Sushi Sensor Series of Temperature and Pressure Sensors for Industrial IoT

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Yokogawa has newly developed a wireless pressure sensor and wireless temperature sensor as new models in the line-up of “Sushi Sensor” wireless solutions for the Industrial Internet of Things (IIoT) to improve the efficiency of equipment maintenance in plants. These sensors use combinations of separate modules, the XS110A wireless communication module, and the XS530 pressure measurement module or XS550 temperature measurement module. This paper introduces the background of adopting separate modules and the technology used in the wireless pressure sensor and the wireless temperature sensor while satisfying intrinsic safety.

INTRODUCTION

With growing awareness of the need to boost productivity and improve the efficiency of equipment maintenance in plants, there is a need to identify the degradation of aging equipment as well as detect and analyze signs of abnormality early, and then decide appropriate actions to be taken. However, in view of the diverse facilities used in plants, a method using data to improve the efficiency of equipment maintenance is needed. Such a method must be able to automatically collect sensor data and help field operators to plan and perform maintenance work. Data can be collected automatically by various kinds of sensing technologies that can identify the degradation state of equipment, while field operators can be supported by a system that saves data.

In March 2018, Yokogawa released the first Sushi Sensor, the XS770A wireless vibration sensor with excellent resistance to severe plant environments, and the company has now accumulated a solid track record of improving maintenance efficiency (1)(2). To respond to users’ growing need to automatically collect more online data in plants and monitor the health of their equipment based on various data, Yokogawa newly developed wireless pressure and temperature sensors for the Sushi Sensor series (Note 1: The wireless vibration sensor has been released in Japan and some other countries. Currently the wireless pressure sensor and the wireless temperature sensor are available only in Japan, but are due to be released overseas).

DEVELOPMENT CONCEPT

Sushi Sensor is a wireless solution for the Internet of Things (IoT) that monitors the trend of equipment condition. Multiple factors affect the performance and life of plant equipment.

- Environmental degradation (environmental conditions such as corrosive gas and dust, climate conditions such as desert, ice, and snow)
- Thermal degradation (conduction and radiation from heat sources)
- Mechanical deterioration (shock and vibration from rotary machines)

Under such severe environments, industrial sensors require environmental resistance and reliability that ensure long-term stable operation with high performance.

In addition to satisfying these requirements, Sushi Sensor has various features including: battery-powered, compact and lightweight, easy installation, easy setting through a smartphone or tablet via near-field communication (NFC), long-distance wireless communication through the LoRaWAN communication standard for wireless networks, and easy data collection and monitoring.

Newly developed wireless pressure and temperature sensors also inherit this concept. In addition, we aimed to satisfy additional user needs, including replacing the batteries without plant shutdown while Sushi Sensor is connected to the production process and reducing the frequency of replacing batteries at high or hazardous locations.

To satisfy these requirements, we adopted a module system; the product consists of the XS110A wireless communication module with a built-in battery and the XS530 pressure measurement module, or the XS550 temperature measurement module. Regarding the battery, we changed from the AA size, which is used in the XS770A wireless vibration sensor, to a separate module with a built-in battery and communication function.
sensor, to the large-capacity D size so that the product can operate with a single battery for a long time. This enables enough power to be fed to sensor modules currently available and those to be developed in the future.

The module system approach described above broadens the Sushi Sensor’s portfolio and allows it to operate on the same wireless infrastructure, enabling customers to monitor the trend of diverse equipment data in their plants.

The features of Sushi Sensor and its technologies are described in the following sections.

SEPARATE SYSTEM

Pressure and temperature measurement values acquired by the XS530/XS550 measuring modules are transmitted to a host system via the XS110A wireless communication module. This wireless communication module, which is equipped with a wireless communication function and battery, is combined with other modules for various measurement purposes. This configuration can satisfy various measurement needs. Figure 1 shows the configuration of the product.

Figure 1 Configuration of the product

To facilitate assembly and disassembly and prevent a connection failure due to cable pinch or buckling, modules are connected directly to each other.

