

Seminar work report
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MEMS PRESSURE SENSOR

for Microsensors and mechanics



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1 Introduction

Pressure is a physical quantity which describes an amount of force applied to every single part of the area in a direction perpendicular to the surface. The formula 1 is mathematical representation of the definition. [2]

$$P = \frac{F}{A} \quad (1)$$

Pressure sensors are one of the most popular and developed sensor type, it become spread especially wide in its MEMS realisation. We are literally surrounded by various number of pressure sensor in every day devises and huge industrial solutions. There are several different technologies which allows to build pressure sensors, all of them has their own strong and weak sides.

Microelectromechanical Systems is complex of mechanical components and devices in size from a few micrometers to a few hundreds of microns. Many different types of sensors have MEMS realisations for example: pressure sensors, accelerometers, gyroscopes and gyrometers. It is also possible to produce actuators in MEMS format. Typical MEMS actuators are microengines, microlocks and discriminators.[19]

2 General principle and main types of the pressure sensor

There are three main types of pressure sensors:

1. Gauge pressure sensor - measures a value relatively to atmospheric pressure.
2. Absolute pressure sensor - use absolute vacuum as origin.
3. Differential pressure sensor - compare pressure with some variable value, can be used to measure difference between two pressure.

2.1 Sensor types

2.1.1 The gauge pressure sensor

This type of sensors contains the ventilation hole on the back-side which connects the sensitive part with the atmosphere and the pressure applied to the front-side of the devise is measured with reference to it, Pic. 1.

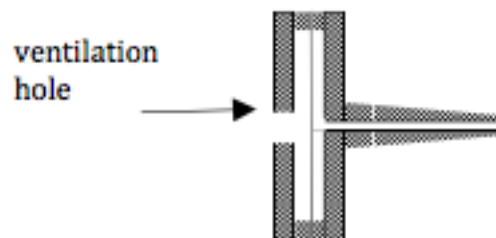


Figure 1: The gauge type pressure sensor

This kind of sensors should not be used for vessels with aggressive liquids and hazardous gases, because only sensor would separate such dangerous substances from "outside world" and damage of the sensor is able to provoke an accident. This type of sensors also is not suitable for the high pressure tanks.[1]

The image 2 demonstrates an example of gauge sensor.



Figure 2: The gauge type pressure sensor example

2.1.2 The absolute pressure sensor

This kind of sensors has reference chamber with pressure close to vacuum inside. Of course it is impossible to create a chamber with an absolute vacuum, it usually has $25 \cdot 10^{-3}$ Torr or $5 \cdot 10^{-4}$ PSI for Smartec sensors, Pic 3.

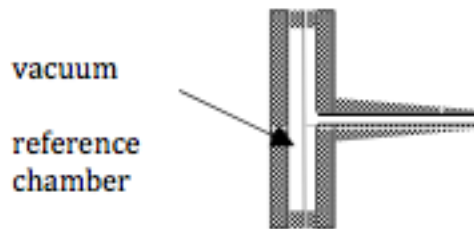


Figure 3: The absolute type pressure sensor

A very important thing is that the vacuum must be very high to avoid an influence of the temperatures difference, anyway this kind of sensors has temperature limits and can be inaccurate outside the range.

The absolute pressure sensor much more safe than gauge one, but it is more expensive because of vacuum chamber.[1]

The image 4 shows an example of absolute sensor.



Figure 4: The absolut type pressure sensor example

2.1.3 The differential pressure sensor

The differential pressure sensor has two inputs, one of them is called negative and another one positive. This type of sensors is able to measure difference of the pressure between the ports, Pic 5.[1]

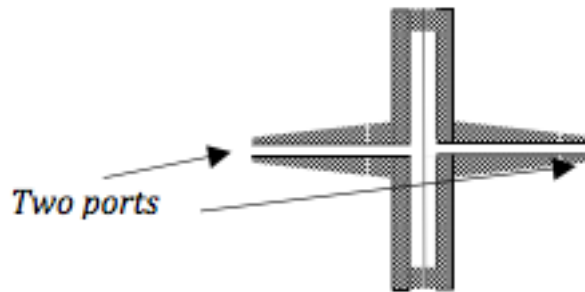


Figure 5: The differential type of pressure sensor

The image 6 shows an example of absolute sensor.



