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RESEARCH ARTICLE

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APPLICATION OF MICRO SENSORS FOR MECHANICAL MEASUREMENT

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ABSTRACT: The rapid development of micro-electromechanical systems (MEMS) technologies in recent years has provided a high degree of spatial miniaturization and integration of electromechanical components, which enable integrated sensing and control in manufacturing. In this paper I presented an overview of the state of the art of micro machined micro sensors for the measurement of mechanical signals in the manufacturing industry for automobiles, manufacturing, medical equipment, environment, robotics, food and other consumer products. I will describe major design parameters of such micro sensors, such as dynamic range, sensitivity, resolutions and accuracy and provide real world applications. In this paper I also dealt with issues related to the spatial integration of signal processing, power supply, and wireless communication with the sensing elements, which are of direct relevance to the overall performance of the micro sensors

***Keywords*—**MEMS, Micro Sensor, Module Integration, Piezoelectric.

INTRODUCTION

Mechanical signals measured by the micro sensors monitor the operational status of the manufacturing equipment, determine the process characteristics, and provide input to the system controller for improving product quality while reducing machine downtime. Measurements of pressure, acceleration, and acoustic emission (AE) are the three physical quantities that are most encountered in industrial and manufacturing applications. I will describe major design parameters of such micro sensors, such as dynamic range, sensitivity, resolutions and accuracy and provide a real world application. I will also discuss issues related to the spatial integration of signal processing, power supply, and wireless communication with the sensing elements, which are of direct relevance to the overall performance of the micro sensors.

MICROSENSORS FOR PRESSURE

Pressure sensors are among the most popular and important sensing devices, accounting for 40% of the total sales in sensors. Pressure sensors find application in automotive systems manufacturing process control, and medical diagnostics. Over the last decade, the need for micro machined pressure sensors has increased rapidly because of their micro scaled dimensions that allow for structural integration into the automobiles and manufacturing equipment. Such integration enables in-situ measurement at the site where actions take place, thus providing a clearer picture of the object to be sensed. This may not be possible using conventional sensors. From the point of view of sensing principles, pressure micro sensors can be generally divided into four categories.

They are

1) Piezoelectric.
2) Piezoresistive.
3) Capacitive.
4) Optical

PIEZORESISTIVE MICROSENSORS

A typical piezoresistive pressure micro sensor uses a flexible silicon membrane as the sensing element as shown in fig-1.

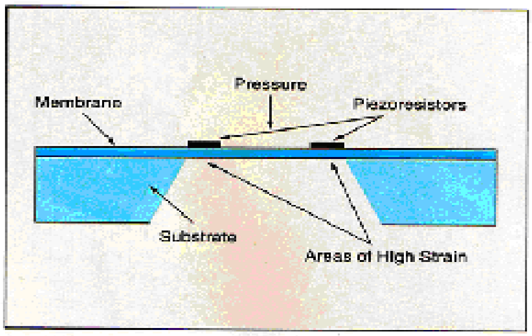

Fig.1 Illustration of a typical Piezoresistive pressure micro sensor based on membrane structure

Piezoresistivity is the phenomenon by which resistance changes in response to mechanical strains. The piezoresistors, arranged in a Wheatstone bridge circuitry, are diffused into the areas of high strain (the areas of the membrane that are closest to the substrate) for maximum sensitivity. Pressure application results in a detection of the membrane, and the developed strain in the membrane subsequently change the resistance of the piezoresistor, proportional to the magnitude of the pressure this change of resistance is readily measured by the bridge circuitry. The design of the membrane thickness is a critical parameter with respect to the sensor sensitivity. Thin membrane thickness, while favorable to maximizing the load-deflection responses, causes large deflection-induced nonlinear effects, which are not desirable. Performance of the piezoresistive sensors is also affected by variations in both the temperature and pressure: sensitivity decreases as the temperature increases and nonlinearity develops.

Typical fabrication techniques used for this are

1) Bulk micromachining: - A batch parallel process based on the same processes used for integrated circuit (IC) fabrications.

