SYTE3:

Skriptum zur Vorlesung

Grundlagen der Elektrotechnik3

Schulstufe 3

Part: Measurements of non-electrical quantities

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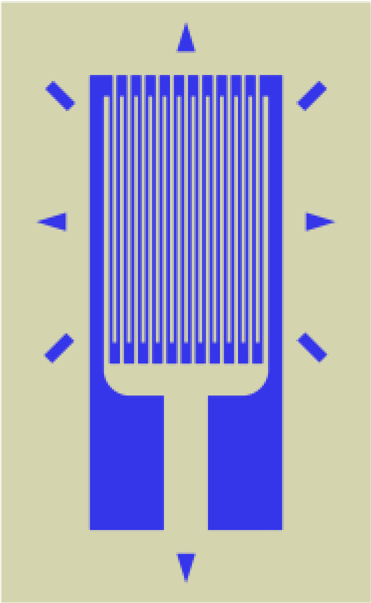
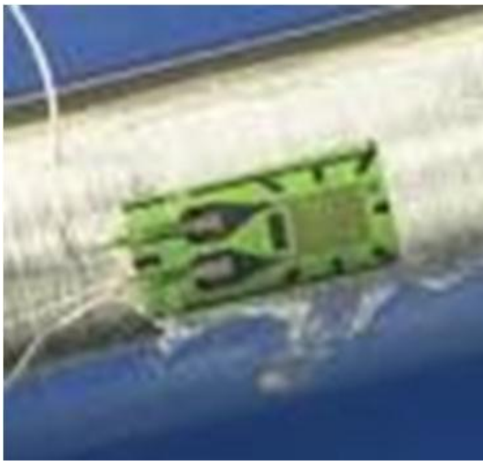
Inhalt

1.Strain gauge

Typical foil strain gauge. The gauge is far more sensitive to strain in the vertical direction than in the horizontal direction. The markings outside the active area help to align the gauge during installation.

A **strain gauge** (also **strain gage**) is a device used to measure the strain of an object. Invented by Edward E. Simmons and Arthur C. Ruge in 1938, the most common type of strain gauge consists of an insulating flexible backing which supports a metallic foil pattern. The gauge is attached to the object by a suitable adhesive, such as cyanoacrylate.[1] As the object is deformed, the foil is deformed, causing its electrical resistance to change. This resistance change, usually measured using a Wheatstone bridge, is related to the strain by the quantity known as the *gauge factor*.

Physical operation

A strain gauge takes advantage of the physical property of electrical conductance and its dependence on the conductor's geometry. When an electrical conductor is stretched within the limits of its elasticity such that it does not break or permanently deform, it will become narrower and longer, changes that increase its electrical resistance end-to-end. Conversely, when a conductor is compressed such that it does not buckle, it will broaden and shorten, changes that decrease its electrical resistance end-to-end. From the measured electrical resistance of the strain gauge, the amount of applied stress may be inferred. A typical strain gauge arranges a long, thin conductive strip in a zig-zag pattern of parallel lines such that a small amount of stress in the direction of the orientation of the parallel lines results in a multiplicatively larger strain over the effective length of the conductor—and hence a multiplicatively larger change in resistance—than would be observed with a single straight-line conductive wire. Strain gauges measure only local deformations and can be manufactured small enough to allow a "finite element" like analysis of the stresses to which the specimen is subject. This can be positively used in fatigue studies of materials.

Gauge factor

The gauge factor GF is defined as:

$$GF = \frac{\Delta R / R_G}{\epsilon}$$

where

> ΔR is the change in resistance caused by strain,
> R_G is the resistance of the undeformed gauge, and
> ϵ is strain.

For metallic foil gauges, the gauge factor is usually a little over 2.[2] For a single active gauge and three dummy resistors, the output v from the bridge is:

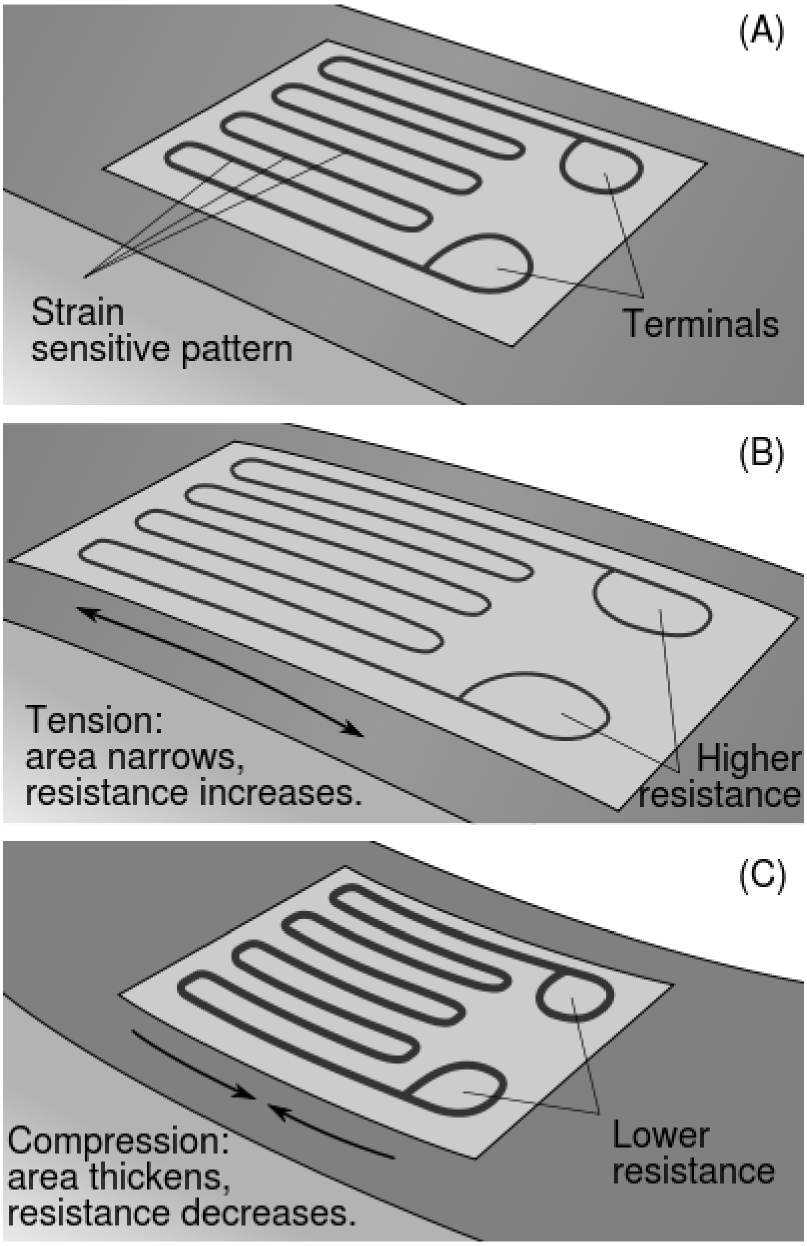
$$v = \frac{BV \cdot GF \cdot \epsilon}{4}$$

where

> BV is the bridge excitation voltage.

Foil gauges typically have active areas of about 2–10 mm^2 in size. With careful installation, the correct gauge, and the correct adhesive, strains up to at least 10% can be measured.

Gauges in practice



Visualization of the working concept behind the strain gauge on a beam under exaggerated bending.

An excitation voltage is applied to input leads of the gauge network, and a voltage reading is taken from the output leads. Typical input voltages are 5 V or 12 V and typical output readings are in millivolts.

Foil strain gauges are used in many situations. Different applications place different requirements on the gauge. In most cases the orientation of the strain gauge is significant.

Gauges attached to a load cell would normally be expected to remain stable over a period of years, if not decades; while those used to measure response in a dynamic experiment may only need to remain attached to the object for a few days, be energized for less than an hour, and operate for less than a second.

Strain gauges are attached to the substrate with a special glue. The type of glue depends on the required lifetime of the measurement system. For short term measurements (up to some weeks) cyanoacrylic glue is appropriate, for long lasting installation epoxy glue is required. Usually epoxy glue requires high temperature curing (at about 80-100°C). The preparation of the surface where the strain gauge is to be glued is of the utmost importance. The surface must be smoothed (e.g. with very fine sand paper), deoiled with solvents, the solvent traces must then be removed and the strain gauge must be glued immediately after this to avoid oxidation or pollution of the prepared area. If these steps are not followed the strain gauge binding to the surface may be unreliable and unpredictable measurement errors may be generated.

Strain gauge based technology is utilized commonly in the manufacture of pressure sensors. The gauges used in pressure sensors themselves are commonly made from silicon, polysilicon, metal film, thick film, and bonded foil.

Variations in temperature

Variations in temperature will cause a multitude of effects. The object will change in size by thermal expansion, which will be detected as a strain by the gauge. Resistance of the gauge will change, and resistance of the connecting wires will change.

Most strain gauges are made from a constantan alloy.[3] Various constantan alloys and Karma alloys have been designed so that the temperature effects on the resistance of the strain gauge itself cancel out the resistance change of the gauge due to the thermal expansion of the object under test. Because different materials have different amounts of thermal expansion, self-temperature compensation (STC) requires selecting a particular alloy matched to the material of the object under test.

Strain gauges that are not self-temperature-compensated (such as isoelastic alloy) can be temperature compensated by use of the dummy gauge technique. A dummy gauge (identical to the active strain gauge) is installed on an unstrained sample of the same material as the test specimen. The sample with the dummy gauge is placed in thermal contact with the test specimen, adjacent to the active gauge. The dummy gauge is wired into a Wheatstone bridge on an adjacent arm to the active gauge so that the temperature effects on the active and dummy gauges cancel each other.[4] (Murphy's Law was originally coined in response to a set of gauges being incorrectly wired into a Wheatstone bridge.[5])

Temperature effects on the lead wires can be cancelled by using a "3-wire bridge" or a "4-wire ohm circuit"[6] (also called a "4-wire Kelvin connection").

In any case it is a good engineering practice to keep the Wheatstone bridge voltage drive low enough to avoid the self heating of the strain gauge. The self heating of the strain gauge depends on its mechanical characteristic (large strain gauges are less prone to self heating). Low voltage drive levels of the bridge reduce the sensitivity of the overall system.

Errors and compensation

Zero Offset - If the impedance of the four gauge arms are not exactly the same after bonding the gauge to the force collector, there will be a zero offset which can be compensated by introducing a parallel resistor to one or more of the gauge arms.

Temperature coefficient of Gauge Factor (TCGF) - This is the change of sensitivity of the device to strain with change in temperature. This is generally compensated for by the introduction of a fixed resistance in the input leg, whereby the effective supplied voltage will increase with temperature, compensating for the decrease in sensitivity with temperature.

Zero Shift with temperature - If the TCGF of each gauge is not the same, there will be a zero shift with temperature. This is also caused by anomalies in the force collector. This is usually compensated for with one or more resistors strategically placed in the compensation network.

Linearity - This is an error whereby the sensitivity changes across the pressure range. This is commonly a function of the force collection thickness selection for the intended pressure and/or the quality of the bonding.

Hysteresis - This is an error of return to zero after pressure excursion.

Repeatability - This error is sometimes tied-in with hysteresis but is across the pressure range.

EMI induced errors - As strain gauges output voltage is in the mV range, even uV if the Wheatstone bridge voltage drive is kept low to avoid self heating of the element, special care must be taken in output signal amplification to avoid amplifing also the superimposed noise. A solution which is frequently adopted is to use "carrier frequency" amplifiers which convert the voltage variation into a frequency variation (as in VCOs) and have a narrow bandwidth thus reducing out of band EMI.

Overloading - If a strain gauge is loaded beyond its design limit (measured in microstrains) its performance degrades and can not be recovered. Normally good engineering practice suggests not to stress strain gauges beyond +/-3000 microstrains.

Humidity - If the wires connecting the strain gauge to the signal conditioner are not protected against humidity (bare wire) a parasitic resistance creates between the wires and the substrate to which the strain gauge is glued, or between the two wires themselves. This resistance introduces an error which is proportional to the resistance of the strain gauge. For this reason low resistance strain gauges (120 ohm) are less prone to this type of error. To avoid this error it is sufficient to protect the strain gauges wires with insulating enamel (e.g., epoxy or polyurethanic type). Strain gauges with unprotected wires may be used only in a dry laboratory environment but not in an industrial one.

Other gauge types

For measurements of small strain, semiconductor strain gauges, so called piezoresistors, are often preferred over foil gauges. A semiconductor gauge usually has a larger gauge factor than a foil gauge. Semiconductor gauges tend to be more expensive, more sensitive to temperature changes, and are more fragile than foil gauges.

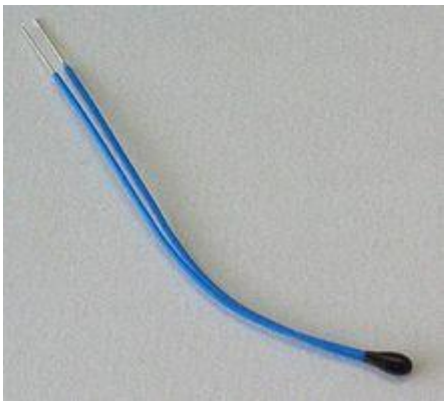
In biological measurements, especially blood flow / tissue swelling, a variant called **mercury-in-rubber strain gauge** is used. This kind of strain gauge consists of a small amount of liquid mercury enclosed in a small rubber tube, which is applied around e.g., a toe or leg. Swelling of the body part results in stretching of the tube, making it both longer and thinner, which increases electrical resistance.

Fiber optic sensing can be employed to measure strain along an optical fiber. Measurements can be distributed along the fiber, or taken at predetermined points on the fiber. The 2010 America's Cup boats Alinghi 5 and USA-17 both employ embedded sensors of this type [1].

