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Overview of Modern Accelerometers

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Abstract—*The paper reviews and analyzes features of MEMS accelerometers. As a result, their advantages and disadvantages are revealed. Examples of miniature devices and their demand are given. The key parameters that must be taken into account when choosing an accelerometer are formulated. There are three categories by which accelerometers can be distinguished.*

Keywords—accelerometers; MEMS; sensitive element; types of accelerometers.

1. Introduction

The prospects for development of modern instrumentation are closely related to design and manufacture of compact devices with low cost, long service life and low power consumption.

Integration of electronic and mechanical components allows to receive superminiature sensors with unique metrological and reliable characteristics at rather moderate cost indicators.

MEMS – technology involves production of inexpensive and compact devices (miniature) (fig. 1) [1].

Accelerometer is measuring device that allows you to determine projection of apparent acceleration. Accelerometer – to measure force of reaction induced by acceleration or gravity.

Figure 1. Examples of miniature devices and their demand

Accelerometers are included in mechatronic systems to measure motion, tilt, vibration and shock.

Accelerometers are widely used to monitor seismic activity (detection of buildings and bridges oscillations), measuring vibration resistance of equipment, testing mechanical strength of housings, virtual reality, sports equipment, telephones, computers (PDA, laptop, etc.), robotics, etc. [2]-[6].

Development of new types of accelerometers and their modifications is urgent task. The solution to this problem involves the use of various methods of analysis, algorithms, and approaches [7]-[11].

2. Related work

Currently, MEMS accelerometers are one of the most promising trends in inertial sensor industry.

The existing works [1], [12]-[15] describe in detail issues related to study of structures.

In [1], three-axis capacitive MEMS accelerometer was investigated.

The work [12] is devoted to design and study of MEMS accelerometers structures, special attention is paid to modeling developed geometric model of MEMS accelerometer sensitive element.

A side-by-side review of MEMS accelerometers for analysis of mechanical vibrations is presented by authors in [13].

Work [14] is devoted to new all-optical sensor design based on tunable resonant nanocavity in microstructure of photonic crystal, applicable in MEMS accelerometers.

An overview of piezoelectric MEMS accelerometers for measuring bone vibration is given in [15].

In [16], polymer piezoresistive MEMS accelerometer SU-8 with built-in ITO (Indium Tin Oxide), its development, manufacture, and characteristics was investigated.

A brief overview of sensing methods and polling methods used in optical MEMS accelerometers is presented in [17], such sensing methods include changes in properties of light signal due to deviation of reference mass under action of inertia.

MEMS accelerometers are widely used in various spheres of human life and applications, for example, for complex industrial applications [18].

Monitoring GNSS landslides using inexpensive MEMS accelerometers is presented in [19].

An overview of inexpensive MEMS accelerometers uses for determining frequency and damping of building structures is described in [20].

3. Overview of Modern MEMS Accelerometers

The accelerometer is one of the most widely used in MEMS technology [1]. It measures projection of full acceleration.

Today, MEMS devices are used almost everywhere. These can be:

1) miniature details:

- hydraulic and pneumatic valves;

- inkjet printer nozzles;

- springs for suspension of hard drive head.

2) micro-tools – scalpels and tweezers for working with micron-sized objects);

3) micromachines:

- motors;

- pumps;

- turbines size of pea.

4) microrobots;

5) microsensors and actuators;

6) analytical micro-laboratories (on one crystal), etc.

Consider several types of accelerometers:

- electronic;

- mechanical;

- piezoelectric;

- thermal;

- optical.

Electronic accelerometers (fig. 2) – combine mechanical parts and electronic components [21], [22]. They allow you to get result more accurately and faster.

The principle of electronic accelerometers operation is based on changing capacitance of capacitors when changing acceleration.

The advantage of such devices is small size.