Figure 6: The differential type pressure sensor example

2.2 General principles

It is also possible to use physical principle of the sensors for classification. The table 1 contains the most complete information about weak and strong sides of different solutions.

In general the sensors are based on changes of electromagnetic or other properties of material due to applied force. For example resistive pressure sensors are based on metals with an impedance sensible for stress. The resistance of the material is dependent from an amount of force applied to it.[2]



Figure 7: Graphical tablet Wacom Intuos Pro Medium [10]

Another approach is to use materials with an ability to emit energy as response to applied force. Piezoelectric pressure sensors are perfect example of the idea. The sensors are based on the Silicon on Insulator (SOI). Force applied to this kind of crystals provoke polarisation and generation of charge proportional to the stress. Piezoelectric effect is typical for quartz, tourmaline, and several other naturally crystals.[3]

Optical and Ultrasonic pressure sensors can be useful to avoid an influence of strong electromagnetic fields. An Optical ones are constructed in the way that pressure applied to them changes an amount of absorbed light in an according with certain transfer function. [4] Ultrasonic sensors are able to measure pressure via changes of sound speed of sound, the wave length and an attenuation of the waves inside the material on stress.[5]

3 Main applications of the pressure sensor

Pressure sensors have a wide area of application in different fields. Usually, they are used to monitor pressure, flow or level of gases and liquids inside tubes or tanks, the sensors are also able to detect physical contact, the touch's position and power. [7]

3.1 Touch detection

Pressure sensors can be used for accurate identification of position and amount of applied force to the spot. The technology can be used in mobile devices [9]. Unfortunately, pressure sensors are not able to detect multiple touches precisely, that's why usually they are used for accurate detection of the force applied to the spot, but exact position of the point is measured by other technology, this kind of approach is used by Apple 3D Touch [8] and graphical tablets Pic. 7. [10] In case of graphical tablet they use network of electromagnetic receivers to calculate an exact position of the electromagnetic transducer inside stylus, build into the stylus pressure sensors is used to detect amount of applied force and exact time of the touch, it gives painter an opportunity to precisely control thickness and shape of lines.

3.2 Automotive Industry

Pressure sensors have a lot of application in modern vehicles:

1. Monitoring of fuel's and oil's amount in tanks
2. Engine management system contains at least one pressure sensor, the sensor is located a manifold and measures the flow of air inside. The data is used to calculate a right amount of fuel for an injection, Pic 8.
3. Pressure sensors are used in brake booster, they are very important part of anti-lock breaking system(Pic. 9), ABS prevents locking of tiers in case of an active breaking.
4. Air bugs are triggered in according with pressure sensor, which is used to detect collision.
5. Diagnostics of particle filters for diesel engines

Table 1: Characterisation of different technologies[2]