The module-connecting mechanism is incorporated in the specially designed hardware to secure wireless, waterproof, dustproof, and vibration resistance performance, as well as connection reliability. This feature will be inherited by measuring modules that are developed in the future.

How to Connect Modules

To secure the electrical contact of the connectors and improve the robustness of the casing, the structure is designed as explained below.

The engagement parts of the casing are provided as positioning guides for connecting modules. Four engagement parts are arranged on the inner edge of the XS110A and the outer edge of the XS530/XS550 as shown in Figure 2, facilitating the connecting procedure.

This engagement makes the structure rigid and improves the electrical reliability of the connectors.

Antenna Characteristics

As the communication protocol, Sushi Sensor uses LoRaWAN, which excels in receiving sensitivity, radio interference immunity, and radio diffraction characteristics. It delivers excellent communication performance even in plants where there are many obstacles to radio waves.

This section explains the antenna design that reduces the influence of the separate system on communication characteristics.

We use a substrate-mount type chip antenna that has shown excellent performance with the XS770A wireless vibration sensor. Note that the GND plain on the substrate functions as part of the antenna. When the XS110A is connected to the XS530/XS550, the GNDs of both substrates...
are also connected via the connector. Therefore, changes in the GND plane may influence the radiation characteristic. Figure 4 shows changes in the GND plane in the separate system.

![Figure 4 Changes in the GND plane in the separate system](image)

We simulated the electromagnetic field to determine the possibility of degradation of the antenna characteristic and took the precaution of inserting ferrite beads in the power source/GND and the signal line that connects the modules.

We selected ferrite beads that ensure high impedance at 920 MHz of the LoRaWAN specification, thus electrically separating the wireless communication module and the measuring module in the target frequency domain. Figure 5 shows the antenna radiation characteristics when the wireless communication module is connected to the pressure module.

![Figure 5 Antenna radiation characteristics (LoRaWAN)](image)

A field test confirmed that the product delivered communication performance equivalent to that of the XS770A wireless vibration sensor both in an outdoor environment with good line of sight and an indoor environment with obstacles.

**Circuit Arrangement and Firmware**

The wireless communication module must be connectable with various measuring modules as shown in Figure 6. Even in the separate system, the wireless communication module must work with the program of each measuring module and perform calculations with parameters specific to the measuring module.

![Figure 6 Combination of modules](image)

For the wireless communication module, we developed firmware (program and parameters) to facilitate expansion and free combination of the lineup.

**CPU and Memory Configuration**

Figure 7 shows the configuration of main parts.

The CPU is mounted in the wireless communication module (not in measuring modules) so that it can efficiently control peripheral devices such as the LoRa communication circuit, the NFC communication circuit, and the power supply circuit. The CPU operates a connected measuring module and controls all peripheral devices; this greatly simplifies the configuration.

![Figure 7 Configuration of main parts](image)
If the program is stored in the wireless communication module, it must be compatible with all measuring modules, requiring a long development period and a large memory size.

To solve this problem, we located the memory in the measuring module and stored the program in it. Parameters specific to a sensor are also stored in the measuring module. This enables the measuring module to continue working even after another (or new) wireless communication module is connected.

Loading the Program
When the wireless communication module detects the connection with a measuring module, it will copy the program stored in the measuring module to the memory in the CPU (see the red arrow in Figure 7). In the case of the pressure module, the wireless communication module copies the pressure program into the pressure measurement module, and likewise copies the temperature program in the case of the temperature measurement module. In this way, the wireless communication module will be able to work with new measuring modules that are released in the future.

Holding Parameters
Correction coefficients specific to a measuring module and parameters specific to wireless communication are stored in the memory of the measuring module.

The program copied to the wireless communication module accesses the correction coefficients set at the time of shipment or parameters stored in the memory of the measuring module and can perform highly precise calculation. With the help of the Sushi Sensor App (an Android app for setting parameters and monitoring the status of wireless pressure and temperature sensors), the program can change the set points of parameters. Since parameters are stored in the measuring module, the product can start with the previous settings even when wireless communication modules are replaced in order to replace the battery.

