Volume 8 Issue 4, 2022
DOI: 10.6919/ICJE.202204_8(4).0041

Application of MEMS Sensor in Foundation Pit Monitoring

Zhicheng Bai[1, a], Dajiang Geng[2, *], Minjian Long[1, b]

[1] China Construction 4th Engineering Bureau Co., Ltd 201100, China

[2] China Construction 4th Engineering Bureau 6th Corp. Limited 201100, China

[a]463803941@qq.com, [*]gdj1410704@alumni.tongji.edu.cn, [b]109687067@qq.com

Abstract

With the continuous development of MEMS sensors, they are more and more widely used in all walks of life. However, the existing widely used foundation pit monitoring methods still have the problems of heavy workload and large human interference factors. Therefore, the applicability of MEMS sensors in foundation pit monitoring is summarized and analyzed by using the theoretical analysis method, mainly including the contents and methods of traditional foundation pit monitoring, the principle of MEMS sensor and MEMS sensor suitable for foundation pit monitoring. The research results show that it is theoretically feasible to introduce MEMS sensors into foundation pit monitoring. The sensors with application prospects in foundation pit engineering monitoring include pressure sensors and inclination sensors. The automation and intelligence of foundation pit monitoring can be realized by introducing MEMS sensors.

Keywords

MEMS; Foundation Pit Monitoring; Pressure Monitoring; Inclination Monitoring.

1. Introduction

At present, the monitoring of foundation pit engineering mainly adopts manual monitoring and wired automatic monitoring. The labor cost of manual monitoring is high, and the monitoring data are discontinuous. When the sudden large deformation occurs in the foundation pit, if the monitoring frequency is not enough, the missing early warning will often occur. Manual monitoring method has low ability of early warning for emergencies. Wired automatic monitoring is mainly the automation of data acquisition. The specific sensors used in the monitoring are still traditional sensors. In the specific monitoring, the data acquisition line is often damaged and invalid. This monitoring method needs to solve the problems of high installation cost and high maintenance cost. In recent years, wireless sensor technology is more and more widely used in civil engineering. The core of wireless sensor technology includes sensor, wireless transmission network and real-time analysis and prediction system. Considering that micro electro mechanical system (MEMS) sensor is a relatively new type of sensor, which has great application prospect in foundation pit engineering monitoring, the application of micro electro mechanical system (MEMS) sensor in foundation pit engineering is analyzed by theoretical analysis method, so as to provide reference for the use of MEMS sensor in Foundation pit monitoring.

2. Contents and Methods of Traditional Foundation Pit Monitoring

In some new and complex foundation pit engineering projects, it is generally necessary to rely on the foundation pit monitoring on the construction site to master the safety state of the whole foundation pit. The previous engineering experience can only be used for reference. Based on the field monitoring of the foundation pit to obtain the measured data, the designed foundation pit strength can

ISSN: 2414-1895 DOI: 10.6919/ICJE.202204_8(4).0041

be understood and analyzed, so as to provide a basis for reducing the project cost in the future. Through monitoring, we can timely understand the impact on the surrounding environment during the construction process and evaluate the degree of impact. The most important thing is to respond and predict some potential dangerous situations in time, so as to provide basis for eliminating dangerous situations when they occur.

As shown in Table 1, the monitoring content of foundation pit engineering mainly includes two aspects: the monitoring of support system and the monitoring of adjacent environment. Among them, the monitoring of foundation pit support system mainly includes settlement, inclination, horizontal displacement, stress monitoring, etc; The monitoring of adjacent environment mainly includes the monitoring of adjacent buildings, structures, traffic roads and municipal pipe networks, as well as the settlement [1], horizontal displacement, earth pressure, pore water pressure and water level height of surface and deep soil, as well as the uplift of pit bottom [2].

n the actual foundation pit monitoring work, not all the monitoring contents should be set in each foundation pit project. The contents to be monitored can be selected according to the specific situation of the foundation pit project. For example, for the foundation pit built in the center of high-rise CBD City, it is necessary to focus on monitoring the bulge or subsidence of roads, the subsidence and inclination of office buildings or large shopping malls, the horizontal displacement and vertical subsidence of reinforced structures, and the rise or fall of groundwater level; The foundation pit project far away from the urban center is relatively simple, so there is no need to focus on the monitoring of the above-mentioned man-made structures. Therefore, the determination of monitoring content should comprehensively consider many factors such as the specific environment next to the foundation pit, the length of construction time and cost saving as far as possible. On the premise of ensuring construction safety, select the most important content that must be monitored for monitoring, and the content that can be selected for monitoring can be selectively monitored according to the requirements of relevant specifications.