Capacitive strain gauges use a variable capacitor to indicate the level of mechanical deformation.

Vibrating wire strain gauges are used in Geotechnical and Civil Engineering applications. The gauge consists of a vibrating, tensioned wire. The strain is calculated by measuring the resonant frequency of the wire (an increase in tension increases the resonant frequency).

2.Thermistor



Negative temperature coefficient (NTC) thermistor, bead type, insulated wires

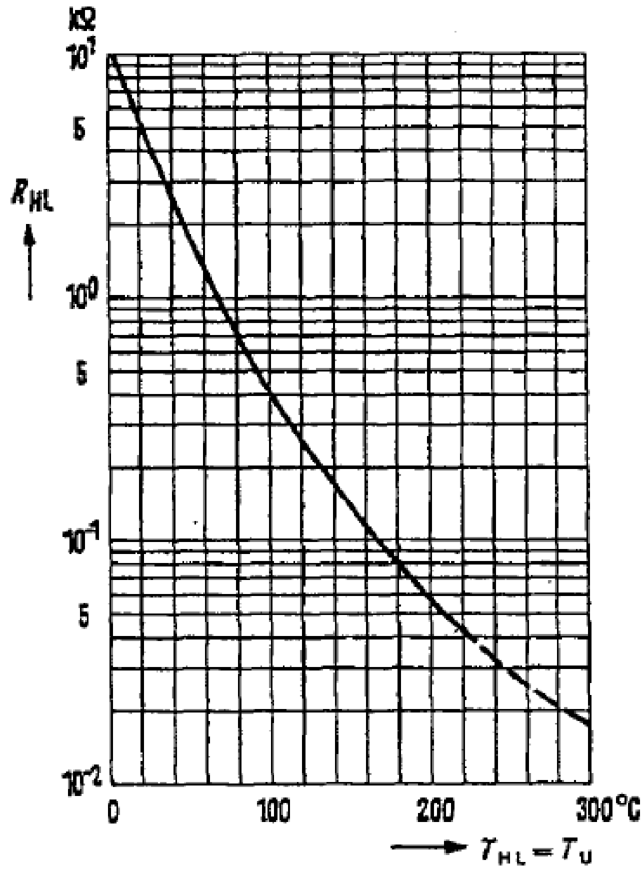
A **thermistor** is a type of resistor whose resistance varies significantly with temperature, more so than in standard resistors. The word is a portmanteau of *thermal* and *resistor*. Thermistors are widely used as inrush current limiters, temperature sensors, self-resetting overcurrent protectors, and self-regulating heating elements.

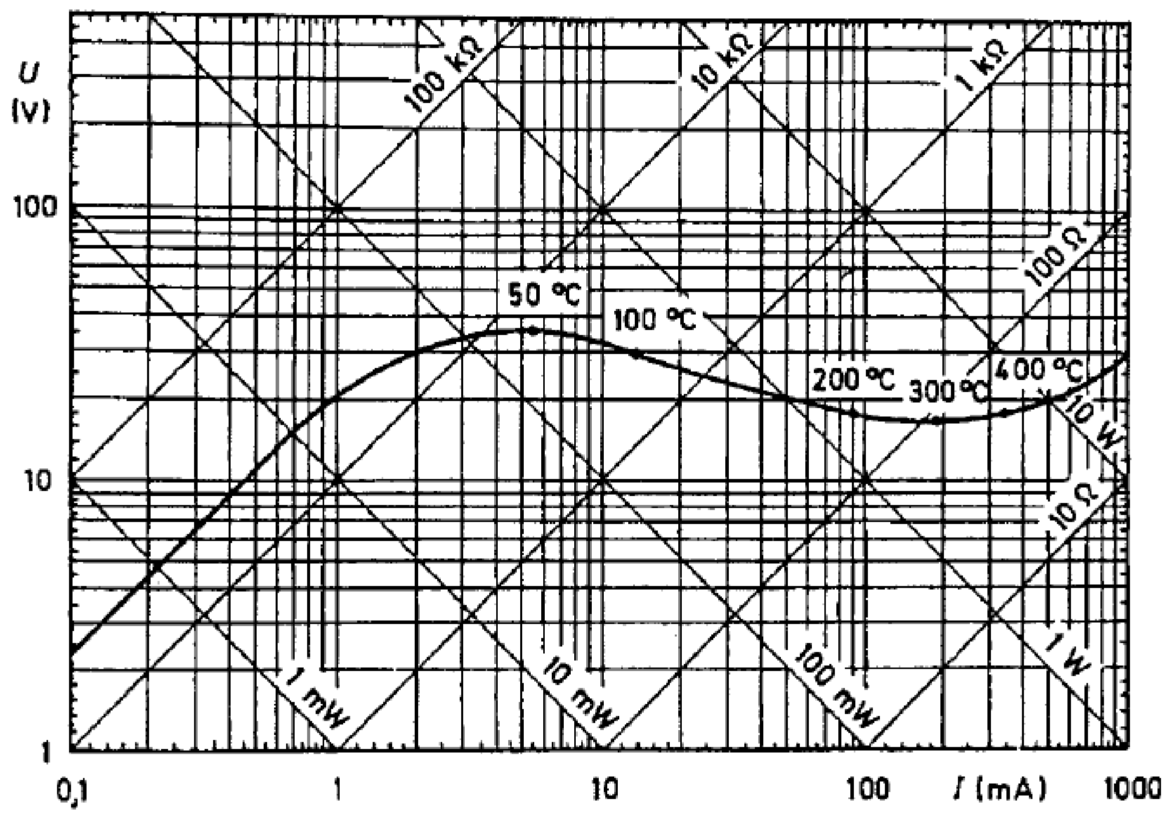
Thermistors differ from resistance temperature detectors (RTD) in that the material used in a thermistor is generally a ceramic or polymer, while RTDs use pure metals. The temperature response is also different; RTDs are useful over larger temperature ranges, while thermistors typically achieve a higher precision within a limited temperature range, typically −90 °C to 130 °C.

Basic operation

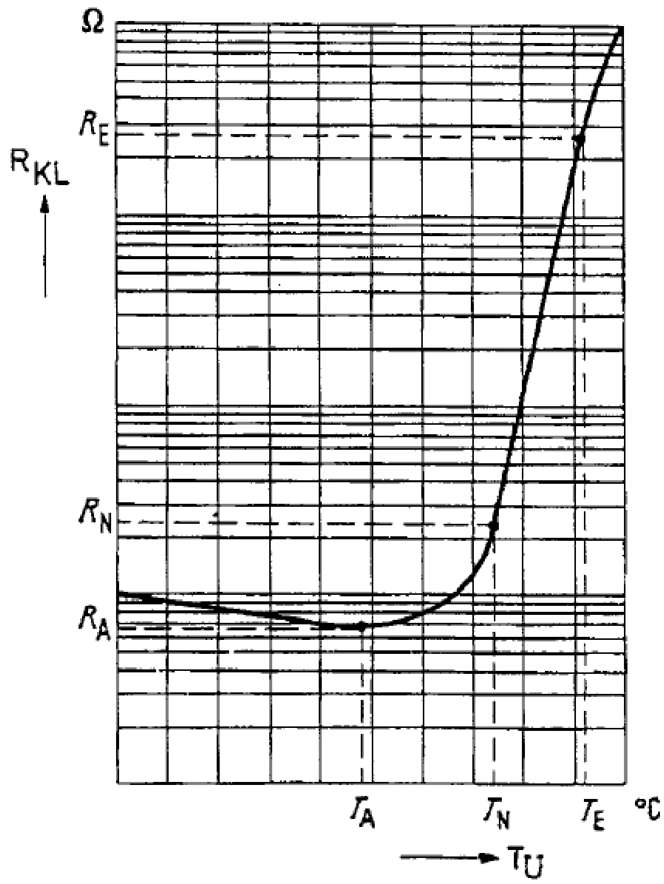
Thermistor symbol

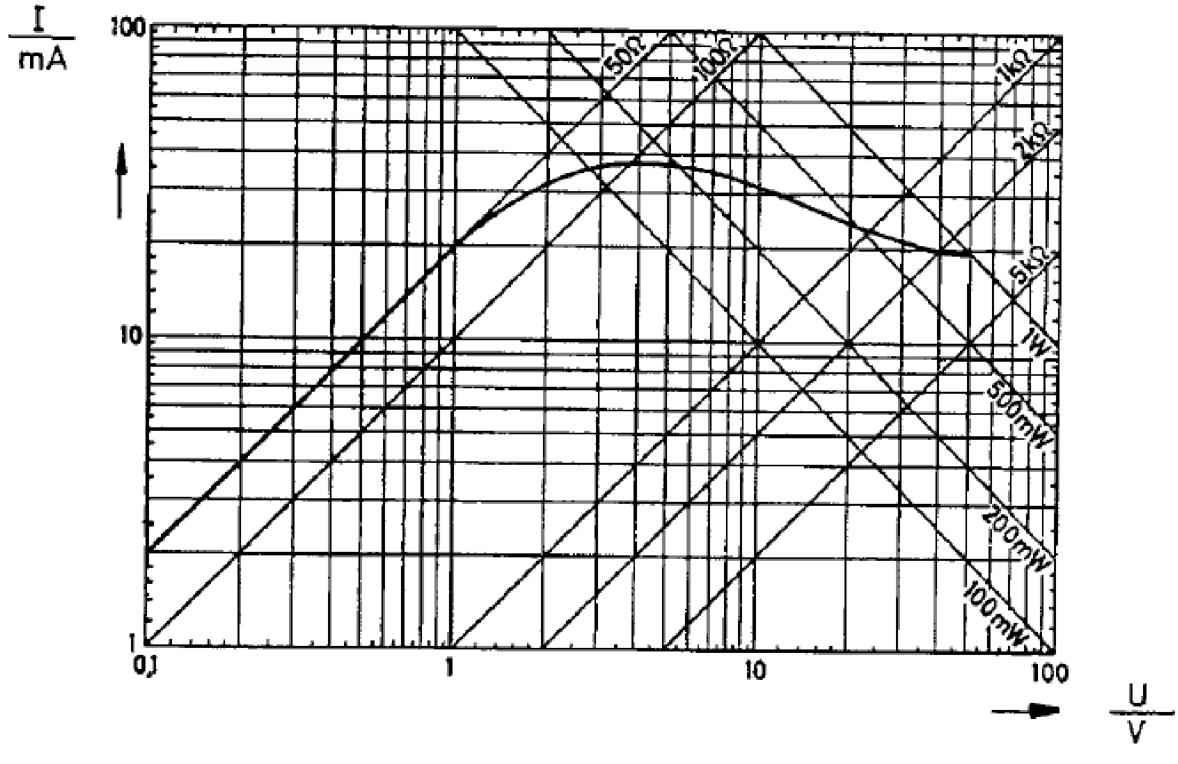
Characteristics of NTC





Characteristics of PTC





Assuming, as a first-order approximation, that the relationship between resistance and temperature is linear, then:

$$\Delta R = k\Delta T$$

where

ΔR= change in resistance
ΔT= change in temperature
k= first-order temperature coefficient of resistance

Thermistors can be classified into two types, depending on the sign of k. If $k$is positive, the resistance increases with increasing temperature, and the device is called a positive temperature coefficient (**PTC**) thermistor, or **posistor**. If $k$is negative, the resistance decreases with increasing temperature, and the device is called a negative temperature coefficient (**NTC**) thermistor. Resistors that are not thermistors are designed to have a $k$as close to zero as possible, so that their resistance remains nearly constant over a wide temperature range.

Instead of the temperature coefficient *k*, sometimes the *temperature coefficient of resistance* α_T(alpha sub T) is used. It is defined as[2]

$$\alpha_T = \frac{1}{R(T)}\frac{dR}{dT}.$$

This $\alpha_T$coefficient should not be confused with the $a$parameter below.

In practice, the linear approximation (above) works only over a small temperature range. For accurate temperature measurements, the resistance/temperature curve of the device must be described in more detail.

Most PTC thermistors are of the "switching" type, which means that their resistance rises suddenly at a certain critical temperature. The devices are made of a doped polycrystalline ceramic containing barium titanate ($BaTiO_3$) and other compounds. The dielectric constant of this ferroelectric material varies with temperature. Below the Curie point temperature, the high dielectric constant prevents the formation of potential barriers between the crystal grains, leading to a low resistance. In this region the device has a small negative temperature coefficient. At the Curie point temperature, the dielectric constant drops sufficiently to allow the formation of potential barriers at the grain boundaries, and the resistance increases sharply. At even higher temperatures, the material reverts to NTC behaviour. The equations used for modeling this behaviour were derived by W. Heywang and G. H. Jonker in the 1960s.

Another type of PTC thermistor is the polymer PTC, which is sold under brand names such as "Polyswitch" "Semifuse", and "Multifuse". This consists of a slice of plastic with carbon grains embedded in it. When the plastic is cool, the carbon grains are all in contact with each other, forming a conductive path through the device. When the plastic heats up, it expands, forcing the carbon grains apart, and causing the resistance of the device to rise rapidly. Like the $BaTiO_3$ thermistor, this device has a highly nonlinear resistance/temperature response and is used for switching, not for proportional temperature measurement.

Yet another type of thermistor is a **silistor**, a thermally sensitive silicon resistor. Silistors are similarly constructed and operate on the same principles as other thermistors, but employ silicon as the semiconductive component material.

Self-heating effects

When a current flows through a thermistor, it will generate heat which will raise the temperature of the thermistor above that of its environment. If the thermistor is being used to measure the temperature of the environment, this electrical heating may introduce a significant error if a correction is not made. Alternatively, this effect itself can be exploited. It can, for example, make a sensitive air-flow device employed in a sailplane rate-of-climb instrument, the electronic variometer, or serve as a timer for a relay as was formerly done in telephone exchanges.

