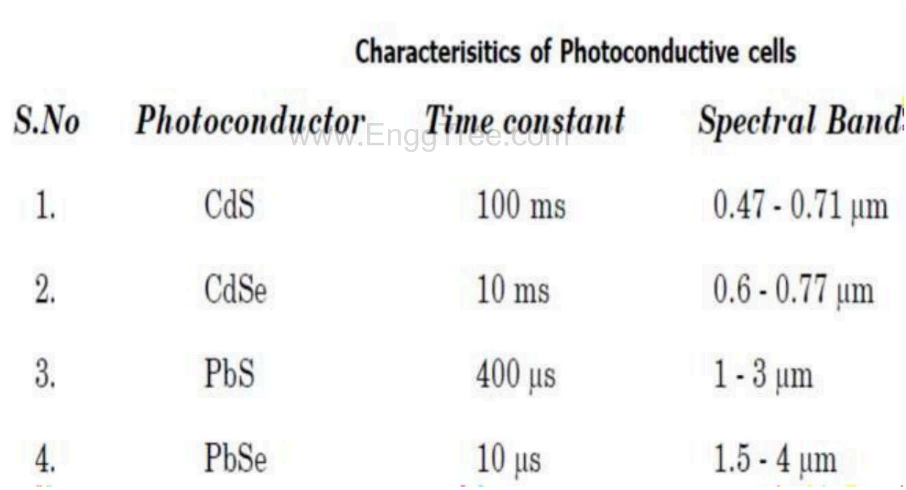
Photoconductive cells are made by chemically sinterning the required powder (Cd S) or (Cd Se) into tablets of the required shape and enclosing them in a protective envelope of glass or plastic. Electrodes are deposited on the tablet surface and are made of materials which give an ohmic contact, but with low resistance compared with that of the phtoconductor.

Goldistypicallyused.Theelectrodesareusuallyinterdigitali.e.,intheformofinterlockedfingers or combs as shown in figure.



Photoconductive Cell

CharacteristicsofPhotoconductiveCells



Characterisitics of Photoconductive cells

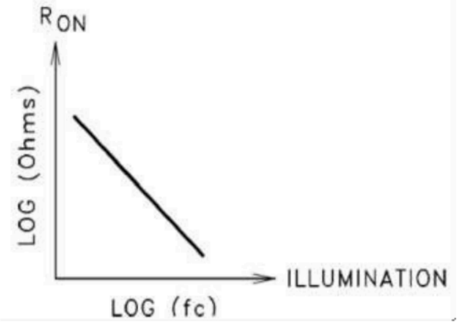
S.No	Photoconductor	Time constant	Spectral Band
1.	CdS	100 ms	0.47 - 0.71 μm
2.	CdSe	10 ms	0.6 - 0.77 μm
3.	PbS	400 μs	1 - 3 μm
4.	PbSe	10 μs	1.5 - 4 μm

1.Sensitivity

The sensitivity of a photodetector is the relationship between the light falling on the device and theresultingoutputsignal.Inthecaseofaphotocell,oneisdealingwiththerelationshipbetween the incident light and the corresponding resistance of the cell.

Definingthesensitivityrequiredforaspecificapplicationcanprovetobeoneofthemoredifficult aspects in specifying a photoconductor.

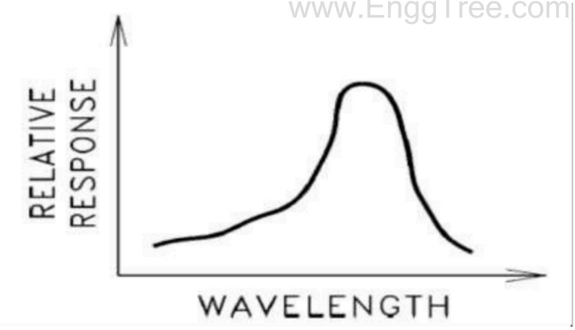
In orderto specifythesensitivityonemust, to somedegree, characterizethelight sourcein terms of its intensity and its spectral content.



2. SpectralResponse

Like the human eye, the relative sensitivity of a photoconductive cell is dependent on the wavelength (color) of the incident light.

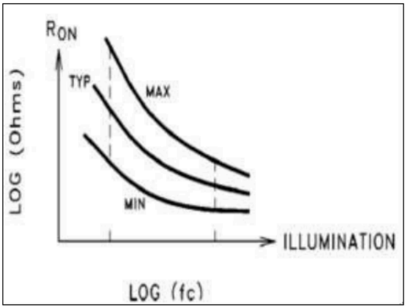
Each photoconductor material type has its own unique spectral response curve or plot of the relative response of the photocell versus wavelength of light.

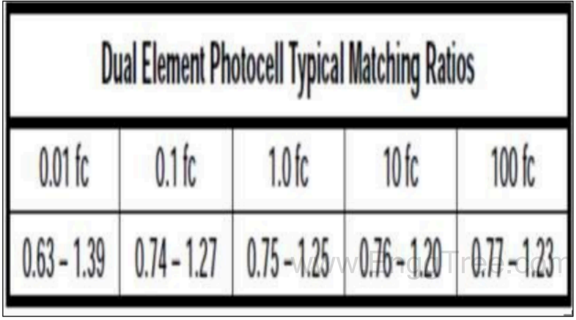


3. ResistanceTolerance

The sensitivity of a photocell is defined as its resistance at a specific level of illumination. Since no two photocells are exactly alike, sensitivity is stated as a typical resistance value plus an allowable tolerance. Both the value of resistance and its tolerance are specified for onlyone light level. For moderate excursions from this specified light level the tolerance level remain more or lessconstant.However,whenthelightlevelthetolerancelevelremainmoreorlessconstant.

However, when the light level is decades larger or smaller than the reference level the tolerance can differ considerably. As the light level decreases, the spread in the tolerance level increases. For increasing light levels the resistance tolerance will tighten.





Dual Element Photocell Typical Matching Ratios				
0.01 fc	0.1 fc	1.0 fc	10 fc	100 fc
0.63 - 1.39	0.74 - 1.27	0.75 - 1.25	0.76 - 1.20	0.77 - 1.23

4.Dark Resistance

Asthenameimplies,thedarkresistanceistheresistanceofthecell underzeroillumination lighting conditions.

In some applications this can be veryimportant since the dark resistance defines what maximum “leakage current” can be expected when a given voltage is applied across the cell.

Toohigh aleakagecurrentcould lead tofalse triggeringin someapplications.

The dark resistance is often defined as the minimum resistance that canbe expected 5 secondsafter the cell has been removed from a light intensity of 2 fc.

Typicalvalues fordarkresistancetendto beinthe500kohm to20M ohm range.

5. TemperatureCoefficientofResistance

Eachtypeofphotoconductivematerialhasitsown resistanceversustemperature characteristic.

Additionally,thetemperaturecoefficientsofphotoconductorsarealsodependentonthelightlevel the cells are operating at.

From the curves of the various types of materials it is apparent that the temperature coefficient is an inverse function of light level.

Thus, in order to minimize temperature problems it is desirable to have the cell operating at the highest light level possible.

6. Speedof Response

Speedofresponseisameasureofthespeedatwhichaphotocellrespondstoachangefromlight- to-dark or from dark-to-light.

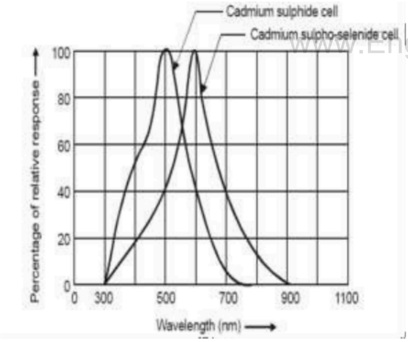
The rise time is defined as the time necessary for the light conductance of the photocell to reach 1-1/e (or about 63%) of its final value.

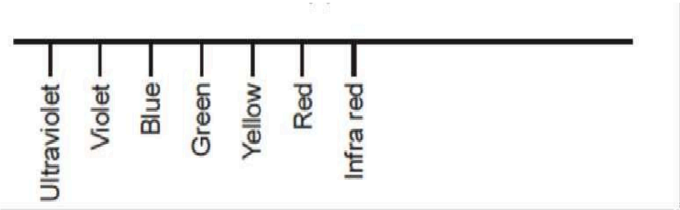
The decay or fall time is defined as the time necessary for the light conductance of the photocell to decay to 1/e (or about 73%) of its illuminated state.

At1 fcofillumination the response timesaretypicallyintherangeof 5msecto 100 msec.

The speed of response depends on a number of factors including light level, light history, and ambienttemperature.All materialtypesshow fasterspeed athigherlightlevels andslowerspeed at lower light levels.

Storageinthedarkwillcauseslowerresponsethanifthecellsarekeptinthelight.Thelongerthe photocellsarekeptinthedarkthemorepronouncedthiseffectwillbe.Inaddition,photocellstend to respond slower in colder temperatures.





Thephotoconductor devicedescribed aboveisalso calledabulk photoconductor.

The photoconductor has a very high resistance at very low illumination levels, which is of theorder of mΩ.

Thehighertheintensityoflight,theloweristheresistance. The

resistance drops to a few KΩ when exposed to light.

When using a photoresistor for a particular application it is important to select the proper dark resistanceaswellasthesuitablesensitivity.Thesensitivityofphotoresistivetransducerisdefined as,

$$S = \frac{\Delta R}{\Delta H} \ \Omega/W-m^2$$

ΔR = Change in resistance, W and

ΔH = Change in irradiation, $\Omega/W-m^2$

Thespectralresponse of thesensor mustmatchthat ofthelight source.

A photoconductor has a relatively large sensitive area. A small change in light intensity causes a large change in resistance. It is common for a photoconductive element to exhibit a resistance change of 1000 : 1 for a dark to light irradiance change of 5 × 10–3 W/m2 to 50 W/m2 .

The relationship between irradiance and resistance is however, not linear. It is closely an exponential relationship.

Theresultmaybe writtenas:

$$R_t = R_i + (R_f - R_i)\left[1 - \exp\left(-\frac{t}{\tau}\right)\right]$$

R_f = Dark resistance, Ω

R_i = Final resistance after application of beam, Ω

R_t = Resistance at any time, t

2.PHOTOVOLTAICCELL

Itisanimportantclassof photo electrons.

Theygenerate avoltage whichisproportionaltoEMradiation intensity.

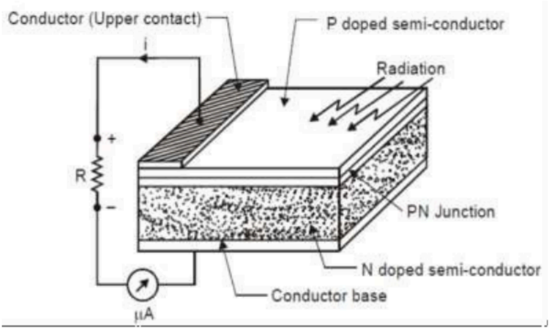
Theyarecalledphotovoltaiccells becauseoftheir voltage generatingcharacteristics.

They,infact,converttheEMenergyintoelectricalenergy.Theyarepassivetransducersi.e.,they do not need an external source to power them.

Thecellisagiantdiode,constructingaPNjunctionbetweenappropriatelydopedsemiconductors.

PhotonsstrikingthecellpassthroughthethinP-dopedupperlayerandareabsorbedbyelectrons and holes.

ThedepletionzonepotentialofthePNjunctionthenseparatestheseconductionholesandelectrons causing a difference of potential to develop across the junction.

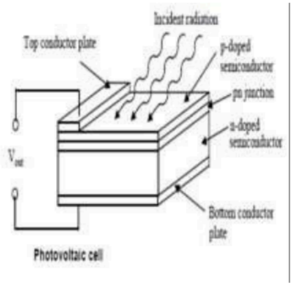


Working principle

The cell is a large exposed diode that is constructed using a pn junction between appropriatelydoped semiconductors.

Photons hitting the cell pass through the thin p-doped upper and are absorbed by electrons in the n-doped layer.

Thiscausesconduction electronsandholes tobecreated



Theupperterminal ispositiveand thelower negative.

In general, the open-circuit voltage V that is developed on a photovoltaic cell varies logarithmically with the incident radiation intensity according to the following equation:

V=Voln(Ir) where

Ir=theradiationintensityinW/m2

Vo=the calibrationvoltagein volts

V=theunloadedoutputvoltagein volts

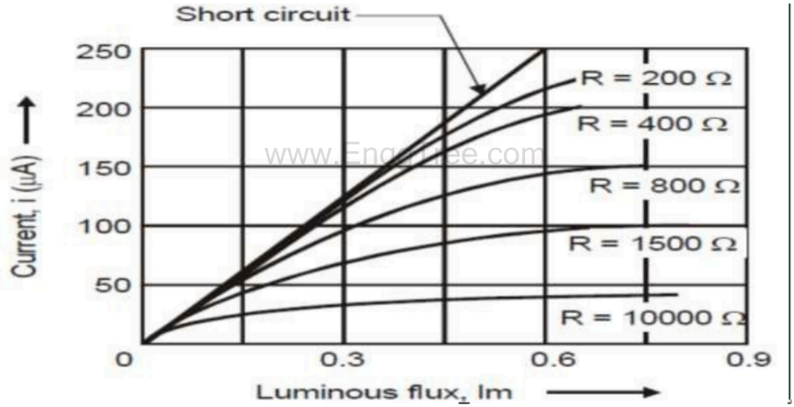
Theopencircuitvoltageisgiven by

$$E_0 = E_c \log_e E_e \text{ (V)}$$

where

E_c = Calibration voltage, V and

E_e = Radiant incidence, W/m^2



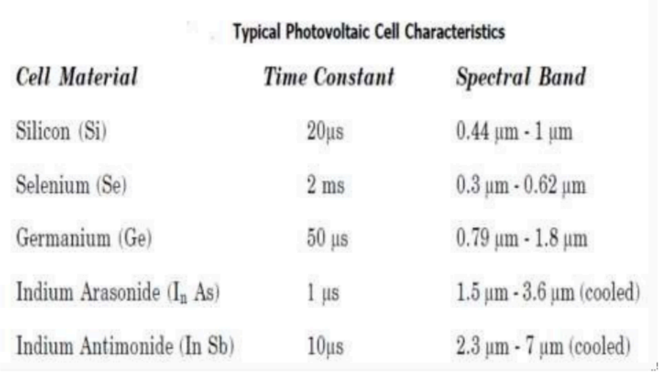
ConductiveV/SLuminousFluxCharacteristicsforaPhotovoltaicCell

These characteristics shows that the current as a function of the cell incident luminous flux and hencemicroammetershowninfiguremaybedirectlycalibratedtoreadluminousfluxorluminous intensity or illuminance.

Thephotovoltaiccellscan operatesatisfactorilyinthe temperaturerangeof 100 to 125°C.

Thetemperaturechangeshavelittleeffectonshortcircuitcurrentbutaffecttheopencircuitvoltage considerably.

Thesechanges maybeofthe order of a few mV/°C in outputvoltage



Typical Photovoltaic Cell Characteristics

Cell Material	*Time Constant*	*Spectral Band*
Silicon (Si)	20μs	0.44 μm - 1 μm
Selenium (Se)	2 ms	0.3 μm - 0.62 μm
Germanium (Ge)	50 μs	0.79 μm - 1.8 μm
Indium Arasonide (I_n As)	1 μs	1.5 μm - 3.6 μm (cooled)
Indium Antimonide (In Sb)	10μs	2.3 μm - 7 μm (cooled)

Advantages

The electricity produced by the solar cells is clean and silent. Because they do not use fuel other than sunlight, PV systems do not release any harmful contamination of air or water into the environment, deplete natural resources or endanger human or animal health.

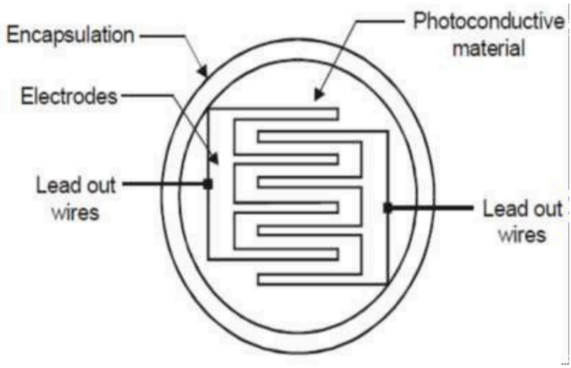
Photovoltaicsystemsare silentandvisuallydiscrete.

Small-scalesolar plantscantakeadvantageofunused spaceon theroofs of existing buildings.

Photovoltaiccellswereoriginallydevelopedforuseinspace,whererepairisextremelyexpensive, if not impossible. Photovoltaic energy still feeds almost all satellites that circulate through the earth, since it works reliably for long periods of time with little maintenance.