Type	Advantages	Disadvantages
Resistive	<ol style="list-style-type: none"> 1. Sensitive 2. Low cost 	<ol style="list-style-type: none"> 1. High power consumption 2. Generally detect single contact point 3. Lack of contact force measurement
Piezoresistive	<ol style="list-style-type: none"> 1. Low cost 2. Good sensitivity 3. Low noise 4. Simple electronics 	<ol style="list-style-type: none"> 1. Stiff and frail 2. Nonlinear response 3. Hysteresis 4. Temperature sensitive
Tunnel effect	<ol style="list-style-type: none"> 1. Sensitive 2. Physically flexible 	<ol style="list-style-type: none"> 1. Nonlinear response
Capacitive	<ol style="list-style-type: none"> 1. Sensitive 2. Low cost 3. Availability of commercial A/D chips 	<ol style="list-style-type: none"> 1. Hysteresis 2. Complex electronics
Optical	<ol style="list-style-type: none"> 1. Sensitive 2. Physically flexible 3. Fast 4. No interconnections 	<ol style="list-style-type: none"> 1. Loss of light by micro bending chirping 2. Power consumption 3. Complex computations
Ultrasonic	<ol style="list-style-type: none"> 1. Fast dynamic response 2. Good force resolution 	<ol style="list-style-type: none"> 1. Limited utility at low frequency 2. Complex electronics 3. Temperature sensitive
Magnetic	<ol style="list-style-type: none"> 1. High sensitivity 2. Good dynamic range 3. No mechanical hysteresis 4. Physical robustness 	<ol style="list-style-type: none"> 1. Suffer from magnetic interference 2. Complex computations 3. Somewhat bulky 4. Power consumption
Piezoelectric	<ol style="list-style-type: none"> 1. Dynamic response 2. High bandwidth 	<ol style="list-style-type: none"> 1. Temperature sensitive 2. Not so robust electrical connection
Conductive rubber	<ol style="list-style-type: none"> 1. Physically flexible 	<ol style="list-style-type: none"> 1. Mechanical hysteresis 2. Nonlinear response



Figure 8: Picture of a MAP module with an Infineon KP21x sensor inside [7]

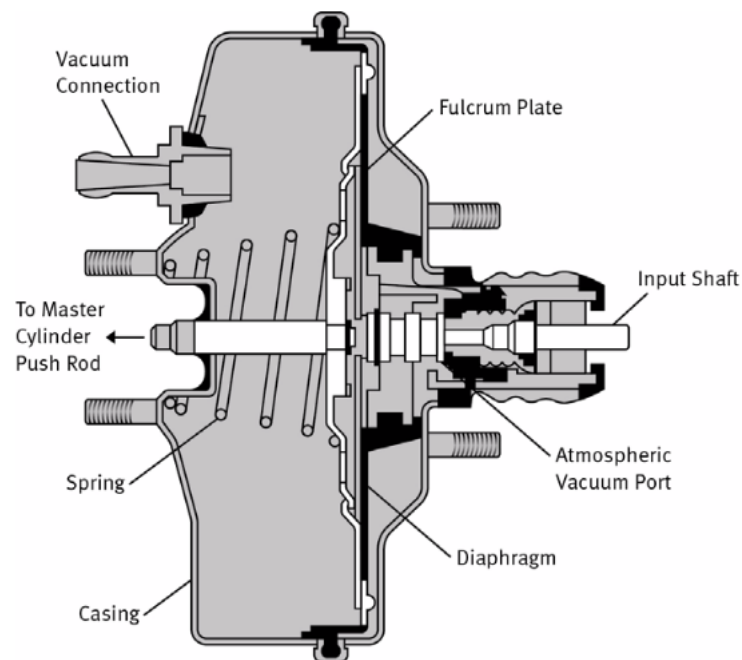


Figure 9: Blueprint of a vacuum power brake booster [7]

Pressure sensors have many other application on automotive industry, which makes car more safe, cheaper, efficient and so on.[7]

3.3 Bio Medical Instrumentation

Air or liquid flow sensors are especially useful for medical application, they are used in digital blood pressure monitors, lungmotors. Pressure sensors are also used in sphygmomanometer (Pic. 10) and various number of other medical devices. [6]

3.4 Industry and factories

Pressure sensors is very important part of industrial control systems. The sensors allow to maintain large chemical reactions in suitable for process condition, reduce risk of explosions for pressure vessel, monitor storage system for liquids and gases (available volume and partial pressures). In addition this kind of sensor are very important for diagnostics of tubes and filtering systems.



Figure 10: Sphygmomanometer [12]

3.5 Marine and aviation

Plane's contraction has several application for pressure sensors, first of all they are used to provide nominal ground like breathing conditions inside, they are also in construction of altimeters especially old-fashion ones. [11] The atmospheric altimeters are able to measure an altitude via difference between reference air pressure at 0 MAMSL and current value. A typical display of analogue altimeter is shown on picture 11.

