

Development of Heaterless Oxygen Sensor for Small Motorcycles

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ABSTRACT

An oxygen sensor for the oxygen feedback system of small size motorcycles was developed. Small size, low cost and low power consumption are required for the oxygen sensor of small size motorcycles. To achieve this heaterless, thin protector, cap and body ground structures were adopted. As a result, the sensor was reduced by 57% in volume, by 43% in mass and by 79% in the projected area of sensing unit compared with conventional sensors. Utilizing a heaterless design cost reduction by reducing parts and lower power consumption were realized. In addition, the engine output and drivability were enhanced due to the miniaturization of the sensing unit, and the flexibility of sensor installation was enhanced. Moreover, the EURO-3 mode emission control limit was achieved by using the developed sensor.

1. Introduction

Concern for global environmental issues has recently increased, also the reduction of motorcycle exhaust emissions has been increasingly required, and countries around the world are enforcing new emissions legislation. From 2006, EURO-3 regulations have been scheduled for motorcycles in the EU, and manufacturers are required to respond.

Air-fuel ratio feedback systems⁽¹⁾ are already being used in automobiles and large motorcycles to reduce emissions. It is essential to also use oxygen feedback systems in small motorcycles.

However, the following issues arise if the oxygen sensors⁽²⁾ used in automobiles and large motorcycles are used without modification in small motorcycles:

- (1) It is difficult to install the sensors in the short, small-diameter exhaust pipes of small motorcycles.
- (2) Small motorcycles have small-diameter exhaust pipes; engine power and throttle response are reduced by exhaust resistance due to a sensor element protruded into the exhaust flow.
- (3) The use of a heater to warm the sensor element increases the range of mounting options, but also necessitates greater electricity consumption, thus increasing friction in the generator and reducing engine output and fuel economy.

A heaterless oxygen sensor for small motorcycles has been developed to resolve these issues.

This paper describes the aims of the newly developed sensor, its features and its achieved performance.

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2. Development Goals

The following three development aims were established based on a consideration of the requirements for an oxygen sensor that would be used in small motorcycles:

- (1) Miniaturization
- (2) Low power consumption (heaterless element)
- (3) Low cost

The oxygen sensor measures the amount of oxygen using an element protruding into the exhaust pipe; a large element generates exhaust resistance. This exhaust resistance contributes to reduce engine output and throttle response.

In the exhaust system of small motorcycles, low-diameter exhaust pipes are used, and the effect on exhaust resistance due to installed oxygen sensor is greater. It is therefore particularly necessary in small motorcycles to reduce the size of the sensor element in order to minimize exhaust resistance.

From the viewpoint of cost reduction, a reduction in the number of parts and the amount of materials used, and miniaturization are required.

The element of an oxygen sensor must be activated to measure the amount of oxygen. To activate the element, it is necessary to maintain the surface temperature of the element at approximately 300 °C or above⁽³⁾.

The oxygen sensors used in large motorcycles use heaters to increase the temperature of the element. The reason for this is that the distance from the exhaust port to the catalyzer, near which the oxygen sensor is located, is long. The high-temperature gas discharged from the cylinder flows through the exhaust pipe into the catalyzer, but the exhaust gas temperature at the catalyzer becomes low in the case of longer exhaust pipe. The low-temperature gas reaching the sensor is unable to increase the temperature of the element sufficiently to maintain activation. The oxygen sensors used in large motorcycles are positioned downstream from the joint of exhaust pipes, and because of space restrictions, almost all sensors are positioned upstream of the catalyzer. Oxygen sensors in vehicles in which the distance from the exhaust port to the sensor position is long are required to use heaters to maintain the activation of the element.

The heater must be fitted inside the body of the sensor; this increases the size of the unit, increases its power consumption and also increases cost by increasing the number of parts used.

Therefore, the sensor was positioned close to the exhaust ports to enable activation of the element by the high-temperature exhaust gas instead of a heater, and the heaterless structure was used for oxygen sensor of small motorcycles. This heaterless structure enabled the miniaturization of the sensor body and reduced power consumption and cost.

The reduction in power consumption achieved by the heaterless structure against an oxygen sensor with a heater led to a reduction in friction in the generator in the vehicle in which the sensor was fitted. Therefore significant benefits in terms of fuel economy, engine output and cost reductions were obtained.