The electrical power input to the thermistor is just:

$$P_E = IV$$

where *I* is current and *V* is the voltage drop across the thermistor. This power is converted to heat, and this heat energy is transferred to the surrounding environment. The rate of transfer is well described by Newton's law of cooling:

$$P_T = K(T(R) - T_0)$$

where *T(R)* is the temperature of the thermistor as a function of its resistance *R*, T_0 is the temperature of the surroundings, and *K* is the **dissipation constant**, usually expressed in units of milliwatts per degree Celsius. At equilibrium, the two rates must be equal.

$$P_E = P_T$$

The current and voltage across the thermistor will depend on the particular circuit configuration. As a simple example, if the voltage across the thermistor is held fixed, then by Ohm's Law we have $I = V/R$ and the equilibrium equation can be solved for the ambient temperature as a function of the measured resistance of the thermistor:

$$T_0 = T(R) - \frac{V^2}{KR}$$

The dissipation constant is a measure of the thermal connection of the thermistor to its surroundings. It is generally given for the thermistor in still air, and in well-stirred oil. Typical values for a small glass bead thermistor are 1.5 mW/°C in still air and 6.0 mW/°C in stirred oil. If the temperature of the environment is known beforehand, then a thermistor may be used to measure the value of the dissipation constant. For example, the thermistor may be used as a flow rate sensor, since the dissipation constant increases with the rate of flow of a fluid past the thermistor.

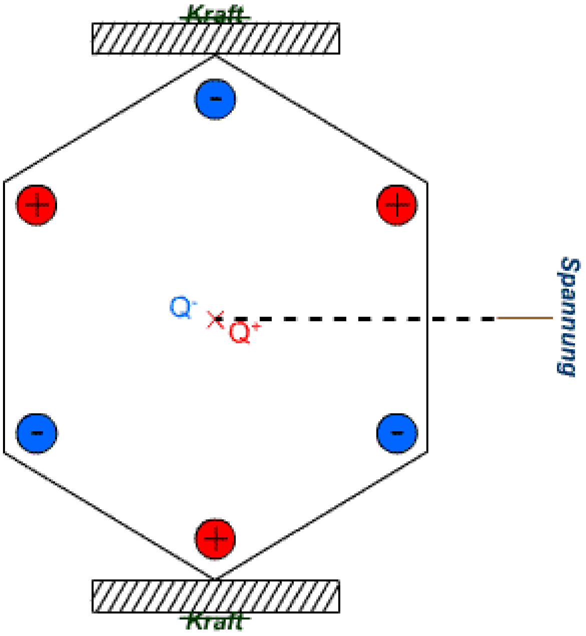
The power dissipated in a thermistor is typically maintained at a very low level to ensure insignificant temperature measurement error due to self heating. However, some thermistor applications depend upon significant "self heating" to raise the body temperature of the thermistor well above the ambient temperature so the sensor then detects even subtle changes in the thermal conductivity of the environment. Some of these applications include liquid level detection, liquid flow measurement and air flow measurement.[4]

Applications

- PTC thermistors can be used as current-limiting devices for circuit protection, as replacements for fuses. Current through the device causes a small amount of resistive heating. If the current is large enough to generate more heat than the device can lose to its surroundings, the device heats up, causing its resistance to increase, and therefore causing even more heating. This creates a self-reinforcing effect that drives the resistance upwards, reducing the current and voltage available to the device.
- PTC thermistors were used as timers in the degaussing coil circuit of most CRT displays. When the display unit is initially switched on, current flows through the thermistor and degaussing coil. The coil and thermistor are intentionally sized so that the current flow will heat the thermistor to the point that the degaussing coil shuts off in under a second. For effective degaussing, it is necessary that the magnitude of the alternating magnetic field produced by the degaussing coil decreases smoothly and continuously, rather than sharply switching off or decreasing in steps; the PTC thermistor accomplishes this naturally as it heats up. A degaussing circuit using a PTC thermistor is simple, reliable (for its simplicity), and inexpensive.

- NTC thermistors are used as resistance thermometers in low-temperature measurements of the order of 10 K.
- NTC thermistors can be used as inrush-current limiting devices in power supply circuits. They present a higher resistance initially which prevents large currents from flowing at turn-on, and then heat up and become much lower resistance to allow higher current flow during normal operation. These thermistors are usually much larger than measuring type thermistors, and are purposely designed for this application.
- NTC thermistors are regularly used in automotive applications. For example, they monitor things like coolant temperature and/or oil temperature inside the engine and provide data to the ECU and, indirectly, to the dashboard.
- NTC thermistors can be also used to monitor the temperature of an incubator.
- Thermistors are also commonly used in modern digital thermostats and to monitor the temperature of battery packs while charging.
- Thermistors are also used in the hot ends of 3d printers, they produce heat and keep a constant temperature for melting the plastic filament.
- NTC Thermistors are used in the Food Handling and Processing industry, especially for food storage systems and food preparation. Maintaining the correct temperature is critical to prevent food borne illness.
- NTC Thermistors are used throughout the Consumer Appliance industry for measuring temperature. Toasters, coffee makers, refrigerators, freezers, hair dryers, etc. all rely on thermistors for proper temperature control

3.Piezoelectricity



Direct Piezoelectric Effect: by mechanical pressure shifts the positive (Q +) and negative charge center (Q). This results in a dipole , or a voltage of the element.

Piezoelectricity describes the change of the electric polarization , and thus the occurrence of an electrical voltage is applied to solids when they elastically deformed *(direct piezoelectric effect).* Conversely deform materials when an electrical voltage *(an inverse piezoelectric effect).*

Principle

By the directional deformation of a piezoelectric material is microscopic form dipoles within the unit cells (shift of charge - focus). The summation over the associated electric field in each unit cell of the crystal leads to a macroscopically measurable electrical voltage . *looking* deformation means that the pressure applied by all sides to the test works, but for example, only from the opposite sides. Conversely, by applying an electrical voltage, a deformation of the crystal (or the component of piezoelectric ceramic) can be achieved.

Like any other solids, can also piezoelectric body perform mechanical vibrations. Piezoelectrics in these vibrations can be excited electrically, and in turn cause an electrical voltage. The frequency of oscillation is from the speed of sound (a material constant) and the dimensions of the piezoelectric body dependent. With a suitable mounting these are natural frequencies hardly affected by environmental influences, which piezoelectric devices such as quartz crystals very well suited for use in precision oscillators are suitable (eg quartz).

Piezoelectric materials

Basics

The piezoelectric effect can be explained by the first change in the geometry. This is the piezoelectric resistive effect. Stretched, thus longer and thinner, a wire has a higher resistance. For metals, the piezoelectric effect is based solely on the change in the geometry. Furthermore, all are non-conductive ferroelectric materials or materials with a permanent electric dipole also piezoelectric, such as barium titanate and lead zirconate titanate (PZT). However, only a part of piezoelectrics behaves ferroelectric.

In crystals, the crystal symmetry is another criterion for the occurrence of piezoelectricity. The piezoelectric polarization does not occur, when the crystal has a center of inversion. For all 21 non-centrosymmetric point groups can piezoelectricity occur, except for the cubic point group *432nd* In other words, a unit cell may no center of symmetry (= a point at which a point mirroring the crystal transferred into itself) have.

The best known material with piezoelectric properties, quartz (SiO_2). Quartz crystals have the non-centrosymmetric point assembly *32*. Each Si atom is located in the center of a tetrahedron of four oxygen atoms. One in the direction of base-to-peak (Crystallographic direction: [111]) acting force deforms now this tetrahedron such that the compressed tetrahedra are electrically polarized and so on the surfaces of the crystal (in the [111] direction), a net voltage occurs.

Technically used materials that exhibit a stronger effect than quartz piezo guide, often of the perovskite structure from, for example: barium titanate ($BaTiO_3$). The cubic perovskite modification itself has *m3m* the centrosymmetric point group, and is thus non-piezoelectric, the material can, however, below a critical temperature - the piezoelectric Curie temperature T_C - (pass into a non-centrosymmetric perovskite structure rhombohedral / tetragonal, see lead zirconate titanate). It then shows a spontaneous polarization , and has ferroelectric properties.

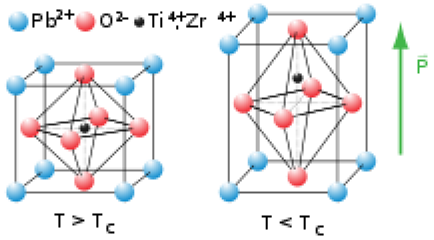
Piezoelectric crystals

- The main piezoelectric quartz crystal is, more precisely up to 573 ° C stable trigonal crystal structure α-quartz. The most important application are oscillating crystals.
- Lithium has increased compared to quartz piezoelectric constants and for piezoelectric filters and SAW devices (English: *surface acoustic wave*, surface acoustic wave) is used.
- Gallium is only since the 1990s, available as piezoelectric. This material is similar to the crystal, but has higher piezoelectric constants and better temperature stability. It is stable up to 900 ° C.

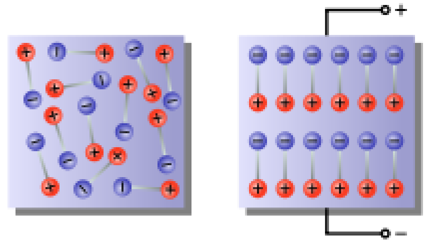
Further piezo-electric crystals are berlinite , minerals of Turmalingruppe , Rochelle salt and all ferroelectrics such as barium titanate (BTO), or lead zirconate titanate (PZT). BTO and PZT but are usually not used as single crystals, but in polycrystalline form (ceramics).

Against piezoelectric crystals piezoelectric ceramics such as PZT have the advantage of substantially higher piezoelectric coefficients. Advantages of the crystals of quartz, gallium and lithium , higher thermal stability, lower losses, a substantially lower hysteresis and it hardly creep (ie delayed deformation) after changing the voltage applied.

Piezoelectric ceramics



Perovskite unit cell of piezoceramics. Below the Curie temperature is formed from a dipole.



Memorize a polarization direction by the alignment of the dipoles in an electric field

Industrially produced piezo elements are mostly ceramics . These ceramics are made from synthetic , inorganic , ferroelectric and polycrystalline ceramic materials made. Typical base materials for high-voltage actuators are modified lead zirconate titanate (PZT), and for low-voltage actuators lead magnesium niobate (PMN).

The composite of the PZT ceramics (Pb, O, Ti / Zr) crystallizes in the perovskite crystal structure, below Curie temperature of the piezoelectric is formed by distortions of the ideal perovskite structure has a dipole moment of. Of ceramic piezoelectric elements, the internal dipoles after sintering process still disordered, which is why there is no show piezoelectric properties. The Weiss' domains or domains have a random spatial orientation and balance each other. Significant measurable piezoelectric property can be only by an external DC electric field impress (some 10^6 V / m), while the material to just below the Curie temperature is heated and cooled. The impressed orientation then remains for the most part obtained *(remanent* polarization) and is referred to as *direction of polarization.*

The rotation of the white 'domains by the polarization leads to a slight distortion of the material and a macroscopic length increase in polarization direction.

Other piezoelectric materials

As an active sensor materials increasingly are piezoelectric thin films used. With the help of semiconductor technology, it is possible to deposit these active piezoelectric thin films on silicon. These are mostly zinc oxide (ZnO) or aluminum nitride (AlN).

The plastic polyvinylidene fluoride (PVDF) can be - like piezoelectric ceramics - polarize and then piezoelectric. Applications include, for example, hydrophones .

Applications

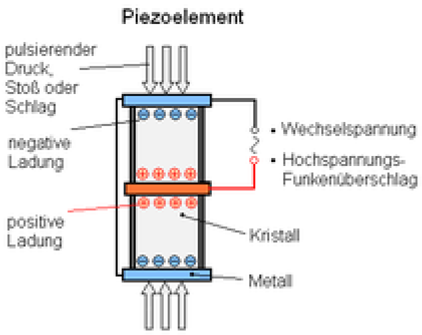
Today, piezoelectric devices are used in many industries: industrial and manufacturing, automotive, medical, telecommunications, etc. In 2010, the global market for piezoelectric devices achieved a turnover of around 14.8 billion U.S. dollars. [2]

Generally, the applications can be divided into three areas:

1. Sensors
2. Actuators
3. Electrical Components

Sensors

The appearance of the piezoelectric charge in the case of mechanical deformation force, pressure and acceleration sensors used. The resulting charge can with a charge amplifier in a voltage with a low source impedance can be converted. For the other option, with this charge charge a capacitor and measure the voltage with a possible high-impedance voltmeter, inadequate insulation resistance, for example, moisture falsify the result and prevent the registration slow deformations.



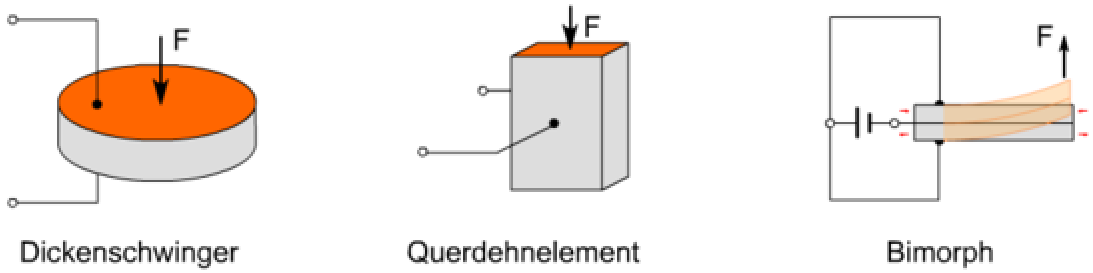
Piezoelectric element for the conversion of mechanical pressure to electrical voltage.