PHOTORESISTIVE

Inphotoresistors,based ontheincidentlight,anelectronisexcitedintheconductionbandrather than being left as free electron from the lattice structure of the photo conducting material.



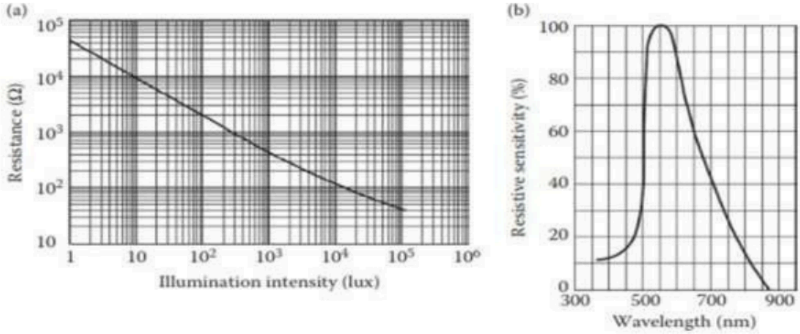
PHOTORESISTIVE

Aphotoresistorisalsocalledalight-dependentresistor(LDR),photoconductor,orphotocellsince its resistance changes as incident light intensity changes.

The relationship between the resistance and light intensity can be described by the characteristic curve of a photoresistive sensor.

Thesensor’sspectralresponse(seeFigure1.b)isabout550nm(yellowtogreenregionofvisible light).

When placed in the dark, its resistance is as high as 1 MΩ and then falls to 400 Ω when exposed to bright light.



Keyperformancecharacteristicsofphotoresistivesensors

1.Responsivity Rd

Theratioofdetectoroutputtolightinput.Itmeasurestheeffectivenessofthedetectorintransducing electromagnetic radiation to electrical voltage or current.

Ifthesensor'soutputisvoltage,Rdistheratiooftherootmeansquare(RMS)oftheoutputvoltage VRMSto the incident radiant power Φe(in watts):

$$R_d = V_{\mathrm{RMS}}/\Phi_e$$

If the sensor's output iscurrent, Rdis the ratio of the RMS of the output currentIRMSto the incident radiant power Φe (in watts) :

$$R_d = I_{\mathrm{RMS}}/\Phi_e$$

Noiseequivalentpower(NEP):theminimumdetectablesignalleveldefinedastheradiantpower that produces an output voltage equal to the noise voltage of the sensor.

$$\mathrm{NEP} = \frac{E_e A_d}{V_s/V_n}$$

where

EeisthepowerdensityatthesurfaceofthesensorinW·cm-2isthesensitiveareaofthe photodetector in cm2, and

VS/Vnisthesignal-to-noiseratio. NEP

has a unit watt (W).

DetectivityD*: Measureof theintrinsicmerit of asensor material.

It is a function of the sensitive area of the photodetector Ad(cm2), bandwidth of the measuring system B (Hz), and NEP (W).

$$D^* = \frac{\sqrt{A_d B}}{\mathrm{NEP}}$$

TheunitofthedetectivityD*iscm·Hz1/2·W−1;D*isoftenusedtocomparedifferent types of detectors.

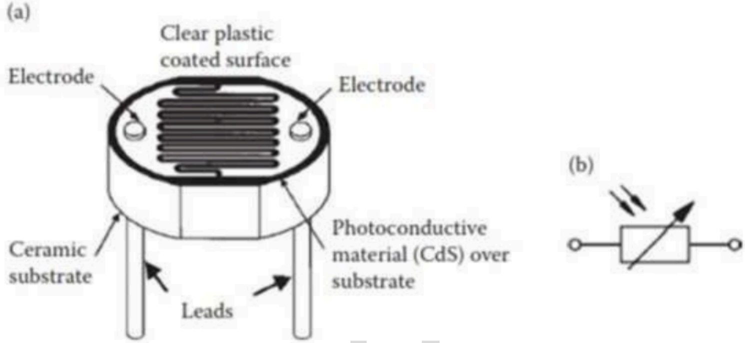
ThehigherthevalueofD*, thebetterthe detector.

Quantumefficiency (QE):

The effectiveness of a photodetector in producing electrical current when exposed to radiant energy. QE (in percentage) can be described by

$$QE = \frac{\text{Number of electrons ejected}}{\text{Number of incident photons}} \times 100\%$$

ConstructionAnd CircuitSymbolsOfAPhotoresistor.



Toincrease“dark”resistancevaluesandreduce“dark”current,theresistivepathisoftendesigned as a zigzag pattern across the ceramic substrate.

Materials used in photoresistors include cadmium sulfide (CdS), lead sulfide (PbS), cadmium selenide (CdSe), lead selenide (PbSe), and indium antimonide (InSb).

CdSisthemostsensitivephotoresistor tovisiblelight.

Its resistance value can change from many megaohms in the dark to several kiloohms when exposed to light.

PbSeisthemostefficientinnear-infraredlightphotoresistor.

Photoresistors, compared to photodiodes or phototransistors, respond relatively slow to light changes.

Forexample,aphotoresistorcannotdetectthecharacteristicblinkingoffluorescentlamps(turning ON and OFF at the 60 Hz power line frequency), but a phototransistor (which has a frequency response up to 10,000 Hz) can.

If both sensors are used to measure the same fluorescent light, the photoresistor would show the light to be always ON and the phototransistor would show the light to be blinking ON and OFF.

Thus, phototransistors can be used to detect an incandescent lamp that acts as a timing start indicator.

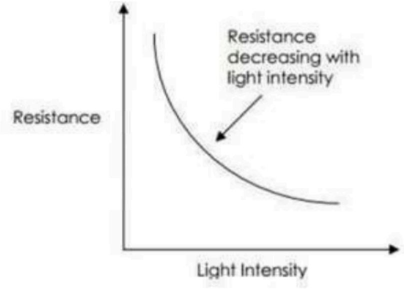
Photocells are commonly used to find certain objects through measuring the reflectivity of a light source such as a red LED (light-emitting diode), but they are sensitive to ambient lighting and usually need to be shielded.

LDR

An LDR is a component that has a (variable) resistance that changes with the light intensity that falls upon it. This allows them to be used in light sensing circuits.

A typical LDR

Variation in resistance with changing light intensity



Applications of LDRs

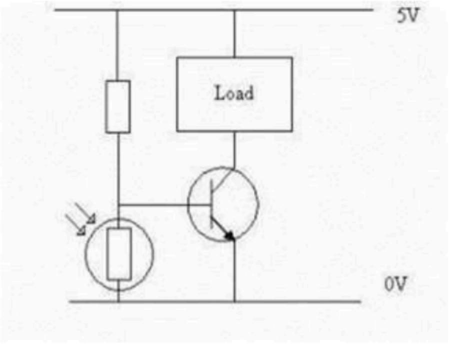
1.Lighting switch

The most obvious application for an LDR is to automatically turn on a light at a certain light level. An example of this could be a street light or a garden light.

2.Camerashuttercontrol

LDRs can be used to control the shutter speed on a camera. The LDR would be used to measure the light intensity which then adjusts the camera shutter speed to the appropriate level.

Example-LDRcontrolledTransistorcircuit



Thecircuitshows asimplewayofconstructinga circuitthat turnsonwhenitgoes dark.

In this circuit the LDR and theother Resistorform asimple 'Potential Divider' circuit, wherethe center point of the Potential Divider is fed to the Base of the NPN Transistor.

Whenthelightleveldecreases,theresistanceofthe LDRincreases.

Asthisresistanceincreasesinrelationtotheother Resistor,whichhasafixedresistance,itcauses the voltage dropped across the LDR to also increase.

Whenthisvoltageislargeenough(0.7VforatypicalNPNTransistor),itwillcausetheTransistor to turn on.

The value of the fixed resistor will depend on the LDR used, the transistor used and the supplyvoltage.

FIBREOPTICSENSORS(FIBREOPTICTRANSDUCERS)

Infiberoptictransducers,opticalfiberisusedassensingelementwhichcantransmitoptical(light) signals from remote place to destination place where the processing of signal s take place.

Opticalfiber is mainlypreferred becauseof signals take place.

Opticalfiber is mainlypreferred becauseof its small sizeand less weight.

Advantages:

1. Donot require anyelectrical power at theremote placeof transmission.

2. Immunitytoelectromagneticinterferenceandnon-conductionof electricity.

PrincipleofFibreOpticTransmission

1. TIR(TotalInternalReflection)

ThelighttransmissionthroughtheopticalfiberisdonebasedontheprincipleofTIR.Itstatesthat all the light striking a boundary between two media will be totally reflected. There is no less in light energy across the boundary.

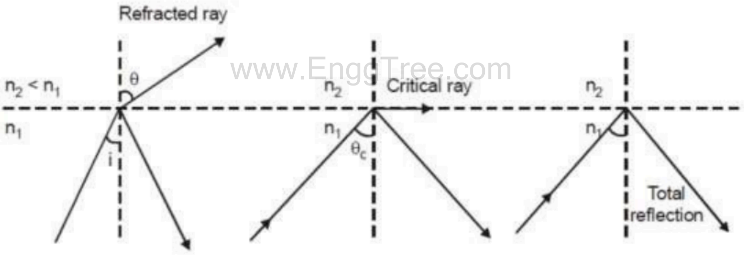
ForPrincipleofTIR totakeplace,thefollowingtwo conditionsaretobe satisfied.

i. The glass around the centre of the fiber (core) should has higher refractive index (n1) than that of the material (cladding) surrounding the fibre (n2).

ii) Thelightshouldbeincidentatanangle ofΦwhichwillbegreaterthanthecriticalangle$\boldsymbol{\theta}$c.

$$\sin \theta_C = \frac{n_2}{n_1}$$

Reflection, refraction and total internal reflection of light waves are shown in figure



(a) When $i < \theta_c$ (b) When $i = \theta_c$ (a) When $i > \theta_c$

Total Internal Reflection of Light Waves

Typesof FiberOptic Sensors

Thereare twotypesof fibreopticsensors.They are,

1. Instrinsic TypeSensor

In an intrinsic type fibre optic sensor, based on the measurement of variable like pressure, temperature, level, etc., the properties of the fiber will be varied.

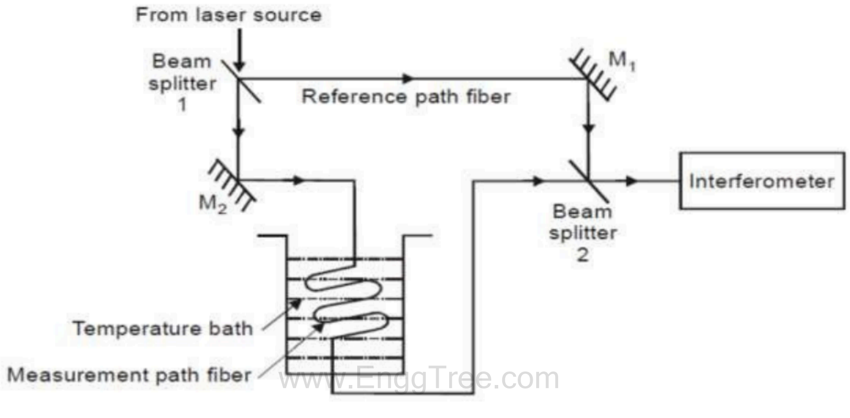
Herethe opticalfiber itselfcan act asasensingmaterial.

2. Extrinsic TypeSensor

Inanextrinsictypefibreopticsensor,theopticalsensoractsasaguideforthelightfromthesource tothesensingdeviceandvice-versa.Duetotheinteractionatthesensingsidehasattainedachange in its parameters.

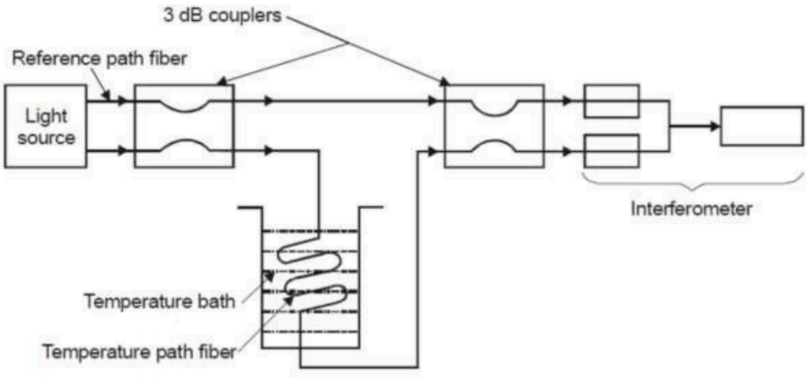
Applicationsof FibreOpticTransducer

Usedforthemeasurementofmanyvariablessuchastemperature,pressure,liquidlevel,flow,etc., (optical, radiation happens to betheenergyrequired fortherespectivemeasurement with fiberas the sensing source as well as the medium).



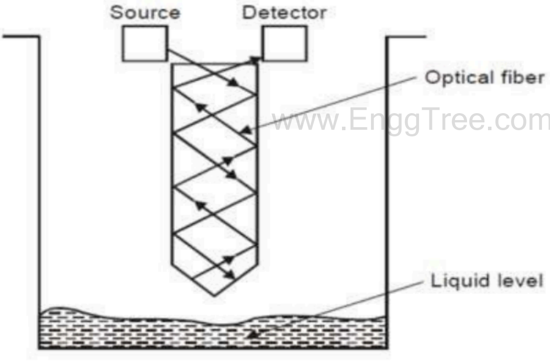
Fibre Optic Transducer for Temperature Measurement

FibreOpticTransducer forTemperature Measurementwith3dBOptic Couples



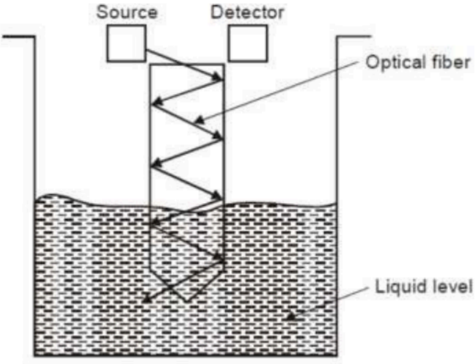
Fibre Optic Transducer for Temperature Measurement with 3 dB Optic Couples

2.a. Fiber Optic Transducer for Liquid Level Measurement



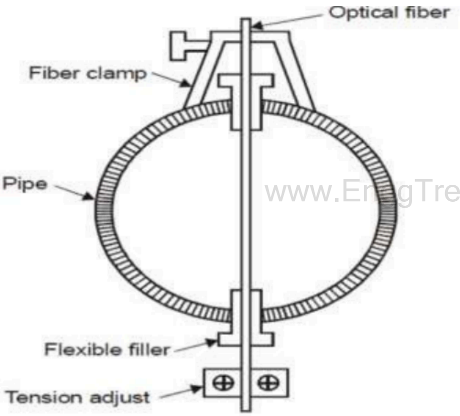
Liquid Level Measurement Using Fiber Optic Sensor Mounted Below the Liquid Level

2.b. Liquid Level Measurement using Fiber Optic Sensor Covering the Liquid Level



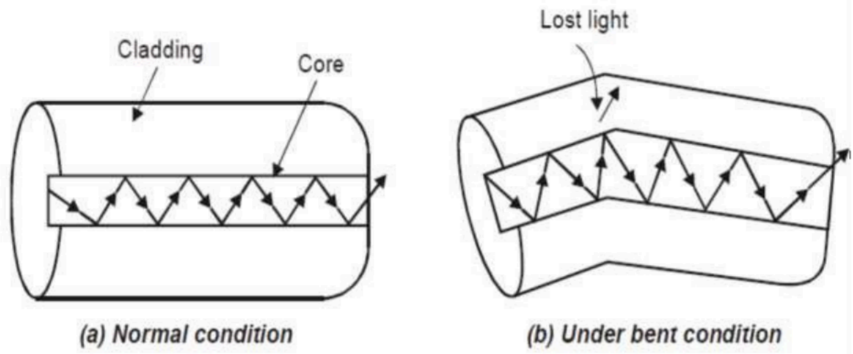
Liquid Level Measurement using Fiber Optic Sensor Covering the Liquid Level

3. FiberOpticTransducerfor FluidFlowMeasurement



Fibre Optic Transducer for the Measurement of Fluid Flow

4. FiberOpticTransduceforAcousticPressure Measurement

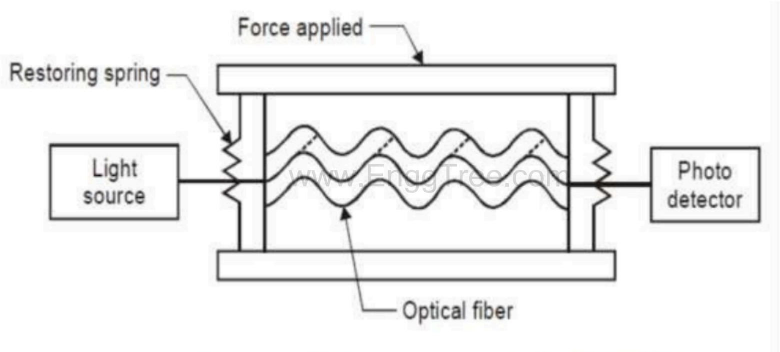


(a) Normal condition

(b) Under bent condition

Micro Bend Sensors

4.FiberOpticTransduceforAcoustic Pressure Measurement



Micro - Bond Pressure Sensor Using Optical Fiber

PRESSURESENSOR

Apressurescissor isadeviceforpressuremeasurement of gases or liquids.