Table 1. Traditional foundation pit monitoring items and methods

Monitoring items	Monitoring method
Horizontal displacement	Collimation line method, polar coordinate method, datum line method, etc
Vertical displacement	Static leveling method
Horizontal displacement of deep soil	Inclinometer
Deep soil settlement	Layered settlement magnetic ring or vertical displacement deep settlement mark
Building inclination	Throwing point method, front intersection method, laser plumber method, vertical hanging method, inclinometer method and differential settlement method, etc.
Crack	Tape measure
Internal force of supporting structure	Strain gauge or stress gauge
Internal force of anchor bolt or soil nail	Reinforcement stress gauge or strain gauge
Soil pressure	Earth pressure box
Pore water pressure	Pore water pressure gauge
Height of groundwater level	Water level gauge

ISSN: 2414-1895 DOI: 10.6919/ICJE.202204_8(4).0041

Based on the traditional monitoring methods in Table 1, it can be seen that the traditional monitoring methods usually need to do a lot of embedding work, and generally need external data acquisition line, which has high requirements for on-site embedded construction and the protection of external data acquisition line. When the MEMS sensor is used, the data collected by the sensor can be transmitted through the wireless transmission network, and the work of external data acquisition line can be omitted, so as to greatly reduce the difficulty of field implementation and ensure the effectiveness of buried monitoring points.

3. Principle of MEMS Sensor

Micro electro mechanical systems (abbreviated as MEMS) is made of micron (10-6m) and nano (10-9m) processing technology. It is a micro system that can be controlled and moved. MEMS technology is the key way to improve the performance of devices and systems. Through MEMS technology, micro devices, microstructure, hardware test circuit, oscilloscope and power supply equipment can be concentrated on single or multiple chips, so that a millimeter or micron level MEMS has accurate and complete electrochemical and mechanical characteristics, has many advantages, and can be used for batch processing. The comparison between MEMS sensor and traditional sensor is shown in Table 2. It is obvious from the table that MEMS sensor is a new sensor based on microelectronics and micromachining technology. Compared with traditional sensors, it has the advantages of small volume, light weight, low power consumption and high reliability, and is easy to realize intelligence and integration [3].

Table 2. Comparison between traditional sensors and MEMS sensors

Comparison items	Traditional sensor	MEMS sensor
Size	The size of traditional mechanical gyroscope is close to that of basketball. Due to the large size and mass of devices, the energy consumption is relatively high.	MEMS gyroscope is smaller than coin; Due to the small size and mass of the device, the energy consumption is low.
Machining	Processing and manufacturing through traditional mechanical means, such as turning, milling, etc; The processing cost is too much to carry out batch processing in a short time.	Using micro machining technology to implement machining; Batch production can be realized. The cost of a single finished product decreases with the increase of output and the reduction of size.
Material	Traditional materials are usually used, such as various metals, polymers, etc.	The most commonly used materials in MEMS processing are silicon, graphene, piezoelectric ceramics and so on.

As shown in Table 3, there are many kinds of MEMS sensors, which can be divided into physical sensors, chemical sensors and biological sensors according to the working principle. According to the function, it can be divided into angular velocity sensor, acceleration sensor, inclination sensor, pressure sensor, flow sensor, magnetic field sensor, electric quantity sensor, temperature sensor, humidity sensor, gas composition sensor, pH value sensor, ion concentration sensor and other types [4].

ISSN: 2414-1895 DOI: 10.6919/ICJE.202204_8(4).0041

Table 3. MEMS sensor classification table

Main classification	Sub classification	Sensor
MEMS physical sensor	MEMS mechanical sensor	MEMS accelerometer
		MEMS angular velocimeter (gyroscope)
		MEMS inertial measurement unit
		MEMS pressure sensor
		MEMS flow sensor
		MEMS inclination sensor
	MEMS electrical sensor	MEMS electric field sensor
		MEMS electric field intensity sensor
		MEMS current sensor
	MEMS magnetic sensor	MEMS magnetic flux sensor
		MEMS magnetic field intensity sensor
	MEMS Thermal Sensor	MEMS temperature sensor
		MEMS heat flow sensor
		MEMS Thermal Conductivity Sensor
	MEMS optical sensor	MEMS infrared sensor
		MEMS visible light sensor
		MEMS laser sensor
	MEMS acoustic sensor	MEMS noise sensor
		MEMS surface acoustic wave sensor
		MEMS ultrasonic sensor
MEMS chemical sensor	MEMS gas sensor	MEMS combustible gas sensor
		MEMS toxic gas sensor
		MEMS air pollution sensor
		MEMS automotive sensors
		MEMS combustible gas sensor
	MEMS humidity sensor	
	MEMS ion sensor	MEMS pH sensor
		MEMS ion concentration sensor
MEMS biological sensor	MEMS physiological sensor	MEMS biological concentration sensor
		MEMS tactile sensor
	MEMS biochemical sensor	

