# Mat Sensor Using Piezoelectric Sheet

## 1. Introduction

VALQUA has been developing organic piezoelectric sheets using fluorine materials[1] and abnormal vibration detection systems as its application[2].

The characteristics of the fluorine material and the carefully designed sheet structure enable piezoelectric properties. As a result, our fluorine-based organic piezoelectric sheet can be used even at high temperatures of 100℃ or higher, which was not possible with conventional organic (polymer-based) piezoelectric materials. Other characteristic of these sheets is that they do not lose their piezoelectric properties even in high temperature and high humidity environments (85℃ and 85% RH). In addition, it is easy to make them large in area, which is a common feature of organic piezoelectric materials. This report introduced the mat sensor we have developed as an item that makes the most of these features.

## 2. Detection Mechanism

### 2-1) Function of piezoelectric sheet

First, the functions of piezoelectric sheet will be explained. Piezoelectric sheets are a form of piezoelectric material. There are many inorganic and organic piezoelectric materials. Also, there are several types of detection mechanisms, but for simplicity, the detection mechanism of our organic piezoelectric sheet will be explained as an example.

As shown in Figure1, piezoelectric materials have two effects. The piezoelectric effect, in which a voltage is generated when force is applied, and the inverse piezoelectric effect, in which the material deforms when a voltage is applied. In this mat sensor application, the piezoelectric effect is used, and the voltage generated by applying force to the piezoelectric sheet is used as a signal.

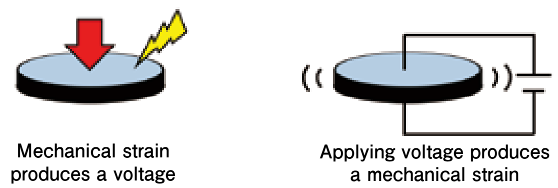


Figure1 Functional expression mechanism of piezoelectric sheet

### 2-2) Detection mechanism of conventional mat sensors

Many mat sensors use a method called contact-type method, as shown in Figure2. In the contact-type method, the contact points inside the sensor make contact with each other due to the applied pressure, which leads to conduction and detection of the pressure. It is a very simple detection mechanism, and the mechanism is easily understandable. On the other hand, this method requires a structure (e.g., a spacer) to separate the contact points, and thus the system is anticipated to become complicated for large-area sensors. In addition, it is expected that the effect of the deterioration of the structure over time must be considered as well.

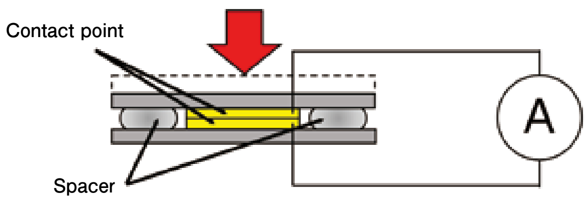


Figure2 Detection mechanism of sensor using contact-type method

### 2-3) Detection mechanism of piezoelectric sheet

Figure3 shows the detection mechanism of a piezoelectric sheet. The sensor has a simple structure consisting of a piezoelectric sheet and electrodes placed on both sides of the sheet. It detects the voltage generated when the sheet itself is distorted in the thickness direction by the applied pressure. This system does not require a spacer, and it is relatively easy to fabricate a thin, large-area sensor.

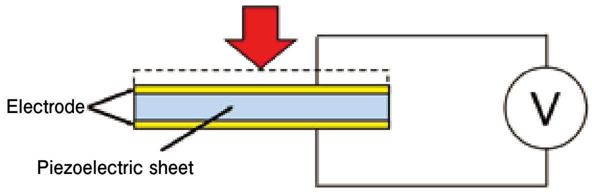


Figure3　Detection mechanism of piezoelectric sheet

Our piezoelectric sheet detects force in the direction perpendicular to the sheet surface. On the other hand, other piezoelectric materials can detect force in the direction of the surface (tension, compression, and torsion). When used as a mat sensor, detecting only vertical force like our type is assumed to be an advantage in some applications.

Next, we are going to explain how piezoelectric sheets detect force. In general, piezoelectric materials, whether inorganic or organic, generate a voltage at the moment when force is applied and thus can detect the force. In contrast, they do not generate voltage when force is continuously applied and thus cannot detect static force.

On the other hand, as a mat sensor, there is also a need to continuously detect force, not only at the moment when force is applied but also in the state when force is being applied (i.e., when a person or object is on it).

Figure4 illustrates the difference between the responsiveness of piezoelectric materials and the responsiveness required for use as a mat sensor. As shown in the figure, to detect continuous force, the output voltage waveform from the piezoelectric material needs to be converted to a form suitable for a mat sensor. In this project, we dealt with it by designing a dedicated control circuit to perform the waveform conversion.

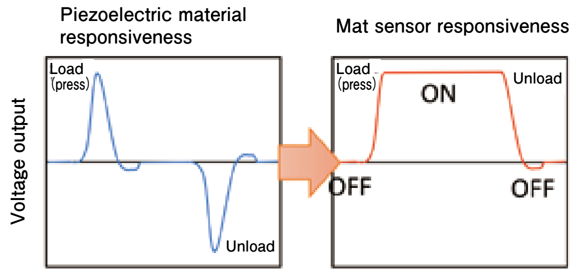


Figure4　Responsiveness of piezoelectric material and mat sensor

## 3. Development Details

### 3-1) Setting target performance

As a performance indicator for our mat sensor, we referred to JIS B 9717-1:2001 (Safety of machinery–Pressure-sensitive protective devices – Part 1: General principles for design and testing of pressure-sensitive mats and pressure-sensitive floors). This JIS summarizes the required properties for mat sensors to be installed in factories and other facilities. In this project, we used this JIS as a reference to proceed with our development of a mat sensor that would satisfy the properties shown in Table1.