BATTERY-POWERED
If a large number of Sushi Sensors are installed in the plant, large amounts of data for equipment maintenance can be acquired. However, the greater the number of products installed, the greater the work required for battery replacement. We solved this problem by designing for easy battery replacement and low power consumption.

Battery Replacement
The thionyl chloride lithium battery is a standard product widely available in the market. Sushi Sensor uses a size D cell of this type. Before battery replacement, the wireless communication module is removed from the measuring module. This specification allows Sushi Sensor to satisfy the user’s need to replace batteries while the sensor remains connected to the process; there is no need to shut down the plant. In addition, the product satisfies the explosion-proof standards because the wireless communication module can be taken to a non-hazardous area and the batteries replaced there. Since this module serves as a battery container, the product has a compact design.

In addition to being held at both ends with springs, the battery is supported with a rubber cushion, so that even a commercially available standard cell can keep supplying stable power in an environment with severe vibration. Figure 8 shows the structure of the battery container of the wireless communication module.

![Easy battery replacement](image)

Figure 8 Structure of the battery container of the wireless communication module

Battery Life
Table 1 shows the battery life of measuring modules. The target battery life is achieved by taking measures to stabilize battery operation as described in the following section.

<table>
<thead>
<tr>
<th>Data update cycle</th>
<th>Battery life (room temperature)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Design target</td>
</tr>
<tr>
<td>1 minute</td>
<td>3.0 years</td>
</tr>
<tr>
<td>10 minutes</td>
<td>8.0 years</td>
</tr>
<tr>
<td>1 hour</td>
<td>10.0 years</td>
</tr>
<tr>
<td>1 day</td>
<td>10.5 years</td>
</tr>
</tbody>
</table>

Measures for stabilizing battery operation
The thionyl chloride lithium cell has a low self-discharge rate and can keep delivering a stable voltage until just before it dies. Therefore, it is suitable as a power source for wireless sensors used in plants, which are required to operate stably for a long time. However, when this type of battery is left unloaded at high temperatures, a thionyl chloride film forms inside, increasing the internal resistance and decreasing the voltage when a large current is applied. When a heavy load is then suddenly applied in this state, it is difficult to maintain the desired voltage, which may cause measurements and wireless communications to fluctuate.
This problem was solved with the two measures described below.

**Voltage recovery function**

The formation of a thionyl chloride film depends on the ambient temperature. The film grows faster at higher temperatures, but can be removed when a moderate current is discharged for a time. Therefore, we equipped the wireless communication module with a voltage recovery function (refresh function). This function measures the ambient temperature, generates the minimum current pulse for electric discharge suitable for each temperature range, discharges the battery periodically, and thus suppresses the growth of the film. This function enables the battery to work stably over a wide range of temperature.

**Exclusive control of heavy load processing**

To minimize the influence of the internal resistance of the battery, firmware is used for exclusive control of processing tasks (wireless communications, sensing, memory access, NFC communication, and so on). This avoids the rapid load change that causes the voltage to drop and suppresses the maximum value of consumption current, achieving long, stable operation.

**CASING DESIGN**

**Casing Design**

The product is designed for portability in the field, easy replacement of batteries, and user-friendly operation for various settings and maintenance work.

For example, as shown in Figure 9, a grooved part for a good grip is arranged on both sides of the wireless communication module to improve the handling when connecting/disconnecting the module. For intuitive operation, an “arrow” shows the direction to fasten the measuring module with screws, and an icon shows where to hold a smartphone for NFC communication.

**Figure 9 User-friendly product design**

**Environmentally Robust Casing**

The casing of the wireless communication and measuring modules requires high reliability and must operate for a long time in outdoor environments subject to rain, snow, sand, dust, etc. while remaining connected to high-temperature and high-pressure process piping.

When the wireless communication module is connected to the measuring module, the product satisfies dustproof and waterproof requirements (IP66/67 and NEMA250 TYPE 4X). Furthermore, vibration resistance and shock resistance are secured so that the product can continue measuring data stably even in severe installation conditions.

To satisfy these specifications, we took the following approach.