2) Surface micromachining: - An additive process where features are built up layer by layer on the surface of a substrate.

CAPACITIVE PRESSURE MICROSENSORS

They are similar to their piezoresistive counterparts. They typically consist of a silicon membrane with a pair of electrodes deposited on the membrane with a pair of electrodes deposited on the membrane and the substrate, respectively, to form a sensing capacitor as shown in fig-2.

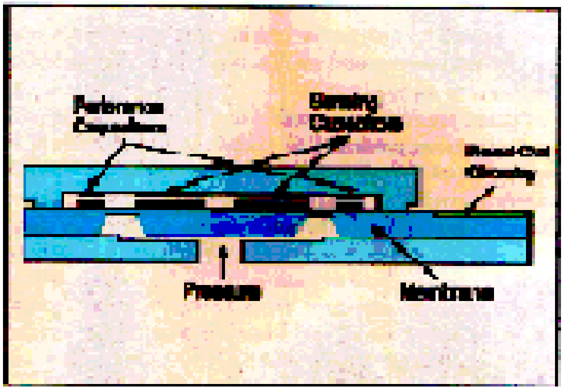

Fig.2 Illustration of a typical capacitive pressure micro sensor based on membrane structure

The displacement of the membrane moves one of the electrodes closer to another and therefore changes the capacitance. Another type of the capacitive pressure microsensors uses the parallel comb structure. The pressure applied parallel to the sensor surface is transformed into changes in capacitance as shown in fig-3.

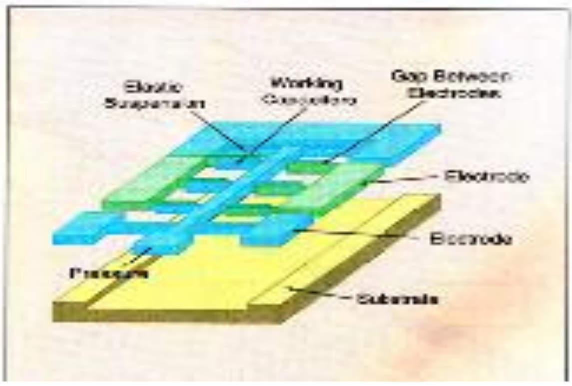

Fig.3 Illustration of a typical capacitive pressure micro sensor based on parallel capacitance

Because of its parallel structure, the capacitance increases on one side of the comb and decreases on the other side resulting in good linearity and sensitivity.

Compared to the piezoresistive pressure microsensors, the capacitive design can achieve higher-pressure sensitivity, and reduced power consumption; it also has a relatively simple structure. However, it requires a larger die area and more sophisticated sensing circuitry. An industrial example of a capacitive pressure microsensor is given in fig-4.

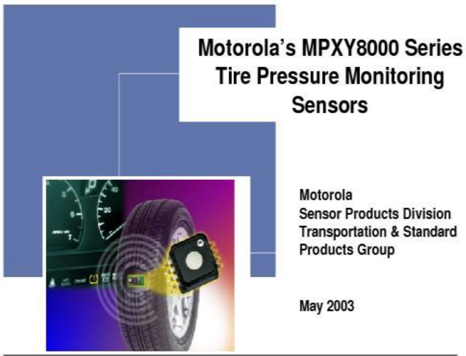

Fig. 4 Introducing Motorola's MPXY8000 Series Tire Pressure Monitoring Sensor

It illustrates a tire pressure-monitoring sensor (Model MPXY8020 from Motorola), which informs the driver of current tire pressure and helps maintain driving safety while reducing fuel consumption. The sensor includes a capacitive pressure sensing element, a temperature-sensing element, and an interface circuit all on a single chip. It is a remote sensing module installed in either the valve stem or the wheel well. It communicates with a receiver module that typically resides in the dashboard of the car. The sensor module is characterized by low power (the standby mode draws less than 0.5 milli Amp current) and small size so it will not introduce imbalance to the tires.

OPTICAL PRESSURE MICROSENSORS

It use laser light as a means for interrogating pressure. Light is brought into the sensor by optical fiber and is split into two beams. One beam crosses a membrane, which can deform by pressure, as shown in fig-5.