- In music, piezo elements as pickups used for acoustic instruments, mainly for string instruments such as guitar , violin or mandolin . The dynamic deformation of the instrument (vibration of the sound source) is converted into a low AC voltage is converted, which is then electrically amplified is.
- With piezoelectric acceleration sensors or transducers, it is in a mechanical deformation (compression or shear) by the acceleration to a charge separation and thus to a tapped charge (or voltage) to the vapor-deposited electrode.
- When quartz crystals, the influence of various factors on the resonance frequency, are exploited in surface acoustic wave components of the influence on the delay time. An important application is the measurement of the force applied to the crystal mass, for example in industrial coating method for the determination of the layer thickness. It can also be the temperature dependence of the oscillation frequency can be measured and such quartz thermometer but are no longer on the market.

actuators

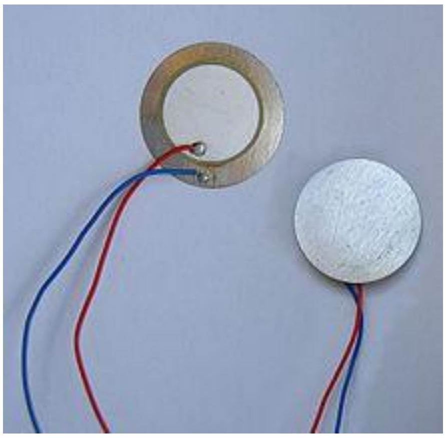
Piezo actuators can be made between two different criteria: by mode (quasi-static or resonant mode) or by the direction of the effect used. Since the transverse and longitudinal effect occur simultaneously, is distinguished according to the used effect.

From the distinction transversal (cross-effect) and Longitudinal (longitudinal effect) results in three different basic elements for piezoelectric actuators: the thickness vibrator, and as the Querdehnelement special design of the U-tube (bimorph). This is a combination of two Querdehnelementen. An opposite control of the elements in this case causes a bending of the actuator, which is why he gets a separate designation.



Piezoaktorische basic elements

Over the cross and longitudinal effect addition, the piezoelectric perpendicular by applying the electric field to the polarization direction, a shearing experienced. But this effect is usually only in acoustic transducers and accelerometers used.



Piezo Buzzer , English *Buzzer*

In the category of quasistatic operation also covers actuators which operate in the kHz range, as long as the case of resonance does not occur. The high accuracy and wide dynamic predestine the piezoelectric actuator for positioning and active vibration control. Through the use of stacked piezoelectric elements or lever can be extended to the relatively short travel ranges of $\Delta l / l = 10^{-3.}$ Limiting the adjustment paths contribute the dielectric strength of the material, the high operating voltage and the current in a saturation characteristic of the material. Typical changes in length are at low voltage elements at 0.1 microns, in high-voltage components at about 1 micron. If larger travel ranges are handled, offers itself to the resonant mode.

In the resonant operation of the rotor of the motor is from the piezo by a traveling wave driven. Additionally, the mass inertia of the rotor is used to produce a continuous movement. Thus possible to meet larger adjustment paths, such as in a lens (optics) .

As examples of the use of quasi-static piezoelectric actuators are: Braille for the blind, which is pushed up by applying a voltage to the blind tactile pins, which is implemented on the PC monitor in tactile Braille text characters.

Classic examples of this form of operation should ink printer (german *drop on demand*, for example, by Epson) and piezo speaker be, in which the sound waves are generated by an audio-frequency alternating voltage. Even diesel injection systems work with piezoelectric actuators (multilayer ceramic components with precious metal internal electrodes) and have the common rail technology improved. Here, the injection of diesel via valves is partially replaced. Since 2005, when are pump-nozzle system used piezoelectric actuators. Industrial companies who manufacture these actuators in large numbers, the company Epcos and Bosch .

The polarization of the piezoelectric element defines the spatial directions fixed in the piezoelectric element. Hence the anisotropic piezoelectric charge constants are predetermined. Typically have: d = -0.5 · d longitudinally transversely. For two-or three-dimensional movements, several piezo elements are combined so that they act in different directions.

Electrical Components

In these applications, a mechanical vibration of a piezoelectric solid body is electrically excited and then electrically detected. There is a fundamental distinction between two types:

- Volume resonators, where substantially all the piezoelectric element vibrates. The main representatives are quartz crystals and ceramic filters.
- SAW devices based on surface acoustic waves (german *surface acoustic wave*, SAW). Examples are SAW filters and delay lines.

As a component is the piezoelectric transformer used as a form of the resonant transformer for generating the high voltage in the range of the inverter . He used to supply tubes (CCFL) as a backlight for TFT displays are used.

Other applications

The piezoelectric effect is used in piezoelectric lighters , here in a piezo igniter is a sudden large pressure (Hammer) used to produce a short-term high electric voltage. The spark discharge will then ignite the gas flame. Impact detonator, such as in the warheads of anti-tank weapons (bazooka / RPG-7), piezoelectric microphones (crystal microphones), piezo speakers in headphones, piezo sirens or - Summer are other uses.

A number of micromechanical sensors makes itself piezoelectricity advantage, such as accelerometers , angular rate - pressure - and force sensors and ultrasonic sensors, micro balances and knock sensors in the car.

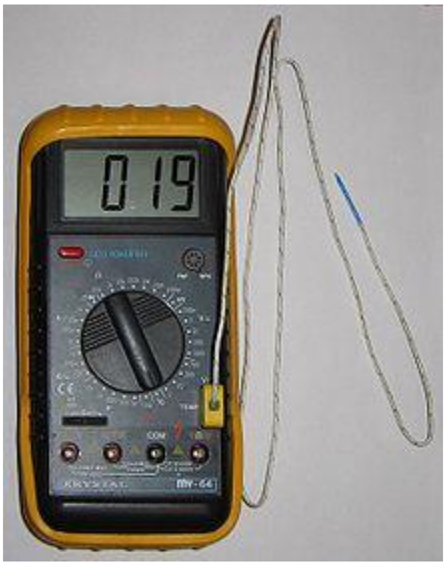
Also, some micromechanical actuators based on piezoelectricity: Piezo Motors (Squiggler), ultrasonic motors , eg for the lens autofocusing or watches drives , in the field of micro-and nanopositioning systems are scanning tunneling microscope , scanning electron microscope and atomic force microscope piezoelectrically driven systems. In valve technology are injectors of cars (production start 2000 for diesel engines), proportional pressure regulator and pressure heads of inkjet printers to mention.

Pickups , electro-acoustic delay lines , such as in older PAL - or SECAM color television sets, powered wireless technology (switch) and optical modulators are also piezoelectric devices.

Feeding uses many of the components mentioned.

http://www.youtube.com/watch?v=Jglork3SDck

4.Thermocouple

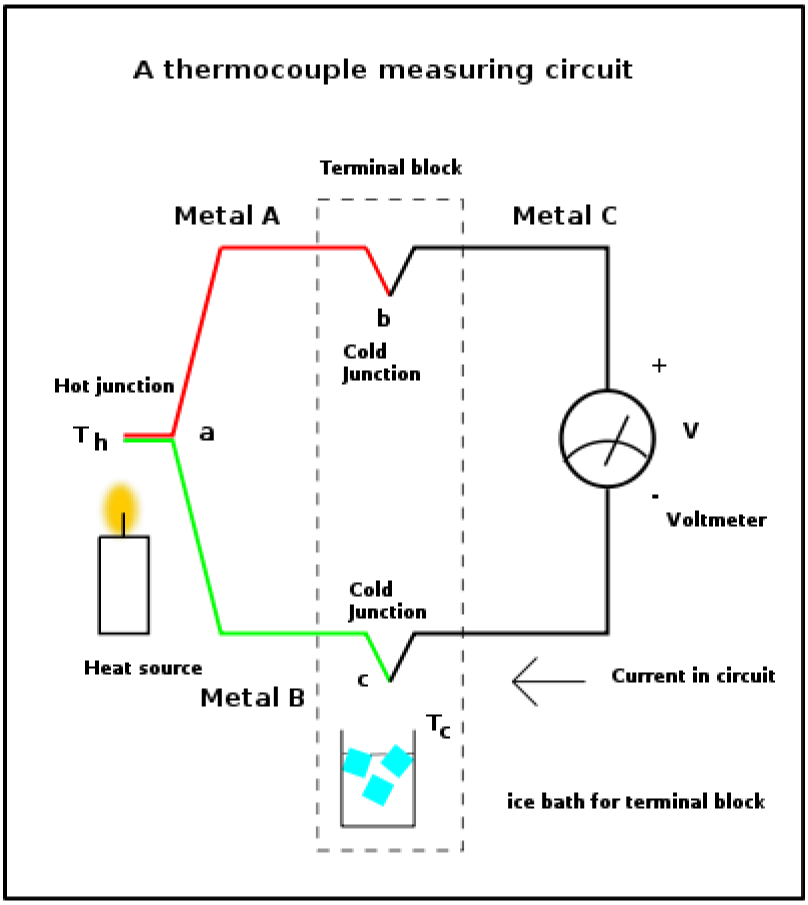


Thermocouple connected to a multimeter displaying room temperature in °C.

A **thermocouple** consists of two conductors of different materials (usually metal alloys) that produce a voltage in the vicinity of the point where the two conductors are in contact. The voltage produced is dependent on, but not necessarily proportional to, the difference of temperature of the junction to other parts of those conductors. Thermocouples are a widely used type of temperature sensor for measurement and control[1] and can also be used to convert a temperature gradient into electricity. They are inexpensive,[2] interchangeable, are supplied with standard connectors, and can measure a wide range of temperatures. In contrast to most other methods of temperature measurement, thermocouples are self powered and require no external form of excitation. The main limitation with thermocouples is accuracy; system errors of less than one degree Celsius (C) can be difficult to achieve.[3]

Any junction of dissimilar metals will produce an electric potential related to temperature. Thermocouples for practical measurement of temperature are junctions of specific alloys which have a predictable and repeatable relationship between temperature and voltage. Different alloys are used for different temperature ranges. Properties such as resistance to corrosion may also be important when choosing a type of thermocouple. Where the measurement point is far from the measuring instrument, the intermediate connection can be made by extension wires which are less costly than the materials used to make the sensor. Thermocouples are usually standardized against a reference temperature of 0 degrees Celsius; practical instruments use electronic methods of cold-junction compensation to adjust for varying temperature at the instrument terminals. Electronic instruments can also compensate for the varying characteristics of the thermocouple, and so improve the precision and accuracy of measurements.

Thermocouples are widely used in science and industry; applications include temperature measurement for kilns, gas turbine exhaust, diesel engines, and other industrial processes.



A thermocouple measuring circuit with a heat source, cold junction and a measuring instrument.

Principle of operation

In 1821, the German–Estonian physicist Thomas Johann Seebeck discovered that when any conductor is subjected to a thermal gradient, it will generate a voltage. This is now known as the thermoelectric effect or Seebeck effect. Any attempt to measure this voltage necessarily involves connecting another conductor to the "hot" end. This additional conductor will then also experience the temperature gradient, and develop a voltage of its own which will oppose the original. Fortunately, the magnitude of the effect depends on the metal in use. Using a dissimilar metal to complete the circuit creates a circuit in which the two legs generate different voltages, leaving a small difference in voltage available for measurement. That difference increases with temperature, and is between 1 and 70 microvolts per degree Celsius (µV/°C) for standard metal combinations.

The voltage is not generated at the junction of the two metals of the thermocouple but rather along that portion of the length of the two dissimilar metals that is subjected to a temperature gradient. Because both lengths of dissimilar metals experience the same temperature gradient, the end result is a measurement of the difference in temperature between the thermocouple junction and the reference junction.

Laws for thermocouple circuits

The properties of thermoelectric junctions with varying temperatures and compositions can be summarized in three laws describing the behaviour of thermocouple circuits.

Homogeneous material

A thermoelectric current cannot be sustained in a circuit of a single homogeneous material by the application of heat alone, regardless of how it might vary in cross section. In other words, temperature changes in the wiring between the input and output do not affect the output voltage, provided all wires are made of the same materials as the thermocouple. No current flows in the circuit made of a single metal by the application of heat alone.[*citation needed*]

Intermediate materials

The algebraic sum of the thermoelectric EMFs in a circuit composed of any number of dissimilar materials is zero if all of the junctions are at a uniform temperature. So If a third metal is inserted in either wire and if the two new junctions are at the same temperature, there will be no net voltage generated by the new metal.[*citation needed*]

Successive or intermediate temperatures

If two dissimilar homogeneous materials produce thermal EMF1 when the junctions are at T1 and T2 and produce thermal EMF2 when the junctions are at T2 and T3, the EMF generated when the junctions are at T1 and T3 will be EMF1 + EMF2, provided T1<T2<T3.[*citation needed*]

Practical use

Voltage–temperature relationship

For typical metals used in thermocouples, the output voltage increases almost linearly with the temperature difference (ΔT) over a bounded range of temperatures. For precise measurements or measurements outside of the linear temperature range, non-linearity must be corrected. The nonlinear relationship between the temperature difference (ΔT) and the output voltage (a few mV) of a thermocouple can be approximated by a polynomial:

$$\Delta T = \sum_{n=0}^{N} a_n v^n$$

The coefficients a_n are given for n from 0 to between 5 and 13 depending upon the metals. In some cases better accuracy is obtained with additional non-polynomial terms.[4] A database of voltage as a function of temperature, and coefficients for computation of temperature from voltage and vice-versa for many types of thermocouple is available online.[4]

In modern equipment the equation is usually implemented in a digital controller or stored in a look-up table;[5] older devices use analog circuits.

Piece-wise linear approximations are an alternative to polynomial corrections.[6]

Cold junction compensation

Thermocouples measure the temperature difference between two points, not absolute temperature. To measure a single temperature one of the junctions—normally the cold junction—is maintained at a known reference temperature, and the other junction is at the temperature to be sensed.