Pressureisanexpressionoftheforcerequiredtostopthisfromexpandingand isusuallystatedin terms of force per unit area.

A pressure sensor usually acts as a transducer, itgenerates a signal as asection of the pressureimposed.

Pressuresensorsareusedforcontrol andmonitoringin thoseeverydayapplications.

Pressuresensorscanalsobeusedtoindirectlymeasurethevariablessuchasfluidgasflow,speed, water level and altitude.

Pressure sensors canalternatively be calledpressure transducer pressure transmitters, pressuresensors pressure indicators barometers and manometers, among other names.

FLUID PRESSURE
Manyofthedevicesusedtomonitorfluidpressureinindustrialprocessesinvolvethemitching of the elastic deformation of diaphragms, capsules, bellows and tubes.

Typesofpressuremeasurements

1. Absolutepressurewherethepressureismeasuredrelativeto zeropressure,ie.a vacuum,
2. Differentialpressurewhereapressuredifferenceismeasured and
3. Gaugepressurewherethepressureismeasured relativeto thebarometricpressure.

1.DIAPHRAGMS

whenthereisadifferenceinpressurebetweenthetwosidesthenthecentreofthediaphragm becomes displaced.

Corrugationsinthediaphragmresultinagreatersensitivity.

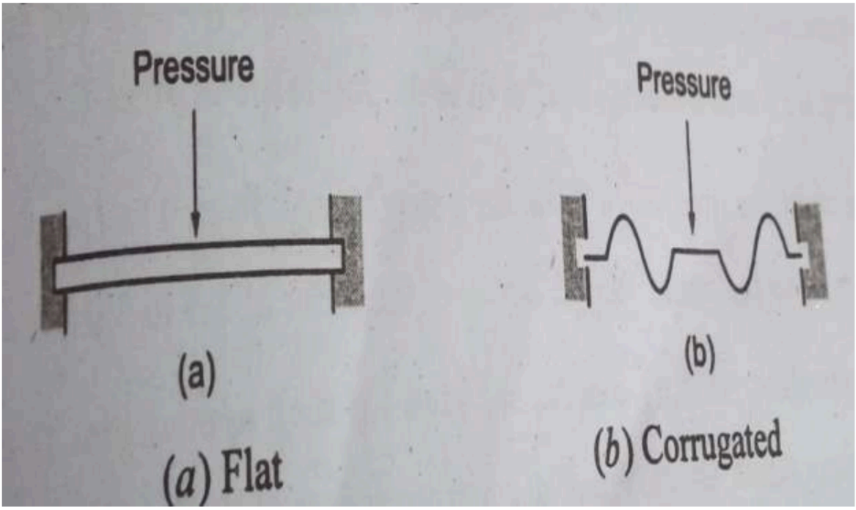
Thismovementcanbemonitoredbysomeformofdisplacementsensor,eg.straingauge,as illustrated in Figure.

Aspeciallydesignedstraingaugeisoftenused,consistingoffourstraingaugeswithtwo measuring the strain in a circumferential direction while two measure strain in a radial direction.

Thefourstraingauges arethenconnected toformthe armsofaWheat stonebridge.

While strain gauges can be stuck on a diaphragm, an alternative is to create a silicon diaphragm with the strain gauges as specially doped areas of the diaphragm.

Such an arrangement is used with the electronic systems for cars to monitor the inlet manifoldpressure.



With the Motorola MPX pressure sensor, the strain gauge elements integrated, together with a resistive network, in a single silicon diaphragm chip.

When a current is passed through the strain gauge element and applied at right angles to it, a voltage is produced.

This element, together with signal conditioning and temperature compensation circuitry, is packaged as the MPX sensor. The output voltage is directly proportional to the pressure.

Such sensors are available for use for the measurement of absolute pressure (the MX numbering system ends with A, AP, AS or ASX), differential pressure (MX numbering system ends with D or DP) and gauge pressure (the MX numbering system ends with GP, GVP, GS, GVS, GSV or GVSX).

Forexample,theMPX2100serieshasapressurerangeof100kPaandsupplyvoltageof16V d.c. gives in the absolute pressure and differential pressure forms a voltage output over the fullrange of 40 mV.

Theresponsetime,10to90%,forastepchangefrom0to100kPaisabout1.0msandtheoutput impedance is of the order of 1.4 to 3.0 kV.

The absolute pressure sensors are used for such applications as altimeter and barometers, the differential pressure sensor for air flow measurement and the gauge pressure sensors for engine pressure and tyre pressure.

2.CAPSULEPRESSUREGAUGE

Capsuleelementpressure gaugesareused tomeasureairanddrygasesatlow pressure.

They cover measuring spans from 2.5 mbar to 600 mbar. The measuring element consists of two metal diaphragms soldered together to form a cylindrical bellows chamber.

This capsule element expands when the pressure inside the element ls higher than the external pressure, and it contracts when the internal pressure is lower

This motion is proportional to the pressure to be measured, and it is coupled to the pointer mechanism.

Capsule pressure gauge working principle
The sensing element of a capsule pressure gauge consists of two corrugated diaphragms welded together at their periphery to form a capsule.

Thepressuretobemeasuredisintroducedintothecapsuleviaanopeninginthecentreofthefirst diaphragm.

The centre of the second diaphragm is connected to the transmission mechanism so that the deflection of the measuring element can be transmitted to the pointer.

When the pressure rises inside the capsule, both diaphragms will slightlydeform. Bymakinguse of two diaphragms, the total deflection of the measuring element is twice as large.

In thepressure gauge, thepressureis goingin and out thecapsule, turning thepointerto theright and back to the left.

3.BELLOWSPRESSURESENSOR

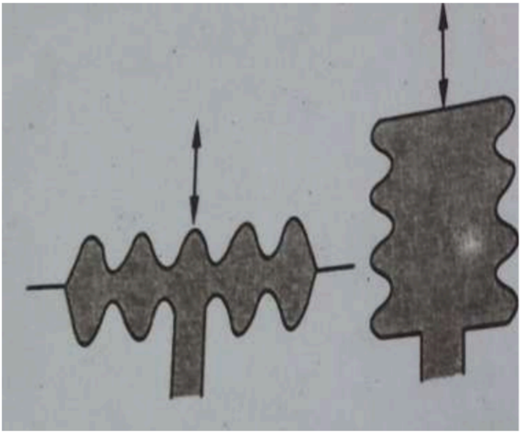
Thebellowspressuresensorismadeofasealedchamberthathasmultipleridgeslikethepleatsof an accordion that are compressed slightly when the sensor is manufactured.

Whenpressureisappliedto thechamber, the chamberwill tryto expand andopen the pleats.

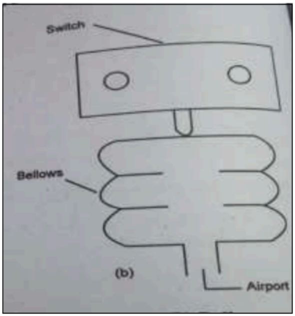
It uses a spring to oppose the movement of the bellows d provides a means to adjust the amount of travel the chamber will be when pressure is applied.

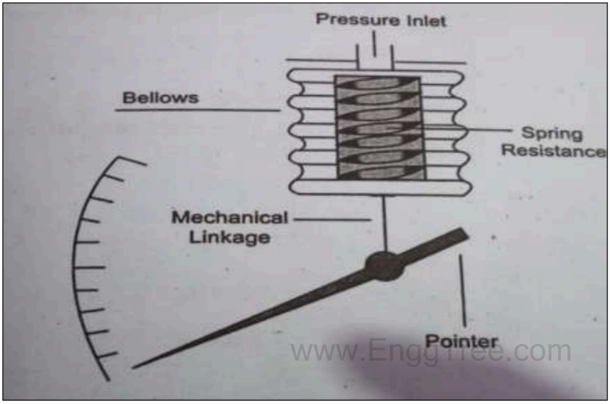
Inlow-pressurebellows sensors,thespringisnot required.

Theveldthebellowscan beconverted tolinearmotionsothataswitch can beactivated,oritcan be connected to a potentiometer. This type of sensor is used in low-pressure applications usually less than 30 psi. The bellows sensor is also used to make a differential pressure sensor.



BELLOWS PRESSURE SENSOR PRINCIPLE WORKING





It is necessary to construct the bellows such that all of the travel occurs on the compression side of the point of equilibrium.

Therefore,inpractice,thebellowsmustalwaysbeopposedbyaspring,andthedeflection characteristics force of the spring and bellows.

PhosphorBronze,Brass,BerylliumCopper,StainlessSteelarenormallyusedasthematerialsfor bellows.

Bellowsaremanufacturedeitherby

(1) Turningfromasolidblock ofmetal, or

(2) Solderingorweldingstampedannularrings, or

(3) Rolling(pressing) atube,

4.TUBEPRESSURE SENSOR

Adifferent formof deformationis obtainedwing ntube withaelliptical cross-section.

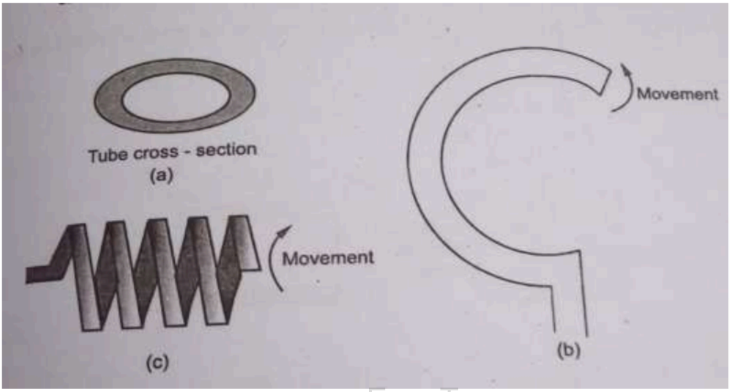
Increasingthepressureinsuch atube causesit to tend toa morecircular cross-section.

WhensuchatubeisintheformofaC-shapedtube,thisbeinggenerallyknownasaBourdontube, the C opens up to some extent when the pressure in the tube increases.

Ahelicalformofsuchatubegivesa greater sensitivity,

The tubes are made from such materials as stainless steel and phosphor bronze and are used for pressure in the range 103 to 108 Pa

4.TUBEPRESSURE SENSOR



5.PIEZOELECTRICSENSORS

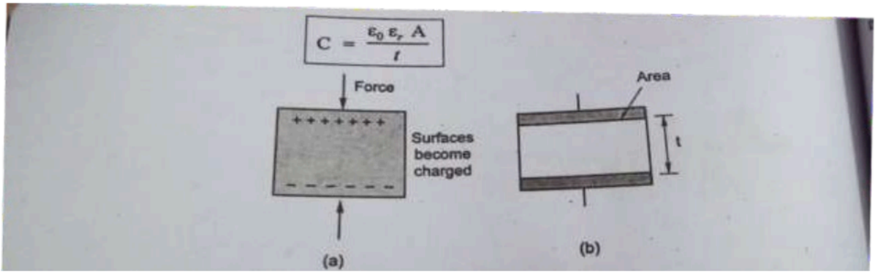
Piezoelectricmaterialswhenstretchedorcompressedgenerateelectricchargewithonefaceofthe material becoming positively charged and the opposite face negatively charged.

Asaresult, avoltageis produced.

Piezoelectric materials are ionic crystals, which stretched or compressed result in the charge distribution in the crystal changing at there is a net displacement of charge with one face of the material becoming positively charged and the other negatively charged.

The net charge q on a surface is proportional to the amount x by which the charges have been displaced, and since the displacement is proportional to the applied F:

$q=kx=SF$



6.TACTILESENSOR

Atactilesensoris aparticularformofpressuresensor.

Suchasensorisusedonthe'fingertips'ofrobotic'hands'todeterminewhenahandhascomeinto contact with an object.

Theyarealso usedfor'touch displaymeasureswhereaphysical contact hasto besensed.

A tactile sensor is a device. It measures the coming information in response to the physical interaction with the environment.

Thesenseoftouchinhumansisgenerallymodeled,i.e.cutaneoussenseandthekinestheticsense.

Typesof TactileSensors

1. Force/TorqueSensor

Force/torquesensorsareusedincombinationwithatactilearraytoinformationforforcecontrol.

Thistypeofsensorscansenseloadanywherelikethedistallinkofamanipulatorandinconstrains as a skin sensor.

Theskin sensor generallyprovides moreaccurate forcemeasurement at higherbowl manipulator link is defined generally, and the signal point contact is the force torque sensor can give the information about the contact location of and moments- it is called as an intrinsic tactile sensing.

2. DynamicSensor

Dynamicsensorsaresmalleraccelerometersatthefingerstripsorattheroboticfinger.Thegeneral function like pacinian corpuscles in his have equally large respective field;

Thus one or two skins accelerometer are for entire finger. These sensors effectively detect the making and breaking of the vibrations linked with the sliding over textured surfaces.

3. ThermalSensor

Thermal sensors are important to the human ability to identify the materials of the objects made, but some are used in the robotics as well. The thermal sensing in die detecting thermal gradients intheskin,whicharecorrespondenttobothtemperatureandthethermalconductivityofanobject.

TEMPERATURESENSORS

Temperaturesensors are vitaltoavarietyofeverydayproducts.

Forexample,householdovens,refrigerators,andthermostatsallrelyontemperaturemaintenance and control in order to function properly.

Temperature control also has applications in chemical engineering Examples of this include maintainingthetemperatureofachemicalreactorattheidealset-point,monitoringthetemperature ofapossiblerunawayreactiontoensurethesafetyofemployees,andmaintainingthetemperature of streams released to the environment to minimize harmful environmental impact.

Whiletemperatureisgenerallysensedbyhumansas"hot","neutral","cold",chemicalengineering requiresprecise,quantitativemeasurementsoftemperatureinordertoaccuratelycontrolaprocess,

Thisisachievedthroughtheuseoftemperaturesensors,andtemperatureregulatorswhichprocess the signals they receive from sensors

From a thermodynamic perspective, temperature changes as a function of the average energy of molecular movement.

As heat is added to a system, molecular motion increases and the system experiences an increase intemperature.Itisdifficult,however,todirectlymeasuretheenergyofmolecularmovement,so temperature sensors are generally property which changes in response to temperature.

The devices are then calibrated to traditional temperature scales using a Standard (ie the boiling point of water at known pressure).

TYPESOFTEMPERATURE SENSORS

1. Contact sensors:

Contacttemperaturesensorsmeasurethetemperatureoftheobjecttowhichthesensorisincontact by assuming or knowing that the two (sensor and the object) are in thermal equilibrium, in other words, there is no heat flow between them.

Examples:

Thermocouples

ResistanceTemperatureDetectors(RTDs)

Full System Thermometers

BimetallicThermometer

2. Noncontact sensors

Mostcommercialandscientificnoncontacttemperaturesensorsmeasurethethermalradiantpower of the Infrared or Optical radiation received from a known or calculated area on its surface or volume within it.

Anexampleofnoncontacttemperaturesensorsisapyrometer,whichdescribedintofurtherdetail at the bottom of this section.

THERMOMETERS
Thermometersarethemostcommontemperaturesensorsencounteredinsimple,everydaymeasurements of temperature.

Twoexamplesofthermometersare the

(i) FilledSystemand

(ii) Bimetal thermometers.

FilledSystemThermometer

The familiar liquid thermometer consists of a liquid enclosed in a tube. The volume of the fluid changes as a function of temperature.

Increasedmolecularmovementwithincreasingtemperaturecausesthefluidtoexpandandmove along calibrated markings on the side of the tube.

The guide should have a relatively Iarge thermal expansion coefficient so that small changes in temperature will result in detectable changes in volume.

A common tube material is glass and a common fluid is alcohol.

Mercuryusedtobeamorecommonfluiduntilitstoxicitywasrealized.

Althoughthefilled-systemthermometeristhesimplestandcheapestwaytomeasuretemperature, its accuracy is limited by the calibration marks along the tube length.

Because filled system thermometers are read visuallyand don't electrical signals, it is difficult to implement them in process control rely heavily on electrical and computerized control

BimetalThermometer

Inthebimetalthermometer.twometals(commonlysteelandcopper)withdifferentthermal expansion coefficients.

Asthetemperatureofthestripincreases,themetalwiththehigherthermalexpansioncoefficients expands to a higher degree, causing stress in the materials and a deflection in the strip.