ISSN: 2414-1895 DOI: 10.6919/ICJE.202204_8(4).0041

4. MEMS Sensor for Foundation Pit Monitoring

According to the monitoring content of foundation pit engineering, it can be seen that it mainly involves displacement and stress. The corresponding sensors with application prospects in foundation pit engineering monitoring include pressure sensor and inclination sensor.

4.1 MEMS Pressure Sensor

Stress or pressure is a very important monitoring quantity in foundation pit engineering monitoring. According to different pressure monitoring mechanisms, pressure sensors mainly include piezoresistive pressure sensor (as shown in Figure 1), resonant pressure sensor (as shown in Figure 2) and capacitive pressure sensor (as shown in Figure 3).

Figure 1. Piezoresistive MEMS sensor

Figure 2. Resonant MEMS sensor

Figure 3. Capacitive MEMS sensor

ISSN: 2414-1895 DOI: 10.6919/ICJE.202204_8(4).0041

MEMS piezoresistive pressure sensor has different varistor values on the strain film under different pressures, so the pressure measurement can be realized according to the relationship between the varistor value and the pressure value calibrated in advance. This kind of pressure sensor has the advantages of low cost, high sensitivity, high integration and mature process. However, considering that it adopts the principle of varistor, it directly leads to poor temperature stability and durability of this kind of sensor, so its service life is short. Therefore, this kind of sensor is not suitable for foundation pit engineering with long monitoring cycle due to large temperature difference between day and night and seasonal temperature difference.

Considering that the period or frequency of some materials will change under different pressures. MEMS resonant pressure sensor mainly realizes pressure measurement by measuring cycle or frequency, but the manufacturing process of this kind of sensor is very complex and difficult, which directly leads to the high procurement cost of this kind of sensor, which directly limits the engineering application and promotion of this kind of MEMS pressure sensor.

MEMS capacitive pressure sensors generally use metal film as one electrode of the capacitor, and the other electrode is a fixed electrode. When the film deforms under pressure, the capacitance between the film electrode and the fixed electrode will change. The pressure can be deduced by measuring the change of capacitance. MEMS capacitive pressure sensor has high sensitivity and temperature stability, but its load capacity and anti-interference ability are poor, so it is not suitable for engineering applications with high range requirements. The specific MEMS pressure sensor selected in the foundation pit engineering monitoring needs to be comprehensively determined in combination with the engineering site environment (such as temperature), monitoring position (such as whether it is under the groundwater level), monitoring cycle, etc.

In recent years, scholars around the world have done a lot of research on improving the range, linearity and sensitivity of MEMS pressure sensor and solving temperature drift. Various indexes of MEMS pressure sensor have been significantly improved, and its application in foundation pit engineering monitoring has become more and more realistic [5,6].

4.2 MEMS Inclination Sensor

The earth's gravity field is stable and the direction is constant. When the MEMS inclination sensor chip tilts, the earth's gravity field will produce a gravity acceleration component on the chip to determine the inclination value. According to the measurement principle, MEMS inclination sensor can be subdivided into capacitive sensor, resonant sensor, thermal convection sensor and optical sensor. The capacitive sensor mainly measures the inclination angle by measuring the capacitance value, and the technology is the most mature. MEMS Capacitive inclination sensor also has the characteristics of high sensitivity, high temperature stability, poor load capacity and poor anti-interference ability. The resonant sensor is mainly based on the resonant detection principle and has the characteristics of high measurement accuracy. Based on the principle of natural heat exchange, the sensor has the advantages of low size, low heat transfer accuracy and low heat transfer accuracy, but it has the advantages of strong heat sharing and convection resistance. The optical sensor is based on the optical principle and needs additional light source to measure the angle, so it is difficult to miniaturize the sensor.

With the continuous accumulation and development of MEMS inclination sensor technology, it will continue to develop in the direction of high precision, miniaturization and integration. Considering the complex and changeable environment of on-site foundation pit monitoring, it is urgent to develop MEMS sensors suitable for extreme climate and harsh environmental conditions.

5. Directions and Suggestions for Further Research

(1) It is theoretically feasible to use MEMS sensor instead of traditional monitoring element to apply MEMS sensor to foundation pit engineering monitoring, but the specific application effect needs to be verified in many practical engineering applications.

