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Research Paper

SENSORS IN ENGINEERING

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ABSTRACT

The aim when writing this research paper was to give the reader a comprehensive as well as comprehensible insight in the world of sensors used in engineering. Along the next chapters we will discuss the following points mentioned below.

First of all we will talk about sensors in general, points like "What are sensors?" and where you can find sensors in everyday life. After that I am going to move to the classification of sensors.

At the end we will outline different sensor types and explain their technical working principle.

INTRODUCTION

This research paper of "sensors in engineering" was written for the robotics competition called "BOTBALL" that takes place in Vienna in year 2016.

It was created during an interdisciplinary collaboration of the subjects "German" and "FMIT". The working paper represents a great opportunity to get into contact with writing scientific papers as they are needed in my next year of school, which will be my last one too. Even in later years I will have to do researches and write final papers in case of bachelor- or master degree course.

The reason why we chose the topic "sensors in engineering" were clear ones: At first, sensors and actors are replacing mechanical control systems more and more. They are less complex and much easier to handle, because of the technical progress in electrical and information industry. It is also a big topic in our professional education to a "Mechatronic Engineer". Another reason to choose this topic was, that we are very interested in steering and controlling processes.

Eventually, I want to give special thanks to our director, Mr. Höller and our supervisor from school, Mr. Rohm, who made it possible, that we are able to take part at this competition this year.

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1 DEFINITION

According to Margaret Rouse, who writes technical articles for many websites on the World Wide Web, a sensor can be defined as follows:

> *"A sensor is a device that detects and responds to some type of input from the physical environment. The specific input could be light, heat, motion, moisture, pressure, or any one of a great number of other environmental phenomena. The output is generally a signal that is converted to human-readable display at the sensor location or transmitted electronically over a network for reading or further processing."* [1]

When talking about sensors, most people immediately think of their sensors in their smartphone or similar. But sensors have much more skills that anybody could even think of.

2 SENORS IN EVERYDAY LIFE

2.1 SENSORS IN PUBLICITY

People counteract with sensors every day, they are everywhere. On the way to work there are sensors e.g. in traffic lights, if the traffic light is steered by traffic. They are in the touchscreen when buying a ticket at the ticket automat at the railway station. In every smartphone is a light sensor and much more sensors.

There are many sensors in your car, for example the speedometer, the rain sensor and the sensor which activates the airbag. There are about 50 different sensors only in your car.

Figure 1: Distance sensors in cars

[1] Rouse, Margaret (2012): Definition sensor, www.whatis.techtarget.com/defintion/sensor, requested 08.03.2016

2.2 SENSORS IN INDUSTRY AND MACHINE ENGINEERING

In Industry, sensors are mainly integrated in production equipment. The provide safety and enable the intensive production the industry is practising this time.

Without sensors, nearly nothing could be automated as effective as it is possible with sensors. If there wouldn't be sensors, everything would have to be automated with mechanical steering mechanisms. These are very expensive and need a lot of time and technical Know-How to be developed. This is very time-consuming too. They are very massive and if there breaks something, it is hard to repair them. In the worst cases, they have to be completely replaced.

That is why more and more developers and construction engineers are using sensors and electrical machines instead of those massive mechanisms. Another advantage for working with sensors is, that the data coming from the sensor can be easily evaluated and represented to the engineer, who is sitting in the control area. Added to this, it is much safer in the working area, because there don't have to be many workers in there, if the plant is controlled and steered with sensors and computer systems.

Figure 2:Example for use of sensors in machine engineering

3 CLASSIFICATION OF SENSORS

3.1 CLASSIFICATION ACCORDING TO ITS ENERGY SOURCE

According to their energy source, sensors can be classified as follows:

3.1.1 ACTIVE SENSORS

Active Sensors are producing the energy, which is necessary for transmission, out of the measure process.