Theamountof thisdeflection isafunctionoftemperature,

Thetemperaturerangesforwhichthesethermometerscanbeusedlimitedbytherangeoverwhich the metals have significantly different thermal expansion coefficient.

Bimetallicstripsareoftenwound intocoilsand placedin thermostats.

Themovingend ofthestrip is anelectrical contact, whichtransmits thetemperature thermostat.

RESISTANCETEMPERATUREDETECTORS (RTD)

A second commonly used temperature sensor is the resistance temperature detector (RTD, also known as resistance thermometer).

Unlike filled system thermometers, the RTD provides an electrical means of temperature measurement, thus making it more convenient for use with a computerized system

A RTD utilizes the relationship between electrical resistance and temperature, which may either be linear or nonlinear.

RTDaretraditionallyused fortheirhigh accuracyandprecision.

However,at high temperatures above 700°C) they become very inaccurate due to degradation of the outer sheath, which contains the thermometer

ATherefore,RTDimageispreferredatlowertemperaturerange,wheretheyarethemostaccurate.

Twomain typesof RTD:
1. ThetraditionalRTDand

2. Thethermistor

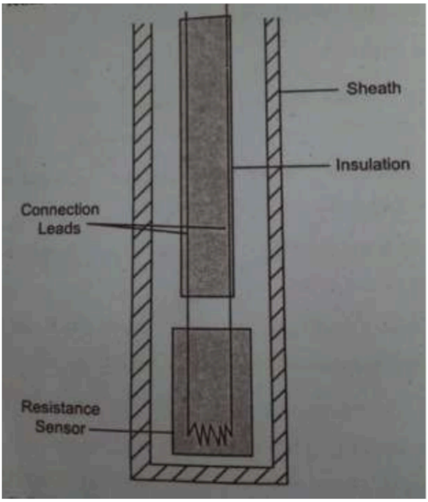
Traditional RTDs use metallic sensing elements that result in a linear relationship between temperatureandresistance.AsthetemperatureofthemetalIncreases,Increasedrandommolecular movementimpedestheflowofelectrons.Theincreasedresistanceismeasuredasareduced current through the metal for a fixed voltage applied.

The thermistor uses a semiconductor sensor, which gives a power function relationship between temperature and resistance.

The resistance sensor itself is responsible for the temperature measurement, as shown in the diagram. Sensors are most commonly composed of metals, such as platinum, nickel, or copper.

The material chosen for the sensor determines the range of temperature which the RTD could be used.

For example, platinum sensors,themost common typeofresistor,rangeof approximately200°C – 800°C.(Asampleofthetemperaturerangesandresistanceforthemostcommonresistormetals is sons Table 4.2). Connected to the sensor are two insulated connection le These leads continue to complete the resistor circuit.



4majorcategories of RTD sensors

1. Carbon resistors

2. Flim thermometers

3. Wire-woundthermometers

4. Coil elements

Carbonresistorsarethemost commonlyused.

Coilelementsaresimilarwire-woundthermometersandhavegenerallyreplacedtheminall industrial applications.

RTD Operation:

MosttraditionalRTDoperationisbaseduponalinearrelationshipbetweenresistanceand temperature, where the resistance increases with temperature.

Forthisreason,mostRTDsaremadeofplatinum,whichislinearovergreaterrangeof temperatures and is resistant to corrosion.

However, when determining a resistor material, factors such as temperature range, temperaturesensitivity, response time, and durability should all be taken into consideration.

Differentmaterialshavedifferent rangesforeach ofthese characteristics

TheprinciplebehindRTDsisbaseduponthe Callendar-VanDusenequationshownbelow,which relates the electrical resistance temperature in C.

Another type of RTD is the thermistor, which operates based upon exponential relationship between electrical resistance and temperature

THERMOCOUPLES

Anothertemperaturesensor often usedin industryis thethermocouple.

Among the various temperature sensors available, the thermoCouple is the most widely used sensor.SimilartotheRTD,thethermocoupleprovidesanelectricalmeasurementoftemperature.

The main principle upon which the thermocouple function is based on is the difference in the conductivitiesofthe two wirematerialsthat thethermocoupleismadeof,at agiven temperature.

This conductivity difference increases at higher temperatures and conversely, the conductivity differencedecreasesatlowertemperatures.Thisdisparityresultsinthethermocouplesbeingmore efficient and useful at higher temperatures.

Sincethe conductivitydifference is small at lower temperatures and thus moredifficult to detect, they are inefficient and highly unreliable at low temperatures

The conductivitydifference between the two wires, along with a temperature difference between the two junctions, creates an electrical current that flows through the thermocouple.

Thefirst junction point, which is thepoint at which thetwo wires are connected, is placed within the medium whose temperature is being measured.

Thesecond junction point is constantlyheld at known referencetemperature.

When the temperature of the medium differs from the reference temperature, a current flows through the circuit.

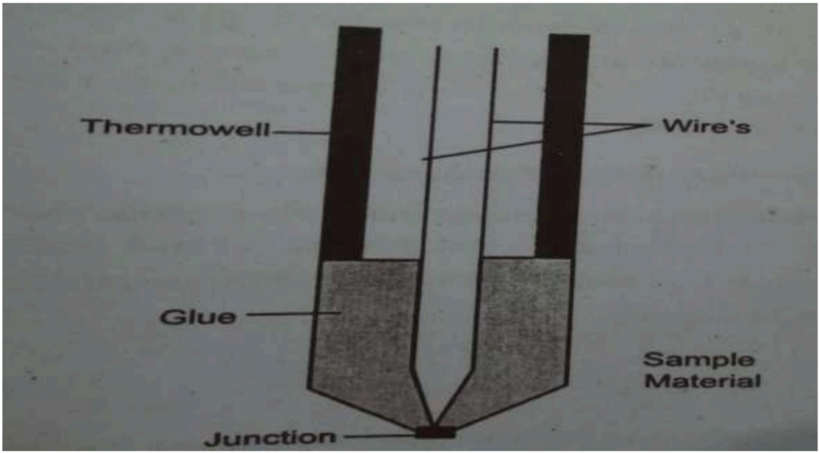
Thestrengthofthiscurrentisbaseduponthetemperatureofthemediumthereferencetemperature, and the materials of the metal wires.

Since the reference temperature and materials are known, the temperature of the medium can be determined from the current strength.

Error associated with the thermocouple occurs at lower temperatures due to the difficulty in detecting a difference in conductivities.

Therefore,thermocouplesaremorecommonlyusedathighertemperatures(above-125C)because it is easier to detect differences in conductivities, Thermocouples are operable over a wide range of temperatures, from 200°C to 2320°C, which indicates its robustness and vast applications.

Shematicdiagramofhowthethermocouple function



Laws for ThermocouplesLawofHomogenous Material

If all the wires and the thermocouple are made of the same material temperature changes in the wiring do not affect the output voltage. Thu need different materials to adequately reflect the temperature.

LawofIntermediateMaterials

Thesumofallthethermoelectricforcesinacircuitwithanumberdissimilarmaterialsatauniform temperature is zero, This implies that third material is added at the same temperature, no net voltage is generated by the new material.

LawofSuccessiveorIntermediateTemperature

IftwodissimilarhomogeneousmaterialsproducethermalemfwhenjunctionsareatTandT,and produce thermal emf2 when the junction are at and T,, the emf generated when the junctions are at T1 and T2 will be emfl + emf2.

Application

1.SteelIndustry

Monitortemperatureandchemistrythroughoutthesteelmakingprocess

2. HeatingApplianceSafety

Thermocouplesinfail-safemodeareusedinovensandwaterheatersdetectifpilotflameis burning to prevent fire and health hazard

3. Manufacturing

Usedfortestingprototypeelectricalandmechanicalapparatus

PYROMETERS

Pyrometers (non-contact Temperature sensors) measures the amount of heat radiated, rather than the amount of heat conducted and convected to the sensor.

Varioustypesofpyrometers,suchastotalradiationandphotoelectricpyrometers,exist.

Pyrometers differ in the type of radiation they measure.

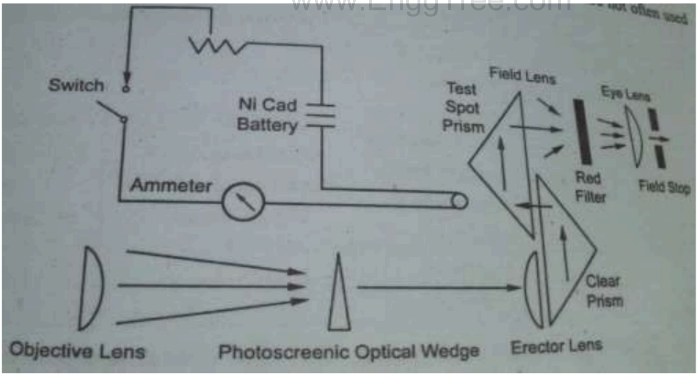
Therearemanyfactors thatinfluencetheamount ofradiatedheatdetected, thustherenumberare many assumptions that must be made regarding the emissivity, or the measure of the manner in which heat is radiated, of the object.

Theseassumptionsarebaseduponthemannerinwhichheatisradiatedaswellasthegeometryof the object.

Because temperature is dependent on the emissivity of a body, these assumptions regarding the emissivity introduce uncertainties and inaccuracies in the temperature readings.

Therefore,becauseoftheerror associated withthem,pyrometersarenotoftenusedinindustry.

OpticalPyrometer



HowOpticalPyrometersWork

Comparesthe color ofvisiblelight given offbytheobject with that ofaelectricallyheated wire

Thewirecanbepresettoacertaintemperature.Thewirecanbemanuallyadjustedtocomparethe two objects.

HowRadiationPyrometersWork

Thissensorworksbymeasuringtheradiation(infraredorvisiblelight)thatanobjectgivesoff The

radiation heats a thermocouple in the pyrometer which in turn induces a current

The larger the current induced, the higher the temperature is Pyrometers are usually used at very high temperatures, but can be used at colder temperature as well.

Therearelotsofindustrialapplicationstopyrometers.Plantoperatorscanusepyrometerstogeta sense of what temperature certain processes are running at.

The downside to pyrometers is that they are not very accurate as thermocouples or RTD sensors are.

This is because theyrelyon quantifyingcolors oflight.

TEMPERATUREREGULATORS

Temperatureregulators,alsoknownastemperaturecontrolvalves(TCVs),physicallycontrol,as well as measure, temperature.

Temperatureregulatorsarenotcapableofdirectlymaintainingasetvalue;instead,theyrelatethe load (in this case de valve opening) with the control (temperature measurement).

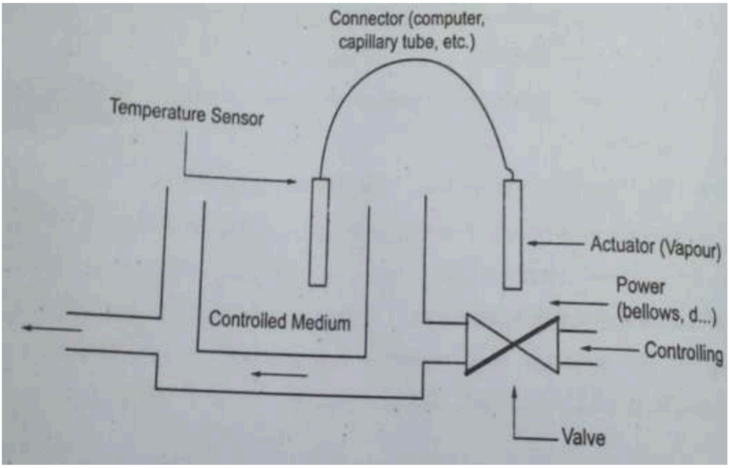
TheseregulatorsareBestusefulwhentemperatureiscorrelatedtoaflowof asubstance.

Forexample,aTCVmaybeusedtocontrolthetemperatureofanexothermicreactionthatrequires constant cooling.

TheTCVmeasuresthetemperatureofthereactionand,baseduponstemperature,eitherincreases or decreases the flow rate of cooling fluid to adjust the temperature of the reaction.

Similarly, theregulatorcould beused to adjust thewamount of steam, whichis typicallyused to heat a substance.

Therefore,byadjustingflowrate,theregulatorcanindirectlyadjusttemperatureofagiven medium.



RegulatorOperation:

Thetemperatureregulatoroperatesbasedupona mechanicalmeansoftemperaturecontrol.

Aspreviouslymentioned,thebulboftheregulatoristypicallyfilledwithaheatconducting substance.

Duetothethermalexpansionpropertiesofthissubstance,thesubstanceexpandsasthe temperature increases.

Thisexpansioncausesachangeinthepressureoftheactuator,whichcorrelatestothetemperature of the medium.

Thispressurechangerepositionsavalveontheregulator,whichcontrolstheflowrateofacoolant. The

temperature of the medium is then altered by the change in the flowrate of this coolant.

TemperatureDetectingElements

Mosttemperatureregulation systemsusethermocouples orRTDas temperaturesensingdevices.

Forthesesystems,theconnectorisacomputerThesensorssendanelectricsignaltothecomputer, which calculates the temperature.

Thecomputerthencomparesthetemperaturemeasuredby thesensoraprogrammedset-point temperature, thus determining the required pressure m a actuator.

Thepressureintheactuatorchangespositionofthepowersource(diaphragmorbellows),which consequently changes the flow rate through the valve.

Sometemperatureregulationsystemsuseafilledbulbasatemperature sensor.

TemperatureDetector Placement

Temperaturedetectioncanbedonewithinternalorremote elements.

For internal temperature detectors, the thermal actuator and temperature detector are located entirely within the valve.

Forremotetemperaturedetectors, theprimarytemperaturedetectingelement is separatefrom the actuator and valve, and is connected to actuator with either electrical wiring or capillary tubing, depending on Mechanism of the temperature sensor.

Remote temperature detectors are Common, as internal temperature detectors are limited in use. Internal temperature

ActuatorType:Thermal Systems

Therearefourmaincategoriesofthermalactuatorsusedintemperature regulators.

Thermal actuators produce power and work, proportional to the measured temperature of the process, on the power source.

Actuator types include the vapor. filled system, the liquid-filled system, the hot chamber system, and the fusion-type or wax-filled system.

Of all the thermal systems mentioned, liquid-filled systems are the most common, because they relate temperature and pressure change in a linear fashion. * the vapor-filled system, the thermal actuator is partially filled with a volatile liquid. As the temperature of the sensor increases, the vapor pressure of the liquid.

Vapor-FilledSystems

Thisincreasesthe pressureon thepowersource, andadjusts theflowrate throughthevalve.

Liquid-FilledSystems

In liquid-filled systems, the thermal actuator is filled with a chemically stable liquid, such as a hydrocarbon. As the temperature increases, the liquid expands which produces a force on the power source.

HotChamber Systems

Inhotchambersystems,thethermalactuatorispartiallyfilledwithavolatilefluid.Anincreasein temperature of the system forces some of this fluid into power unit, where the heat of the unit causes this liquid to turn into a superheat vapor. The pressure increase produces a force on the power source.

Fusion-Type(Wax-Filled) Systems

Ofallthesystemsmentioned,thefusion-typesystemistheleastcommon. In fusion-typesystem, the thermal actuator is filled with special waxes such as hydrocarbons, silicones, and natural waxes.

THERMISTOR

Asthenameimplies,the thermistor(ie,thermalresistor) istemperature-sensing device whose resistance is a function of temperature.

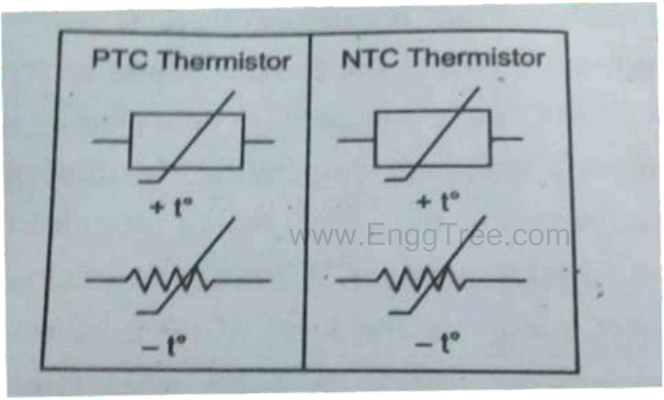
A thermistor (or thermal resistor) is defined as a type of resistor who electrical resistance varies with changes in temperature.

Although resistors; resistance will fluctuate slightly with temperature, a thermistor particularlysensitive to temperature changes.

Thermistorsareavailableintwotypes:PTC(positivetemperaturecoefficient)andNegative temperature coefficient.

TheresistanceofaPTC thermistorincreases asthetemperature increases.

In contrast, the resistance ofan NTC thermistor decreases as temperatureincreases, and this type seems to be the most commonly used thermistor.



Usesof Thermistors

Thermistors have a variety of applications. They are widely used as a way to measure temperatureasathermistorthermometerinmanydifferentliquidandambientairenvironments.