3. Features of the Developed Oxygen Sensor for Small Motorcycles

Figures 1 and 2, respectively, show an external view and a structural diagram of the developed sensor. Table 1 shows a comparison of the major specifications of the developed and conventional sensors. The volume and mass of the sensor and the projecting area of the sensing section were reduced by 57%, 43%

and 79%, respectively.

The unique features of this sensor are the cap structure, which resembles the spark plug in a gasoline engine, and the ceramic sleeve (outer tube).

In a conventional sensor, the sensor signal wire, the earth wire and the heater wire run from the sensor lead through the rubber parts (cap, grommet, etc.) and are caulked into the metallic parts (the sensor body). This configuration was changed to the cap structure, which is removable; this cap structure not only reduced the size of the sensor body, but also reduced the working space required when the sensor is mounted. This increased the flexibility of mounting the unit.

In addition, because it was no longer necessary to caulk the lead wire outlet, the structure of the outlet was changed from metal to an alumina ceramic sleeve. Alumina ceramic is a material with high strength and high insulating ability even under high temperatures. In consideration of their characteristics, the alumina ceramic was employed to ensure a balance between the strength of the body component and the insulating function. This also reduced the number of parts used and simplified the production process.



Fig. 1 External view of developed heaterless O₂ sensor

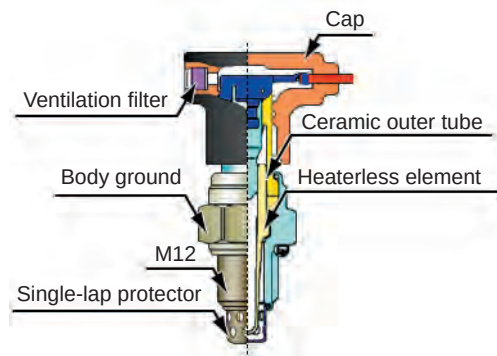


Fig. 2 Structure of heaterless O₂ sensor

Table 1 Specifications of sensors

Sensors	Developed	Conventional	Reduction rate
Flange height (mm)	40	55	27%
Screw radius	M12	M18	33%
Protector	Outer diameter (mm)	10.4	29%
	Projection area (mm ²)	206.5	79%
Parts number	15	26	—
Volume (cm ³)	6.4	14.8	57%
Mass (g)	38	67	43%
Heater	Unattached	Attached	—

In addition, one feature of this sensor is its miniaturized size⁽²⁾ compared with conventional sensors, which allows it to be mounted near the exhaust port, where the temperature of the exhaust gas is highest (Fig. 3).

Miniaturizing the body of the sensor increases flexibility in mounting the unit, and also contributes to cost reduction. Making the sensing element smaller also contributes significantly to preventing any deterioration in engine output and throttle response.

The key structures of the sensor are as follows:

- (1) Thin protector structure
- (2) Heaterless structure
- (3) Cap structure
- (4) Body ground structure

These structures were employed to achieve the development aims described in Chapter 2.

3.1. Thin Protector Structure

The outer shape of the protector for the element that protrudes into the exhaust flow to enable the sensor to determine the amount of oxygen in the exhaust gas were reduced as much as possible (the projecting area of the sensing section was reduced by 79% against conventional sensors).

If the area protruding into the exhaust pipe is large, it generates exhaust resistance, and this affects engine output and throttle response.

Figure 4 shows exhaust pressure against vehicle speed for different protector projecting areas measured using a 50 cm³ scooter. The 0 km/h in Fig. 4 shows the idling state. The exhaust pipe of the test vehicle was 16.8 mm in diameter. "Without sensor" in the figure means that no sensor was mounted in the exhaust pipe.

Figure 4 shows that in a small motorcycle with a small exhaust pipe, the projecting area of the sensor has a significant effect on increasing exhaust pressure at the maximum speed of 57 km/h. The projecting area of the protector in the new sensor was reduced to 43.6 mm², thus reducing exhaust resistance.

The (sensor of) heaterless structure, discussed in Section 3.2., requires high temperatures to activate the sensor element by using the heat of the exhaust gas. This includes antithetical requirements that the protruding area into exhaust pipe of the sensor should be reduced for reducing the exhaust resistance, but on the other hand, the protruding area should be increased for activating the sensor element.

