Japanese Reliable Temperature Sensor listed in EPPL

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Abstract

In this paper, we introduce Resistance Temperature Detector type temperature sensor developed for Japanese space program, and listed in EPPL. These temperature sensors have been playing important roles in Japanese space program such as Japanese launch vehicle H-2, H-2A/B and H-2 Transfer Vehicle (HTV), etc.

Temperature ranges of these sensors are -260 degree Celsius to 930 degree Celsius. They can also operate in severe environment, such as random vibration ~90 Grms, mechanical shock~3400G, etc.

They are manufactured in the clean room where cleanliness, temperature, humidity and the others are strictly controlled. With respect to quality management, many inspection processes are placed at each step of production.

1. Introduction

Temperature measurement is the key issue for satellite or launch vehicle. Its propellants are cryogenic liquid hydrogen or oxygen, etc. Accuracy of the sensor is so significant as to evaluate propellant cavitation margin, thermal stress and heat flux. In particular launch vehicle's operating environment is very severe for sensors due to random vibration, mechanical shock, so robustness is required for the temperature sensors.

In the early development stage, we experienced a lot of problems such as disconnection of wire and breakage of the sensing element. Finally those problems had overcome.

MITSUBISHI and OKAZAKI have been supplying these sensors since 1990. MITSUBISHI and OKAZAKI are supplier and manufacture of these sensors respectively. MITSUBISHI is also given QML certification by JAXA. In recent years annual delivery quantity is almost 700, and total deliveries are up to 10000. In addition we have never experienced serious failure so far.

In this paper, Remarkable features and manufacturing system of developed temperature sensor are presented.

2. The principle of measurements

There are several methods to measure temperature. The most famous way is using thermocouple. Thermocouple has some advantages, such as cost, wide temperature range and no need of external excitation. However, disadvantage of thermocouple is accuracy. System error of less than one degree Celsius can be difficult to achieve.

On the contrary, resistance temperature detector is used for its high accuracy. The total error can be less than 0.2 degree Celsius. Its principle of temperature measurements is that the change of element's resistance is almost proportional to change of temperature, so it can be converted to temperature by calibration data.

3. Resistance Temperature Detector (RTD)

Platinum is adopted as material of fine coiled wire for sensing element of temperature sensor. And its purity is very high. The benefit of platinum sensing element is high stability, because platinum is the second least reactive metal. Sensing element is composed of platinum fine coiled wire and glass coating. Platinum fine coiled wire is wound around mineral insulated cable and alumina insulator if necessary, and coated by T-enamel which consists of glass, see Fig.1. The grey part is fine coiled wire, white and clear parts indicate T-enamel. After coated by T-enamel, element is sintered in high temperature oven.

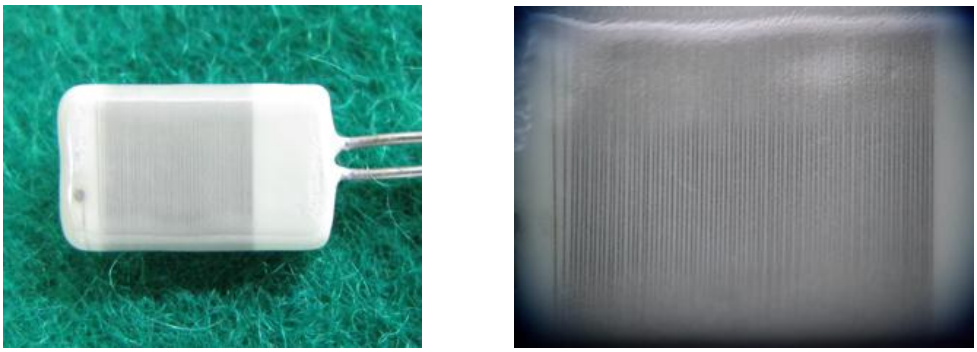

Fig.1. Details of sensing element

Mineral insulated cable has an outer sheath with two inner conductors. The insulation material is made of highly compressed aluminum oxide powder and conductor that is also consists of platinum alloy like sensing element, see Fig.2. Figure of left side shows section of mineral insulated cable.