Examples:

- thermal element
- induction coil
- hall-effect probe
- pH-electrode

Some of active sensors are producing a electrical variable, which has to be converted into voltage, to be processed.

Examples:

- piezo-crystal
- photo-diode
- Wiegand-sensor

3.1.2 PASSIVE SENSORS

On passive sensors, energy has to flow through it. The sensor changes his resistance and modulates a defined variable of this flow of energy. The resistance can be resistive, capacitive or inductive.

Examples:
resistive:

- potentiometer
- strain gauge (DMS)
- PTC/NTC
- photo transistor [2]

[2] refer to: MÜLLER, Walter (2010): Sensorgrundlagen, http://www.ces.karlsruhe.de/culm/culm/culm2/th_messtechnik/sensoren/sensorgrundlagen.pdf, requested 09.03.2016, p. 3-4

capacitive: by manipulation of

- distance of capacitor plates
- the dielectric medium's retraction depth

inductive: by manipulation of

- permeability
- cross section
- distance of air gap

Sensors with an optical signal output, the light flux can be influenced by:

- intensity
- frequency
- wave length
- polarisation
- spectral resolution

3.2 CLASSIFICATION ACCORDING TO MEASURED VARIABLES

According to the measured variables, sensors can be classified as follows:

- sensors for geometrical variables
- sensors for motion quantities
- sensors for forces and derived quantities
- sensors for hydrostatic and hydrodynamic quantities
- sensors for thermometric and calorimetric quantities
- sensors for chemical quantities and rates of special substances
- sensors for electrical and magnetic quantities
- sensors for electromagnetic radiation
- sensors for optical quantities
- sensors for ionizing radiation [3]

[3] refer to: MÜLLER, Walter (2010): Sensorgrundlagen, http://www.ces.karlsruhe.de/culm/culm/culm2/th_messtechnik/sensoren/sensorgrundlagen.pdf, requested 09.03.2016, p. 2-3

4 FUNCTIONAL PRINCIPLES OF SENSORS

4.1 SENSORS FOR MEASURING DISTANCES AND POSITIONS

4.1.1 INDUCTIVE SENSORS

4.1.1.1 Inductive transducer

Principe:

By measuring distance with inductive sensors, you are measuring the change of its inductance.

The inductance can be changed by a moving iron or ferrite core inside the coil form (Figure 3a).

> *"The inductance increases or decreases based on how much the core has moved into the coil form. These coils are called slug-tuned inductors. Adjustable inductors either have taps for changing the number of desired turns, or consist of several fixed inductors that can be switched into various series or parallel combinations (Figure 3b)."* [4]

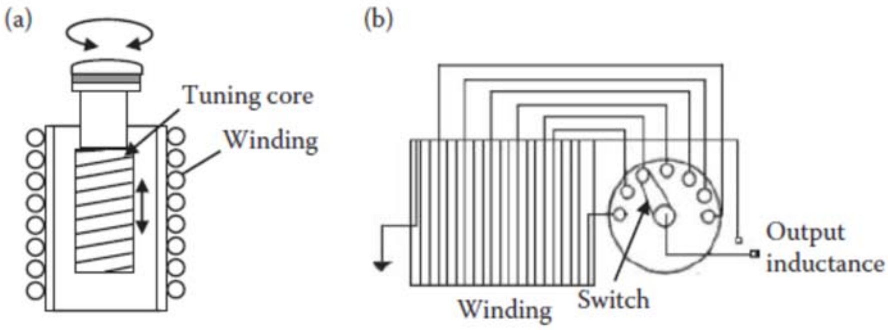

Figure 3: (a) An adjustable inductor; (b) a variable inductor

Inductance L:

When current flows in a conducter, it creates a magnetic field and hence magnetic flux around the circuit. The inductance defines the ratio of the magnetic flux ϕ [Wb, V*s] to the current I [A]. [5]