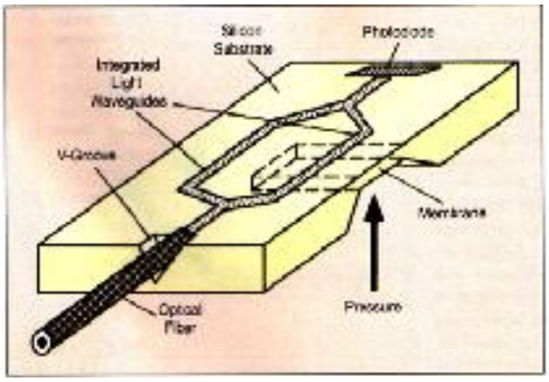

Fig. 5 Illustration of an optical pressure micro sensor

The deformation changes the light properties and different propagation speeds result in a phase shift. The pressure can be inferred by measuring the difference between the phases of the two optical signals. Optical fiber pressure sensors have a number of potential advantages in comparison to their electrical counterparts. They are insensitive to electromagnetic interference, requiring no connecting leads in electrically noisy environments. Optical sensing is also advantageous, particularly in harsh environments where high temperature, vibration, or electromagnetic interference dominates. Furthermore, they are also less sensitive to packing stress; they measure the displacement instead of strain. Above all, the compatibility of these sensors with the next generation fiber optic data network makes them a good choice.

MICROSENSORS FOR VIBRATION

Vibration is an important parameter in monitoring the condition of operating machines. Accelerometers are widely used to measure vibration, as commonly seen in the automotive and manufacturing industries.

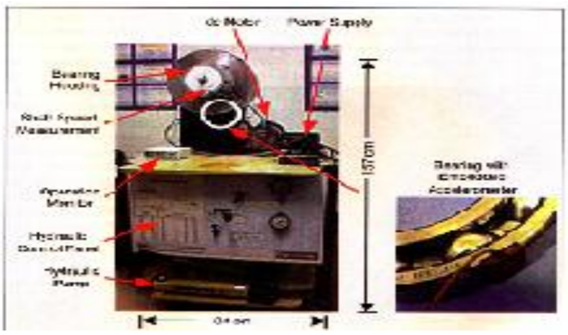

Fig.6 Condition monitoring of a bearing by micro sized accelerometers

Fig-6 shows an example of microsized accelerometers used for condition monitoring of a bearing where a ball bearing with an embedded sensor prototype is tested in a customized sensor prototype is test in a customized test rig. The sensor consists of a piezoceramic plate of about 5 x 3 x 1 mm and a wireless data transmission chip of 17 x 13 x 4 mm. Over the past few years, research on micromachined inertial sensors has led to a variety of piezoresistive, capacitive, capacitive, tunneling current, and resonant types of accelerometer. The piezoresistive accelerometer incorporates a piezoresistor on a cantilever beam structure, as shown in fig-7.

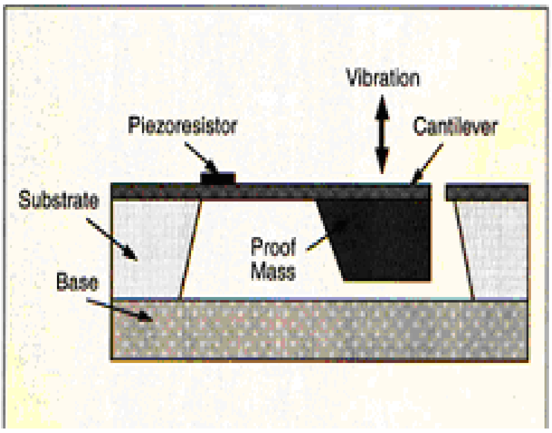

Fig.7 Illustration of a typical piezoresistive micro accelerometer using the cantilever design

Vibration-induced movement of the proof mass deflects the beam, which changes the resistance of the embedded piezoresistive accelerometers have a relatively high sensitivity to temperature and smaller overall sensitivity when compared to capacitive sensors and hence they need a large proof mass. Often space limitation prohibits its structural integration. Piezoresistive accelerometers are generally fabricated using bulk-micromachining technology and can achieve a sensitivity of about 0.5-3 mV/g, with a dynamic range as low as 1g.Capacitive accelerometers measure changes of the capacitance between a proof mass and a fixed conductive electrode separated by a narrow gap (fig-8).