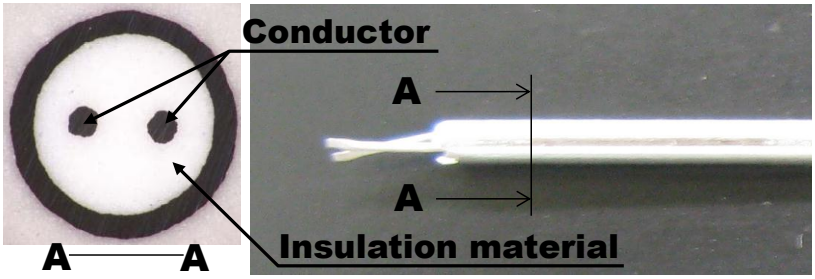

Fig.2. Structure of mineral insulated cable

To measure temperature, resistance of sensing element has to be measured. Famous methods are 2-wire connection and 4-wire connection. However, in terms of accuracy 4-wire connection is widely used.

Fig.3 shows typical wiring diagram of 4-wire connection. Sensing element is connected to 4-wire, role of two wire is to provide excitation current, that of another two is to extract voltage, see Fig.3. Current is supplied via current lead, A, D. Then voltage drop is generated between lead B and C.

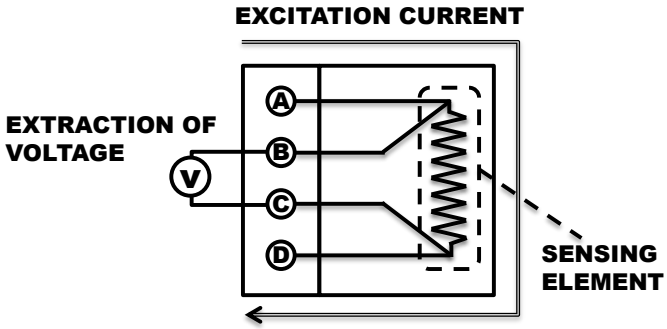

Fig.3. Wiring diagram for 4-wire connection

RTD listed in EPPL has three types, surface type, extension wire sheath type and probe sheath type. Details of those three sensors are described in next section.

4. Feature and Performance

More detailed specification of each sensor is described in JAXA-QTS-2180. In this section typical characteristics of sensor are described.

4.1. General description

Temperature sensors that are listed in EPPL are mainly introduced in this paper. But these sensors are only part of our total line-up. In Japanese space programs temperature sensors were mainly developed for launch vehicle. Equipment used for launch vehicle must withstand severe environments. In Particular rocket engine generates very severe vibration, mechanical shock and high temperature due to its combustion. As previously described, sensing element is constructed from platinum and its purity is very high. So, all our sensors including one used for launch vehicle have following characteristics.

- Robust to vibration.
- Compatible to cryogenic fluid.
- Capability to measure high temperature ~930 degree Celsius.
- High stability and repeatability for its sensing element consisting of platinum.

4.2. Surface type

This sensor is used for measuring the temperature of crucial components, for instance electronic devices that are installed for satellite and launch vehicle. This sensor is usually used as 2-wire connection.

This sensor's typical performance is shown in Table.1. Figure of this sensor is also shown in Fig.4.

Table.1. Performance of surface type platinum resistance temperature detector

Item	Specification	
	90 series	91series
Measured temperature range	-260°C to +400°C	-196°C to +400°C
Maximum operating Pressure	Atmospherics pressure	Atmospherics pressure
Compatible special Fluid	Cryogenic fluid	Cryogenic fluid
Repeatability	0.65°C or less	0.60°C or less
Supply Current	Max.5mA	Max.5mA
Nominal Resistance	2000±4Ω(at 0°C)	500±1Ω(at 0°C)
Random vibration	45Grms	~90Grms
Mechanical shock	50~600Hz 6dB/oct, 600~4000Hz 2000G	50~600Hz 6dB/oct, 600~4000Hz 2000G Half-sine 0.2ms 3400G

Typical dimension: Max.Φ4.9 × 96

Fig.4. Surface type platinum resistance temperature detector

4.3. Extension wire sheath type

This sensor is mainly used for measuring temperature of fuel, such as hydrazine that is commonly used for satellite. And this sensor is also used as level sensor, which mounted on fuel tank in equidistant manner. Typical performance and appearance are shown in Table.2 and Fig.5 respectively. This sensor is constructed from three parts, sensing element see right side of Fig.5, mineral insulated cable see center of Fig.5 and extension cable see right side of Fig.5. Besides mineral insulated cable could be formed arbitrary shape. This sensor also used as 2-wire connection like surface type.