Condensed water adhering to the sensor element may break the ceramic element by thermal shocks. Therefore, in a conventional sensor, a double protector structure is used to reduce contact with the exhaust gas because the element activation temperature is

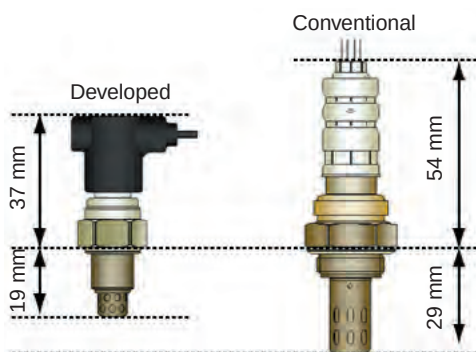


Fig. 3 Comparison of sensor dimensions

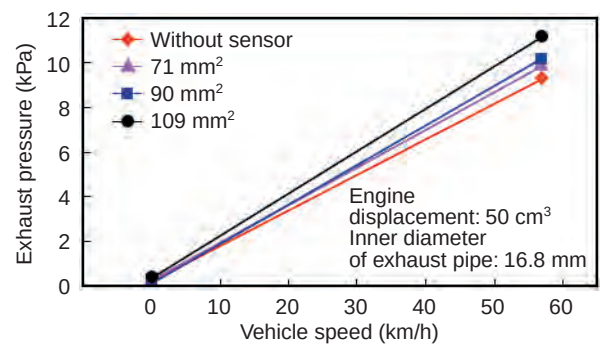


Fig. 4 Relationship between sensors projection area in exhaust pipe and exhaust pressure by vehicle speed

ensured by heating with a heater, and to reduce the adhesion to the element of condensed water in the exhaust pipe. The use of a heaterless structure⁽⁴⁾ in the newly developed sensor reduced the temperature of the element in driving conditions under which condensed water is produced, thus the incidence of thermal shock due to adhesion of condensed water was reduced. This allowed the use of a single protector with a thin structure.

In addition, this single thin protector structure enables more exhaust gas to contact the element than the conventional double protector structure, despite the reduced projecting area of the sensor, and thus contributes to the use of a heaterless structure. Figure 5 shows a comparison of protector structures in the conventional and newly developed sensors.

3.2. Heaterless Structure

As described in the section on development aims, conventional oxygen sensors use a heater to activate the element. These heaters require approximately 6.6 W of power consumption.

Figure 6 shows the results of measurements of the exhaust gas temperature at different points on the exhaust pipe at various vehicle speeds, using a 50 cm³ scooter.

Positioning the oxygen sensor close to the exhaust port in the upstream of exhaust pipe enables high-temperature exhaust gas to contact the sensor, and thus the element is maintained in the activated state required for sensing even without the heater. This makes the heaterless structure possible.

To position the sensor close to the exhaust port, it is necessary to determine changes in the amount of residual oxygen from the exhaust port to the catalyzer in the exhaust pipe. In the case of long exhaust pipes or complexly shaped exhaust pipes with multiple cylinders, the amount of residual oxygen in the exhaust gas is significantly different at the sensing section and at the inlet of the

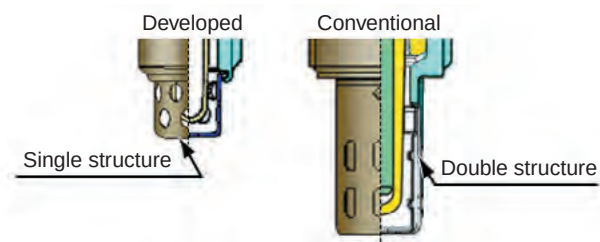


Fig. 5 Comparison of protector structures

catalyzer due to afterburning, and that would affect oxygen feedback control. However, in the case of a small motorcycle with a short, small-diameter exhaust pipe, the difference in A/F values calculated from changes in residual oxygen is less than 0.1. The effect of this difference on oxygen feedback control can be ignored.

