Compact Oxygen Sensor for Motorcycles – Concept of Simple Heaterless Sensors –*

Kinji HODAIRA　Takehiro WATARAI　Zhenzhou SU

The concept and evaluation results of the compact heaterless O_2 sensor (activated with exhaust gas heat) that is suitable for the FI (Fuel Injection) system for small motorcycles are introduced. To realize the heaterless, low temperature operation at 280℃ is achieved by using high ion conductive solid electrolytes and low interface resistance electrodes, and the element temperature could be kept to 350° C and above during an actual vehicle EC mode driving by a small-thin element and a high heat receiving cover. As a result, early rises in temperature and early activation with the heaterless O_2 sensor are made possible at engine cold starting.

Key words :

Oxygen Sensor, Motorcycle, FI system,

半導体／センサ

1. Introduction

Emission standards for motorcycles have been strengthened in emerging countries. Therefore, FI systems are required in small motorcycles that currently used conventional carburettor systems, and O_2 sensor is essential as main parts in FI systems. Compared with 4-wheel vehicles, the demands on O_2 sensors for reducing mounting space, low costs, and reliability in poor environments are high when it comes to small motorcycles. Therefore, the below is a report on O_2 sensor technology with compact and simple heaterless type for meeting such demands (Fig. 1).

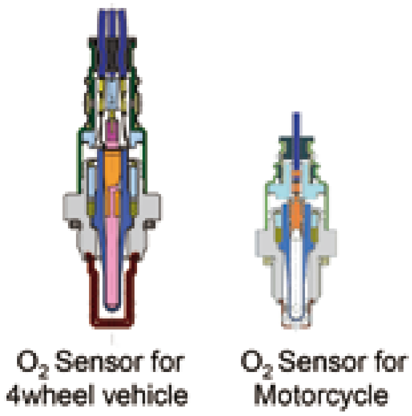

Fig. 1　O_2 Sensor

2. Concept of oxygen sensor for motorcycles

The O_2 sensor described in this paper is targeted at small motorcycles, which will become very widely spread in emerging countries.

＊ Reprinted with permission from Springer Nature.

FI systems for small motorcycles require more reduced space and lower costs when compared with those for 4-wheel vehicles and large motorcycles. Therefore, the concept of O_2 sensors is compactness in design for motorcycles, heaterless with high heat receiving, and high performance in low-temperature activation as they can be operated only with exhaust gas heat due to the simplicity of their systems, power-saving, and low costs of their components. Furthermore, O_2 sensors are made with a highly waterproof structure for withstanding high levels of water pressure as motorcycles require robustness for rough roads, bad weather, and high pressure water washing due to their components being externally exposed.

3. The Designing of O_2 sensor for motorcycles

3.1 The role of O_2 sensor

An example configuration of an FI system is as shown in Fig. 2. As can be seen in Fig. 3, the three-way catalyst shows a high conversion efficiency with harmful HC, CO, and NOx in exhaust gas only in a narrow area (window) close to the theoretical air-fuel ratio. This means that the air-fuel ratio must constantly be controlled at the center of the window in order to effectively exert the three-way catalyst. With that, the concentration of oxygen is detected with the O_2 sensor that has been attached directly below the engine and the amount of fuel injection is adjusted using the ECU to produce the theoretical air-fuel ratio with the intake air mass.