Engineering plastic of polycarbonate (PC) is used for the casing of the wireless communication module. This material minimizes the influence on wireless communications, improves the portability of the product, and lowers the cost. There are some points to be considered when using resin materials: how to secure shock resistance under low temperatures, heat resistance, UV resistance, flame retardance, and vibration resistance not less than those of existing field products. We selected a material that satisfies the explosionproof and safety standards of destination countries.

Before manufacturing the casing by injection molding, we used a simulator to check the flowability of the resin and confirmed its applicability.

Measuring modules must not affect users’ equipment such as piping and ducts with which they come into contact. For this reason, stainless steel having excellent rigidity and corrosion resistance is used. This casing delivers outstanding environmental resistance and reliable connection with the wireless communication module. In addition, it is sufficiently rigid for vibration resistance (IEC60770-1) and shock resistance (IEC60068-2-27).

**MEASURING MODULES**

To satisfy major user needs of measuring pressure and temperature, we developed two measuring modules and expanded solutions for monitoring the health of equipment with Sushi Sensor. The main features of both modules are described below.

**Pressure Measurement Module**

Conventionally, gauge pressure is measured by operators in round checks. The XS530 pressure measurement module replaces this task with online monitoring. Incorporating technologies accumulated in Yokogawa’s EJX/EJA/FP series transmitters, the XS530 is a compact, lightweight, and highly reliable module for measuring gauge pressure up to 5 MPa (E range). A Hastelloy C-276 diaphragm is used for the pressure-receiving section, and stainless-steel equivalent to SUS316 is used for the casing, achieving high corrosion resistance and long life equivalent to those of transmitters.

A piezo resistance pressure sensor is used for measuring pressure. This type of sensor shows excellent noise resistance...
and its intermittent operation consumes less power. The influence of sensor linearity and ambient temperature on measurements is adjusted by the value determined at the shipping inspection. As a result, the accuracy is ±0.25% of full scale and the influence of ambient temperature is ±0.02% of full scale/°C. Figure 10 shows the influence of ambient temperature before and after adjustment.

**Temperature Measurement Module**

The XS550 temperature measurement module can measure a wide range of temperatures and is useful for either operator rounds or online equipment maintenance. The XS550 converts inputs from a thermocouple (any of nine types specified by IEC60584, including type B, E, and J) to temperature values after reference junction compensation and outputs them. Although it is a compact module, the XS550 accepts two non-insulated inputs. Therefore, this temperature module can be used in applications that need to simultaneously measure a target point and ambient temperature, as well as in a redundant configuration with a double element thermocouple. Table 2 shows the main specifications of the XS550 temperature measurement module.

**Table 2 Temperature module specifications**

<table>
<thead>
<tr>
<th>Item</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of inputs</td>
<td>2</td>
</tr>
<tr>
<td>Accuracy (typical)</td>
<td>Type J: ±0.75°C</td>
</tr>
<tr>
<td></td>
<td>Type K: ±1.5°C</td>
</tr>
<tr>
<td></td>
<td>Type T: ±1.0°C</td>
</tr>
<tr>
<td>Accuracy after reference junction compensation</td>
<td>±1°C</td>
</tr>
<tr>
<td>Ambient temperature</td>
<td>-40°C to 85°C (standard product)</td>
</tr>
</tbody>
</table>

**CONCLUSION**

This paper described the features of the newly developed wireless pressure and temperature sensors, as well as their technologies. Both sensors keep monitoring the health of plant equipment for a long time, and these data can be easily obtained online. These sensors help reduce the workload of operator rounds, periodical inspection and maintenance; quantify and visualize inspection results; stabilize inspection quality; and avoid overlooking items during inspections.

As a result, customers can obtain a comprehensive view of plant conditions and invest efficiently in equipment maintenance in order of priority of eliminating risks. Furthermore, by combining AI, machine learning, and the cloud, the Sushi Sensor can improve the efficiency of operation, detect signs of abnormality, and predict the possibility of equipment failure.

Yokogawa will continue developing the Sushi Sensor wireless solution for the IIoT and help customers to perform efficient equipment maintenance.

**REFERENCES**


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