Having a junction of known temperature, while useful for laboratory calibration, is not convenient for most measurement and control applications. Instead, they incorporate an artificial cold junction using a thermally sensitive device such as a thermistor or diode to measure the temperature of the input connections at the instrument, with special care being taken to minimize any temperature gradient between terminals. Hence, the voltage from a known cold junction can be simulated, and the appropriate correction applied. This is known as cold junction compensation. Some integrated circuits are designed for cold junction temperature compensation for specific thermocouple types.

Grades

Thermocouple wire is available in several different metallurgical formulations per type, typically, in decreasing levels of accuracy and cost: special limits of error, standard, and extension grades.

Extension grade wires made of the same metals as a higher-grade thermocouple are used to connect it to a measuring instrument some distance away without introducing additional junctions between dissimilar materials which would generate unwanted voltages; the connections to the extension wires, being of like metals, do not generate a voltage.

In the case of platinum thermocouples, extension wire is a copper alloy, since it would be prohibitively expensive to use platinum for extension wires. The extension wire is specified to have a very similar thermal coefficient of EMF to the thermocouple, but only over a narrow range of temperatures; this reduces the cost significantly.

The temperature-measuring instrument must have high input impedance to prevent any significant current draw from the thermocouple, to prevent a resistive voltage drop across the wire. Changes in metallurgy along the length of the thermocouple (such as termination strips or changes in thermocouple type wire) will introduce another thermocouple junction which affects measurement accuracy.

Applications

Thermocouples are suitable for measuring over a large temperature range, up to 2300 °C. They are less suitable for applications where smaller temperature differences need to be measured with high accuracy, for example the range 0–100 °C with 0.1 °C accuracy. For such applications thermistors, silicon bandgap temperature sensors and resistance temperature detectors are more suitable. Applications include temperature measurement for kilns, gas turbine exhaust, diesel engines, and other industrial processes.

Steel industry

Type B, S, R and K thermocouples are used extensively in the steel and iron industries to monitor temperatures and chemistry throughout the steel making process. Disposable, immersible, type S thermocouples are regularly used in the electric arc furnace process to accurately measure the temperature of steel before tapping. The cooling curve of a small steel sample can be analyzed and used to estimate the carbon content of molten steel.

Heating appliance safety

Many gas-fed heating appliances such as ovens and water heaters make use of a pilot flame to ignite the main gas burner when required. If it goes out, gas may be released, which is a fire risk and a health hazard. To prevent this, some appliances use a thermocouple in a fail-safe circuit to sense when the pilot light is burning. The tip of the thermocouple is placed in the pilot flame, generating a voltage which operates the supply valve which feeds gas to the pilot. So long as the pilot flame remains lit, the thermocouple remains hot, and the pilot gas valve is held open. If the pilot light goes out, the thermocouple temperature falls, causing the voltage across the thermocouple to drop and the valve to close. Some combined main burner and pilot gas valves (mainly by Honeywell) reduce the power demand to within the range of a single universal thermocouple heated by a pilot (25mV open circuit falling by half with the coil connected to 10~12mV @ 0.2~0.25A typically) by sizing the coil to be able to hold the valve open against a light spring, only after the initial turning-on force is provided by the user pressing and holding a knob to compress the spring during first lighting. These systems are identifiable by the 'press and hold for x minutes' in the pilot lighting instructions. (The holding current requirement of such a valve is much less than a bigger solenoid designed for pulling the valve in from closed would require.) Special test sets are made to confirm the valve let-go and holding currents as an ordinary milliameter cannot be used as it introduces more resistance than the gas valve coil. Apart from testing the open circuit voltage of the thermocouple, and the near short-circuit DC continuity through the thermocouple gas valve coil, the easiest non-specialist test is substitution of a known good gas valve.

Some systems, known as millivolt control systems, extend the thermocouple concept to both open and close the main gas valve as well. Not only does the voltage created by the pilot thermocouple activate the pilot gas valve, it is also routed through a thermostat to power the main gas valve as well. Here, a larger voltage is needed than in a pilot flame safety system described above, and a thermopile is used rather than a single thermocouple. Such a system requires no external source of electricity for its operation and so can operate during a power failure, provided all the related system components allow for this. Note that this excludes common forced air furnaces because external power is required to operate the blower motor, but this feature is especially useful for un-powered convection heaters. A similar gas shut-off safety mechanism using a thermocouple is sometimes employed to ensure that the main burner ignites within a certain time period, shutting off the main burner gas supply valve should that not happen.

Out of concern for energy wasted by the standing pilot, designers of many newer appliances have switched to an electronically controlled pilot-less ignition, also called intermittent ignition. With no standing pilot flame, there is no risk of gas buildup should the flame go out, so these appliances do not need thermocouple-based pilot safety switches. As these designs lose the benefit of operation without a continuous source of electricity, standing pilots are still used in some appliances. The exception is later model instantaneous (aka "tankless") water heaters that use the flow of water to generate the current required to ignite the gas burner, in conjunction with a thermocouple as a safety cut-off device in the event the gas fails to ignite, or the flame is extinguished.

Thermopile radiation sensors

Thermopiles are used for measuring the intensity of incident radiation, typically visible or infrared light, which heats the hot junctions, while the cold junctions are on a heat sink. It is possible to measure radiative intensities of only a few $\mu W/cm^2$ with commercially available thermopile sensors. For example, some laser power meters are based on such sensors.

Manufacturing

Thermocouples can generally be used in the testing of prototype electrical and mechanical apparatus. For example, switchgear under test for its current carrying capacity may have thermocouples installed and monitored during a heat run test, to confirm that the temperature rise at rated current does not exceed designed limits.

Power production

A thermocouple can produce current to drive some processes directly, without the need for extra circuitry and power sources. For example, the power from a thermocouple can activate a valve when a temperature difference arises. The electrical energy generated by a thermocouple is converted from the heat which must be supplied to the hot side to maintain the electric potential. A continuous transfer of heat is necessary because the current flowing through the thermocouple tends to cause the hot side to cool down and the cold side to heat up (the Peltier effect).

Thermocouples can be connected in series to form a thermopile, where all the hot junctions are exposed to a higher temperature and all the cold junctions to a lower temperature. The output is the sum of the voltages across the individual junctions, giving larger voltage and power output. In a radioisotope thermoelectric generator, the radioactive decay of transuranic elements as a heat source has been used to power spacecraft on missions too far from the Sun to use solar power.

Thermopiles heated by kerosene lamps were used to run batteryless radio receivers in isolated areas.[10] There are commercially produced lanterns that use the heat from a candle to run several light-emitting diodes, and thermoelectrically-powered fans to improve air circulation and heat distribution in wood stoves.

Thermoelectric cooling

The Peltier effect can be used for cooling, in the reverse process to a thermoelectric generator. Instead of generating electric power, the thermocouple consumes it, working as a heat pump.

Process plants

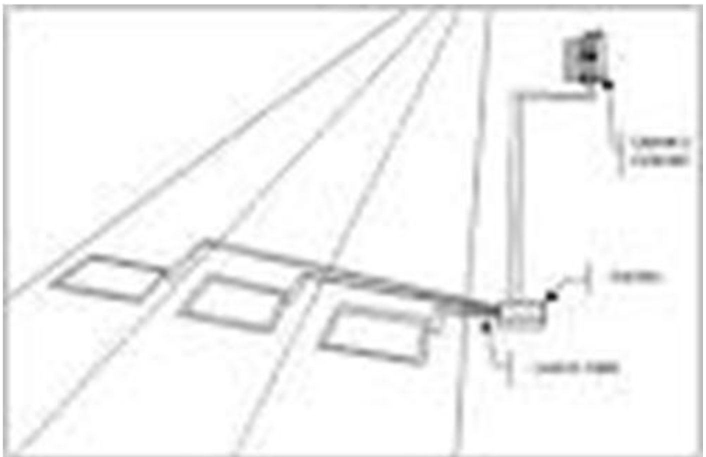
Chemical production and petroleum refineries will usually employ computers for logging and limit testing the many temperatures associated with a process, typically numbering in the hundreds. For such cases a number of thermocouple leads will be brought to a common reference block (a large block of copper) containing the second thermocouple of each circuit. The temperature of the block is in turn measured by a thermistor. Simple computations are used to determine the temperature at each measured location.

5.Induction loop

An **induction loop** is an electromagnetic communication or detection system, which uses a moving magnet to induce an electrical current in a nearby wire. Induction loops are used for transmission and reception of communication signals, or for detection of metal objects in metal detectors or vehicle presence indicators. A common modern use for induction loops is to provide hearing assistance to hearing-aid users.

Implementation





An example of the Inductance loop installed in the road for cars and bikes

The "aerial" system of an induction loop installation can consist of one or more loops of a conductive element.

In industrial applications this might be a large single- or multi-turn, loop, or a complex multi-lobed, phase coincident sub-loop design, most effectively mounted above the required reception area in industrial applications.

An audio induction loop might have one or more loops sometimes with a phase shift between them, and either near to or around the area in which a hearing aid user would be present. Many different configurations can be used depending on the application.[1]

Such an induction loop receiver is classically a very small iron-cored inductor (telecoil), although Rediffusion demonstrated a prototype Hall-Effect system in its PLL FM system.

The system commonly uses an analogue power amplifier matched to the low impedance of the transmission loop. The transmission is normally direct rather than superimposed or modulated upon a carrier, though multi-channel systems have been implemented using modulation.

Vehicle detection

Vehicle detection loops are used to detect vehicles passing or arriving at a certain point, for instance approaching a traffic light, and in motorway traffic management. An insulated, electrically conducting loop is installed in the pavement. The electronics unit transmits energy into the wire loops at frequencies between 10 kHz to 200 kHz, depending on the model. The inductive-loop system behaves as a tuned electrical circuit in which the loop wire and lead-in cable are the inductive elements. When a vehicle passes over the loop or is stopped within the loop, the vehicle induces eddy currents in the wire loops, which decrease their inductance. The decreased inductance actuates the electronics unit output relay or solid-state optically isolated output, which sends a pulse to the traffic signal controller signifying the passage or presence of a vehicle[2]. Parking structures for automobiles may have Parking Guidance and Information systems. Railways may use an induction loop to detect the passage of trains past a given point, as an electronic treadle.

Other uses

A different sort of "induction loop" is applied to metal detectors, where a large coil, which forms part of a resonant circuit, is effectively "detuned" by the coil's proximity to a conductive object. The detected object may be metallic (metal and cable detection) or conductive/capacitive (stud/cavity detection). Other configurations of this equipment use two or more receiving coils, and the detected object modifies the inductive coupling or alters the phase angle of the voltage induced in the receiving coils relative to the oscillator coil.

An increasingly common application is for providing hearing aid-compatible "assistive listening" telecoil. In this application a loop or series of loops is used to provide an audio frequency oscillating magnetic field in an area where a hearing aid user may be present. Many hearing aids contain a telecoil which allows the user to receive and hear the magnetic field and remove the normal audio signal provided from the hearing aid microphone[3] site. These loops are often referred to as a hearing loop or audio induction loop.

6.Capacitive sensing

This article is about the sensing technology used in human interfaces. For the device used in distance measurements, see Capacitive displacement sensor.

In electrical engineering, **capacitive sensing** is a technology based on capacitive coupling which takes human body capacitance as input.

Capacitive sensing is used in many different types of sensors, including those to detect and measure proximity, position or displacement, humidity, fluid level, and acceleration. Capacitive sensing as a human interface device (HID) technology, for example to replace the computer mouse, is growing increasingly popular.

Capacitive touch sensors are used in many devices such as laptop trackpads, digital audio players, computer displays, mobile phones, mobile devices, tablets and others. More and more design engineers are selecting capacitive sensors for their versatility, reliability and robustness, unique human-device interface and cost reduction over mechanical switches.

Capacitive sensors detect anything that is conductive or has a dielectric different than that of air. While capacitive sensing applications can replace mechanical buttons with capacitive alternatives, other technologies such as multi-touch and gesture-based touchscreens are also premised on capacitive sensing.

Design

Capacitive sensors are constructed from many different media, such as copper, Indium tin oxide (ITO) and printed ink. Copper capacitive sensors can be implemented on standard FR4 PCBs as well as on flexible material. ITO allows the capacitive sensor to be up to 90% transparent (for one layer solutions, such as touch phone screens). Size and spacing of the capacitive sensor are both very important to the sensor's performance. In addition to the size of the sensor, and its spacing relative to the ground plane, the type of ground plane used is very important. Since the parasitic capacitance of the sensor is related to the electric field's (e-field) path to ground, it is important to choose a ground plane that limits the concentration of e-field lines with no conductive object present.

Designing a capacitance sensing system requires first picking the type of sensing material (FR4, Flex, ITO, etc.). One also needs to understand the environment the device will operate in, such as the full operating temperature range, what radio frequencies are present and how the user will interact with the interface.

There are two types of capacitive sensing system: mutual capacitance,[3] where the object (finger, conductive stylus) alters the mutual coupling between row and column electrodes, which are scanned sequentially;[4] and self- or absolute capacitance where the object (such as a finger) loads the sensor or increases the parasitic capacitance to ground. In both cases, the difference of a preceding absolute position from the present absolute position yields the relative motion of the object or finger during that time. The technologies are elaborated in the following section.