The unit of Inductance is Henry (H), named after physicist Josph Henry, born in USA. [6]

$$L = \frac{\phi}{I} = \frac{[Wb]}{[A]} = [H]$$

[4] Winncy, Y. Du (2015): Resistive, Capacitive, Inductive, and Magnetic Sensor Technologies, CRC Press, p. 155

[5] refer to: ibid., p. 155

[6] refer to: a.u. (2016): Induktivität, https://de.wikipedia.org/wiki/Induktivit%C3%A4t, requested 10.03.2016

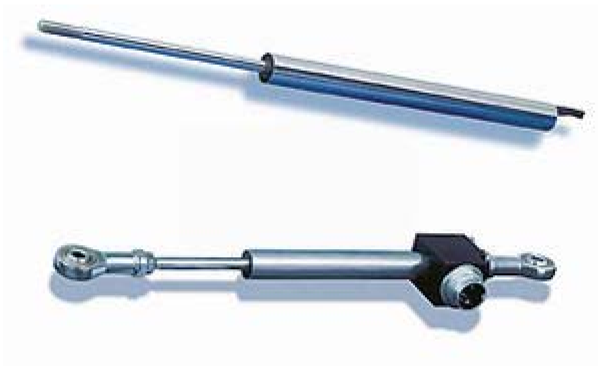

Figure 4: inductive transducers

4.1.1.2 Inductive Proximity Sensors

Inductive proximity sensors are used for non-contact detection of metallic objects.

Their operating principle is based on a coil and oscillator that creates an electromagnetic field in the close surroundings of the sensing surface. The presence of a metallic object (actuator) in the operating area causes a dampening of the oscillation amplitude. The rise or fall of such oscillation is identified by a threshold circuit that changes the output of the sensor. The operating distance of the sensor depends on the actuator's shape and size and is strictly linked to the nature of the material. [7]

Figure 5: inductive proximity sensor

[7] refer to: a.u. (2013): Operating principles for inductive proximity sensors, http://www.fargocontrols.com/sensors/inductive_op.html, requested 08.03.2016

4.1.2 CAPACITIVE SENSORS

Capacitive proximity sensors are used for contact-free detection of arbitrary objects. As contrasted to inductive proximity sensors, which only are able to detect metallic objects, capacitive sensors can detect non-metallic materials too. Typical application areas are in the timber, paper, glass, plastics, food and chemical industry. Capacitive sensors are checking for example in a packaging machine if there are enough cardboards left as well as the level of the medium inside the cardboard. Another example is the surveillance of glass or wood plates on a conveyor belt. [9]

Principe:

> *"A capacitor is a passive electrical or electronic component that can store energy in the form of an electric field. Capacitance, typified ba a parallel-plate arrangement, is defined in terms of charge storage, where C in the capacitance (In farads, F), Q is the charge (in coloumb, C) and V is the voltage difference between the two plates (in volts, V): "* [8]

$$C = \frac{Q}{V}$$

In principle, the capacity of the active electrode of the sensor to ground potential is measured. An approximated object is affecting this alternating electric field between this two capacitor plates and its capacity. This affects is caused by metallic as well as non-metallic objects. The sensitivity of the sensor can be changed with a potentiometer. [10, 11]

Figure 6:capacitive proximity sensors

[8] Winncy, Y. Du (2015): Resistive, Capacitive, Inductive, and Magnetic Sensor Technologies, CRC Press, p. 155
[9] refer to: a.u. (2016): Kapazitive Sensoren, http://www.ifm.com/ifmat/web/pinfo010_020_040.htm, requested 11.03.2016
[10] refer to: ibid., requested 11.02.2016
[11] refer to: a.u. (2013): Operating principles for capacitive proximity sensors, http://www.fargocontrols.com/sensors/capacitive.html, requested 11.03.2016