Table1　Test items and conditions

| Test item | Test conditions |
|---|---|
| **Mechanical properties** | |
| Durability test | 2 million cycles vertical / diagonal room temperature |
| | 1 million cycles diagonally 14.5 degrees -20℃ , 50℃ |
| Vibration test | 1⇔30Hz/ up / down / left / right/ front/ back / 5 minutes each |
| Static load test | Φ11/750N/8h, φ80/2000N/8h |
| Impact resistance test | R:10mm/1kg/ Dropped from:1000mm |
| **Weather resistance properties** | |
| Waterproof test | IP6X |
| Cycle test | −20℃ (12h)⇔50℃ (12h)×10 |
| Heat aging test | 66℃ /90 days room temperature 8 years equivalent to exposure |
| High temperature and high humidity test | 40℃ /90–95%RH/56 days |
| High temperature test | 50℃ /72 hours |
| Low temperature test | −30℃ /72 hours |
| **Electrical properties** | |
| Dielectric strength test | AC0.72kV/1mA、DC1kV/ >100MΩ |

### 3-2) Examining mat sensor structure

We examined the structure of a mat sensor that would satisfy the required properties described above. The pressure-sensing itself could be realized with a simple structure of a sensor consisting of a piezoelectric sheet and electrodes as described above.

However, this sensor is very thin (several hundred microns) and does not have sufficient mechanical strength. The optimal structure was determined by examining a variety of structures to satisfy the mechanical properties, weather resistance (water resistance), and electrical properties.

### 3-3) Performance evaluation method and results

The performance test was conducted according to the JIS standard (JIS B 9717-1:2001). We measured the voltage output when force was applied to the mat sensor before and during each test, evaluating the pressure detection performance of the mat sensor.

For the durability test, we fabricated JIS-compliant test equipment and conducted the test. Figure5 shows an example of the equipment, a durability test machine for the vertical load. Two million cycles of force were applied for the durability test.

The developed mat sensor satisfied the properties shown in Table1.

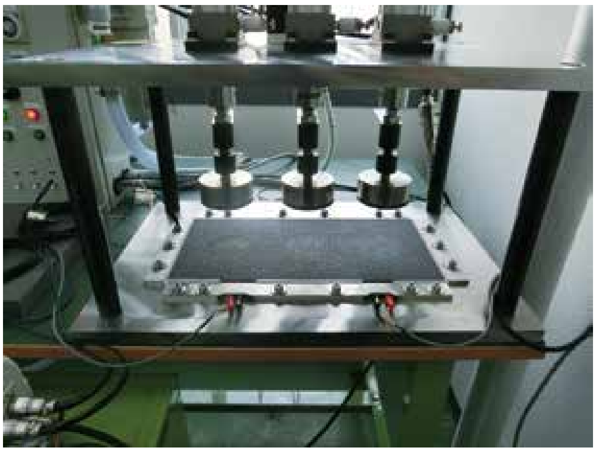

Figure5　Durability test machine (example)

## 4. Characteristics of developed product

Figure6 shows the appearance of the developed mat sensor system. The system consists of a mat sensor (right) and a control circuit (left). The latter is used for output waveform conversion.

In this system, the LED lamp of the control circuit lights up when pressure is applied to the mat sensor. The control circuit can be further downsized and expanded functionally.

As for the functional expansion of the control circuit, for example, it will be possible to detect only the force of arbitrary magnitude by adding a threshold setting function. Also, patterning the electrodes on both sides of the piezoelectric sheet will make it possible to detect the force distribution. Furthermore, if a wireless communication function is built-in, it can be used as an IoT device and monitored remotely.

Figure6　Developed mat sensor system

## 5. Conclusion

Our fluorine-based organic piezoelectric sheet was introduced. This time, we were able to develop a mat sensor that complies with the required properties of JIS B 9717-1:2001. The piezoelectric sheet has no mechanical mechanism and can be used for a long time. It is thus expected to have a long time stable performance as a mat sensor.

The size, shape, and detection sensitivity can be designed according to the application. Also, since the piezoelectric sensor is extremely thin (several hundred microns) and flexible, it can be applied as a thin mat sensor. Taking advantage of these features, the sensor could be used in the security and health care, which are related to safety and security. We would also like to respond from our readers.

## 6. Acknowledgments

I would like to express our gratitude to Dr. Yoshiro Tajitsu of Kansai University (Professor of the Faculty of Engineering Science Department of Electrical and Electronic Engineering, Trustee of Kansai University) for his great cooperation in the design and development of the conversion circuit for the output voltage waveform. I sincerely appreciate his contribution to the project.

## 7. References

1) Yoshiro Tajitsu and Tetsuya Komeda: *Valqua Technology News*, No.26, 12-17 (2014) .
2) Makoto Haneda, Hisataka Sato, Tetsuya Komeda, Yasushi Aburatani: *Valqua Technology News*, No.36, 3-6 (2019) .

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