Someofthemost common usesof thermistors include:

Digitalthermometers (thermostats)

Automotiveapplicationstomeasureoilandcoolanttemperaturesincars&trucks) Household

appliances (like microwave, fridges, and ovens)

Circuit protection

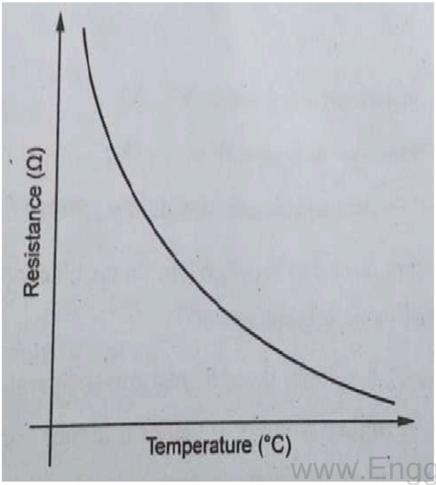
Rechargeablebatteries(ensurethecorrectbatterytemperatureis maintained)

Workingprincipleof athermistor

Theworkingprincipleofathermistoristhatitsresistanceisdependentonitstemperature We can

measure the resistance of a thermistor using an ohmmeter.

Ifweknowtheexactrelationshipbetweenhowchangesinthetemperaturewillaffecttheresistance of the thermistor - then by measuring the thermistor resistance we can derive its temperature.



Twotypesofthermistors NTC

Thermistor

In an NTC thermistor, when the temperature increases, resistance decreases. And when temperature decreases, resistance increases. Hence in an NTC thermistor temperature and resistance are inversely proportional. These are the most common type of thermistor.

Abovewe can clearlyseethat the**α**has anegativesign.

ThisnegativesignindicatesthenegativeresistancetemperaturecharacteristicsoftheNTC thermistor

If **β**= 4000 K and T = 298 K, then the**α** =0.0045°K.

ThisismuchhigherthanthesensitivityofplatinumRTD.

Thiswould be ableto measurethe verysmallchanges in thetemperature.

PTCThermistor

A PTC thermistor has the reverse relationship between temperature and resistance. When temperature increases, the resistance increases.

And when temperature decreases, resistance decreases. Hence in a PTC thermistor temperature and resistance are inversely proportional.

Although PTC thermistors are not as common as NTC thermistors, they are frequently used as a form of circuit protection. Similar to the function of fuses, PTC thermistors can act as current-limiting device.

Whencurrentpassesthroughadeviceitwillcauseasmallamountoresistiveheating.Ifthecurrent is large enough generate more heat the device can lose to its surroundings then the device heats up.

InaPTCthermistor,thisheatingupwillalsocauseitsresistanceincrease.Thiscreatesaself- reinforcing effect that drives the resistance upwards, therefore limiting the current.

Inthisway,itactsasacurrentlimitingdevice -protectingthecircuit. Thermistor

Characteristics:

$$R_1 = R_2 e^{\beta\left(\frac{1}{T_1} - \frac{1}{T_2}\right)}$$

ThermistorConstruction
Tomakethermistor,twomoresemiconductorpowdersmademetallicoxidesaremixedwith binder form a slurry.

Smalldrops thisslurryformedover lead wires.

Fordryingpurpose,wehaveputinto sintering furnace.

Duringthisprocess,thatslurrywillshrinkontotheleadwiresmakeelectricalconnection. This

processed metallic oxide sealed by putting glass coating on it.

Thisglasscoatinggiveswaterproofproperty–helpingtoimprovetheirstability. There

are different shapes and sizes of thermistors available in the market.

Smallerthermistors aretheformof beadsof diameterfrom 0.15millimeters 1.5 millimeters.

Thermistorsmay alsobetheformofdisksandwashersmadepressingthethermistormaterial under high pressure into flat cylindrical shapes with diameter from millimeters 25 millimeters.

Thetypicalsizeofthermistor 0.125mm1.5 mm.

Commercially available thermistors have nominal values of IK, 2K, 10K, 20K, 100K, etc. Thisvalue indicates the resistance value at temperature of 25°C.

Advantagesofthermistors:

Themajoradvantages of thermistors aretheirsmall sizeandrelativelylowcost.

This size advantage means that the time constant of thermistors operated in sheaths is small, although the size reduction also decreases its heat dissipation capability and so makes the self-heating effect greater. This effect can permanently damage the thermistor.

To prevent this, thermistors have to be operated at low levels of electric current compared to resistance thermometer - resulting in lower measurement sensitivity.

Thermistorvs Thermocouple:

Thermistors:

Amorenarrowrangeofsensing(55to+150°C–althoughdependingonthebrand) Sensing

parameters = Resistance

Nonlinearrelationshipbetweenthesensingparameter(resistance)andtemperature

NTCthermistors havearoughlyexponential decreasein resistancewith increasingtemperature

Good for sensing small changes in temperature (it's hard to use a thermistor accurately and with high resolution over more than a 50°C range)

Thesensingcircuitissimpleanddoesn'tneedamplification&isverysimple

Accuracy is usually hard to get better than 1°C without calibration

Thermocouples

Have a wide range of temperature sensing (Type T -200-350° C; Type J = 95 -760°C; Type K = 95 -1260°C; other types go to even higher temperatures)

Can bevery accurate

Sensingparameter=voltagegeneratedbyjunctionsatdifferent

temperatures

Thermocouple voltageis relatively low

Linearrelationshipbetweenthesensingparameters(voltage)andtemperature.

UNIT-V

SIGNALCONDITIONING:

Need for Signal Conditioning – Resistive, Inductive and Capacitive Bridges for Measurement – DC and AC Signal Conditioning - Voltage, Current, Power and Instrumentation Amplifiers – Filter and Isolation Circuits – Fundamentals of Data Acquisition System

Theoutputsignalfromthesensorofameasurementsystemhasgenerallytobeprocessedinsome way to make it suitable for the next stage of the operation.

The signal may be, for example, too small and have to be amplified, contain interference which hastoberemoved,benon-linearandrequirelinearisation,beanalogueandhavetobemadedigital, bedigitalandhavetobemadeanalogue,bearesistancechangeandhavetobemadeintoacurrent change, be a voltage change and have to be made into a suitable size current change, etc.

Allthesechanges canbereferredto assignalconditioning.

Forexample,theoutputfromathermocoupleisa smallvoltage,a few millivolts.

Asignalconditioningmodulemightthenbeusedtoconvertthisintoasuitablesizecurrentsignal, provide noise rejection, linearisation and cold junction compensation (i.e. compensating for the cold junction not being at 0°C).

SIGNALCONDITIONING PROCESSES

1. Protection to prevent damage to the next element, e.g. a microprocessor, as a result of high current orvoltage. Thus there can be series current limitingresistors, fuses to break if the current is too high, polarity protection and voltage limitation circuits.

2. Gentingthesignalintotherighttypeofsignal.Thiscanmeanmakingthesignalintoadcvoltage or current. Thus, for example, the resistance change of a strain gauge has to be converted into a voltage change. This can be done bythe use of a Wheatstone bridge and usingthe out-of balance voltage. It can mean making the signal digital or analogue

3. Getting the level of the signal right. The signal from a thermocouple might be just a few millivolts. If the signal is to be fed into an analog to digital converter for inputting to a microprocessor then it needs to be made much larger, volts rather than millivolts. Operational amplifiers are widely used for amplification

4. Eliminatingorreducingnoise.Forexample,filtersmightbeusedtoeliminatemainsnoisefrom a signal

5. Signal manipulation, eg, making it a linear function of some variable The signals from some sensors, eg a flow meter, are non-linear and thus a signal conditioner might be used so that the signal fed on to the next element is linear.

AMPLIFICATION

An amplifier can be considered to be essentially a system which has an input and an output, the voltagegainoftheamplifierbeingtheratiooftheoutputandinputvoltageswheneachismeasured relative to the earth.

The input impedance of an amplifier is defined as the input voltage divided by the input current, the output impedance being the output voltage divided by the output current.

Thebasisofmanysignalconditioningmodulesistheoperational amplifier.

Theoperationalamplifierisahigh-gaind.c.amplifier,thegaintypicallybeingoftheorderof100 000 or more, that is supplied as an integrated circuit on a silicon chip.

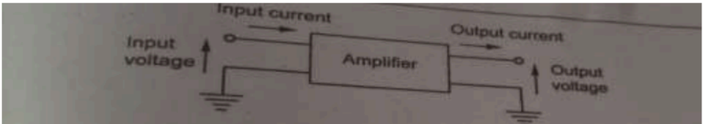
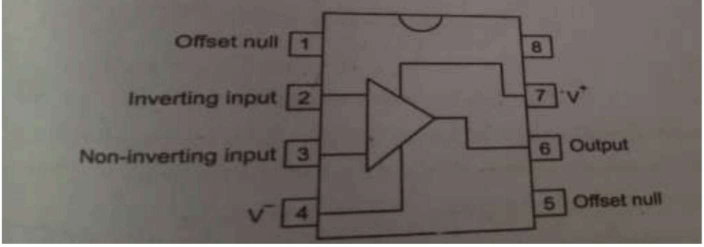


Fig. 5.1. Amplifier



Operationalamplifier

Ithastwoinputs,knownastheinvertinginput(2)andthenon-invertinginput(1). The

output depends on the connections made to these inputs.

There are other inputs to the operational amplifier, namely a negative voltage supply, a positive voltagesupplyandtwoinputstermedoffsetnull,thesebeingtoenablecorrectionstobemadefor the non-ideal behaviour of the amplifier.

An ideal model for an operational amplifier is as an amplifier with an infinite gain, infinite input impedance and zero output impedance, i.e, the output voltage is independent of the load.

INVERTINGAMPLIFIER

TheinputistakentotheinvertinginputthrougharesistorR,withthenon-invertinginputbeing connected to ground.

Afeedback pathis providedfrom theoutput,via theresistorR, tothe invertinginput.

Theoperationalamplifier hasavoltagegainofabout100000andthechangeinoutput voltageis typicallylimited toabout 10V. Theinputvoltagemustthen bebetween+0.0001and-0.0001 V.

Thisis virtuallyzeroandso pointX is at virtuallyearth potential.

Hence,foranidealoperationalamplifierwithaninfinitegain,andhenceV=0,theinputpotential V, can be considered to be across R. Thus

$$V=I1R1$$

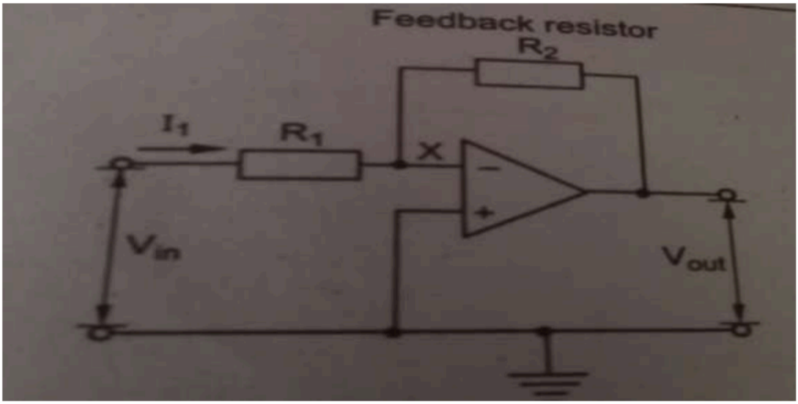
Theoperational amplifierhas averyhigh impedancebetween its input terminals; fora 741 about 2 M2.

Thusvirtuallynocurrentflows throughXinto it.

Foranidealoperationalamplifiertheinputimpedanceistakentoinfiniteandsothereisnocurrent flow through X. Hence the current be through R, must be the current through R.

ThepotentialdifferenceacrossR,is(Vx-Vout)andthus,sinceVXiszerofortheidealamplifier, potential difference across R, is – Vout.

Thus -Vout=I1R2

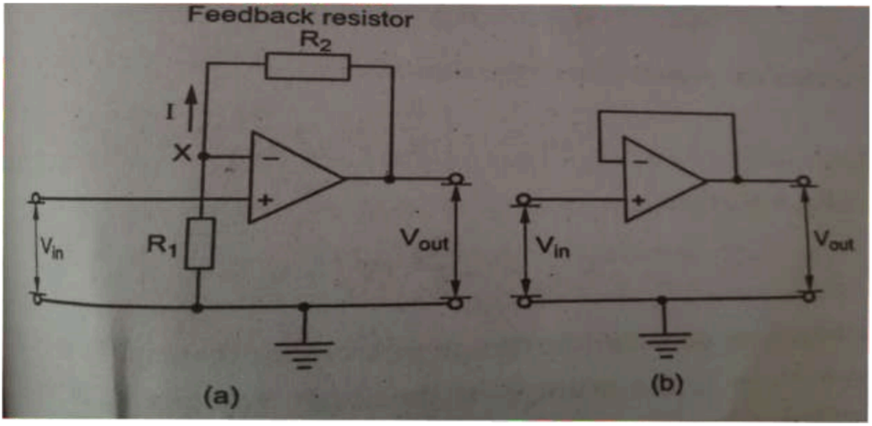


NONINVERTINGAMPLIFIER

Theinput tothecircuitto alargeresistance,the inputresistancetypicallybeing2 MD.

Theoutputresistance,i.e.theresistancebetweentheoutputterminalandthegroundline,is, however, much smaller, eg. 75 V.

Thustheresistanceinthecircuitthatfollowsisarelativelysmalloneandislesslikelytoloadthat circuit. Such an amplifier is referred to as a voltage follower,



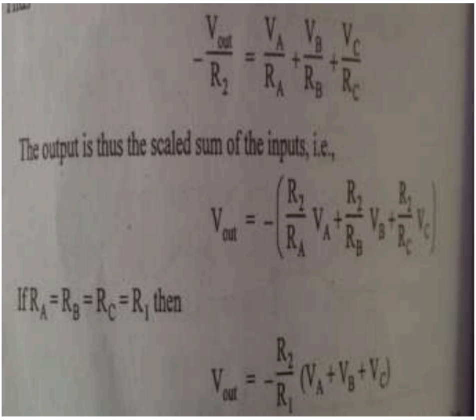
SUMMINGAMPLIFIER:

As with the inverting amplifier (Section 3.2.1), X is a virtual earth. Thus the sum of the currents entering X must equal that leaving it. Hence

I=IA+IB+IC

ButI=VA/ RA and Vc/Rc.

Alsowemusthavethesamecurrentlpassingthroughthefeedbackresistor.Thepotential difference across R, is (Vx - Vout). Hence, since V, can be assumed to be zero.



$$-\frac{V_{out}}{R_2} = \frac{V_A}{R_A}+\frac{V_B}{R_B}+\frac{V_C}{R_C}$$

The output is thus the scaled sum of the inputs, i.e.,

$$V_{out} = -\left(\frac{R_2}{R_A}V_A+\frac{R_2}{R_B}V_B+\frac{R_2}{R_C}V_C\right)$$

If $R_A=R_B=R_C=R_1$ then

$$V_{out} = -\frac{R_2}{R_1}(V_A+V_B+V_C)$$

FILTERING

The term filtering is used to describe the process of removing a certain band of frequencies from a signal and permitting others to be transmitted.

The range of frequencies passed by a filter is known as the pass band, the passing as the cut-off frequency.

Filtersareclassifiedaccordingto the frequencyranges theytransmit orreject

i) A low-pass filter has apass band which allows all frequencies from zero up to some frequency to be transmitted.

ii) A high-pass filter has a pass band which allows all frequencies from some value up to infinity to be transmitted.

iii) Aband-passfilter allowsallthefrequencieswithinspecifiedbandtobe transmitted.

iv) Aband-stopfilterstopsfrequencies withall particularband frombeingtransmitted.

Inallcasesthecut-offfrequencyisdefinedasbeingthatatwhichoutputvoltageis70.7%ofthat in the pass band.

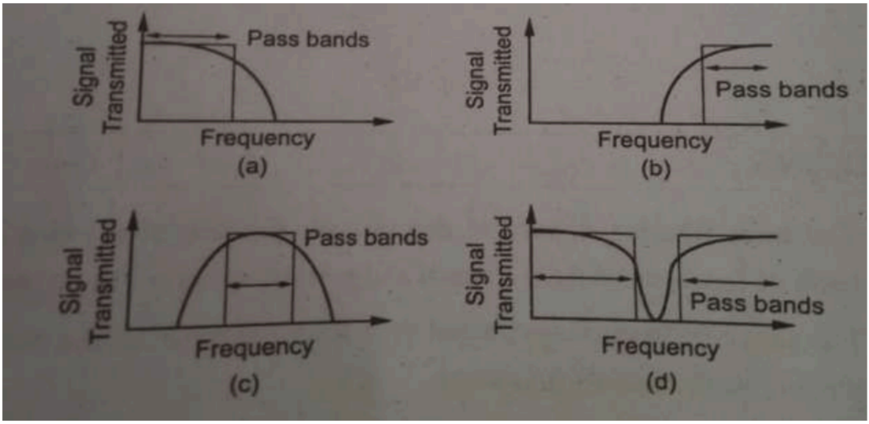
Attenuation:

Thetermattenuationisusedfortheratioofinputandoutputpowers,thisbeingwrittenastheratio of the logarithm of the ratio and so gives the attenuation in units of bels.