4.1.3 MAGNETIC PROXIMITY SENSORS

4.1.3.1 Hall sensors

Hall sensors operate based on the Hall Effect. A thin sheet of metal or semiconductor material with a current passing through it is placed in a magnetic field, and then a voltage is generated perpendicular to the field and the direction of the current flow. To evaluate their reaction, Hall sensors require amplification and signal conditioning. A feature of it is, that it is very small and can easily be mounted on diverse surfaces. [12]

Hall sensors are widely used in automobile and production industry. There are many types of Hall sensors. The most common are Hall Position Sensors, Flow Rate Sensors [13]

4.1.3.2 Magneto-resistive Sensors

Magnetic sensors are actuated by the presence of a permanent magnet. Their operating principle is based on the use of reed contacts, which consist of two low reluctance ferro-magnetic reeds enclosed in glass bulbs containing inert gas. The reciprocal attraction of both reeds in the presence of a magnetic field, due to magnetic induction, establishes an electrical contact. [14]

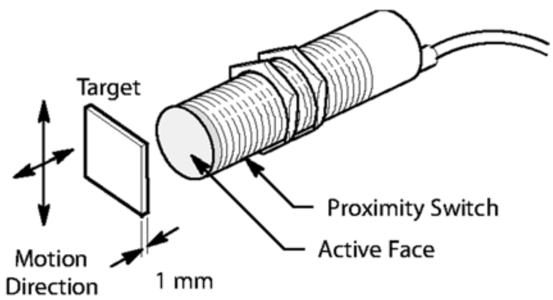

Figure 7:scheme of a magnetic sensor

[12] refer to: WINNCY, Y. Du (2015): Resistive, Capacitive, Inductive, and Magnetic Sensor Technologies, CRC Press, p. 228
[10] refer to: ibid., pp. 234-237
[14] refer to: a.u. (2013): Operating principles for capacitive proximity sensors, http://www.fargocontrols.com/sensors/magnetic.html, requested 11.03.2016

4.1.4 PHOTOELECTRIC SENSORS

Photoelectric sensors use light sensitive elements to detect objects and are made up of an emitter as the light source and a receiver.

Four types of photoelectric reflection are commonly used:

4.1.4.1 Direct Reflection (Diffused)

Emitter and receiver are housed together and use the light reflected off the object for detection. In the use of these photocells, it is important to bear in mind the color and the type of surface of the object. With dark surfaces, the sensing distance is affected by the color of the object. Light colors match to the maximum distances and vice versa. In the case of shiny objects, the effect of the surface is more important than the color. The sensing distance in the technical data is related to flat white paper.

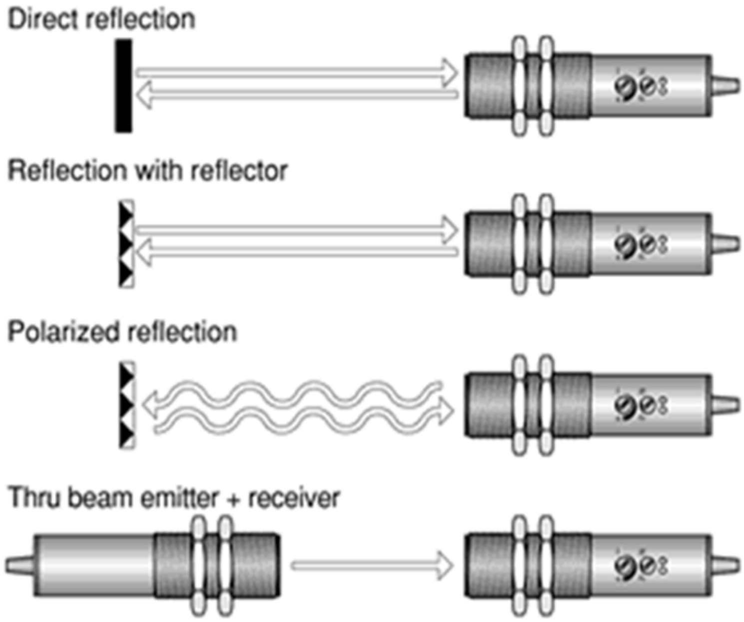

Figure 8:different types of photoelectric sensors

4.1.4.2 Reflection with Reflector (Retro-reflective)

Emitter and receiver are in one housing and require a reflector. An object is detected when it interrupts the light beam between the sensor and reflector. These Photocells allow longer sensing distances, as the rays emitted are almost totally reflected towards the receiver.