Table.2 Performance of extension wire sheath type platinum resistance temperature detector

Item	Specification	
	70 series	71series
Measured temperature range	-18°C to +930°C	-80°C to +430°C
Maximum operating Pressure	Atmospherics pressure	Atmospherics pressure
Compatible special Fluid	Corrosive fluid	Corrosive fluid
Repeatability	3.83°C or less	0.754°C or less
Supply Current	Max.5mA	Max.5mA
Nominal Resistance	100±0.5Ω(at 0°C) Excluding the resistance at the extension wire section	500±2.5Ω(at 0°C) Excluding the resistance at the extension wire section
Random vibration	40.7Grms	
Mechanical shock	100~1350Hz 9dB/oct, 1350~4000Hz 2000G	

Typical dimension: Max.Φ7.2 × 127 (excluding extension wire)

Fig.5. Extension wire sheath type platinum resistance temperature detector

4.4. Probe sheath type

This sensor has been mainly used for measuring temperature of launch vehicle's fuel and oxidizer. Nearly same sensors are used a lot for H-2A/B launch vehicle. Its typical performance and appearance are shown in Table.3 and Fig.6 respectively.

Table.3. Performance of probe sheath type platinum resistance temperature detector

Item	Specification
Measured temperature range	-260°C to +135°C
Maximum operating Pressure	6.865MPa
Compatible special Fluid	Corrosive fluid
Repeatability	0.2°C or less
Supply Current	Max.5mA
Nominal Resistance	1000±2Ω(at 0°C)
Random vibration	43Grms
Mechanical shock	50~600Hz 6dB/oct, 600~4000Hz 2000G

Typical dimension: Φ19 × 74,

Fig.6. Probe sheath type platinum resistance temperature detector

4.5. Failure rate

Failure rates of all the sensors were calculated. They are based on various data from development of sensors and accumulated test durations. Details of failure rates are shown in Table.4. The reliability level shall be 90 percent.

Table.4. Failure rate

	Surface type	Extension wire sheath type	Probe sheath type
Actual failure rate 10^{-6}/h (At the completion of the qualification test)	0.758	1.390~5.322	0.176

5. Quality assurance aspect

Our quality assurance is conducted in many aspects. We explain typical items in this section.

5.1. Quality conformance inspection

All the products are subjected to quality conformance inspection in accordance with JAXA-QTS-2180. Items of inspection are listed below.

- Externals, dimensions, marking and others
- Proof pressure
- Leakage
- Insulation resistance
- Dielectric withstanding voltage
- Interchangeability
- Humidity resistance
- Cleanliness

5.2. General process

Condition of the products is checked several times between each process by both operating workers and other workers. Typical processes are listed below.

- Shaping core wire
- Sands blast
- Sealing terminated
- Coating inner layer
- Spot welding
- Adjustment of element's resistance
- Coating outer layer
- Checking surface state of sensing element

5.3. Special process

After special processes such as welding, brazing and coating, condition of the products is strictly checked by member of the quality assurance department.

5.4. Micro-focus X-ray inspection

Condition of both winding wire and lead are checked by micro-focus X-ray at the final stage of manufacturing. Purpose of this inspection is excluding potential failure concerning sensing element and lead. Micro-focus X-ray inspection facility and some images are shown in Fig.7

Fig.7. Micro-focus X-ray facility and some images

6. Production Facility

To make a high quality sensing element and right calibration data, several factors have to be taken into considerations. Several production facilities that are considered to be important for both of them are introduced in this section.

Almost every production process is done in the clean room, so a lot of facility is installed in clean room. Fig.8 shows coating facility and furnace. Coating facility is used for splaying finely powdered T-enamel to mineral insulated cable. After winding platinum fine wire, to protect platinum fine coiled wire, it is splayed again. To sinter T-enamel, this furnace is used. Our furnace can sinter 4 sensing elements at the same time.

Fig.8 Coating facility with furnace

Fig.9 shows winding wire facility. This machine is used to make platinum fine coiled wire. This machine is able to wind fine coil up to almost several 10 μm. Operators use this machine while checking the condition of coiled wire by microscope.

Fig.9. Winding wire facility

Fig.10 shows calibration facility. Our calibration facility could measure temperature from -269 degree Celsius to 1100 degree Celsius. Calibration data of all the sensors is obtained automatically by this facility.

Fig.10. Calibration facility

7. Contact

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