On-A-Chip Integrated Pressure Sensors for Diesel Engines

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1. Introduction

For the production of normal trucks in Japan, the number of gasoline engine cars is decreasing and the number of diesel cars is increasing (Table 1). Even in the extended market for the recent year's RV (recreational vehicle) and MPV (multipurpose vehicle), the ratio of diesel engines in passenger cars is also increasing.

Use of a direct injection system reduces the fuel cost for the gasoline engine. This system is also becoming mainstream in diesel engines. The main characteristics of diesel are a higher heat efficiency and expensive fuel. The cost of fuel is so high that it reduces CO_2 generation and prevents global warming.

Because the exhaust gas of the diesel engine is inferior to the gasoline one, improvements to the catalytic system and combustion using the electronic fuel injection system have been made. Thus, due to a more ideal burning of the gas, generations of not only NO_x but also particulate matter should be sharply reduced.

In the case of diesel engine control, reductions in fuel cost and exhaust gas are achieved by optimum controls that include volume of fuel injection and starting time of fuel injection. Although both fuel cost and engine ability have improved, exhaust gas increases in cases of imperfect engine control. In order to optimize both fuel cost and engine ability, microcomputers have been used to control injection time and the fine mixing ratio of air to fuel.

For that reason, information from various sensors are very important in detecting all signals that indicate engine condition.

The engine has been optimally controlled by the ECU (electronic control unit — the electronic circuit unit for engine control) through these signals.

For optimum control of the fuel injection system, inhalant air volume must be precisely measured and the output pressure signal of the intake manifold transferred to the ECU. Fine volume control of the inhalant air is determined by the pressure and rpm signals in the engine by the ECU.

Fuji Electric has mass-produced the semiconductor pressure sensors used in the measurement of inhalant air pressure of the fuel injection system for the gasoline engine. This paper will present a summary of the semiconductor pressure sensor for the diesel engine.

Table 1 Truck production

(Unit: cars)

Type / Year	Normal trucks		Small size trucks	
	Gasoline engine	Diesel engine	Gasoline engine	Diesel engine
1992	509,694	546,478	410,058	745,268
1993	410,934	510,531	326,475	628,892
1994	431,153	538,307	298,457	606,275
1995	232,514	573,206	304,495	604,825
1996	213,774	568,556	329,500	564,855

2. Features of the Pressure Sensor

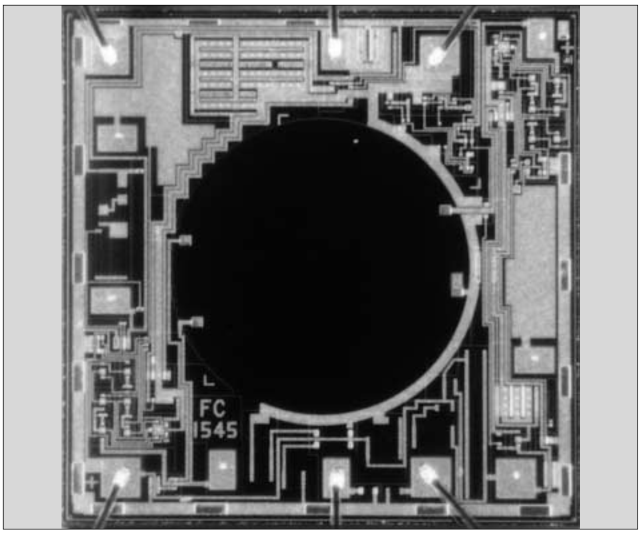
2.1 On-a-chip (single chip) integrated circuit

The pressure sensor manufactured using monolithic integrated circuit technology. The sensing resistor, amplifier and temperature compensatory circuit are all mounted on a single chip only a few mm square. A diaphragm is produced in a thickness of a few tens µm using etching technology of the micromachine. Mechanical displacement (strain) of the diaphragm under different pressures is transferred into an electric signal by a wheastone bridge made from piezoresistance. Although the signal strength is in the few tens of millivolts and there is a strong dependence due to the amplification circuit and the temperature compensatory circuit, we are able to maintain a linear relationship between the output voltage and the mechanical strain, allowing for facilitated control of the circuit. Fuji Electric has mass produced the pressure sensor of the single chip integrated sensor for the automobile's electronic fuel injection unit (Fig. 1). As the single chip integrated circuit sensor is manufactured with a bipolar integrated circuit process and diaphragm etching technology, high mass production, reliability and cost performance are all possible. The sensor can cover a wide pressure range through the thickness of the diaphragm, which can be changed by altering the etching time.