Submarines use sensor in very same way with planes, they use pressure to measure depth, they also use pressure sensors to evaluate amount of compressed air in tanks and maintain right condition inside living areas. [6]



Figure 11: Screen of analogue altimeter [11]

3.6 The weather forecasting

An air flow is always going for high to low pressure area, it makes pressure sensors one of the main tool for the weather forecasting. A network of barometers distributed around wide area allows accurately predict wind and cyclone's velocity.

3.7 Research

As any other sensor pressure ones have wide area of original application for different types of research outside of their traditional range of usage, mention above.

3.8 Robotics

Robots need to have hand to be able to manipulate things around them. Pressure sensor is very important part of the hand, because it allows to make more precise control over grip. Pressure monitoring can prevent damage to goods and predict false. Robots usually use specially constructed pressure sensors called tactile sensors. Actually tactile sensor is set of pressure sensors, the type of devices gained a lot from MEMS approach, because it allows to stick together much bigger number of pressure sensors and in result have better resolution. The tactile sensors can also include temperature and other types of sensors to get information about the surface.[6]

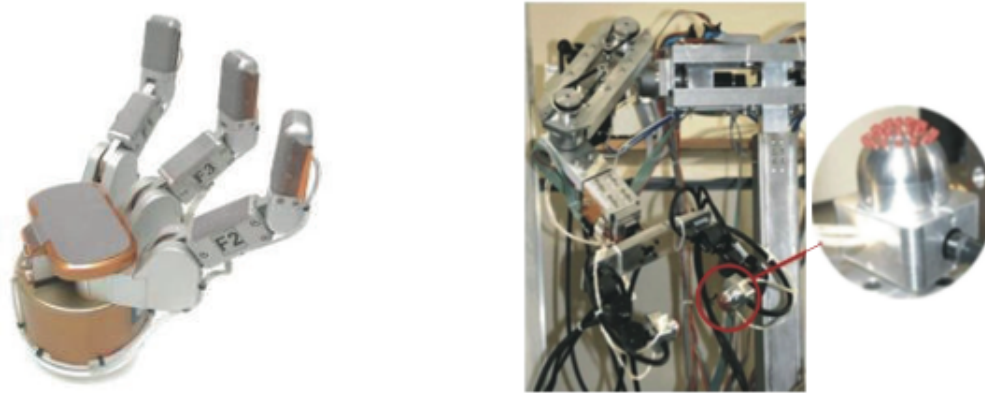


Figure 12: Robo-hands examples [6]

4 Markets and history of the pressure sensor

4.1 Early development

The development of pressure sensors was started from in early 50-s from piezoresistive semiconductors. The research proofed that piezoresistive materials are able to change resistance linearly to the amount of applied stress. The main advantage of the technology was low price and small size of the device.

4.2 80-s

The technology was improved in 1985, by founding of silicon on insulator (SOI) material. This kind of sensors was even small, it also required much more simple electronics to handle measurements and as result the sensors were cheaper.

4.3 90-s

Mono mode optical Fabry-Perot interferometer was developed, the invention was key to design of a new resonant differential pressure sensor. The sensor is based on mix of optical and ultrasound effects, that's why very stable and accurate.

Piezoresistive sensor was also significantly improved by high pressure protection, this type of sensors started to be suitable for a wide range of very high pressures. Capacitor pressure sensors started to be produced, they have had better performance for low temperature environment, than piezoresistive ones.

4.4 00-s

At early 00-s, new CCD sensors and Wollaston prism helped to develop self-calibrated optical pressure sensor. A Fabry-Perot cavity pressure sensor was improved by micromachining techniques at 2003.

At 2006 brand-new Fabry-Perot interferometer optical fibre pressure sensor was released. The sensor is based on phase demodulation method. The data processing of for the technique includes Fourier transformation of the Phase demodulation method, which allows to eliminate the light source intensity variation errors.