Surface capacitance

In this basic technology, only one side of the insulator is coated with conductive material. A small voltage is applied to this layer, resulting in a uniform electrostatic field.[5] When a conductor, such as a human finger, touches the uncoated surface, a capacitor is dynamically formed. Due to the sheet resistance of the surface, each corner is measured to have a different effective capacitance.[*citation needed*] The sensor's controller can determine the location of the touch indirectly from the change in the capacitance as measured from the four corners of the panel: the larger the change in capacitance, the closer the touch is to that corner. With no moving parts, it is moderately durable, but has low resolution, is prone to false signals from parasitic capacitive coupling, and needs calibration during manufacture. Therefore, it is most often used in simple applications such as industrial controls and interactive kiosks.[6]

Projected capacitance

Projected capacitive touch (PCT) technology is a capacitive technology which allows more accurate and flexible operation, by etching the conductive layer. An X-Y grid is formed either by etching one layer to form a grid pattern of electrodes, or by etching two separate, perpendicular layers of conductive material with parallel lines or tracks to form the grid; comparable to the pixel grid found in many liquid crystal displays (LCD).[7]

The greater resolution of PCT allows operation with no direct contact, such that the conducting layers can be coated with further protective insulating layers, and operate even under screen protectors, or behind weather and vandal-proof glass. Due to the top layer of a PCT being glass, PCT is a more robust solution versus resistive touch technology. Depending on the implementation, an active or passive stylus can be used instead of or in addition to a finger. This is common with point of sale devices that require signature capture. Gloved fingers may or may not be sensed, depending on the implementation and gain settings. Conductive smudges and similar interference on the panel surface can interfere with the performance. Such conductive smudges come mostly from sticky or sweaty finger tips, especially in high humidity environments. Collected dust, which adheres to the screen due to the moisture from fingertips can also be a problem. There are two types of PCT: self capacitance, and mutual capacitance.

Mutual capacitive sensors have a capacitor at each intersection of each row and each column. A 12-by-16 array, for example, would have 192 independent capacitors. A voltage is applied to the rows or columns. Bringing a finger or conductive stylus near the surface of the sensor changes the local electric field which reduces the mutual capacitance. The capacitance change at every individual point on the grid can be measured to accurately determine the touch location by measuring the voltage in the other axis. Mutual capacitance allows multi-touch operation where multiple fingers, palms or styli can be accurately tracked at the same time.

Self-capacitance sensors can have the same X-Y grid as mutual capacitance sensors, but the columns and rows operate independently. With self-capacitance, current senses the capacitive load of a finger on each column or row. This produces a stronger signal than mutual capacitance sensing, but it is unable to resolve accurately more than one finger, which results in "ghosting", or misplaced location sensing

Circuit design

Capacitance is typically measured indirectly, by using it to control the frequency of an oscillator, or to vary the level of coupling (or attenuation) of an AC signal.

The design of a simple capacitance meter is often based on a relaxation oscillator. The capacitance to be sensed forms a portion of the oscillator's RC circuit or LC circuit. Basically the technique works by charging the unknown capacitance with a known current. (The equation of state for a capacitor is $i = C\ dv/dt$. This means that the capacitance equals the current divided by the rate of change of voltage across the capacitor.) The capacitance can be calculated by measuring the charging time required to reach the threshold voltage (of the relaxation oscillator), or equivalently, by measuring the oscillator's frequency. Both of these are proportional to the RC (or LC) time constant of the oscillator circuit.

The primary source of error in capacitance measurements is stray capacitance, which if not guarded against, may fluctuate between roughly 10 pF and 10 nF. The stray capacitance can be held relatively constant by shielding the (high impedance) capacitance signal and then connecting the shield to (a low impedance) ground reference. Also, to minimize the unwanted effects of stray capacitance, it is good practice to locate the sensing electronics as near the sensor electrodes as possible.

Another measurement technique is to apply a fixed-frequency AC-voltage signal across a capacitive divider. This consists of two capacitors in series, one of a known value and the other of an unknown value. An output signal is then taken from across one of the capacitors. The value of the unknown capacitor can be found from the ratio of capacitances, which equals the ratio of the output/input signal amplitudes, as could be measured by an AC voltmeter. More accurate instruments may use a capacitance bridge configuration, similar to a wheatstone bridge.[8] The capacitance bridge helps to compensate for any variability that may exist in the applied signal.

Comparison with other touchscreen technologies

Since capacitive screens respond to only materials which are conductive (human finger used most commonly), they can be cleaned with cloths with no accidental command input. Capacitive touchscreens are more responsive than resistive touchscreens.[9]

A standard stylus cannot be used for capacitive sensing unless it is tipped with some form of conductive material, such as anti-static conductive foam.[10] However, capacitive styli—different from standard styli—can be used as well as finger input on capacitive screens. Capacitive touchscreens are more expensive to manufacture and offer a significantly lesser degree of accuracy than resistive touchscreens.[9] Some cannot be used with gloves, and can fail to sense correctly with even a small amount of water on the screen.

Power supplies with high electronic noise can reduce accuracy.

Styli

Capacitive styli

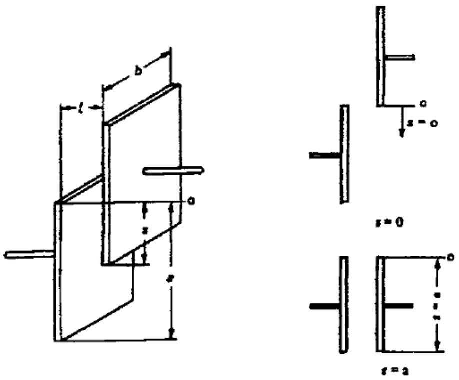
A stylus designed for resistive touchscreens will not register on capacitive sensors. Styli that work on capacitive touchscreens primarily designed for fingers are required to simulate the difference in dielectric offered by a human digit.[11]

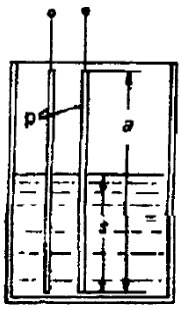
According to a report by ABI Research, styli are especially needed in China for handwriting recognition because of the nature of its writing system.[12]

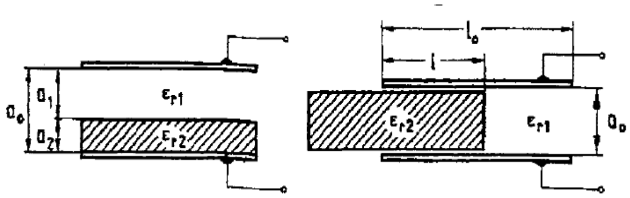
HTC patented a capacitive stylus in 2009. The design features a magnetic tip which is smaller and therefore more precise than the human finger.

7.Capacitive displacement sensor

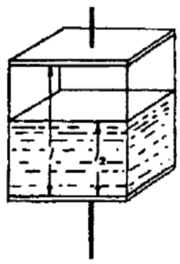
Capacitive displacement sensors “are non-contact devices capable of high-resolution measurement of the position and/or change of position of any conductive target”.[1] They are also able to measure the thickness or density of non-conductive materials.[2] Capacitive displacement sensors are used in a wide variety of applications including semiconductor processing, assembly of precision equipment such as disk drives, precision thickness measurements, machine tool metrology and assembly line testing. These types of sensors can be found in machining and manufacturing facilities around the world.







Anwendung: Füllstandsmessung in Flüssigkeiten und Schüttgütern.



Basic capacitive theory

Capacitance is an electrical property which is created by applying an electrical charge to two conductive objects with a gap between them. This property is most commonly illustrated using the example of two parallel conductive plates with a gap between them and a charge applied to them. In this situation, the Capacitance can be expressed by the equation:

$$C = \frac{\varepsilon_0 K A}{d}$$ [3]

Where C is the capacitance, ε_0 is the permittivity of free space constant, K is the dielectric constant of the material in the gap, A is the area of the plates, and d is the distance between the plates.

There are two general types of capacitive displacement sensing systems. One type is used to measure thicknesses of conductive materials. The other type measures thicknesses of non conductive materials or the level a fluid.

A capacitive sensing system for conductive materials uses a model similar to the one described above, but in place of one of the conductive plates, is the sensor, and in place of the other, is the conductive target to be measured. Since the area of the probe and target remain constant, and the dielectric of the material in the gap (usually air) also remains constant, "any change in capacitance is a result of a change in the distance between the probe and the target." [4] Therefore, the equation above can be simplified to:

$$C \propto \frac{1}{d}$$

Where α indicates a proportional relationship. Due to this proportional relationship, a capacitive sensing system is able to measure changes in capacitance and translate these changes into distance measurements.

The operation of the sensor for measuring thickness of non-conductive materials can be thought of as two capacitors in series, with each having a different dielectric (and dielectric constant). The sum of the thicknesses of the two dielectric materials remains constant but the thickness of each can vary. The thickness of the material to be measured displaces the other dielectric. The gap is often an air gap, (dielectric constant = 1) and the material has a higher dielectric. As the material gets thicker, the capacitance increases and is sensed by the system.

A sensor for measuring fluid levels works as two capacitors in parallel with constant total area. Again the difference in the dielectric constant of the fluid and the dielectric constant of air results in detectable changes in the capacitance between the conductive probes or plates.

Applications

Precision positioning

One of the more common applications of capacitive sensors is for precision positioning. Capacitive displacement sensors can be used to measure the position of objects down to the nanometer level. This type of precise positioning is used in the semiconductor industry where silicon wafers need to be positioned for exposure. Capacitive sensors are also used to pre-focus the electron microscopes used in testing and examining the wafers.

Disc drive industry

In the disc drive industry, capacitive displacement sensors are used to measure the runout (a measure of how much the axis of rotation deviates from an ideal fixed line) of disc drive spindles. By knowing the exact runout of these spindles, disc drive manufacturers are able to determine the maximum amount of data that can be placed onto the drives. Capacitive sensors are also used to ensure that disc drive platters are orthogonal to the spindle before data is written to them.

Precision thickness measurements

Capacitive displacement sensors can be used to make very precise thickness measurements. Capacitive displacement sensors operate by measuring changes in position. If the position of a reference part of known thickness is measured, other parts can be subsequently measured and the differences in position can be used to determine the thickness of these parts.[5] In order for this to be effective using a single probe, the parts must be completely flat and measured on a perfectly flat surface. If the part to be measured has any curvature or deformity, or simply does not rest firmly against the flat surface, the distance between the part to be measured and the surface it is placed upon will be erroneously included in the thickness measurement. This error can be eliminated by using two capacitive sensors to measure a single part. Capacitive sensors are placed on either side of the part to be measured. By measuring the parts from both sides, curvature and deformities are taken into account in the measurement and their effects are not included in the thickness readings.

The thickness of plastic materials can be measured with the material placed between two electrodes a set distance apart. These form a type of capacitor. The plastic when placed between the electrodes acts as a dielectric and displaces air (which has dielectric constant of 1, different than the plastic). Consequently the capacitance between the electrodes changes. The capacitance changes can then be measured and correlated with the material's thickness.[6]

Capacitive sensors circuits can be constructed that are able to detect changes in capacitance on the order of a 10^{-5} picofarads (10 attofarads).[7]

Non-conductive targets

While capacitive displacement sensors are most often used to sense changes in position of conductive targets, they can also be used to sense the thickness and/or density of non-conductive targets as well.[4] A non-conductive object placed in between the probe and conductive target will have a different dielectric constant than the air in the gap and will therefore change the Capacitance between probe and target. (See the first equation above) By analyzing this change in capacitance, the thickness and density of the non-conductor can be determined.

Machine tool metrology

Capacitive displacement sensors are often used in metrology applications. In many cases, sensors are used "to measure shape errors in the part being produced. But they also can measure the errors arising in the equipment used to manufacture the part, a practice known as machine tool metrology".[8] In many cases, the sensors are used to analyze and optimize the rotation of spindles in various machine tools, examples include surface grinders, lathes, milling machines, and air bearing spindles.[9] By measuring errors in the machines themselves, rather than simply measuring errors in the final products, problems can be dealt with and fixed earlier in the manufacturing process.

Assembly line testing

Capacitive displacement sensors are often used in assembly line testing. Sometimes they are used to test assembled parts for uniformity, thickness or other design features. At other times, they are used to simply look for the presence or absence of a certain component, such as glue.[10] Using capacitive sensors to test assembly line parts can help to prevent quality concerns further along in the production process.

8.Flow measurement

Flow measurement is the quantification of bulk fluid movement. Flow can be measured in a variety of ways. Positive-displacement flow meters accumulate a fixed volume of fluid and then count the number of times the volume is filled to measure flow. Other flow measurement methods rely on forces produced by the flowing stream as it overcomes a known constriction, to indirectly calculate flow. Flow may be measured by measuring the velocity of fluid over a known area.

Units of measurement

Both gas and liquid flow can be measured in volumetric or mass flow rates, such as liters per second or kilograms per second. These measurements can be converted between one another if the material's density is known. The density for a liquid is almost independent of the liquid conditions; however, this is not the case for gas, the density of which depends greatly upon pressure, temperature and to a lesser extent, the gas composition.

When gases or liquids are transferred for their energy content, such as the sale of natural gas, the flow rate may also be expressed in terms of energy flow, such as GJ/hour or BTU/day. The energy flow rate is the volume flow rate multiplied by the energy content per unit volume or mass flow rate multiplied by the energy content per unit mass. Where accurate energy comes to the time of the legit flow rate is desired, most flow meters will be used to calculate the volume or mass flow rate which is then adjusted to the energy flow rate by the use of a flow computer.

In engineering contexts, the volumetric flow rate is usually given the symbol Q, and the mass flow rate, the symbol $\dot{m}$.

Gas

Gases are compressible and change volume when placed under pressure, are heated or are cooled. A volume of gas under one set of pressure and temperature conditions is not equivalent to the same gas under different conditions. References will be made to "actual" flow rate through a meter and "standard" or "base" flow rate through a meter with units such as *acm/h* (actual cubic meters per hour), *kscm/h* (kilo standard cubic meters per hour), **LFM** (linear feet per minute), or *MSCFD* (thousands of standard cubic feet per day).

Gas *mass* flow rate can be directly measured, independent of pressure and temperature effects, with thermal mass flow meters, Coriolis mass flow meters, or mass flow controllers.

Liquid

For liquids, various units are used depending upon the application and industry, but might include gallons (U.S. liquid or imperial) per minute, liters per second, bushels per minute or, when describing river flows, cumecs (cubic metres per second) or acre-feet per day. In oceanography a common unit to measure volume transport (volume of water transported by a current for example) is a sverdrup (Sv) equivalent to 10^6 m^3 / s.