The total length of the sensor element was shortened (-16 mm against the conventional sensor) allowing heat to be more effectively conducted to the sensor element body, and reducing its overall size. Figure 7 shows a comparison of element structures.

The use of a heaterless structure enabled the elimination of the heater body and the reduction of the heater wiring and heater support components. These are effective methods for miniaturization of the sensor body, reduction of electric power of the element heater, and cost reduction.

3.3. Body Ground Structure

The body ground structure is shown in Fig. 8. The number of parts was reduced by using the body ground structure instead of conventional lead wires. Use of the body ground configuration required torque management of the screw when mounting the sensor and ensuring of proper grounding of the sensor.

The required thread length for the sensor body screws was ensured for mounting on the aluminum cylinder head.

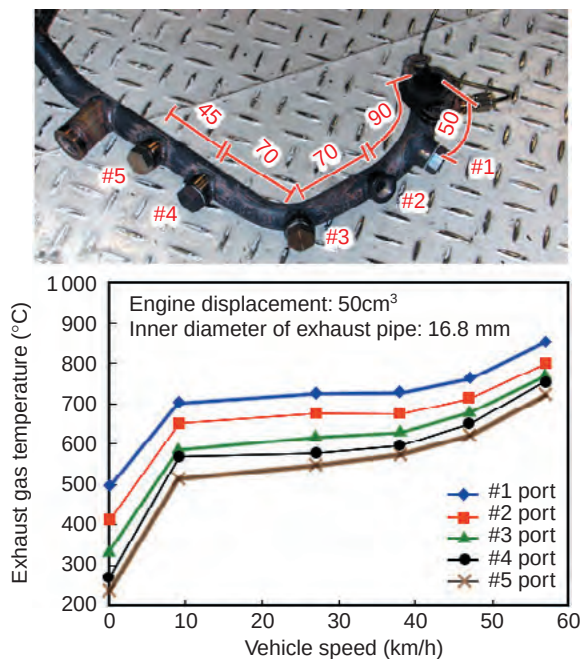


Fig. 6 Measurement result of exhaust gas temperature in each port

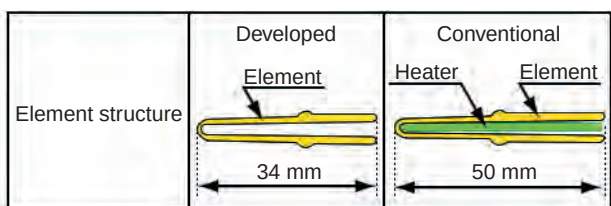


Fig. 7 Comparison of element structures

The body component of a conventional sensor was constructed using a metal outer casing⁽²⁾, and ceramic separators were used to insulate the sensor output wire, the ground wire and the heater wire. The body component of the newly developed sensor was constructed using a ceramic sleeve made of an alumina ceramic, and excellent insulation performance ensured both strength and insulation, simplified the structure, reduced the number of parts, and simplified the production process.

3.4. Cap Structure

The cap structure is shown in Fig. 9. A dividable cap structure for the body and the signal wire outlet was employed to downsize the sensor body.

The L-shaped cap structure enables the signal wires to bend at a right angle, thus increasing the ease of mounting the sensor in the confined space of a small motorcycle exhaust pipe (Fig. 10).

The dividable structure does not require a special tool to mount the body of the sensor to the vehicle, thus contributing to increased productivity.

A waterproof ventilating filter (made by PTFE) is mounted in the cap to ensure that the required amount of oxygen reaches the interior of the sensor. Just in case any gas that affects sensing performance is produced inside the sensor, the unit has a self-cleaning function.

The water proofing property of the cap provides the same level of waterproof pressure as a standard waterproof coupler, ensuring that the toughness required for mounting on motorcycles was achieved.

The sensor mounting is exposed in high temperature as the sensor is mounted on the exhaust pipe; therefore fluorine rubber was used for the exterior of the cap. The cap can resist temperatures of up to 230 °C.

The use of the body ground structure and the cap structure simplified the configuration of the conducting terminals between the sensor element and the lead wire, thus contributing to a reduction in the size of the sensor body.