Mesa diaphragm type optical MEMS pressure sensor was presented in 2009, the general concept is based on Fabry-Perot interference. In 2009, Extrinsic Fabry-Perot Interferometric (EFPI) pressure sensor was improved by high temperature immunity.[13]

5 Fabrication of the pressure sensor

Different types of pressure sensors have very different fabrication process and I am not able to explain all of them in high in details, but I will try to highlight the most typical things for the mechanism. As many other types of MEMS devices pressure sensors are usually based on semi-conductive technologies. The general structure of the sensor is usually created with help of SU-8 Lithography Process, the technology is very helpful in building of tiny structures.

Let's take a little bit deeper look into construction of piezoresistive sensors. The production starts from creation of a cavity by surface micro-machining process. After that the cavity is covered by diaphragm made from polysilicon layer or a low stress nitride. The piezoresistive material is placed on top of the diaphragm. The sensor fabrication process is shown on Pic. 13.[14]

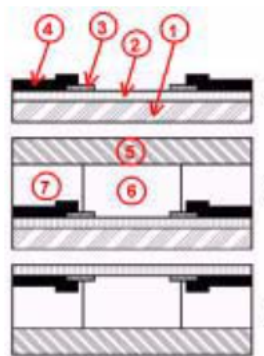


Figure 13: Fabrication process of the pressure sensor: 1) silicon wafer, 2) polysilicon diaphragm, 3) piezoresistive sensor, 4) metal lead, 5) Pyrex glass, 6) cavity and 7) SU-8 layer

6 Commercial manufacturers of the pressure sensor

There are many manufactures of pressure sensors, but I will be focused on three key player of the market.

6.1 Honeywell

Multinational conglomerate from UAS, was found at 1906, Wabash, Indiana by Mark C. Honeywell. The company has approximately 130,000 whole over the world and almost half of them are located in States. The main office is

located in Morristown, New Jersey. The CEO is David M. Cote.

The company was initially focus on thermostats and control systems for electric motors, but the area was extended to computing by joint venture with Raytheon.

Honeywell produce a lot of goods for army, aircraft and NASA. [15]



Figure 14: The logo of Honeywell

6.2 Omron

The company was found in Osaka, at 1933 as Tateisi Electric Manufacturing Co. Omoron was always focused on support of an industry with innovative solutions and advanced technologies. Talent and philosophy of the founder, Kazuma Tateisi, have had very strong influence to the corporative culture of OMRON.[16]



Figure 15: The logo of Omron

The Omron history in milestones:

- 1933 - started production of X-ray timers,
- 1959 - "OMRON" trademark established.
- 1960 - started production of world first non-contact switch
- 1960 - developed the world's first automated traffic signal
- 1969 - released the smallest in the world electronic calculator
- 1971 - the world first online automated cash dispenser created
- 1987 - developed the world's first ultra-high-speed fuzzy logic controller
- 1991 - In-line inspection system released
- 1998 - Created machine for identification of capable counterfeit notes in various currencies
- 2007 - The world's first real-color 3D Vision Sensor is created

6.3 STMicroelectronics

STMicroelectronics is one of the largest producer of semiconductors in the world. In 2014 year, it had net revenues of US\$ 7.40 billion. The company provides wide range of products.

STMicroelectronics has various solutions for automotive products, embedded-processing solutions, sense and power technologies. They are also a big supplier of MEMS and advance analogues solutions. The Embedded Processing Solutions contains digital consumer, microcontrollers and image signal processors.

Products of the company is used in almost every microelectronic device which brings positive contribution to people's lives. They are leaders at several markets:

- Semiconductors for industrial applications
- Inkjet print-heads
- MEMS (Micro-Electro-Mechanical Systems)
- Automotive integrated circuits
- Computer peripherals
- Chips for wireless and mobile applications
- And much more...

In 1987, SGS Microelettronica of Italy and Thomson Semiconducteurs of France were merged into one company named STMicroelectronics. The company has about 43,600 employees, 11 main factories, R&D centres in 10 countries and sales offices whole around the world.

21% of revenue is spent for R&D and about 20% of employees are working at the field. ST is the most innovative companies in the field, it has almost 15 000 patents and pending applications in 9 000 of patents family. They have made 500 applications for brand-new patents for 2014.[17]

The STMicroelectronics logo is shown on Pic. 16.