2.2 Function trimming

The chip has 6 thin film resistors for function trimming. The resistors are finely corrected by laser on a chip trimming equipment for amplitude of output voltage, offset trimming and temperature characteristics (offset and sensitivity) generated at the sensing region. Offset trimming and the offset temperature characteristic trimming can be trimmed from both positive and negative. The sensor can be used quickly as a fine pressure sensor by merely connecting it to a power supply.

Fig.1 Surface photograph of on-a-chip integrated pressure sensor



2.3 Package

A small can package is standard for a gasoline engine and has shown satisfactory results and high reliability.

The outer resin case structure which is included in the package can be custom mounted on various forms and adapted to extreme environments such as an engine room.

3. Specification of Characteristics

Table 2 shows the typical characteristics of the pressure sensors for the diesel engine. EPX083, EPX084, EPX068 and EPX059 have been developed for the small car's diesel engine, large car's diesel engine, passenger car, and truck, respectively. The outer resin case package is mounted directly to the engine room.

After connection to a printed circuit board and assembled by the user, the can package is mounted to the engine room.

3.1 Pressure range

As the maximum pressure values are in the range of 250kPa to 400kPa, two diaphragm thicknesses are prepared for up to 300kPa and up to 400kPa sensitivity.

The final sensitivities occur after the thin film resistors on the chip are trimmed by the laser.

3.2 Temperature range

As the can packaged sensor is suitable for use in severe, high temperature environments such as an engine room, it has proven itself on the mass produced gasoline engine without reliability problems between

Table 2 Characteristics of the pressure sensor for the diesel engine

Item \ Type		EPX083	EPX084	EPX068	EPX059
Pressure range (kPa)		20 to 250	50 to 300	20 to 250	50 to 400
Maximum over pressure (kPa)		500	500	500	600
Output voltage range (V)		0.40 to 4.65	0.78 to 4.75	0.5 to 4.5	0.5 to 4.5
Storage temperature (°C)		– 40 to +130	– 40 to +130	– 40 to +125	– 40 to +140
Temperature range (°C)		– 40 to +125	– 40 to +125	– 40 to +125	– 40 to +120
Errors	Pressure (kPa)	±1.48%FS : 50 to 220 ±1.83%FS : 20, 250	±1.89%FS : 70 to 270 ±2.39%FS : 50, 300	±0.87%FS : 100 to 200 ±1.74%FS : 20, 250	±1.00%FS : 70 to 360 ±1.80%FS : 50, 400
	Temperature (°C)	Multiplier 1.00 : 10 to 85 Multiplier 2.00 : – 30/125 Multiplier 3.00 : – 40	Multiplier 1.00 : 20 to 110 Multiplier 1.60 : 125 Multiplier 3.00 : – 40	Multiplier 1.00 : 10 to 85 Multiplier 2.00 : – 40/125	Multiplier 1.00 : 20 to 110 Multiplier 1.60 : 120 Multiplier 3.00 : – 40
Supply voltage range (V)		4.5 to 5.5		4.75 to 5.25	4.5 to 5.5
Supply current (mA max)		10			
Sink currant (mA min)		1			
Source current (mA min)		0.1			
Output impedance (Ω max)		10			
Response time (ms max)		5			
Package		Fig. 2		——	Fig. 3