4.1.4.3 Polarized Reflection with Reflector

This type is similar to reflection with Reflector, but these photocells use an anti-reflex device. The use of such a device, which bases its functioning on a polarized band of light, offers considerable advantages and secure readings even when the object to be detected has a very shiny surface. They aren't affected by any random reflection.

4.1.4.4 Thru Beam

Emitter and receiver are housed separately and detect an object when it interrupts the light beam between the emitter and receiver. These photocells allow for the longest distances. [15]

[15] refer to: a.u. (2012): OPERATING PRINCIPLES FOR PHOTOELECTRIC SENSORS, http://www.fargocontrols.com/sensors/photo_op.html, requested 11.03.2016

4.1.5 ULTRASONIC SENSOR

In industrial applications, ultrasonic sensors are characterized by their reliability and outstanding versatility, Ultrasonic sensors can be used to solve even the most complex tasks involving object detection or level measurement with millimetre precision, because their measuring method works reliably und almost all conditions. [16]

Two examples of use are surveillance of the maximum filling level of containers or detection of parts made out of glass (seen in figure 2).

> *"At manufacturing glass, the place for installation is in most cases very small and cannot get detection well, caused by the transparency of glass. Most optical Systems are segregated because of this reasons."* [17]

In this special cases, measuring or detecting with ultrasonic sensors is very in common.

Principe:
Ultrasonic sensors are working with a similar principle like photoelectric sensors are working with.
A special sonic transducer is used for the ultrasonic proximity sensors, which allows for alternate transmission and reception of sound waves. The sonic waves emitted by the transducer are reflected by an object and received back in the transducer. After having emitted the sound waves, the ultrasonic sensor will switch to receive mode. The time elapsed between emitting and receiving is proportional to the distance of the object from the sensor.

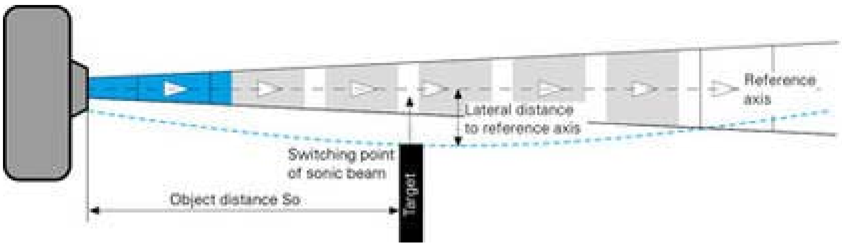

Figure 9: measuring method of ultrasonic sensors

[16] refer to: a.u. (2016): Ultrasonic Sensors, http://www.pepperl-fuchs.us/usa/en/classid_182.htm?view=productgroupoverview, requested 11.02.2016
[17] a.u.: Ultrasonic Sensors, automation, 06/2015, p. 26-27

4.2 MOTION SENSORS

In industry, it is very important to measure the motion quantities, like acceleration, vibration or velocity in the machine, to get sure, that there are no risks or failures in the working process.

4.2.1 ACCELERATION AND VIBRATION SENSORS

Acceleration sensors for the measurement of acceleration, shock or vibration come in many types using different principles of operation.

4.2.1.1 Capacitive Version

Accelerometers that implement capacitive sensing output a voltage dependent on the distance between two planar surfaces. One or both of these "plates" are charged with an electrical current. Changing the gap between the plates changes the electrical capacity of the system, which can be measured as a voltage output. This method of sensing is known for its high accuracy and stability. Capacitive accelerometers are also less susceptible to noise and variation with temperature, typically dissipate less power, and can have larger bandwidths due to internal feedback circuitry.