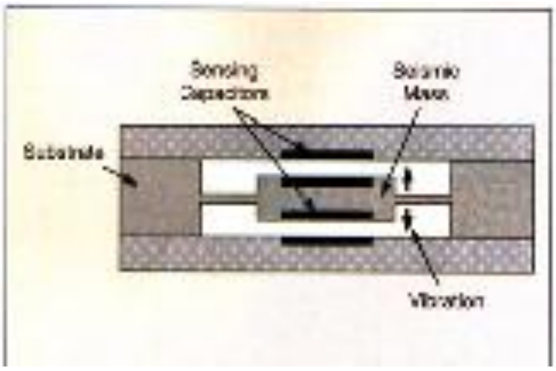

Fig.8 Illustration of a capacitive accelerometer based on proof mass and electrode

They feature high sensitivity, good noise performance, low-power dissipation, and simple structure. These features make them attractive for machine integrations. However, one drawback of the capacitive accelerometers is their susceptibility to electromagnetic interference, which is problematic for applications in a manufacturing environment. Among the various designs, both vertical and lateral structures have been reported. The combined bulk and surface micromachining process has enabled the capacitive accelerometer designs to achieve accelerometer designs to achieve a microgram and sub microgram resolution.

A tunneling current accelerometer uses the tunneling effect to sense the displacement. Tunneling accelerometers can achieve high sensitivity with a relatively small size, since the tunneling current is highly sensitive to displacement, typically changing by a factor of two for each angstrom of displacement.

A resonant accelerometer is a device whose output is the frequency shift of a resonant beam due to the transfer of proof-mass inertial force to axial force on the resonant beam. These sensors have some advantage because of their direct digital output.

MICROSENSORS FOR ACOUSTIC EMISSION

AE is the effect of elastic waves generated by rapid release of energy from localized sources within a material. Monitoring of AE is a nondestructive means of evaluation. Typical applications of AE in manufacturing include detecting material and structural flaws, monitoring micro damage progression, studying fundamental deformation of materials, and monitoring real time manufacturing processes.

Applications of AE monitoring in precision manufacturing include metal turning, milling, grinding, lapping and polishing. A typical application of AE monitoring can be found in laser precision machining, which needs real-time process monitoring and control. In this situation, AE often serves as the reference parameter to set the process control parameters related to the laser, optics, work piece material, and motion system. AE signals from the laser-material interaction zone, after signal processing, are closely correlated with variations within the incident laser pulse energy and therefore can be used as a reference parameter.

In most of the AE applications of the out-of-plane displacements created by the AE are extremely small typically on the order of picometers or even smaller. Therefore, the performance of AE monitoring may be improved by developing micro-AE sensors. These micro-scale AE sensors can be embedded in the structure and tools to detect sound waves emitted by small structural defects such as cracks.

The major groups of AE microsensors are piezoelectric and capacitive. In piezoelectric AE microsensors, the sound pressure is detected and converted to a voltage by a piezoelectric cantilever, membrane or thin film.

Capacitive AE sensors detect the out-of-plane displacement that changes the capacitance the electrode plates. The primary study in this area has been focused on microphones. A microphone is an air coupled acoustic sensor with a useful bandwidth generally in the low frequency audio range between 20Hz and 20KHz. More and more researchers have studied capacitive microphones in recent years because of their high sensitivities (10 mV/ Pa), low noise levels (26dB re, 20 mPa) and flat frequency responses in wide bandwidth, as compared with piezoelectric microphones.

Fig.9 A condenser capacitive microphone

An example of the condenser capacitive microphone is shown in fig-9.