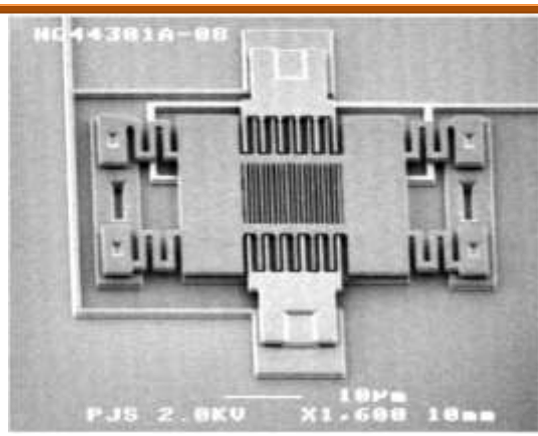

Figure 2. Electronic accelerometer

Mechanical accelerometers are simplest, have simple design. In this accelerometer, suspended element is suspended body, which is attached to elastic suspension. When position of body changes, then suspended body compensates for this action on spring on which it is fixed [23].

Piezoelectronic accelerometers – have solid rod in middle, which is constantly under pressure and acts on piezoelectric crystal. As a result of vibration, electric current is generated [24].

Thermal accelerometers – have small air bubble. When accelerating, this bubble deviates from its position [25].

Optical accelerometers – have an emitter, two LEDs and photo detector [26].

Designed for use in measuring technology.

In general, there are many MEMS accelerometers that are structurally different, have different applications and parameters.

Accelerometers have number of characteristics. Depending on this or that parameter their characteristics also change.

Accelerometers can be distinguished:

- by number of axes: one, two or three;

- by type of output: analog and digital;

- by frequency range.

The greatest interest at moment is in production of piezoelectric, piezoresistive or capacitive acceleration sensors.

1. Consider features of piezoelectric accelerometers (PE).

There are 3 main accelerometer configurations: shear, compression and bending.

The shear mode of piezoelectric plate is tuned to shear deformation as result of acceleration (that is piezoelectric plate is perpendicular to base).

This configuration has become most popular because piezoelectric plates are insulated from base, which helps to reduce temperature sensitivity and susceptibility to deformation of base.

But this configuration usually has relatively low sensitivity to mass ratio, which means that you will need charge amplifier.

Compression mode. With piezo in its compressed state, it is right in line with base and seismic mass above. This provides moderately high sensitivity to mass ratio, but it results in efficient spring-mass system between piezoelectric element and base. This can lead to easily misleading results due to base bending or thermal expansion. Therefore, this configuration is rarely used except in case of heavy impacts due to its reliability.

Piezoelectric pipe bender. The simplest configuration to understand is piezoelectric element that acts like cantilever beam with mass of tip. This provides best sensitivity-to-mass ratio, so much so that this type of accelerometer does not require power.

But this configuration also exhibits highest temperature sensitivity, is relatively fragile (therefore multilayer / packaged piezoelectric transducers can be advantageous), and generally has lower resonant frequency and therefore lower bandwidth.

As such, they are rarely used for accurate testing these days, but they offer great advantage as no-power sensor to wake up main sensing system.

The direct piezoelectric effect makes it possible to convert mechanical effect on quartz crystal or piezoceramic element. After displacement of crystal lattice on surface of sensitive material appears proportional to applied force electrical charge.

Natural quartz crystals are one of best materials for piezoelectric sensor elements.

As rule, sensitivity and resonant frequency depend on mass of accelerometer.

Examples of design of piezoelectric accelerometers are shown in fig. 3 [15], [24].

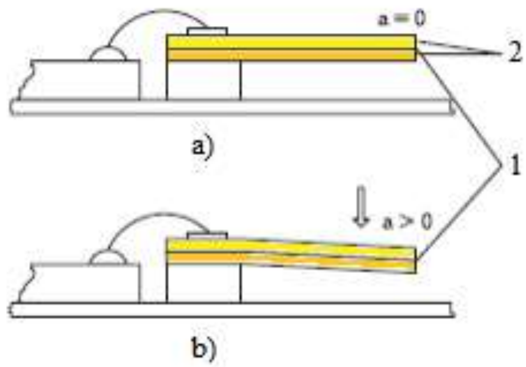

Figure 3. Example of piezoelectric accelerometer:

a) at rest; b) under action of acceleration

1 – piezoceramic bimorph elastic element working on bending ("measuring beam");

2 – layers with antiparallel (opposite) direction of polarization.