4.2.1.2 Piezoelectric Version

Inside a piezoelectric version, the sensing element is a crystal, which has the property of emitting a charge when subjected to a compressive force. In the accelerometer, this crystal is bonded to a mass such that when the accelerometer is subjected to a 'g' force, the mass compresses the crystal which emits a signal. This signal value can be related to the imposed 'g' force.
The sensing element is housed in a suitable sensor body to withstand the environmental conditions of the particular application. Body are usually made in stainless steel with welding of the various parts to prevent the ingress of dust, water and other influencing variables from ambience.
Many present accelerometers have internal electronic circuitry to give outputs which can be directed used by the associated acquisition or control systems.
Mechanical fixing of the sensor is important in order to achieve true transfer of the vibration or acceleration. Many fixing methods are used including beeswax, hard glues, threaded stud or magnetic mounts.

[18] refer to: a.u. (n.d.): The Piezoelectric Accelerometer, http://www.sensorland.com/HowPage003.html, requested 13.02.2016

[19] refer to: gbarrette (2013): Accelerometer, http://www.sensorwiki.org/doku.php/sensors/accelerometer, requested 13.03.2016

4.2.2 VELOCITY SENSORS

Piezo-Velocity (PVT) sensors are solid state piezoelectric velocity measurement devices. They are essentially accelerometers with an internal integration circuit which will produce an output relative velocity. Many vibration analysts prefer to examine vibration signals in terms of velocity to amplify the signal of interest. PVT sensors basically decrease high frequency signals allowing better measurement of low frequency vibration.

PVTs can reduce signal noise in many low frequency measurements. The integration circuit amplifies low frequency signals and attenuates high frequency signals. This increases the voltage output at low frequency and filters high frequency noise. The increase in low frequency voltage output reduces the noise contribution of the acquisition equipment. The inherent filtering reduces intermodulation distortion caused when high frequency signals overload the amplifier and may reduce the "ski slope" noise in many applications. [20]

4.3 FORCE SENSORS

Force sensors weigh freight on manufacturing and transportation equipment. They also monitor loads on machines subject to stringent safety standards, such as mini lifts, construction cranes, industrial tanks or grain silos, to ensure equipment isn't overloaded.

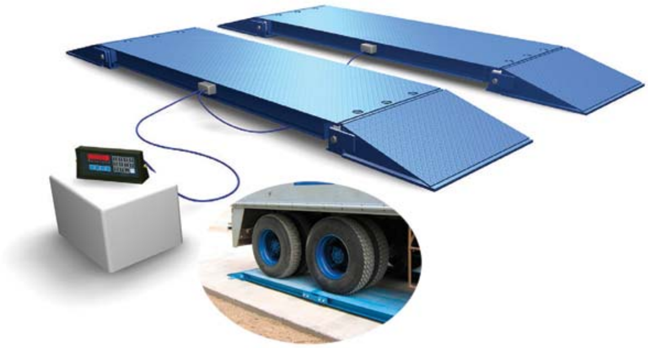

Figure 10: usage of force sensors

At the core of force sensors are load cells, transducers that convert force into measureable electrical outputs. There are hydraulic, pneumatic, piezoelectric and capacitive load cells. For industrial usage, strain-gauge-based load cells are most common.

[20] refer to: a.u. (2014): Velocity sensors, http://www.wilcoxon.com/velocity-sensors-and-transmitter.cfm, requested 13.02.2016

4.3.1 STRAIN-GAUGE SENSORS

The most common force sensors based on strain gauges are load pins, shear beams and tension links

4.3.1.1 Tension links

Tension links, also called a tension cells, consist of two steel padeyes and a center body housing the load cell. They measure the force in cables, chains, and pulleys, and are most common in lifting, pulling, and winching applications on cranes and wire tensioners on safety cages used in mines. Standard tension links measure 11000 to 45000 kilograms, though custom versions can measure more.