The frequency bandwidth of an AE signal is typically wide (on the order of 100 KHz), due to its short time transient nature. Therefore, for this type of sensor, bandwidth is an important issue. Commercially available wideband AE sensors can cover a frequency range from 50 kHz up to several megahertz.

MODULE INTEGRATION

Proper integration of various constituent elements into a sensor module is important for enhancing the performance of microsensors. Integration increases reliability of the sensor or allows for multiple quantities to be measured in one chip. It also allows for the integration of signal processing, wireless communication, remote powering module, and ease of field installation.

Integration of a wireless module onto the sensor chip eliminates cable attachment and enables remote communication of a signal. For most microsensors, however, a battery is necessary for power. A battery not only increases the size and weight of the microsensor but also suffers from a limited lifetime and frequent replacement, which is not acceptable for many real-world applications. To overcome this bottleneck, two types of remote powering have been developed to eliminate the battery. The first is to extract electrical energy from a vibrating piezoelectric device through a mechanical-to electrical energy -converting device, usually a piezoelectric converter. This type of remote powering is best suited for the sensing of vibration using accelerometers. The other approach is passive remote powering using an inductive link to receive electromagnetic power from an external coil.

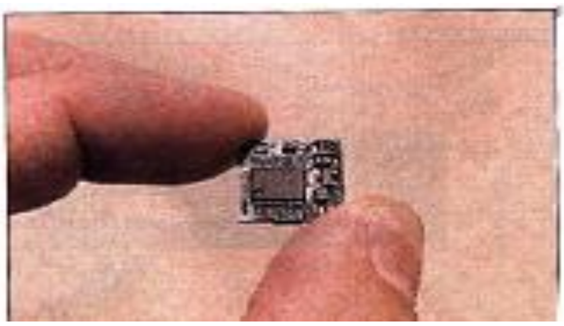

Fig.10 Passive remote powering module

An example of the passive remote powering module is the Embed Sense (Microstrain) wireless sensor module, shown in fig-10.

It uses an inductive link to receive power from an external coil and to return digital strain, temperature, and other identification information. The module can be subject to high g-levels and high temperature and uses no batteries, thus is applicable in places where no data could be obtained previously.

The integration of signal processing and conditioning modules into a microsensor chip also received great attention recently.

An example is the iMEMS ADXRS gyroscope (Analog Devices) illustrated in fig-11.

It is a device that has integrated both n angular rate sensor and signal processing electronics onto a single substrate of silicon. Through this integration, the ADXRS gyroscope can deliver stable output in the presence of mechanical noise to 2000 g over a wide frequency range.

The benefit and significance of MEMS technologies are threefold:

1) They allow for a high level of dimensional miniaturization, which is critical to the structural integration of sensors into the mechanical host environment.

2) They provide multiplicity capability, which enables the fabrication of a large number of identical sensing units at the same time as one component, thus keeping the final cost of the product low (the low-cost aspect is critical to the industry's acceptance and technology transfer).

3) They provide a natural interface to microelectronics, allowing for the union of localized signal conditioning with a microsized physical sensing element, all within a single MEMS sensing chip. This sensing chip is not only smaller in size than the traditional sensors but is also more robust in design. Many wire connections are eliminated and the interface is optimized among the various electromechanical subsystems

CONCLUSION

This paper reviewed microsensors for mechanical measurement applications, focusing on the measurement of pressure, acceleration, and AE. For the pressure microsensors, three major design principles, piezoresistive, capacitive, and optical, were introduced; tire pressure sensors served as an industrial example. For monitoring machine vibrations, the piezoresistive, capacitive, tunneling, and resonant accelerometers were introduced, exemplified by a bearing diagnosis and prognosis system. The application for AE microsensors in precision machining and other manufacturing and nondestructive testing areas were described, with special attention given to capacitive and piezoresistive microphones. In addition, the spatial integration of signal processing, power supply and wireless communication with the sensing elements was discussed, which has significance in improving the overall performance of the microsensors. This review provides a glimpse into how microsensors can help improve the performance of machine, as well as achieve better control of the manufacturing process.

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