Advantages of piezoelectric accelerometer:

- frequency response – accelerometers have wide frequency range;

- temperature stability – accelerometers are by nature stable in wide temperatures range;

- strength – accelerometers are essentially strong, which is due to their solid construction;

- low noise level.

Disadvantages of piezoelectric accelerometers:

- such accelerometers are "optimal" in their relatively wide frequency range, but at outer boundaries they can experience very large deviations;

- piezoelectric accelerometers are not able to operate on direct current.

2. Consider features of piezoresistive accelerometers.

Bendable silicon resistors also known as strain gauges are used to measure acceleration in piezoresistive accelerometers.

The design of such accelerometers for measuring acceleration is one or more cantilever beams on which movable mass is fixed.

Due to bending of consoles, resistance of silicon resistors changes and due to change in resistance of measuring arms of Winston bridge by measuring voltage, it becomes possible to detect effect of acceleration on accelerometer sensitive element.

Thanks to their design features, piezoresistive MEMS accelerometers can measure static acceleration.

Sensitive elements in PE accelerometers consist of bends on middle plate, clamped between upper and lower plates.

Sensing elements are usually mounted on printed circuit boards housed in titanium or aluminum housings.

Advantages of piezoresistive accelerometers:

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- suitable for speed and displacement measurements because DC outputs are less susceptible to simple and double integration errors than AC outputs.

- suitable for low frequencies (up to 0 Hz);

- measure static angles of rotation;

- have differential output signal.

Disadvantages of piezoresistive accelerometers:

- practically unsuitable for dynamic characteristics;

- equipped with internal electronic components, that is, they have limited temperature range;

- have fairly low frequency range.

The most common applications for piezoresistive accelerometers are:

- tests in aerospace and defense industries;

- measurements of strong shock effects;

- various measurements of static shock and vibration.

3. The features of smart accelerometers are easy to see.

The most widespread among MEMS accelerometers are capacitive accelerometers based on capacitive transformation of microdisplacements of inertial mass.

Compared to piezoelectric sensors, which only require special materials and dynamic minimum frequency input, capacitive accelerometers can be built on silicon and provide ability to detect DC acceleration without signal attenuation and significant zero offset (which is important, for example, in inertial navigation systems).

The typical design of capacitive MEMS accelerometer is differential capacitor. It consists of two rigidly fixed electrodes between which there is electrode – plate, mechanically connected to moving mass.

Standard capacitive accelerometers (as well as MEMS accelerometers) consist of moving sensing mass with plates attached to mechanical suspension at reference point in fig. 4 [27], [28].

The sensing element (SE) of capacitive accelerometer is made in form of mass, which is movable plate of differential capacitor and is fixed on elastic suspension with rigidity.

Generally, capacitive accelerometers are better suited for low frequencies.

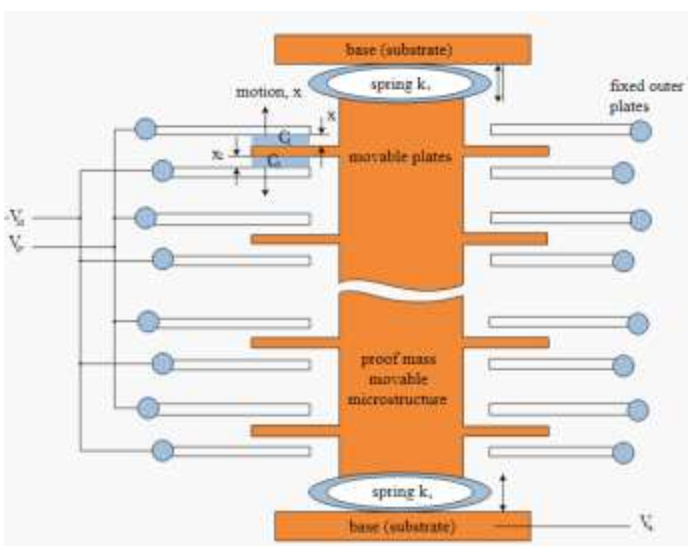

Figure 4. MEMS variable capacitive DC accelerometer construction

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Capacitive accelerometers allow measurement of accelerations in any direction of six degrees of freedom due to different locations of sensing element.