(2) When MEMS sensors are used in foundation pit engineering monitoring, considering that the monitoring work is carried out automatically, the main cost of monitoring work is the sensor cost, that is, the number of sensors directly affects the monitoring cost. It is a very valuable research direction to optimize the type, installation quantity and installation points of sensors to reduce the monitoring cost as much as possible. It is suggested that the optimization method can be introduced to study the sensor installation optimization in the future.

(3) MEMS sensors are developing towards passivity. If the wireless MEMS sensor system collects and stores the vibration kinetic energy, geothermal energy, solar energy and water flow kinetic energy of the surrounding environment, it will eventually deliberately realize the passive application. Obviously, this work has very important research value and significance. The excavation of foundation pit generally requires precipitation, and the precipitation activity will inevitably produce water flow kinetic energy. It should be feasible to collect this kind of kinetic energy for MEMS sensors.

(4) The firm and stable connection between the sensor and the measured device is the premise for the sensor to play its role accurately. Compared with the general indoor environment or workshop environment, it is obvious that the environment of foundation pit engineering is worse. Developing the firm connection mode between MEMS sensor and the measured components in foundation pit is obviously a problem that must be solved before MEMS sensor is used for foundation pit engineering monitoring. It is suggested that the MEMS pressure sensor can be stably connected by embedding, and the MEMS inclination sensor can be stably fixed by small bolts.

(5) The key to affecting the performance of MEMS sensors is the selection of sensitive materials. Therefore, exploring new materials and studying their characteristics so that they can be applied to the fabrication of MEMS devices is undoubtedly an important direction of MEMS sensors, and has attracted extensive attention in multi-disciplinary fields. At present, more and more new materials such as ferroelectric and piezoelectric are used as sensitive materials of MEMS sensors. Their physical and chemical effects, such as magnetoelectric coupling effect, piezoelectric effect and ferroelectric effect, are used to improve the performance and sensitivity of devices. Devices based on magnetoelectric and multiferroic materials have become and will continue to be a powerful driving force for the development of condensed matter physics and micro nano technology, and have made important contributions to understanding the mechanism of magnetoelectric coupling and polarization. Compared with the thin-film iron sensors, most of them are more sensitive to the inner diameter of iron, which is expected to improve the sensitivity of iron sensors.

6. Conclusion

In order to clarify the applicability of MEMS sensor in foundation pit monitoring, the traditional foundation pit monitoring content and monitoring method, the principle of MEMS sensor and MEMS sensor suitable for foundation pit monitoring are summarized and analyzed by using theoretical analysis method, and the direction and suggestions for further research are given. The results show that:

(1) Traditional foundation pit monitoring methods have large workload, low degree of automation and intelligence and high monitoring cost. Introducing MEMS sensor into foundation pit monitoring can make foundation pit monitoring automatic and intelligent.

(2) Sensors with application prospects in foundation pit engineering monitoring include pressure sensor and inclination sensor. It is theoretically feasible to apply MEMS sensor to foundation pit

ISSN: 2414-1895 DOI: 10.6919/ICJE.202204_8(4).0041

engineering monitoring, but the specific application effect needs to be verified in many practical engineering applications.

(3) MEMS sensor installation optimization, MEMS sensor passivity, and the firm and stable connection between the sensor and the measured device are very valuable research directions.

Acknowledgments

The authors are grateful to funding received from the Project of China Construction 4th Engineering Bureau under grant numbers CSCEC4B-2021-KTB-27, SCEC4B-2021-KTB-31 and CSCEC4B-2022-KTA-10.

References

[1] D.J. Geng, N. Dai, P.J. Guo, et al. Implicit numerical integration of highly nonlinear plasticity models, Computers and Geotechnics, vol. 132 (2021), 1-10.

[2] C. Zhu, Z. Yan, Y. Lin, et al. Design and application of a monitoring system for a deep railway foundation pit project, IEEE Access, vol. 7 (2019), 107591-107601.

[3] J.W. Judy. Microelectro mechanical systems (MEMS): fabrication, design and applications, Smart materials and Structures, vol. 10 (2001), 11-15.

[4] Q.Y. Wu. MEMS pressure sensor and its anti-interference design, Nanjing University of information engineering, 2021.

[5] Q. Gao, Q.S. Chen, G.Y. Yang, et al. Research status and development trend of MEMS inclination sensor, Micro nano electronic technology, vol. 12 (2021), 1054-1063 + 1076.

[6] Y. Yin. Review on the development of intelligent sensor technology, Microelectronics, vol. 04 (2018), 504-507 + 519.