4.3.1.2 Load pins

Load pins are used to measure occurring shear forces. Typically, a beam is machined to be almost completely hollow save for one segment with a solid cross section. Sensing elements mounted on this remaining wall of material (called web). The tubular body of the load pin withstands bending stresses while the solid cross section withstands vertical and horizontal shear stresses. The web's strain gauges measure these shear stresses. Standard capacities exceed 9000 kg, though custom pins go higher.

4.3.1.3 Shear beams

Just like load pins shear beams measure shear forces. There are Single-ended shear beams and double-ended shear beams. Single-ended are cantilevered sensors which load is applied at the free, double-ended ones are supported at both ends where the load is in the centre. Single ended shear beams weigh loads in blenders, hoppers and floor scales. Double ended shear beams weigh tanks and items and large capacity platforms. Both shear beams detect loads to 18000 kg in 10 to 20 kg steps. [21]

4.3.2 LOAD CELLS

A load cell is a device that is used to convert a force into electric signal. Strain gauge load cells are the most common types of load cells. There are other types of load cells such as hydraulic load cells, pneumatic load cells, piezoelectric load cells or capacitive load cells.
Load cells are used for quick and precise measurements. Compared with other sensors, load cells are relatively more affordable and have a longer life span.

[21] refer to: WILLIAMS, Del (2013): Force sensors and their uses, http://machinedesign.com/sensors/force-sensors-and-their-uses, requested 13.02.2016

4.3.2.1 Strain Gauge load cells

The principle of operation of the Strain Gauge is based on the fact that the resistance of the electrical conductor used in strain gauge construction changes when its length changes due to stress.
A load cell usually consists of four strain gauges in a Wheatstone bridge configuration. The electrical signal output is typically very small in the order of a few mV. It is amplified by an instrumentation amplifier before sending it to the measurement system.

4.3.2.2 Capacitive load cells

Capacitive load cells are based on the principle where the capacity of a capacitor changes as the load presses the two plates of a capacitor closer together. The construction of a capacitive sensor is simpler than a resistive load cell.

4.3.2.3 Hydraulic load cells

Hydraulic load cells are force-balance devices, measuring weight as a change in loading head is transferred to a piston that in turn compresses a filling fluid confined within an elastomeric membrane chamber. As the force increases, the pressure of the hydraulic fluid increases. This pressure can be locally indicated or transmitted for remote indication or control. This sensor has no electric components and immune to transient voltages so it's ideal for use in hazardous areas. The disadvantages of hydraulic load cells are, that they are very expensive and complex.

4.3.2.4 Pneumatic load cells

Pneumatic load cells operate on the force-balance principle. These devices use cushion chambers to provide higher accuracy than a hydraulic device. Pneumatic load cells are often used to measure relatively small weights in industry where cleanness and security are of prime concern. [22]

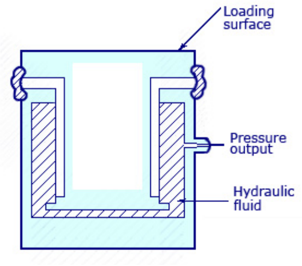

Figure 11: hydraulic load cell

[22] refer to: SHUKLA, Vinaykumar (2013): Load cell working, types, advantages and disadvantages, http://www.instrumentationengineers.org/2013/07/load-cell-working-types-advantages-and.html, requested 13.02.2016

5 SENSORS IN BOTBALL

The sensors which are included in our BOTBALL-set are primarily Photoelectric Sensors, e.g. ET, Tophat as well as Photodiodes and resistive sensors like the linear slide.

I would recommend some other types of sensors for future competitions. This would be capacitive sensors instead of touch and lever sensors, because they are easily breaking down. Another improved solution would be to ETs through ultrasonic sensors, because they are much more reliable than ETs.

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