Mechanical flow meters

A bucket and a stopwatch is an analogy for the operation of a positive displacement meter The stopwatch is started when the flow starts, and stopped when the bucket reaches its limit. The volume divided by the time gives the flow rate. For continuous measurements, we need a system of continually filling and emptying buckets to divide the flow without letting it out of the pipe. These continuously forming and collapsing volumetric displacements may take the form of pistons reciprocating in cylinders, gear teeth mating against the internal wall of a meter or through a progressive cavity created by rotating oval gears or a helical screw.

Piston meter/Rotary piston

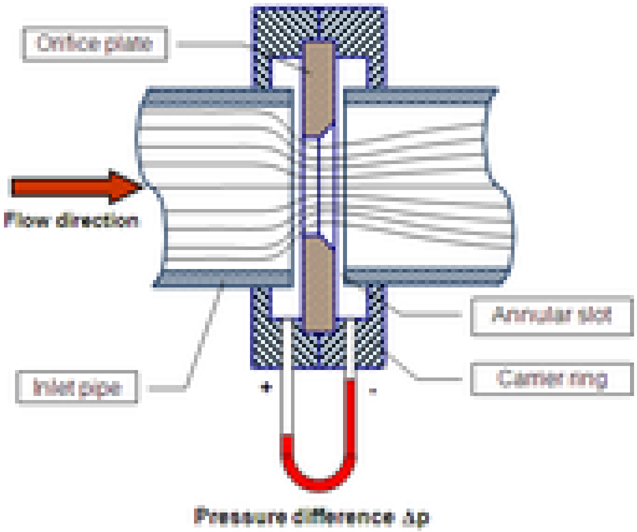
Because they are used for domestic water measurement, piston meters, also known as rotary piston or semi-positive displacement meters, are the most common flow measurement devices in the UK and are used for almost all meter sizes up to and including 40 mm (1½″). The piston meter operates on the principle of a piston rotating within a chamber of known volume. For each rotation, an amount of water passes through the piston chamber. Through a gear mechanism and, sometimes, a magnetic drive, a needle dial and odometer type display are advanced.

Pressure-based meters

There are several types of flow meter that rely on Bernoulli's principle, either by measuring the differential pressure within a constriction, or by measuring static and stagnation pressures to derive the dynamic pressure.

Venturi meter

A Venturi meter constricts the flow in some fashion, and pressure sensors measure the differential pressure before and within the constriction. This method is widely used to measure flow rate in the transmission of gas through pipelines, and has been used since Roman Empire times.The coefficient of discharge of Venturi meter ranges from 0.93 to 0.97.



ISO 5167 Orifice Plate

Optical flow meters

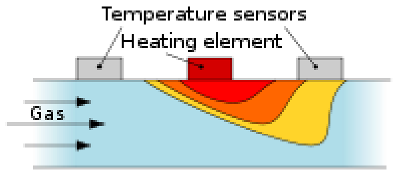
Optical flow meters use light to determine flow rate. Small particles which accompany natural and industrial gases pass through two laser beams focused a short distance apart in the flow path. in a pipe by illuminating optics. Laser light is scattered when a particle crosses the first beam. The detecting optics collects scattered light on a photodetector, which then generates a pulse signal. As the same particle crosses the second beam, the detecting optics collect scattered light on a second photodetector, which converts the incoming light into a second electrical pulse. By measuring the time interval between these pulses, the gas velocity is calculated as $V = D/t$where $D$is the distance between the laser beams and $t$is the time interval.

Laser-based optical flow meters measure the actual speed of particles, a property which is not dependent on thermal conductivity of gases, variations in gas flow or composition of gases. The operating principle enables optical laser technology to deliver highly accurate flow data, even in challenging environments which may include high temperature, low flow rates, high pressure, high humidity, pipe vibration and acoustic noise.

Optical flow meters are very stable with no moving parts and deliver a highly repeatable measurement over the life of the product. Because distance between the two laser sheets does not change, optical flow meters do not require periodic calibration after their initial commissioning. Optical flow meters require only one installation point, instead of the two installation points typically required by other types of meters. A single installation point is simpler, requires less maintenance and is less prone to errors.

Commercially available optical flow meters are capable of measuring flow from 0.1 m/s to faster than 100 m/s (1000:1 turn down ratio) and have been demonstrated to be effective for the measurement of flare gases from oil wells and refineries, a contributor to atmospheric pollution.[6]

Thermal mass flow meters



Temperature at the sensors varies depending upon the mass flow

Thermal mass flow meters generally use combinations of heated elements and temperature sensors to measure the difference between static and flowing heat transfer to a fluid and infer its flow with a knowledge of the fluid's specific heat and density. The fluid temperature is also measured and compensated for. If the density and specific heat characteristics of the fluid are constant, the meter can provide a direct mass flow readout, and does not need any additional pressure temperature compensation over their specified range.

Technological progress has allowed the manufacture of thermal mass flow meters on a microscopic scale as MEMS sensors; these flow devices can be used to measure flow rates in the range of nanolitres or microlitres per minute.

Thermal mass flow meter (also called thermal dispersion flowmeter) technology is used for compressed air, nitrogen, helium, argon, oxygen, and natural gas. In fact, most gases can be measured as long as they are fairly clean and non-corrosive. For more aggressive gases, the meter may be made out of special alloys (e.g. Hastelloy), and pre-drying the gas also helps to minimize corrosion.

Today, thermal mass flow meters are used to measure the flow of gases in a growing range of applications, such as chemical reactions or thermal transfer applications that are difficult for other flow metering technologies. This is because thermal mass flow meters monitor variations in one or more of the thermal characteristics (temperature, thermal conductivity, and/or specific heat) of gaseous media to define the mass flow rate.

Electromagnetic, ultrasonic and coriolis flow meters

A magnetic flow meter at the Tetley's Brewery in Leeds, West Yorkshire.

Modern innovations in the measurement of flow rate incorporate electronic devices that can correct for varying pressure and temperature (i.e. density) conditions, non-linearities, and for the characteristics of the fluid.

Magnetic flow meters

Industrial magnetic flowmeter

Magnetic flow meters, often called "mag meter"s or "electromag"s, use a magnetic field applied to the metering tube, which results in a potential difference proportional to the flow velocity perpendicular to the flux lines. The potential difference is sensed by electrodes aligned perpendicular to the flow and the applied magnetic field. The physical principle at work is Faraday's law of electromagnetic induction. The magnetic flow meter requires a conducting fluid and a nonconducting pipe liner. The electrodes must not corrode in contact with the process fluid; some magnetic flowmeters have auxiliary transducers installed to clean the electrodes in place. The applied magnetic field is pulsed, which allows the flowmeter to cancel out the effect of stray voltage in the piping system.

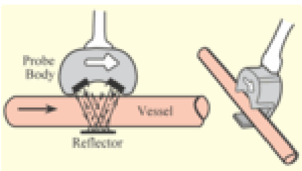
Ultrasonic (Doppler, transit time) flow meters

Ultrasonic flow meters measure the difference of the transit time of ultrasonic pulses propagating in and against flow direction. This time difference is a measure for the average velocity of the fluid along the path of the ultrasonic beam. By using the absolute transit times both the averaged fluid velocity and the speed of sound can be calculated. Using the two transit times t_{up} and t_{down} and the distance between receiving and transmitting transducers L and the inclination angle α one can write the equations:

$$v = \frac{L}{2\ \sin\left(\alpha\right)}\ \frac{t_{up} - t_{down}}{t_{up}\ t_{down}} \quad \text{and} \quad c = \frac{L}{2}\ \frac{t_{up} + t_{down}}{t_{up}\ t_{down}}$$

where v is the average velocity of the fluid along the sound path and c is the speed of sound.

Ultrasonic flow meters are also used for the measurement of natural gas flow.[8] One can also calculate the expected speed of sound for a given sample of gas; this can be compared to the speed of sound empirically measured by an ultrasonic flow meter and for the purposes of monitoring the quality of the flow meter's measurements. A drop in quality is an indication that the meter needs servicing.[9] Recently, Ultrasonic flow meters are also being used for measurement of LNG flow.



Schematic view of a flow sensor.

Measurement of the Doppler shift resulting in reflecting an ultrasonic beam off the flowing fluid has also been used in the past. Due to limited accuracy this method is only suitable for applications that do not require a high accuracy. By passing an ultrasonic beam through the tissues, bouncing it off a reflective plate, then reversing the direction of the beam and repeating the measurement, the volume of blood flow can be estimated. The frequency of the transmitted beam is affected by the movement of blood in the vessel and by comparing the frequency of the upstream beam versus downstream the flow of blood through the vessel can be measured. The difference between the two frequencies is a measure of true volume flow. A wide-beam sensor can also be used to measure flow independent of the cross-sectional area of the blood vessel.

For the Doppler principle to work in a flowmeter it is mandatory that the flow stream contains sonically reflective materials, such as solid particles or entrained air bubbles.

Laser Doppler flow measurement

A beam of laser light impinging on a moving particle will be partially scattered with a change in wavelength proportional to the particle's speed (the Doppler effect). A Laser Doppler velocimeter (LDV), also called a laser Doppler anemometer (LDA), focuses a laser beam into a small volume in a flowing fluid containing small particles (naturally occurring or induced). The particles scatter the light with a Doppler shift. Analysis of this shifted wavelength can be used to directly, and with great precision, determine the speed of the particle and thus a close approximation of the fluid velocity.

A number of different techniques and device configurations are available for determining the Doppler shift. All use a photodetector (typically an avalanche photodiode) to convert the light into an electrical waveform for analysis. In most devices, the original laser light is divided into two beams. In one general LDV class, the two beams are made to intersect at their focal points where they interfere and generate a set of straight fringes. The sensor is then aligned to the flow such that the fringes are perpendicular to the flow direction. As particles pass through the fringes, the Doppler-shifted light is collected into the photodetector. In another general LDV class, one beam is used as a reference and the other is Doppler-scattered. Both beams are then collected onto the photodetector where optical heterodyne detection is used to extract the Doppler signal.[11]

Anemometer

THE ROBINSON ANEMOMETER.

A hemispherical cup anemometer of the type invented in 1846 by John Thomas Romney Robinson

An **anemometer** is a device for measuring wind speed, and is a common weather station instrument. The term is derived from the Greek word *anemos*, meaning wind, and is used to describe any airspeed measurement instrument used in meteorology or aerodynamics. The first known description of an anemometer was given by Leon Battista Alberti around 1450.[1]

Anemometers can be divided into two classes: those that measure the wind's speed, and those that measure the wind's pressure; but as there is a close connection between the pressure and the speed, an anemometer designed for one will give information about both.

Velocity anemometers

Cup anemometers

Cup-type anemometer with vertical axis, a sensor on a remote meteorological station deployed on Skagit Bay, Washington July–August, 2009.

A simple type of anemometer, invented (1846) by Dr. John Thomas Romney Robinson, of Armagh Observatory. It consisted of four hemispherical cups each mounted on one end of four horizontal arms, which in turn were mounted at equal angles to each other on a vertical shaft. The air flow past the cups in any horizontal direction turned the cups in a manner that was proportional to the wind speed. Therefore, counting the turns of the cups over a set time period produced the average wind speed for a wide range of speeds. On an anemometer with four cups it is easy to see that since the cups are arranged symmetrically on the end of the arms, the wind always has the hollow of one cup presented to it and is blowing on the back of the cup on the opposite end of the cross.

When Robinson first designed his anemometer, he asserted that the cups moved one-third of the speed of the wind, unaffected by the cup size or arm length. This was apparently confirmed by some early independent experiments, but it was incorrect. Instead, the ratio of the speed of the wind and that of the cups, the anemometer factor, depends on the dimensions of the cups and arms, and may have a value between two and a little over three. Every previous experiment involving an anemometer had to be repeated.

The three cup anemometer developed by the Canadian John Patterson in 1926 and subsequent cup improvements by Brevoort & Joiner of the USA in 1935 led to a cupwheel design which was linear and had an error of less than 3% up to 60 mph (97 km/h). Patterson found that each cup produced maximum torque when it was at 45 degrees to the wind flow. The three cup anemometer also had a more constant torque and responded more quickly to gusts than the four cup anemometer.

The three cup anemometer was further modified by the Australian Derek Weston in 1991 to measure both wind direction and wind speed. Weston added a tag to one cup, which causes the cupwheel speed to increase and decrease as the tag moves alternately with and against the wind. Wind direction is calculated from these cyclical changes in cupwheel speed, while wind speed is as usual determined from the average cupwheel speed.

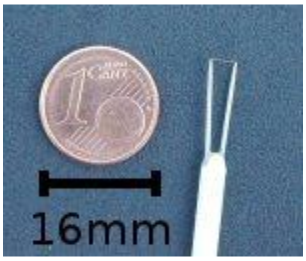
Three cup anemometers are currently used as the industry standard for wind resource assessment studies.

Windmill anemometers

A windmill style of anemometer

The other forms of mechanical velocity anemometer may be described as belonging to the windmill type or propeller anemometer. In the Robinson anemometer the axis of rotation is vertical, but with this subdivision the axis of rotation must be parallel to the direction of the wind and therefore horizontal. Furthermore, since the wind varies in direction and the axis has to follow its changes, a wind vane or some other contrivance to fulfill the same purpose must be employed. An *aerovane* combines a propeller and a tail on the same axis to obtain accurate and precise wind speed and direction measurements from the same instrument. In cases where the direction of the air motion is always the same, as in the ventilating shafts of mines and buildings for instance, wind vanes, known as air meters are employed, and give most satisfactory results.