Since this is a rather large unit, decibels (dB) are used and then attenuation in dB -10 log (input power output power). Since the power through an impedance is proportional to the square of the voltage, the attenuation in dB - 20 log(input voltage/output voltage).

Theoutputvoltageof70.7%ofthatinthepassbandisthusanattenuationof3dB

Characteristics of ideal filters



TypesofFilters:

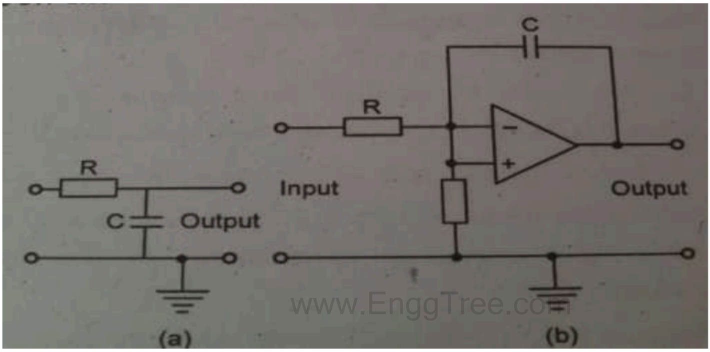
Thetermpassiveisusedtodescribeafiltermadeupusingonlyresistors,capacitorsandinductors, the term active being used when the filter also involves an operational amplifier.

Passive filters have the disadvantage that the current that is drawn by the item that follows canchangethefrequencycharacteristicofthe filter.Thisproblemdoesnotoccurwithanactivefilter.

Low-pass filters are very commonly used as part of signal conditioning. This is because most of the useful information being transmitted is low frequency.

Sincenoisetendstooccurathigherfrequencies,alow-passfiltercanbeusedtoblockitoff.Thus a low-pass filter might be selected with a cut-off

PassiveandActiveFilter



SAMPLEANDHOLDCIRCUITS

Sample-holdcircuitsarethedevicesthatstoreanaloginformationandreducetheaperturetimeof an AD converter.

A sample hold is simply a voltage-memorydevice voltage is acquired and then stored on a high-quality capacitor.

A1 is an input buffer amplifier with a high input impedance so that the source, which may be an analog multiplexer, is not loaded.

The output of A, must be capable of driving thehold capacitor with stability andenough drivecurrent to charge it rapidly.

S1isanelectronicswitch,generallyanFET,whichisrapidlyswitchedonoroffbyadrivercircuit that interfaces with TIL inputs.

Cisacapacitorwithlowleakageandlowdielectricabsorptioncharacteristics;itisapolystyrene, polycarbonate, polypropylene, or Teflon type

Twomodesof operation

Sample-holdsamplemode,whentheswitchisclosed;and Hold

mode, when the switch is open

Sample-boltsareusuallyoperated inoneor two basic ways.

The device can continuously track the input signal and be switched into the hold mode only at certain specified times, spending most of the time in tracking mode

This is the case for a sample-hold employed as a deglitcher at the output of a D/A converter, for example.

Alternatively, the device can stay in the bold mode most of the time and go to the sample mode justtoacquireanewinputsignallevel.Thisisthecaseforasampleholdusedinadataacquisition system following the multiplexer.

SAMPLE-HOLDASADATA-RECOVERY FILTER

Acommonapplicationforsample-holdcircuitsisdata-recovery,orsignal reconstruction,filters.

The problem is to reconstruct a train of analog samples into the original signal; when used as a recovery filter, the sample-bold is known as zero order hold.

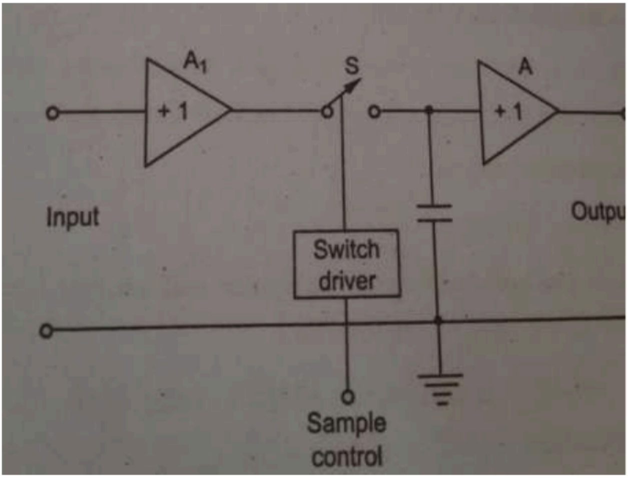
Itis ausefulfilterbecauseitfills in thespacebetween samples,providingdata smoothing

Aswithotherfiltercircuits,thegainandphasecomponentsofthetransferfunctionareofinterest.

ByananalysisisbasedontheimpulseresponseofasampleholdandusetheLaplacetransform,the transfer function is found to be:

Where,isthesampling frequency.

The sample-hold is therefore a low-pass filter with a cutoff frequency slightlyless than f, 12 and a linear phase response that results in a constant delay time of T/2, where T is the time between samples. Notice that the gain function also has significant response lobes beyond fs.



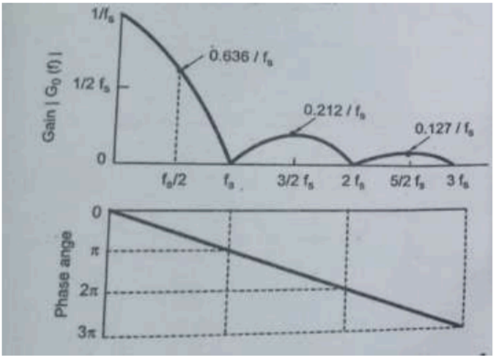
SAMPLE-HOLDCHARACTERISTICS:

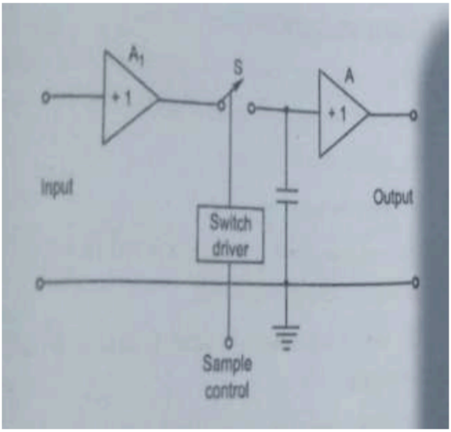
Anumberofparametersareimportantincharacterizingsample-holdperformance.Probablymost important of these is acquisition time.

Thedefinitionis similartothat ofsettlingtime for an amplifier.

It is the time required, after the sample-command is given, for the hold capacitor to change to a full-scale voltage charge and remain within a specified error band around final value.

SAMPLE-HOLDCHARACTERISTICS





Hold-modespecifications:

1.Hold-mode droop is the output voltage change per unit time when the sample switch is open. This droop is caused bythe leakage currents of the capacitor and switch and the output amplifier bias current.

2. Hold-mode feed-through is the percentage of input signal transferred to the output when the sample switch is open. is measured with a sinusoidal input signal and caused by capacitive coupling.

Criticalphaseof sample-hold operation

Sample-to-hold offset (or step) erroris the change in output voltagefromthesample modeto the hold mode, with a constant input voltage. It is caused by the switch transferring change onto the hold capacitor as it turns off.

Aperturedelayisthetimeelapsedfromtheholdcommandtowhentheswitchactuallyopens;itis generally much less than a microsecond.

Apertureuncertainty(oraperturejitter)isthetimevariation,fromsampletosample,oftheaperture delay. It is the limit on how precise is the poi time of opening the switch.

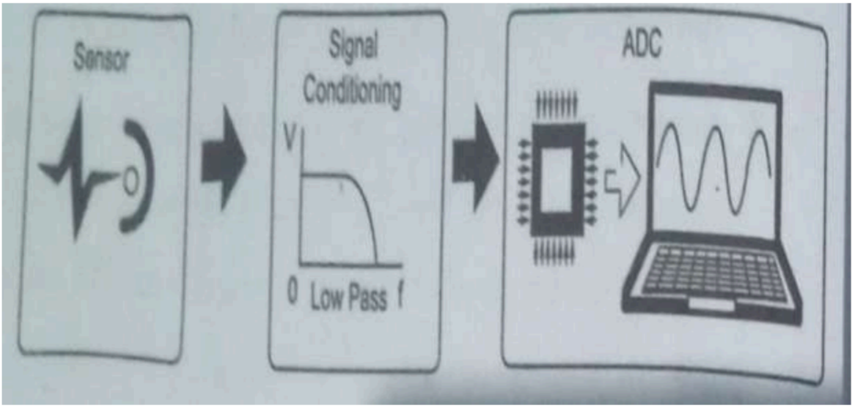
DATAACQUISITION

Dataacquisitionistheprocessofsamplingsignalsthatmeasurerealworldphysicalconditions and converting the resulting samples into digital numeric values that can be manipulated by a computer.

Dataacquisitionsystems, abbreviatedbytheacronymsDASorDAQasitisoftenreferred,isthe processofdigitizingdatafromtheworldaroundussoitcanbedisplayed,analyzed,andstoredin a computer.

A simple example is the process of measuring the temperature in a rooms a digital value using a sensor such as a thermocouple.

COMPONENTS OFA DATAACQUISITION SYSTEM



1. Analog-to-DigitalConverter(ADC).
2. Sensors
3. SignalConditioning

i.Analog-to-DigitalConverter(ADC)

AtthecoreofalldataacquisitionsystemsisanAnalogDigitalAsthenameimplies,thischiptakes data from the environment and Converter (ADC)

Convertstodiscretelevels thatcanbeinterpreted byprocessor.

Thesediscretelevels correspondtothe smallestdetectablechangeinthesignalbeingmeasured.

Thehigherthe numberofan ADC (12-bit, 16-bit, 18-bit thegreaterthenumberofdiscretelevels that can represent an analog signal and the greater the resolution of the ADC.

TheresolutionofanADCisessentiallyanalogoustothemeasuringstick.Ameasuringstickwith tick has more resolution than measuring stick with only tick marks

ii. Sensors

Sensors,oftencalledtransducersconvertrealworldphenomenonliketemperature,force,and movement to voltage or current signals that can be used as inputs to the ADC.

Commonsensorsincludethermocouples,thermistors,andRTDtomeasuretemperature, accelerometers to measure movement, and strain gauges to measure force.

Whenchoosingtherightsensorforyourmeasurementimportanttoconsiderfactorslikethe accuracy of the sensor and the signal conditioning required to record readable signal.

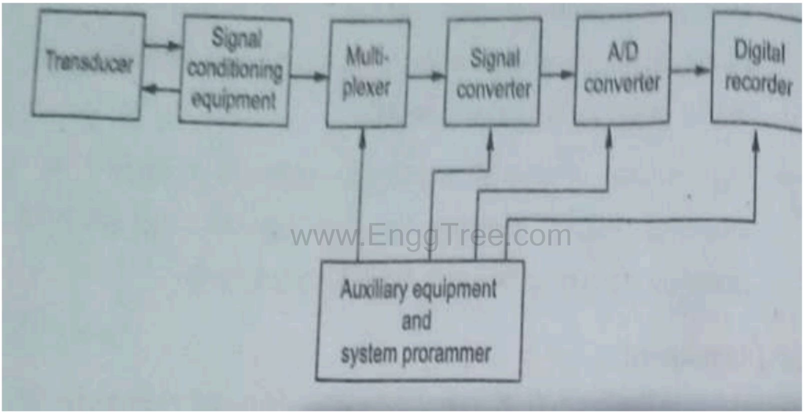
iii. SignalConditioning

Tomakequality measurementstransducers,additionalneededbetweenthetransducerandthe ADC.

This circuitry is generally referred to signal conditioning and include amplification attenuation, Wheatstone bridge completion, excitation, linearization, calibration and cold-junction compensation (CJC)

Differentsensorshavedifferentsignalconditioningneeds.Forinstance,signalconditioningfor a strain gauge requires excitation, bridge completion and calibration.

DIGITALDATAACQUISITIONSYSTEM



1. Transducers

They convert a physical quantity into an electrical signal which is acceptable by data acquisition system.

2. SignalConditioning

EquipmentSignal conditioninghasalreadybeen describedin detailsin chapter,

3. Multiplexer

Multiplexing is the process of sharing a single channel with more than one input. multiplexer accepts multiple analog inputs and connects them sequentially to one measuring instrument. Another name for a multiplexer is "scanner"

4. SignalConverter

A signal converter translates the analog signal to form acceptable by the analog to digital (AND) converter. An example of the signal converter is an amplifier for living the low-level signal voltages produced by transducers.

5. AnalogtoDigitalConverter (A/DConverter)

AnA/Dconverterconvertstheanalogvoltagetoits equivalentdigitalform.Theoutputoutofthe A/D converter may be fed to digital display devices for visual display or may be fed to digital recorders for recording. It may be fed to a digital computer for data reduction and further processing.

6. Auxiliary Equipment

Thiscontainsdevicesforsystemprogrammingfunctionsanddigitaldataprocessing.Someofthe typical functions done by auxiliary equipment are linearization and limit comparison of signals. These functions may be performed by individual devices or by a digital computer.

7. Digital Recorders

Records of information in digital form may be had on punched cards, perforate paper tapes, typewritten pages, floppy disk, magnetic tape, or a combination these systems.

8. Digital Printers

Afterallthetestshavebeencompletedandthedatagenerated,itbecomesnecessarytorecordthe numbers and in some cases reduce the data to more meaningful form.

USES OFDATA ACQUISITION SYSTEMS

Data acquisition systems are being used in ever increasing, large and wide fields in a variety of industrial and scientific areas, including the aerospace, biomedical and telemetry industries.

Thetypeofdataacquisitionsystemtobeuseddependsupontheapplicationandtheintendeduse of recorded input data. Analog data acquisition systems are used when wide frequency width is required or when lower accuracies can be tolerated.

Digitaldataacquisitionsystemsareusedwhenthephysicalquantitybeingmonitoredhasanarrow bandwidth (ie., when the quantity varies slowly).

Digitalsystemsarealsoused whenhighaccuracyandlow perchannelcostis required.

Digital data acquisition systems arein general, morecomplex than analogsystems, both in terms of instrumentation involved and the volume and complexity of ne data they can handle.

SINGLECHANNELDATAACQUISITIONSYSTEM

ASingleChannelDataAcquisitionSystemconsistsofasignalconditionerfollowedbyananalog to digital (A/D) converter, performing repetitive conversions at a free running, internally determined rate.

The outputs are in digital code words including over range indication, polarityinformation and a status output to indicate when the output digits are valid.

The digital outputs arefurther fed to a storage or printout device, or to a digital computer device, or to a digital computer for analysis.

ThepopularDigital panel Meter(DPM)is awell knownexampleofthis.However,therearetwo major drawbacks in using it as a DAS.

It is slow and the BCD has to be changed into binary coding, if the output is to be processed by digital equipment.

Whileitsfreerunning,thedatafromA/Dconverteristransferredtotheinterfaceregisteratarate determined by DPM itself, rather than commands beginning from the external interface

ANALOGTO DIGITALCONVERTERS (A/D)

AnalogtodigitalconvertersusedforDASapplicationsdesignedtoreceiveexternalcommands to cover and hold. For de ad low frequency signals.

The advantage is that it has a linear averaging capability and has a null response for frequencies harmonically related to the federation period.

A/D converters based on dual slope techniques are useful for conversion of low frequency data, such as from thermocouples, especially in the presence of noise. The most popular type of converter free data System applications is the successive approximation type.

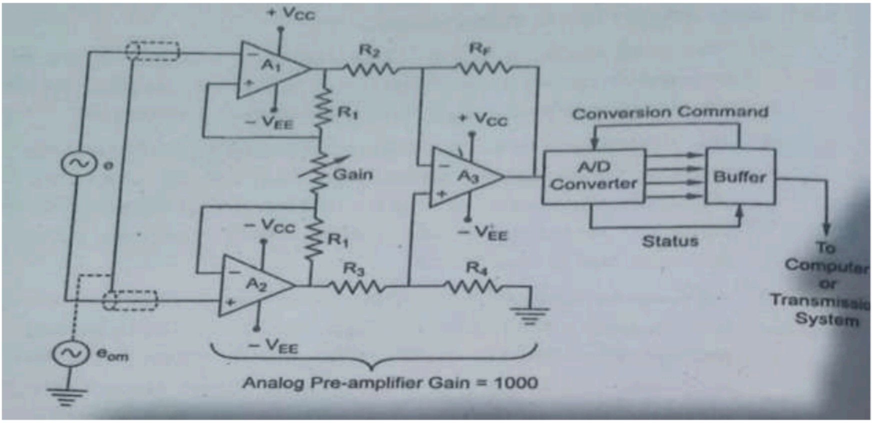
Higherspeedsareobtained byprecedingthe A/Dconverter byasemplehold (S/H).