Figure 16: The logo of STMicroelectronics

7 Presentation of a commercial pressure sensor with main specifications

I want to introduce you MEMS Gauge Pressure Sensor Featuring Small Size and Low Power Consumption, pic. 17. Typical the sensor is used for medical equipment, home appliance, air movement control, level indicators, leak detection or pressure control.

The sensor is gauge piezoresistive and can be used for non-corrosive, dust free gases.

The main features:

- Size - 6.1 4.7 8.2 mm (L W H).
- Piezo Resistive element provides electrical characteristics that are superior to capacitive type pressure sensors.
- The range of measurable pressure vary for different specifications:

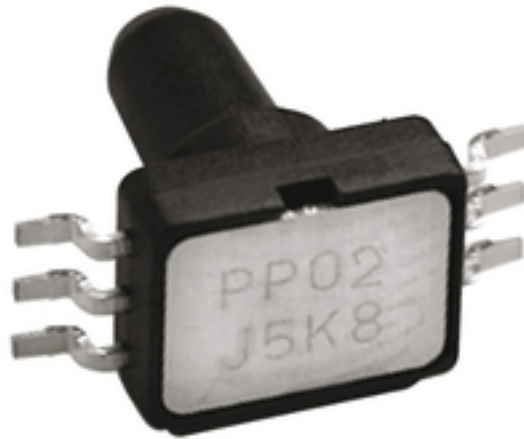


Figure 17: MEMS Gauge Pressure Sensor Featuring Small Size and Low Power Consumption

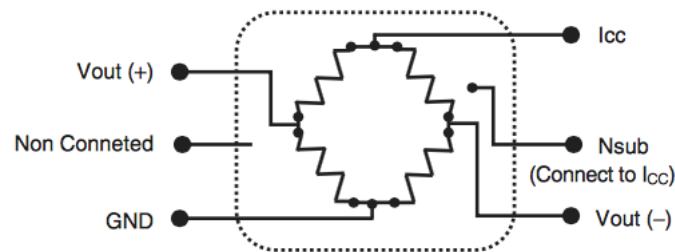


Figure 18: Conection of the sensor

- 0 to 37 kPa for 2SMPP-02
- -50 to 50 kPa for 2SMPP-03
- Low Power consumption - 0.2 mW
- Low Temperature Influence
- RoHS Compliant
- SOP stricture
- Price 6.25€

The sensor has to be connected according with schema on pic. 18. The pressure can be calculated in according with output voltage, look at transfer function on Pic. 19.[18]

7.1 Testing environment

In according with definition the best way to test the sensor is to apply some known amount of force to some well known area. I would prefer to you some cargo as force source, because it would be very easy to calculate the pressure in according with the weight of object with well known mass.

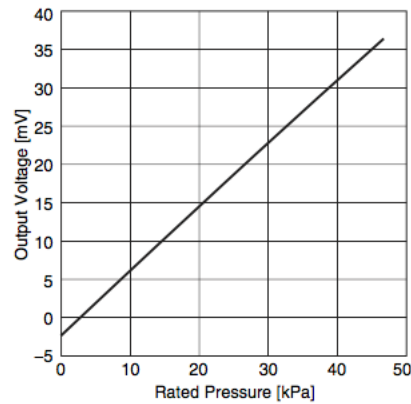


Figure 19: Sensor's transfer function

8 Conclusion

We are surrounded by pressure sensors. The type of devices has long history, but it became especially popular in its MEMS realisation. This type of sensors is used in a wide range of applications. Many different solutions are available in the market, the devices can have different construction and physical principle behind, because there is no best solution, every approach has its own advantage and suits well for specific case.

Pressure sensors are mainly used at:

- touch detection
- auto-mobile industry
- research
- factories
- marina and aviation
- forecasting
- robotics
- medicine

Main suppliers of MEMS pressure sensors are huge international companies specialised on microelectronics and sensors, because production of the devices is based on semi-conductive technologies and lithography.

It is externally difficult to over estimate importance of pressure sensors and imagine modern technologies without them.

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