The use of capacitive technology is main direction in field of acceleration measurement, and has large number of implementation options:

- capacitive accelerometers without use of silicon, for example, from nickel and its alloys (accelerometers made of such materials allow measuring both static and dynamic acceleration with very wide range – from 1g to 20,000g. This type of accelerometers can withstand shocks of order 10,000 g / with and operate at temperatures above 200 ° C);

- servo accelerometers, etc.

Advantages of capacitive accelerometers:

- measure static and dynamic acceleration;

- small size, low cost (with relative limitation of accuracy).

Disadvantages of capacitive accelerometers:

- bandwidth is less than that of piezoelectric, charge and IEPE accelerometers;

- shock resistance and permissible operating temperatures are worse than those of charge accelerometers.

The most common applications for capacitive accelerometers are:

- mobile phones – to rotate image when you rotate device and detect sudden change in acceleration (protection against falls);

- drones;

- cars – deployment of airbags;

- game controllers – determination of spatial position.

The most relevant design of differential capacitive MEMS accelerometer at moment is interdigital arrangement of electrodes.

Variable Capacitance (VC) MEMS accelerometers are highly sensitive devices.

Piezoresistive (PR) MEMS accelerometers are devices with higher range and lower sensitivity.

There are three categories by which accelerometers can be distinguished:

- by number of axes: one (fig. 5), two or three;

- by type of output: analog and digital;

- by frequency range.

Figure 5. PCB Piezotronics DC uniaxial accelerometer MEMS [29]

Thus, electronic MEMS accelerometers have become widespread.

Advantages of MEMS accelerometers:

- ideal for static and low frequency measurements (down to 0 Hz);

- measure static angles of rotation.

Disadvantages of MEMS accelerometers:

- equipped with internal electronic components, that is, they have limited temperature range;

- have fairly low frequency range;

- amplitude range – no more than 400 g.

Working with 3D-MEMS technology opens wide prospects in design of various accelerometers, which will have different forms of execution. This flexibility allows sensors to be used in new devices that require small dimensions.

Today, MEMS is combined with nanoelectromechanical systems (NEMS), which allows to expand their scope.

Parameters to consider when choosing an accelerometer:

- accuracy;

- sensitivity;

- bandwidth (frequency range);

- low-frequency range (upper cutoff frequency of accelerometer should be less than measured frequencies);

- amplitude range;

- level of residual noise determines minimum amplitude range of sensor;

- operating temperature.

4. CONCLUSION

Thus, use of MEMS accelerometers in various gadgets allows you to implement new features.

Accelerometers are widely used in our lives in smartphones, fitness bracelets, video recorders, automotive, seismic stations, aircraft.

In course of analysis, following features of MEMS accelerometers were determined:

- MEMS accelerometers haverather limited amplitude range (no more than few hundred g);

- level of residual noise determines minimum amplitude range of accelerometer, that is, MEMS accelerometers have smaller dynamic range;

- temperature range of MEMS accelerometers is limited by built-in electronics (from –40 to +125 ° C);

- optimal for measuring static or constant acceleration (MEMS measure frequencies up to 0 Hz);

- piezoresistive accelerometers are simple in design, easy to manufacture and have built-in immunity to parasitic capacitance and electromagnetic interference.

The paper reviews and analyzes features of MEMS accelerometers. As a result, their advantages and disadvantages are revealed.

Examples of miniature devices and their demand are given. The key parameters that must be taken into account when choosing accelerometer are formulated.

There are three categories by which accelerometers can be distinguished.

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