Direct digital conversion carried out near the signal source is very advantageous in cases where data needs to be transmitted through a noisy environment.

PRE-AMPLIFICATIONAND FILTERING

Manylowresolution(8/10bit)ADconvertersareconstructedwithsingleendedinputandhavea normalised analog input range of the order of 5-10 V, bipolar or unipolar.

For signal levels which are low compared to input requirements, amplification may be used in ordertobringupthelevelofttheinputtomatchconverterinputrequirements,sothatoptimumuse can be made in terms of accuracy and resolution.



If thesignal levels arebelow a tenth ofan mV, or when resolution of14 bits or16 bits is needed, the use of differential amplifiers can become necessity

Whendifferentialoutputhastobehandledfrom abridgenetwork,instrumentationamplifiersare employed.

The accuracy, linearity and gain stability specifications should be carefully considered, to ensure the system is not affected by any limitations.

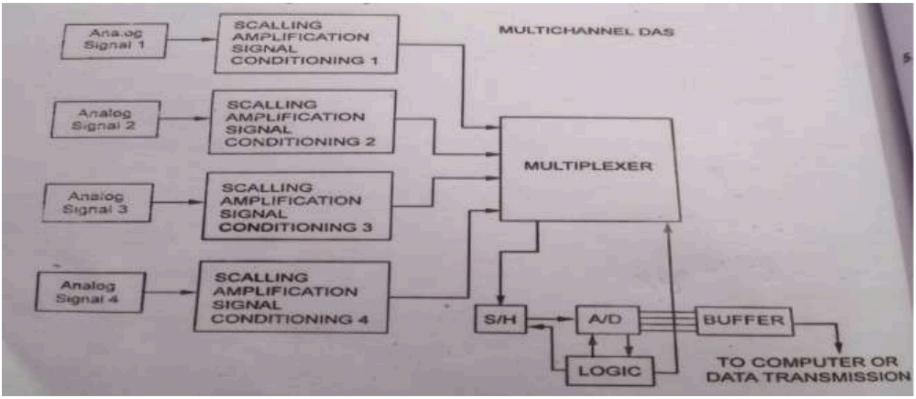
If theinput signals are to bephysicallyisolated from thesystem, theconductivepaths arebroken by using a transformer coupled or an opto-coupled isolation amplifier.

Thesetechniquesareadvantageousinhandlingsignalsfromhighvoltagesourcesandtransmission towers.Inbiomedicalapplicationssuchisolationpre-amplifierscanbecoupledwithactivefilters beforeprocessingof data, becomesessential. in orderto minimizetheeffect ofnoisecarriersand interfering high frequency components.

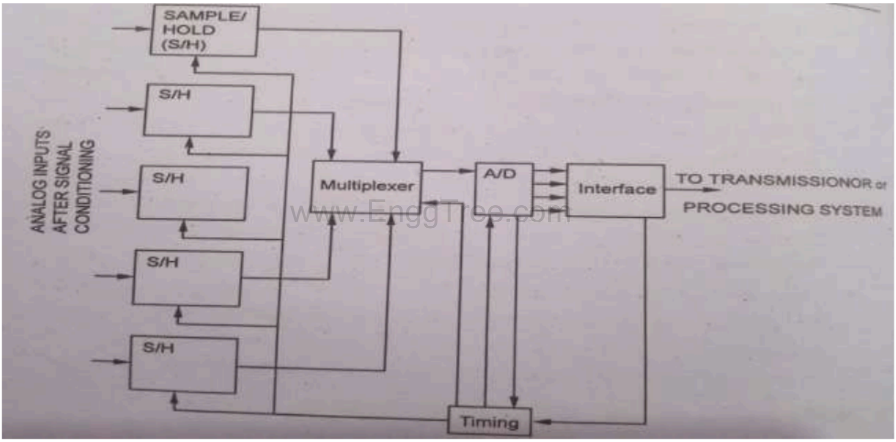
They effective compensate for transmission sensitivity loss at high frequency and hence enable measurements over an enhanced dynamic frequency range.

Specialpurposefilters,such astracking filters,areusedforpreservingphasedependent data.

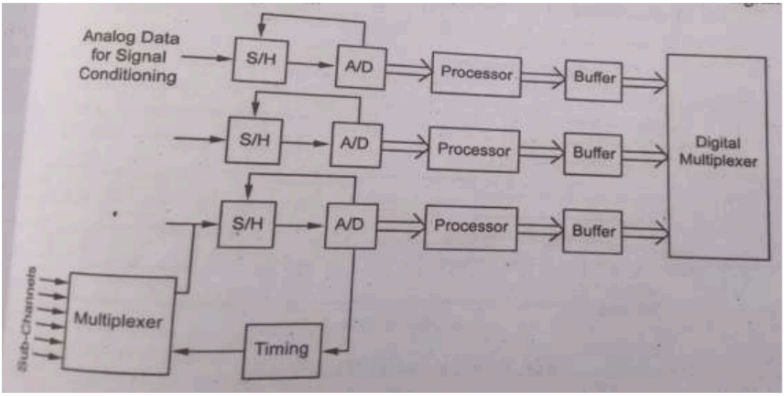
MULTICHANNELDATAACQUISITIONSYSTEM



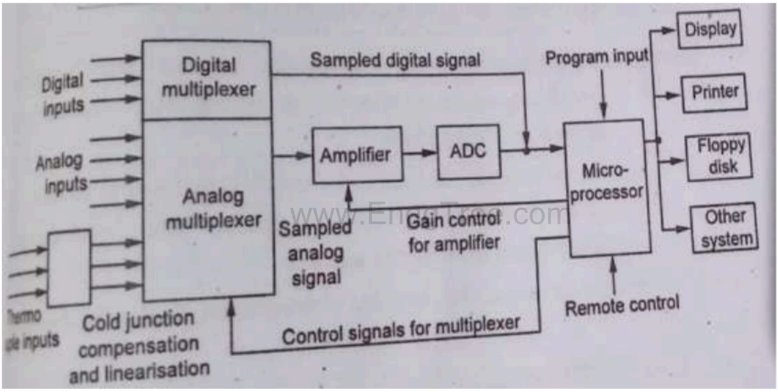
MULTIPLEXINGTHEOUTPUTSOFS/H



MULTIPLEXINGAFTERA/D



DATA LOGGERS

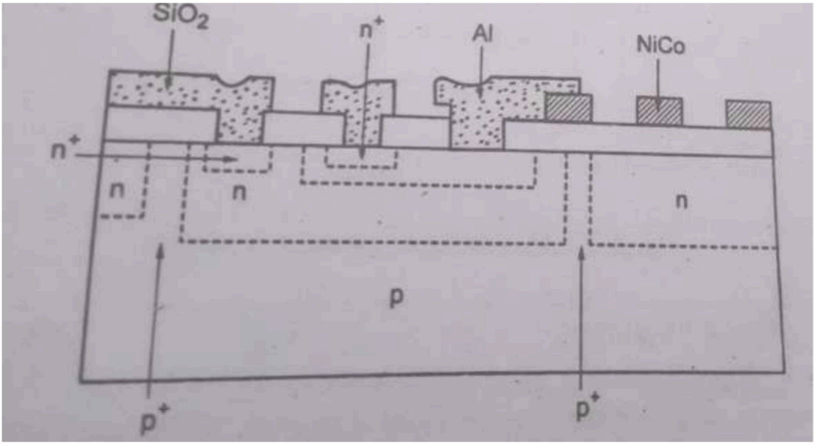


TORQUEANDPOSITIONSENSORS

A torque sensor is a device for measuring and recording the torque on a rotating system, such as an engine, crankshaft, gearbox, transmission, rotor, etc.

Static torque isrelativelyeasytomeasure.

Dynamictorqueisnoteasytomeasure,sinceitgenerallyrequirestransferofsomeeffect(electric, hydraulic or magnetic) from the shaft being measured to a static system.



The magnetic characteristics of these domains will vary according to the applied torque and thus can be measured using non-contact sensors.

Such magnetoelastic torque sensors are generally used for in-vehicle applications on race cars, automobiles, aircraft and hovercraft.

Thepowertrainsbywhichanautomobileisrunconsistsoftheengineitself,thetransmissionline, differential gear, axle and wheels. The torque generated in the engine is distributed to the wheels through power trains,

Atorquesensorforeachcomponentatappropriatepositionofthepowertrainprovidesquickand precise response to power controls.

Non-contactsensorisfoundtobesuitableforpracticaladaptabilitysuchsensorisminiatureinsize and works on the magneto resistive effect and which can be installed in main bearing and hence, mean output torque can be detected for multi-cylinder engine with a single sensor.

Position sensing is another important aspect in automobiles for detecting shaft position, engine speed, throttle position, potentiometer position and so on. Here also non-contact sensors receive preference.

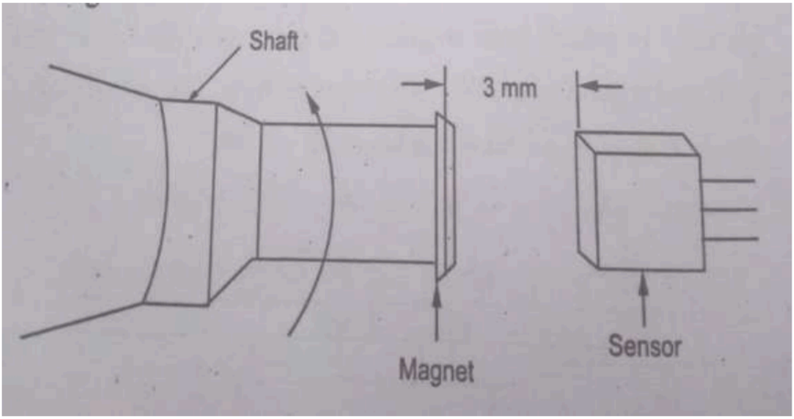
The semiconducting sensors such as Hall and magneto resistive ones and the other varieties such as ferromagnetic, electromagnetic pick up, optical modular device, wiegand wire and capacitive modular device are also considered suitable.

Forelectromagneticpickup,proximitysensorsaremostcommonlyusedbecauseofhighresolution and low cost offered.

Integratedmagneticsensor usingferromagneticresistiveelementisalso beingincreasinglyused.

Ithashighsensitivityatlowmagneticfieldandcomparativelylesssensitivetotemperature variations.

MOUNTINGOFPROXIMITY SENSOR



AEROSPACESENSORS:

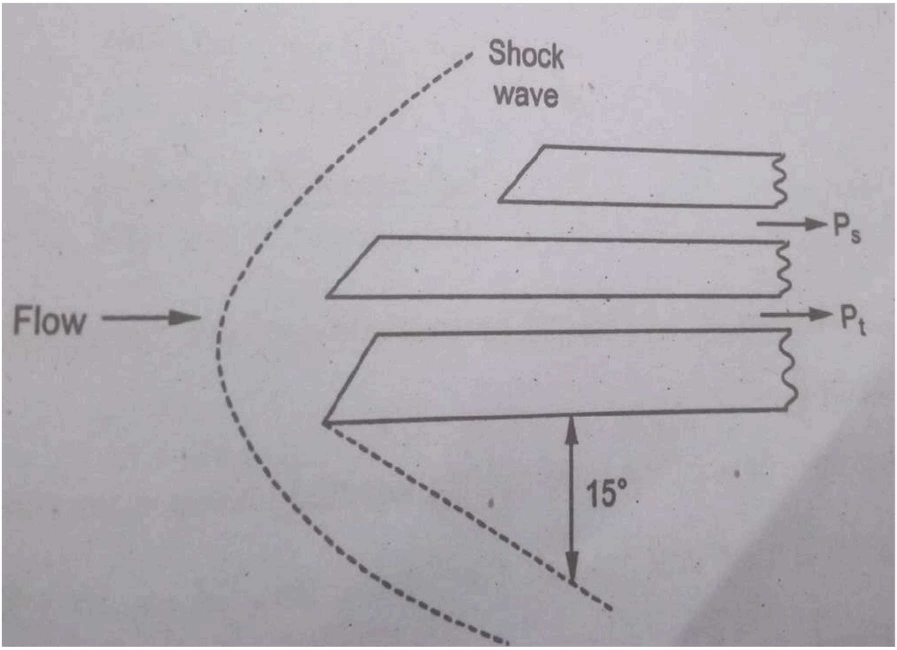
1) Staticpressuresensors
2) Temperaturesensing
3) Fluid velocitysensors
4) Sensingdirection ofAir-flow,
5) Strain,Force,ThrustandAccelerationmonitoringsensors

STATICPRESSURE SENSORS

Ingeneral,thestaticpressuresensorisadifferentialpressuresensordesignedtomonitorthe difference in pressure between the inside and outside of a building

Itsfeaturesare

1) Differentialpressuresensor.
2) Easyinstallation and configuration.
3) Ruggedenclosure(corrosionresistant,waterresistantandfireretardant



In aerospace, the static pressure sensor is used to monitor vertical speed static pressure (ie.) foraltitude and time rate of change of altitude.

Forthis,probesareusedwhicharePitottubesofappropriatedesignandrequiretobealigned accurately.

Besideslength, noseshapeand cross section oftheprobeare also equallyimportant.

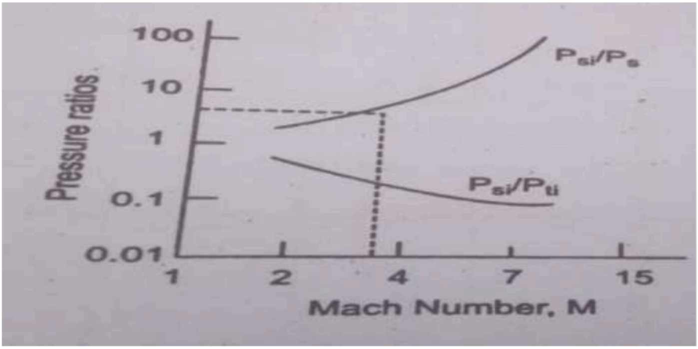
Forsupersonicflow,thereisadifferenceintheactualpressureP,andtheindicatedstaticpressure.

Correction and evaluation of static pressure, is possible by Mach number versus pressure ratios curve.

Machnumberistheratioofspeedofthebodytothespeedofthesoundinthesurroundingmedium. Mach

number =Object speed /speed of sound

Pressureratios=Indicatedstaticpressure/static pressure



TEMPERATURESENSING:

Statictemperatureisthesimplestreamlinetemperatureneededtoestablishtheacousticspeedand hence, the gas velocity from the knowledge of Mach number M. It is denoted as Ts.

TotaltemperatureisdenotedasTs.

Itis the onethat gas acquires ifit is isotropicallystagnated.

Stagnatedmeansgastonotmoveorflow,oftenresultinginitbecomingdirty. For

measurement of temperature, usually two types of probes are used.

1.RTD(ResistanceTemperaturedetectors)

2.Thermocouple

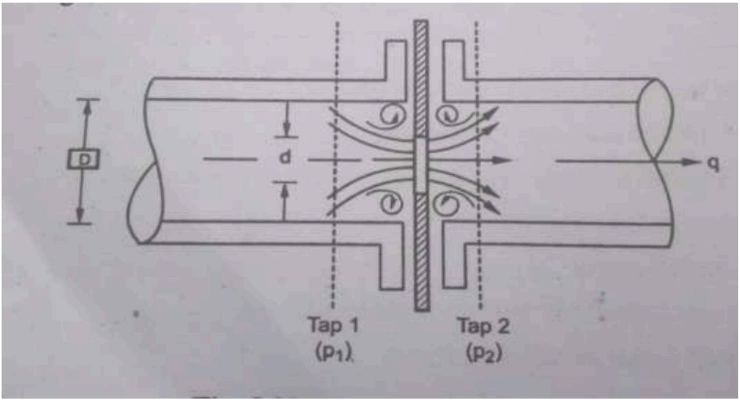
Intheaerospaceterminology,thesesensorsarecalled'temperaturesensitiveelements(TSE). For

measure of success of stagnating two parameters should be considered

1.Recoveryratio

2. Recoveryfactor

FLUIDVELOCITYSENSORS

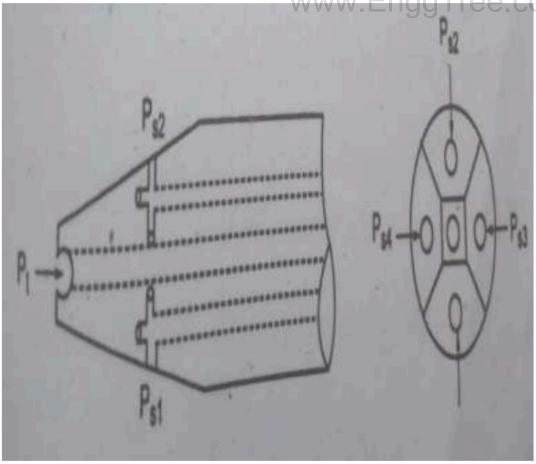


SENSINGDIRECTION OFAIRFLOW

It is important to determine the direction of air-flow in aerospace services. In coretype probes or probesresemblingcoreorwedge,twoholesontheInclinedsurfacesthatliediametricallyopposite to each other are used.