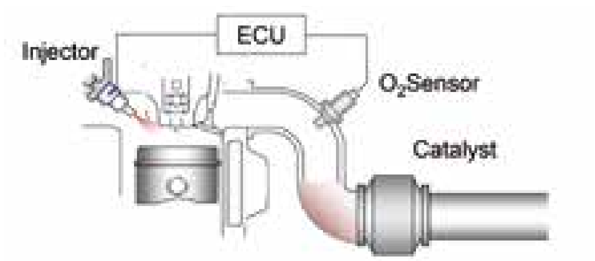

Fig. 2 FI system

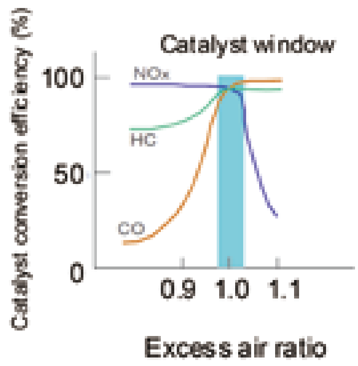

Fig. 3 Catalyst

3.2 Heaterless O_2 sensor technology

3.2.1 The principles of O_2 sensors and heaterless design technology

As a basic principle, O_2 sensors use zirconia solid electrolytes and oxygen concentration cells configured with platinum electrodes placed on both sides. If a reference oxygen atmosphere (normally atmospheric air) and a measured oxygen atmosphere (engine exhaust gas) are introduced to both electrodes of oxygen concentration cells, electromotive force is generated between both electrodes in accordance with the oxygen concentration (partial pressure of oxygen) ratio of both electrodes, and this becomes the sensor output. Typical oxygen concentration cells normally operate at 350°C or more. As sensors do not have their own heating means, the exhaust heat must be effectively used along with elements that activate as low temperature as possible in order to activate O_2 sensors with heat from engine exhaust gas alone.

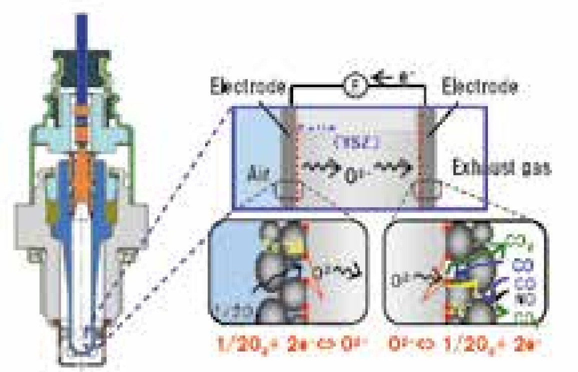

Fig. 4 O_2 sensor mechanism

3.2.2 Low-temperature activation technology

As previously described, O_2 sensor elements are configured with zirconia solid electrolytes and platinum electrodes, and the activation perfomance of the elements is produced with the ion conduction resistance of solid electrolytes and gas reaction resistance of the electrodes. Therefore, they become more active as each form of resistance reduces. At solid electrolytes, resistance is controlled by the ion conductivity of the materials. At electrodes, it is controlled by the gas reactivity and the exchange reaction resistance from the oxygen molecules to oxygen ions in the three-phase boundary of the electrodes, solid electrolyte and gas.

Each resistance characteristic is dependent on the temperatures.

Ion conduction of solid electrolytes is generated through the transferring of oxygen ion resulting from the oxygen concentration diffusion in the oxygen vacancy generated by the introduction of the yttria solid solution into zirconia, and ion conductivity is dependent on the volume of the yttria solid solution as shown in Fig. 5[1]. On the other hand, mechanical strength drops with the yttria solid solution. 6mol% has been chosen as the yttria solid solution volume for the developed product so that high ion conductivity can be maintained while securing resistance to environments with severe thermal shock.

Electrodes are made with platinum that has excellent reactivity and are formed with chemical plating that can maintain lower oxygen reaction resistance in the three-phase boundary through the forming of small pores with thin film.

Comparative results of element internal resistance which is an indicator of ion conductance are as shown in Fig. 6. The element which low-temperature activation technology has been adopted shows a 65% decrease in internal resistance than that of the comparative product.

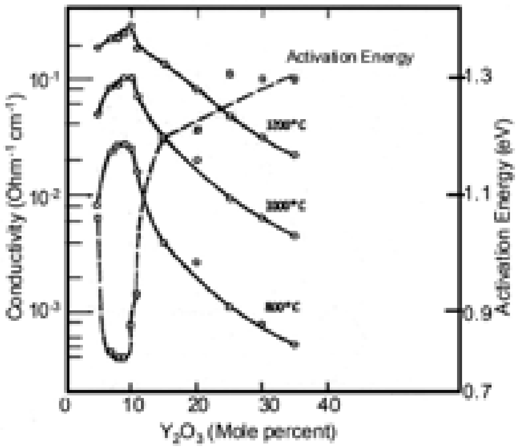

Fig. 5 Y_2O_3 content vs. conductivity [1]