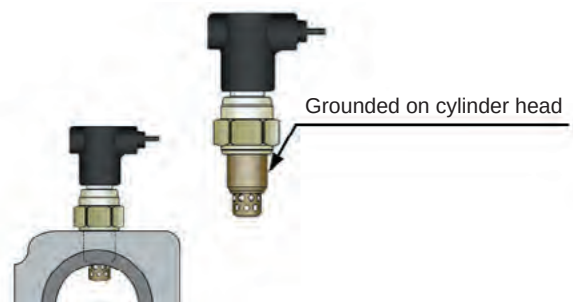


Fig. 8 Structure of body ground

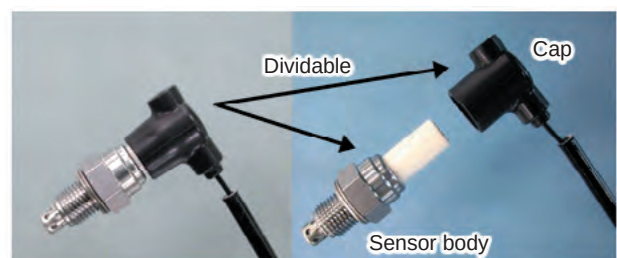


Fig. 9 Structure of cap

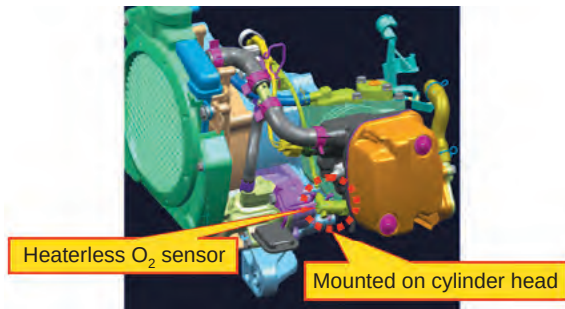


Fig. 10 Example of O₂ sensor mounted on scooter engine

4. Results of Complete Vehicle Tests

A complete vehicle (a 100 cm³ class scooter) equipped with the newly developed oxygen sensor with heaterless structure, satisfied EURO-3 mode emissions requirements.

Changes in the temperature of each section of the sensor during EURO-3 emissions measurements are shown in Fig. 11, and the results of the emissions measurements are shown in Table 2.

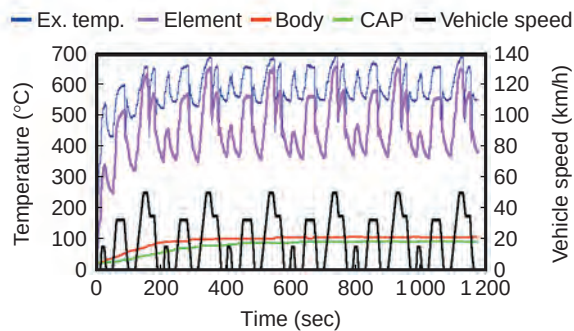


Fig. 11 Measured temperatures during emission measurement test

Table 2 Emission results

Emission	CO	HC	NOx
Result value	1.03	0.14	0.05
Limit value	2.0	0.8	0.15

5. Conclusion

An oxygen sensor with a compact sensing section has been developed for use in small motorcycles.

- (1) The sensor body has been miniaturized by using a heaterless, thin protector, cap and body ground structures; the volume of the new sensor was reduced by 57%, its mass by 43% and the projecting area of the sensing section by 79% over those of a conventional sensor.
- (2) The compact heaterless sensor has a minimal effect on engine output and fuel economy; a complete vehicle with the new sensor installed satisfied EURO-3 emissions requirements in mode tests.

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References

- (1) Nishio, K.: Sensors for Automobile Engine Control, SANKAIDO PUBLISHING Co., Ltd, p. 77-100 (1999)
- (2) Nakahara, Y., Takami, A.: Automobile Combustion Control Sensors (4), Internal Combustion Engine, Vol. 30, No. 11, p. 72-82 (1991)
- (3) Nakahara, Y., Takami, A.: Automobile Combustion Control Sensors (6), Internal Combustion Engine, Vol. 31, No. 3, p. 69-76 (1992)
- (4) Nakahara, Y., Takami, A.: Automobile Combustion Control Sensors (5), Internal Combustion Engine, Vol. 30, No. 12, p. 73-84 (1991)

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