Thedifferenceofthepressuresofthesetwotapsismeasuredwhichismoreorlessproportionalto the angle between the axis of the probe and direction of air-flow.

Therearevariationsin thedesignof probeandholepositions.



MEASURINGAIR-SPEED ON AIRCRAFTS

Airspeedonaircraftcanbecomputedfromthemeasurementoftotalpressure(P),temperature(T) and static pressure (P) using the ideal gas equations.

1.Theequationsuseidealgaslaws

2. Change in specific heats with temperature occurs at high temperaturesdue to increased andvibrational energies.

3. Atimelagappearsfor equilibrium betweentheaboveenergiesnear theshock front.

3.Atveryhightemperatures, ionizationand dissociationof moleculesoccur andso on.

MONITORINGSTRAIN,FORCE, THRUSTAND ACCELERATION

Aerospace research and studies involve measurement of strain, force, thrust, acceleration and so on for operation, innovation and safety consideration.

Both state and total pressures and other parameters we measured using the usual sensors such as strain gauges specially for strain and force.

Appropriatepositioningofthegaugesandcompensationfortemperaturevariationsaretobetaken care

Fordynamicstrainalonewithfluctuationfrequencyofseveral Hertz,thegaugematerialischosen to be fatigue free or to understand high fatigue.

Loadcellsarealsomadeofstraingaugesbondedtoaspringwhosedeflectionissensed. Load cells

are wed for weighing aircrafts sold for measurements of thrust forces.

Engine thrust of a rocket is sensed or determined in the test center from the integral of dynamic pressure which is measured by an army of total head (pressure) tubes at the exhaust,

Acceleration measurement in an aircraft is very important during acrobatics movements or gusts when stressed in the structures increases and require to be obtained by correlating stress with acceleration.

HOMEAPPLIANCESENSOR

Semiconductortechnologyhasgrownfastoveralastfewdecadesleadingtodevelopmentofmicro miniaturized processors, circuits.

Sensors enhancing the capabilities of home appliances depends largely on of automation, safety and efficiency.

Smartoperationofthehomeappliancesdependslargelyonappropriatesensorswhichhavemade the equipment more convenient, energy economic and safe.

Basically, the sensors are used in electronic control of the appliances and when coupled with microcomputers, all these requirements are almost fully met.

Therefore,thebasicrequirementsforthesensorsforhomeappliancescannowberevisitedasthey must have low cost, small size, light weight, better reliability, and easy reliability, and cash handling.

Thesensorsused in homeappliances arenothing newthough thetendencyis to miniaturizethem retainingthereliabilityandefficiency.Sensorssousedbelongtoallcategories,thatis,mechanical, chemical, magnetic, temperature, and radiation types - the last two types having major applications. In the mechanical category, silicon pressure sensors, metal diaphragms, and potentiometers are also used in washing machines.

Radiation sensors, that is photodiodes, and phototransistors are used as the major elements in refrigerators, washing machines, air-conditioners, TV sets, CD players, stereo players, and video disc players.

Photoresistors such as CdS are used in TV sets while VCR camera uses charge control device (CCD) image sensors and MOS image sensors.

Thepyroelectric IRsensorusedinmicrowaveovenscomes,ingeneral,inTO package.

ItconsistsofaL/TO,pyroelectricelementonasiliconbaseplateandisirradiatedthroughasilicon window.

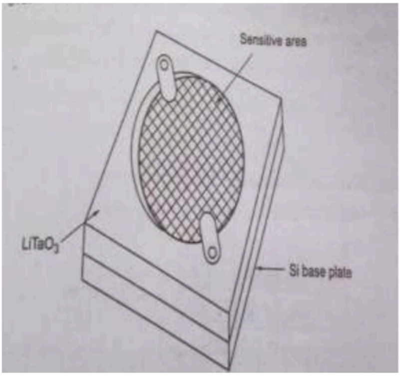
Its responsivity is 200 - 300 V/W, NEP is less than 2 n W/Hz, response time is around 0.2s, temperature range is - 20°C to 100°C, and with silicon window.

Sensorsusedinwashingmachine

In a microprocessor controlled washing machine, water level is sensed using optics principles thatcompriseunitslikealightemittingdiode(LED),photodiode/phototransistor,andalightslit.

Thelight slit movedbythewater level.

Thistypeofsensorisalsousedinrinsingchambersforthedetectionofrinsingwhichprovides information about the concentration of residual detergents.

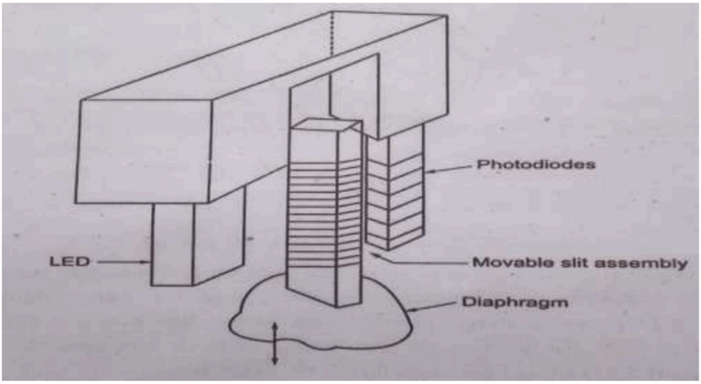


Thesensor usedforspindrysystemin washingmachines isa PZTceramicsensor.

Itisbasedontheprinciplethatwhenwaterdripsontothesurfaceofthesensor,voltage developed in the sensor becomes less with more impinging force of water on it.

Attheclothesaredried,voltagealsoincreases,PZTisasolidsolutionofleadzirconateandlead titanate, it is belongs to perovskite structures.

PiezoelectricpropertydependsonT/2,T/Z)ratio.Mostceramicpiezoelectrictransducersbelong to this group.



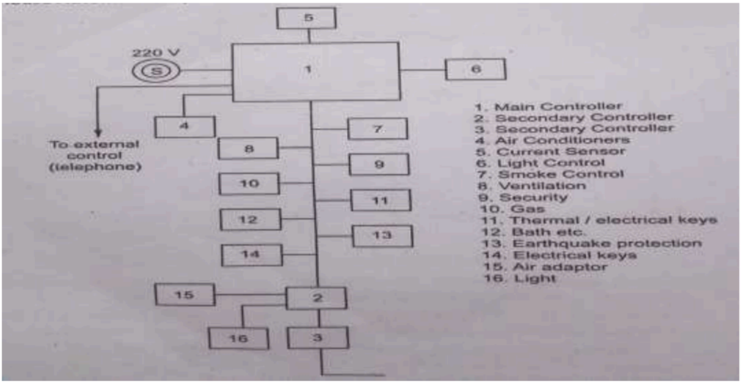
Photodiode-LEDassemblyhasalsobeenusedforfrostdetectioninrefrigerators.

With frost, the light intensity received by the photodetector is reduced as in the case of a rinsing system.

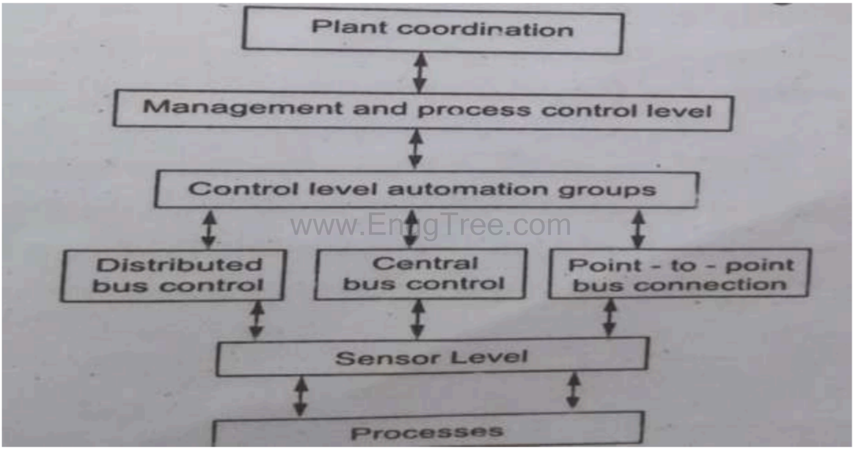
Analternativesystemfor thisuseis piezocrystaloscillatorandaPTCthermistor system.

The crystal in an oscillator circuit vibrates at its natural frequency and with frost formation, itsresonance frequency changes. PTC thermistor heats the crystal for making it frost free.

HOUSEAUTOMATION SYSTEM



SENSORSFORMANUFACTURING



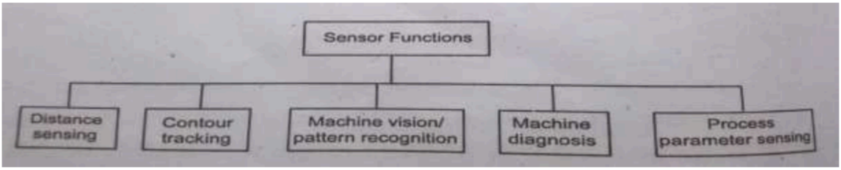
SENSORS FUNCTIONS

Sensorsusedinproductionprocesseshavetoperformfunctionswhicharenotconventional process control functions. The Fig.5.40 depicts the sensor functions briefly.

Theyarenotalwaysasdistinctasindicatedinthediagrambutmaybeperformingin combination on demand.

Mostofthesensorsusedhavebeenconsideredearlierbutforroboticactions,specificsensorsare applied in production engineering.

Sensorsusedinsuchactionsarediscussedinthissubsectionwiththeactionsforwhichtheyare meant for.



DISTANCE SENSING:

During processing, the workpiece and the tool face the possibility of collision.

Therefore,thedistancesbetweenthetwoforvariousoperationsneedbemonitored.

In some processingoperations, the distance between the two should be maintained constant as in lase cutting.

Sensorsfordistancemeasurementareof twotypes, namelycontacttypeand non-contact type.

The non-contact type is gaining ground because the sensors in this typo are free from wear and tear.Contact type distance sensors are common meteorological instrument components such as pins, gauge blocks, dial gauges, and many others. Switches and buttons with potentiometric or inductive pick-up are also used.

Inthenon-contacttypedistancesensors,inductive,capacitive,acoustic,andopticaltechniquesare adopted.The inductive pick-ups are designed and named proximity sensors.

Singlecoilandmulti-coildesignsarealsocommon.

Multi-coildesignsallow to measurethe distanceintwo coordinates.

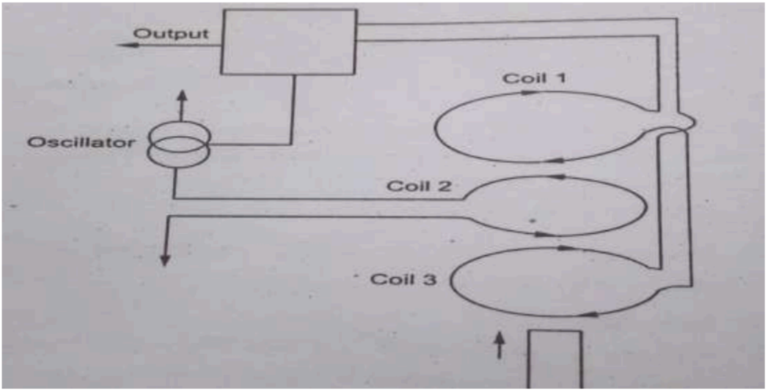
EXAMPLEOFINDUCTIVEPROXIMITYSENSOR

The middle coil , coil 2, is fed with ac of appropriate frequency allowing it to produce an ac magnetic field in its own proximity.

Coil 1 and coil 3 symmetrically positioned with respect to coil 2 are also electrically energized withphaseoppositionwithrespecttosupplyofcoil2inabsenceofanymetallicbodyapproaching the set up (coils 1 and 3).

With any metallic body approaching, as shown, the magnetic field distributions to coils 1 and 3 change and a signal is generated which can be seen to be proportional to the distance and angle between the body and the coil (s).

Ultrasonic sensors housed in robot gripper utilize the period between the reflected pulse (echo) and the original pulse sent by transmitter for distance measurement.



Contour tracking

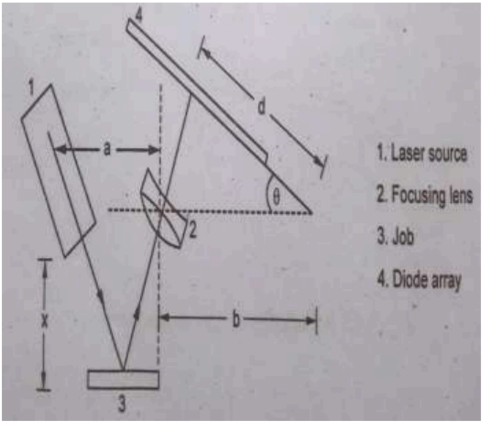
Inoptoelectronictechniqueofdistancesensing,alaserbeamisfocusedotheapproachingbody and its reflection is then detected by a properly aligned photodiode after being converged by a lens.

Thiscanbedetecteither

(i) Theintensityoflight

(ii) Theangleof approach.Thesecond technique isknown asopticalTriangulation.

Thedetectorsystemconsistsofabout1000diodesarrangedinanarraywhichcanhelptoenhance resolution.



Machine Vision:

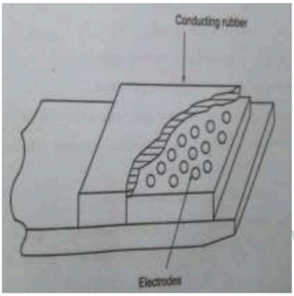
Machinevisionisanintelligentsensingsystem. Itinvolvesscanningtheobjectwithavideocamera whoseoutputis convertedtodigital byan ADC forimageprocessing, and featurecomputingand identification.

Thencomparisonwithmodel,calledpatternrecognition,isperformedforthedesiredoutput. The system obviously requires a very sensitive viewing of the object with adequate resolution and discrimination. Images are obtained by

(i) ultrasonictransducer scanner

(ii) X-rayscanner

The transducers so used may be conducting rubber type, the capacitance type, or piezoresistive type.Therubbingpressuresproducechangeinresistanceintheconductiverubbertypetransducers whilecapacitancechangesinthesecondeventouching.Inthepiezoresistivetransducer,thenormal piezoresistive action take place.The scanned output obtained from a multiplexer may be stored. Response time of each sensors is less than 1 ms per 100 units in an array.



Machine diagnosis:

Formachinediagnosis,thetechniquesappliedare

(i) Processparametermonitoring,

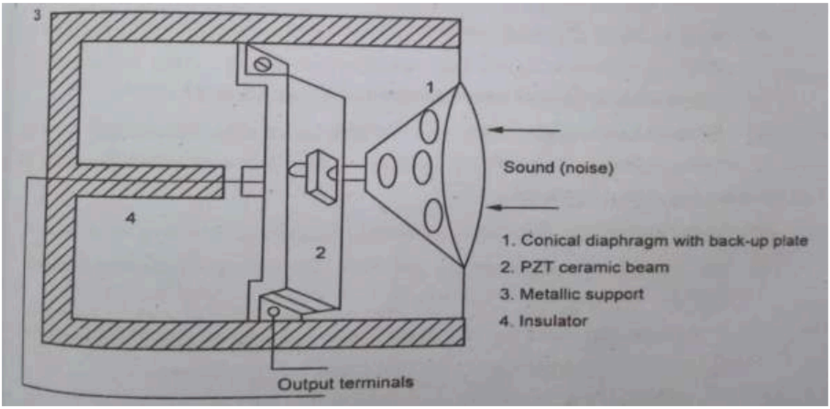
(ii) Powerconsumptionbythemachineandedgesofwork-pieces(their condition)

(iii) Forceandtorquesensing, and

(iv) Changein thenoiseofthemachinein operation.

The first technique is not very straightforward. In force and torque sensing, strain gauges are extensively used. Noise sensing, however, has become an important technique with the advancement of device technology.

Noisesensorsare,ingeneral,capacitivetype,Often,ceramicpiecesofPZTmaterialconsistingof lead zirconate and lead titanate are used for the purpose.


3
1
Sound (noise)
4
2
1. Conical diaphragm with back-up plate
2. PZT ceramic beam
3. Metallic support
4. Insulator
Output terminals