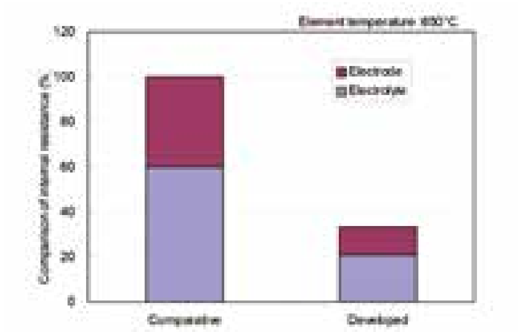

Fig. 6 Sensor internal

3.2.3 Effective utilization of exhaust gas heat

In order to activate the elements with exhaust gas heat, compact and thin elements with an internal diameter of Φ3.8mm and a thickness of 0.5mm were realized due to high accuracy production technology so that the elements would have low heat capacity and low heat release for high temperature rising characteristics.

A type of 2-row/12-pore has been adopted for the element cover in order to increase exhaust gas heat receiving efficiency with the elements.

Simulation results of the temperature rising characteristics for element thickness are shown in Fig. 7. Performance of the element with a thickness of 0.5mm was 5 second faster than that of the comparative element with a thickness of 0.7mm to reach 300°C on element tip in environment temperature 450°C, showing superiority in element activation.

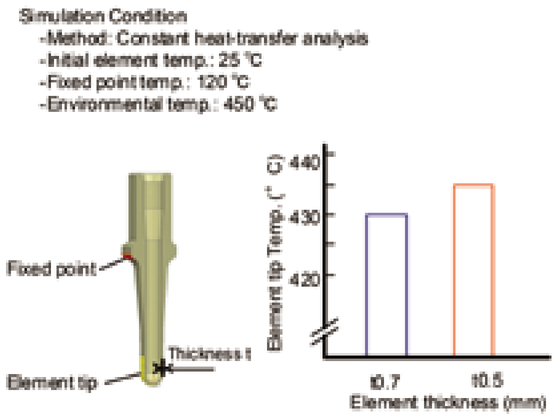

Fig. 7　Temperature effect of element

4. Evaluation results

4.1 Low-temperature activation performance evaluation results

A low-temperature activation element was assembled as a sensor assembly and evaluated with the engine bench. The test conditions and results of the evaluation are as shown in Fig. 8. The developed product maintained larger output amplitudes than the comparative product at 280 °C, which is a low element tip temperature.

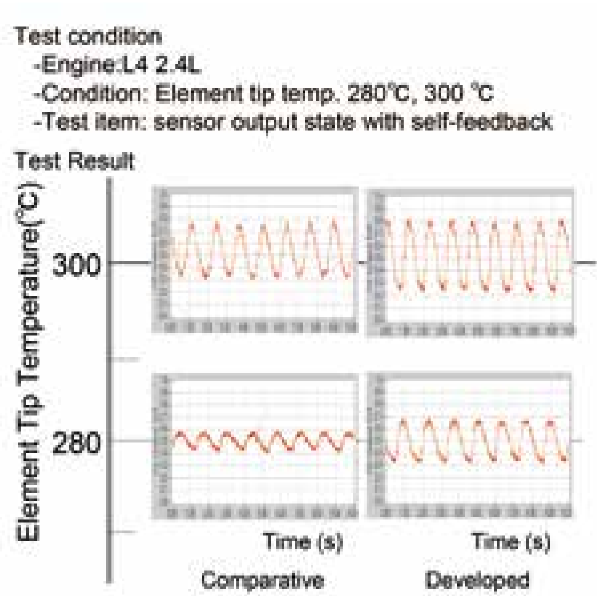

Fig. 8　Sensor output under low element

4.2 Exhaust gas heat utilization performance evaluation results

Eelement temperature behavior was observed during operation in EC mode driving with a motorcycle in order to verify heat utilization performance with compact and thin elements and a high temperature receiving element cover. The test conditions and the results are as shown in Fig. 9. The evaluation results of the developed product show that the temperature of the element maintained higher temperatures than those of the comparative product and that they were 350 °C and above in all areas of the EC mode driving.