Hot-wire anemometers



Hot-wire sensor

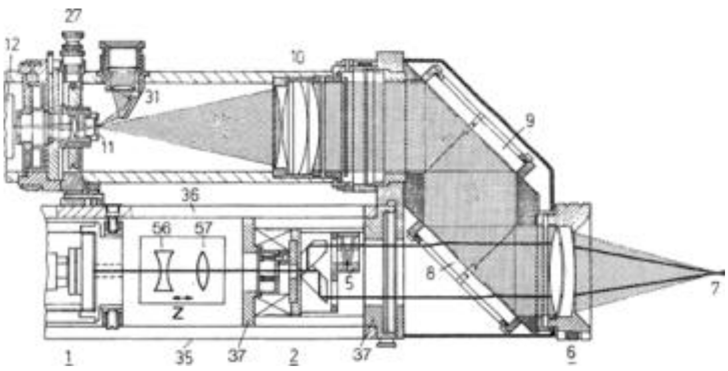
Hot wire anemometers use a very fine wire (on the order of several micrometres) electrically heated up to some temperature above the ambient. Air flowing past the wire has a cooling effect on the wire. As the electrical resistance of most metals is dependent upon the temperature of the metal (tungsten is a popular choice for hot-wires), a relationship can be obtained between the resistance of the wire and the flow speed.[2]

Several ways of implementing this exist, and hot-wire devices can be further classified as CCA (Constant-Current Anemometer), CVA (Constant-Voltage Anemometer) and CTA (Constant-Temperature Anemometer). The voltage output from these anemometers is thus the result of some sort of circuit within the device trying to maintain the specific variable (current, voltage or temperature) constant.

Additionally, PWM (pulse-width modulation) anemometers are also used, wherein the velocity is inferred by the time length of a repeating pulse of current that brings the wire up to a specified resistance and then stops until a threshold "floor" is reached, at which time the pulse is sent again.

Hot-wire anemometers, while extremely delicate, have extremely high frequency-response and fine spatial resolution compared to other measurement methods, and as such are almost universally employed for the detailed study of turbulent flows, or any flow in which rapid velocity fluctuations are of interest.

Laser Doppler anemometers



Drawing of a laser anemometer. The laser is emitted (1) through the front lens (6) of the anemometer and is backscattered off the air molecules (7). The backscattered radiation (dots) re-enter the device and are reflected and directed into a detector (12).

Laser Doppler anemometers use a beam of light from a laser that is divided into two beams, with one propagated out of the anemometer. Particulates (or deliberately introduced seed material) flowing along with air molecules near where the beam exits reflect, or backscatter, the light back into a detector, where it is measured relative to the original laser beam. When the particles are in great motion, they produce a Doppler shift for measuring wind speed in the laser light, which is used to calculate the speed of the particles, and therefore the air around the anemometer.[3]

Sonic anemometers

3D ultrasonic anemometer

Sonic anemometers, first developed in the 1950s, use ultrasonic sound waves to measure wind velocity. They measure wind speed based on the time of flight of sonic pulses between pairs of transducers. Measurements from pairs of transducers can be combined to yield a measurement of velocity in 1-, 2-, or 3-dimensional flow. The spatial resolution is given by the path length between transducers, which is typically 10 to 20 cm. Sonic anemometers can take measurements with very fine temporal resolution, 20 Hz or better, which makes them well suited for turbulence measurements. The lack of moving parts makes them appropriate for long term use in exposed automated weather stations and weather buoys where the accuracy and reliability of traditional cup-and-vane anemometers is adversely affected by salty air or large amounts of dust. Their main disadvantage is the distortion of the flow itself by the structure supporting the transducers, which requires a correction based upon wind tunnel measurements to minimize the effect. An international standard for this process, ISO 16622 *Meteorology—Sonic anemometers/thermometers—Acceptance test methods for mean wind measurements* is in general circulation. Another disadvantage is lower accuracy due to precipitation, where rain drops may vary the speed of sound.

Since the speed of sound varies with temperature, and is virtually stable with pressure change, sonic anomometers are also used as thermometers.

Two-dimensional (wind speed and wind direction) sonic anemometers are used in applications such as weather stations, ship navigation, wind turbines, aviation and weather buoys. Three-dimensional sonic anemometers are widely used to measure gas emissions and ecosystem fluxes using eddy covariance method when used with fast-response infrared gas analyzer or laser-based analyzer.

Pressure anemometers

Britannia Yacht Club clubhouse tour, burgee, and wind gauge on roof

The first designs of anemometers which measure the pressure were divided into plate and tube classes.

Tube anemometers

Helicoid propeller anemometer incorporating a wind vane for orientation.

James Lind's anemometer of 1775 consisted simply of a glass U tube containing a liquid manometer (pressure gauge), with one end bent in a horizontal direction to face the wind and the other vertical end remains parallel to the wind flow. Though the Lind was not the first it was the most practical and best known anemometer of this type. If the wind blows into the mouth of a tube it causes an increase of pressure on one side of the manometer. The wind over the open end of a vertical tube causes little change in pressure on the other side of the manometer. The resulting liquid change in the U tube is an indication of the wind speed. Small departures from the true direction of the wind causes large variations in the magnitude.

The highly successful metal pressure tube anemometer of William Henry Dines in 1892 utilized the same pressure difference between the open mouth of a straight tube facing the wind and a ring of small holes in a vertical tube which is closed at the upper end. Both are mounted at the same height. The pressure differences on which the action depends are very small, and special means are required to register them. The recorder consists of a float in a sealed chamber partially filled with water. The pipe from the straight tube is connected to the top of the sealed chamber and the pipe from the small tubes is directed into the bottom inside the float. Since the pressure difference determines the vertical position of the float this is a measured of the wind speed.

The great advantage of the tube anemometer lies in the fact that the exposed part can be mounted on a high pole, and requires no oiling or attention for years; and the registering part can be placed in any convenient position. Two connecting tubes are required. It might appear at first sight as though one connection would serve, but the differences in pressure on which these instruments depend are so minute, that the pressure of the air in the room where the recording part is placed has to be considered. Thus if the instrument depends on the pressure or suction effect alone, and this pressure or suction is measured against the air pressure in an ordinary room, in which the doors and windows are carefully closed and a newspaper is then burnt up the chimney, an effect may be produced equal to a wind of 10 mi/h (16 km/h); and the opening of a window in rough weather, or the opening of a door, may entirely alter the registration.

While the Dines anemometer had an error of only 1% at 10 mph (16 km/h) it did not respond very well to low winds due to the poor response of the flat plate vane required to turn the head into the wind. In 1918 an aerodynamic vane with eight times the torque of the flat plate overcame this problem.

Effect of density on measurements

In the tube anemometer the pressure is measured, although the scale is usually graduated as a velocity scale. In cases where the density of the air is significantly different from the calibration value (as on a high mountain, or with an exceptionally low barometer) an allowance must be made. Approximately 1½% should be added to the velocity recorded by a tube anemometer for each 1000 ft (5% for each kilometer) above sea-level.

9.Laser scanning

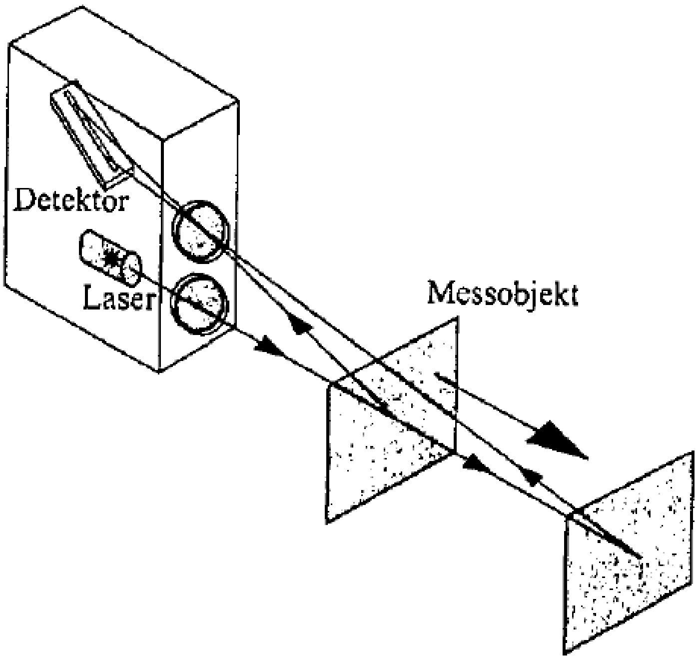
In modern engineering, the term `laser scanning' is used to describe two related, but separate meanings. The first, more general, meaning is the controlled **deflection of laser beams**, visible or invisible. Scanned laser beams are used in stereolithography machines, in rapid prototyping, in machines for material processing, in laser engraving machines, in ophtalmological laser systems for the treatment of presbyopia, in confocal microscopy, in laser printers, in laser shows, in Laser TV, in LIDAR, and in barcode scanners.

The second, more specific, meaning is the controlled steering of laser beams **followed by a distance measurement** at every pointing direction. This method, often called **3D object scanning** or **3D laser scanning**, is used to rapidly capture shapes of objects, buildings and landscapes.

This article focuses on the general meaning, i.e., on the methods and applications of scanned laser beams.

Technology

Scanning mirrors



Laser scanning module with two galvanometers, from Scanlab AG. The red arrow shows the path of the laser beam.

Most laser scanners use moveable mirrors to steer the laser beam. The steering of the beam can be **one-dimensional**, as inside a laser printer, or **two-dimensional**, as in a laser show system.

Additionally, the mirrors can lead to a **periodic** motion - like the rotating *mirror polygons* in a barcode scanner or so-called *resonant galvanometer* scanners - or to an **freely addressable** motion, as in servo-controlled galvanometer scanners. One also uses the terms **raster scanning** and **vector scanning** to distinguish the two situations.

To control the scanning motion, scanners need a rotary encoder and control electronics that provides, for a desired angle or phase, the suitable electrical current to the motor or galvanometer. A software systems usually controls the scanning motion and, if 3D scanning is implemented, also the collection of the measured data.

In order to position a laser beam in **two dimensions**, it is possible either to rotate one mirror along two axes - used mainly for slow scanning systems - or to reflect the laser beam onto two closely spaced mirrors that are mounted on orthogonal axes. Each of the two flat or polygonal mirrors is then driven by a galvanometer or by an electric motor. Two-dimensional systems are essential for most applications in material processing, confocal microscopy, and medical science.

Some applications require to position the focus of a laser beam in **three dimensions**. This is achieved by a servo-controlled lens system, usually called a 'focus shifter' or 'z-shifter'.

Many laser scanners further allow changing the laser intensity.

In laser projectors for laser TV or laser displays, the three fundamental colors red blue and green are combined in a single beam and then reflected together over the two mirrors.

The most common way to move mirrors is, as mentioned, the use of an electric motor or of a galvanometer. However piezoelectric actuators or magnetostrictive actuators are alternative options. They offer higher achievable angular speeds, but often at the expense of smaller achievable maximum angles.

Scanning refractive optics

When two Risley prisms are rotated against each other, a beam of light can be scanned at will inside a cone. Such scanners are used for tracking missiles. (See www.optra.com)

When two optical lenses are moved or rotated against each other, a laser beam can be scanned in a way similar to mirror scanners. (See www.haaslti.com)

Material effects

Some special laser scanners use, instead of moving mirrors, acousto-optic deflectors or electrooptic deflectors. These mechanisms allow the highest scanning frequencies possible so far. They are used, for example, in laser TV systems. On the other hand, these systems are also much more expensive than mirror scanning systems.

Phased array scanning

Research is going on to achieve scanning of laser beams through phased arrays. This method is used to scan RADAR beams without moving parts. With the use of Vertical-cavity surface-emitting laser (VCSELs), it might be possible to realize fast laser scanners in the foreseeable future.

Applications

3D object scanning

3D object scanning allows enhancing the design process, speeds up and reduces data collection errors, saves time and money, and thus makes it an attractive alternative to traditional data collection techniques. 3D scanning is also used for mobile mapping, surveying, scanning of buildings and building interiors, and in archaeology.

Material processing

Depending on the power of the laser, its influence on a working piece differs: lower power values are used for laser engraving and laser ablation, where material is partially removed by the laser. With higher powers the material becomes fluid and laser welding can be realized, or if the power is high enough to remove the material completely, then laser cutting can be performed. Modern lasers can cut steel blocks with a thickness of 10 cm and more or ablate a layer of the cornea that is only a few micrometers thick.

The ability of lasers to harden liquid polymers, together with laser scanners, is used in rapid prototyping, the ability to melt polymers and metals is, with laser scanners, to produce parts by laser sintering.

The principle that is used for all these applications is the same: software that runs on a PC or an embedded system and that controls the complete process is connected with a scanner card. That card converts the received vector data to movement information which is sent to the scanhead. This scanhead consists of two mirrors that are able to deflect the laser beam in one level (X- and Y-coordinate). The third dimension is - if necessary - realized by a specific optic that is able to move the laser's focal point in the depth-direction (Z-axis).

Scanning the laser focus in the third spatial dimension is needed for some special applications like the laser scribing of cruved surfaces or for in-glass-marking where the laser has to influence the material at specific positions within it. For these cases it is important that the laser has as small a focal point as possible.

For enhanced laser scanning applications and/or high material throughput during production, scanning systems with more than one scanhead are used. Here the software has to control what is done exactly within such a multihead application: it is possible that all available heads have to mark the same to finish processing faster or that the heads mark one single job in parallel where every scanhead performs a part of the job in case of large working areas.

Barcode readers

Many barcode readers, especially those with the ability to read bar codes at a distance of a few meters, use scanned laser beams. In these devices, a semiconductor laser beam is usually scanned with the help of a resonant mirror scanner. The mirror is driven electromagnetically and is made of a metal-coated polymer.

Space flight

When a space transporter has to dock to the space station, it must carefully maneuver to the correct position. In order to determine its relative position to the space station, laser scanners built into the front of the space transporter scan the shape of the space station and then determine, through a computer, the maneuvering commands. Resonant galvanometer scanners are used for this application.