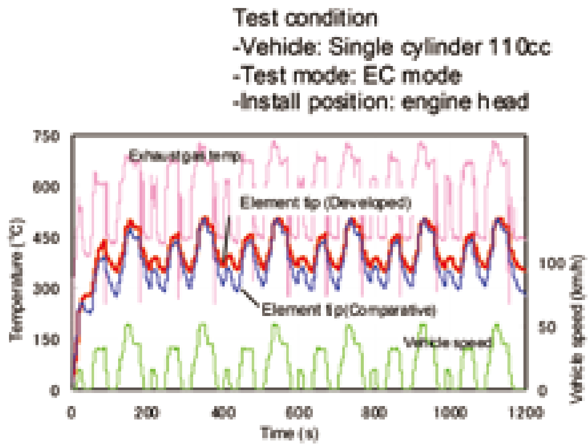

Fig. 9　Sensor temperature at EC mode

4.3 Observation results of the performance of the developed product

The test conditions and results of the activation performance of the developed product after the engine cold start are as shown in Fig. 10.

In the same condition of exhaust gas temperature behavior, the element tip temperature of the developed sensor turned out 40 °C higher than that of comparative product at 20 seconds from engine cold start. This was the effect by the element thinning. About the sensor activation, the developed product confirmed that it was 14s earlier than that of the comparative product at the time when the sensor output became 0.45V which can be judged as the sensor activated.

This result shows that the lower activation temperature as well as the faster element temperature rising of developed product contributes to the faster sensor activation.

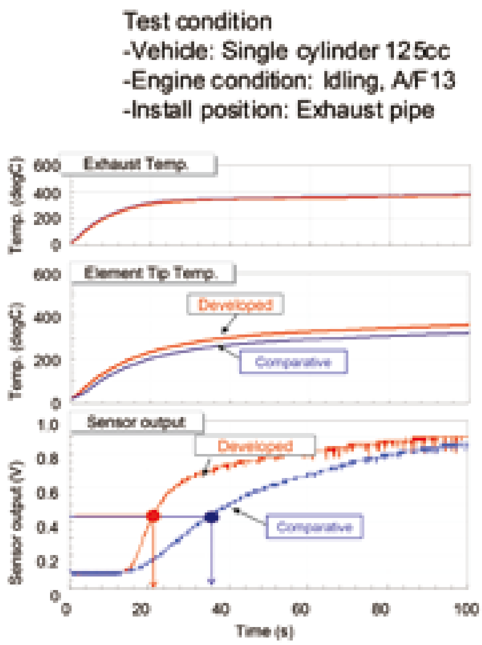

Fig. 10　Sensor performance at cold

5. Conclusions

This has been the concept and evaluation results of the compact heaterless O_2 sensor that is suitable for the FI system for small motorcycles.

(1) Operation with an element temperature of 280 °C with sensor elements characterized by high ion conductivity solid electrolytes and electrodes with low interface resistance was achieved.

(2) Temperatures of 350 °C and above were sustained with the elements during operation with an actual vehicle in EC mode driving with the use of compact and thin elements and a high heat receiving element cover.

(3) It was observed that the developed sensor makes possible early temperature rises and early activation during engine start with an actual vehicle. This O_2 sensor concept may very well contribute to the widespread use of low-cost FI systems in small motorcycles.

References

1） Strickler, J. Am. Ceram. Soc., 47, No.3, p.122 (1964),

著者

宝平 欣二
ほうだいら きんじ

セラミック技術部
排気系製品の設計開発に従事

度会 武宏
わたらい たけひろ

エンジン機器技術部
点火システム／製品設計とパワーデバイス製品開発に従事

蘇 振洲
そ しんしゅう

エンジン機器品質保証部　博士（工学）
品質企画業務に従事