Fig.2 Outside and cross section of the can package

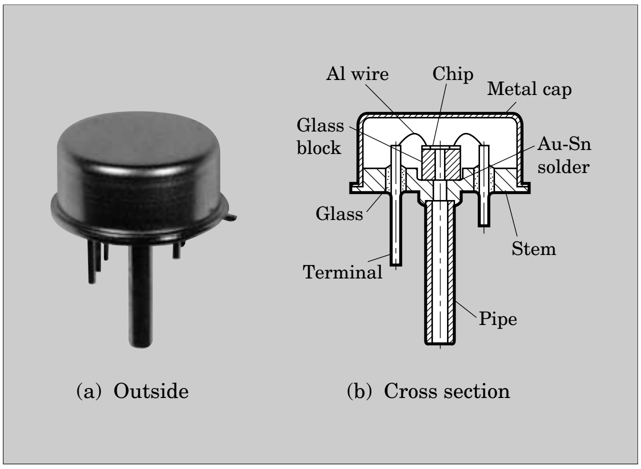
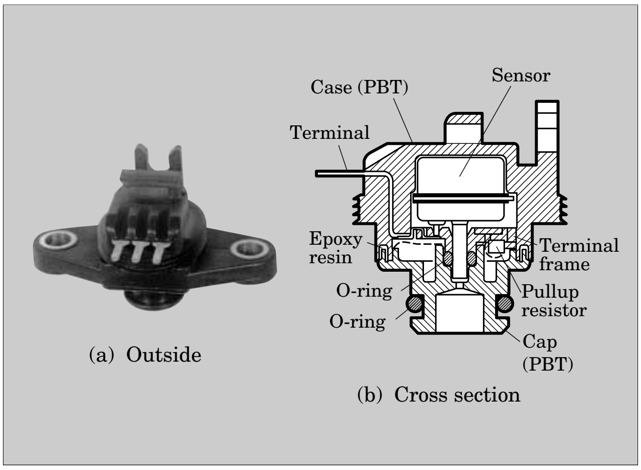


Fig.3 External view and cross section of outer case (EPX059)



the temperature range of −40°C to +125°C.

3.3 Error

There are various specifications for pressure error. The requirement of high precision has grown strict for the progressive fuel injection control system due to global and environmental demands for a greater reduction in fuel cost and exhaust gas. The pressure error of the outer resin case package is highly precise, to within ±1% FS (full scale). As the sensor has integrated all of the functions on one chip, uniformity of characteristics and higher specification by using the high precision function trimming for the requirement have been accomplished.

3.4 Package

Figure 2 shows the can package sensor. It has had good results when mounted on a gasoline engine and is suitable for use in severe environments. The sensor chip is anodically bonded on a glass block in order to ease the thermal stress of the outer environment. It is then fixed to a Fe-Ni alloy stem with a high melting solder. The sensor has excellent anti-corrosive properties due to the use of Au-Sn high melting solder. The chip is vacuum sealed with a metal cap and is tested by the absolute pressure specification. The outer dimension of the can package is $\phi 15.2 \times 19.6$ (mm).

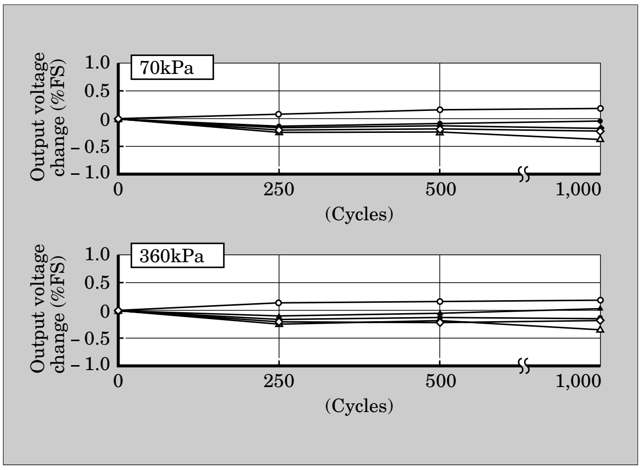
Figure 3 shows the outer case mounted in the engine room. In order to withstand the vibration specific to the diesel engine, the structure is welded through the terminal frame between the edges of the can package and case. The reliability of the welded type is higher than the bonded on the printed circuit board.

Using a low melting solder with the low temperature cycle characteristc of low thermal fatigue, bonding of the pullup resistor for diagnosis is reliable.

3.5 Diagnosis

The check and judging function of the ECU micro computer determines correct operation of the sensor actuator and wire harness for the engine control system.

Fig.4 Output voltage change in the thermal shock test of EPX059 (temperature : −50 to +150°C)



Specification of the same functions are also demanded by the pressure sensor. Outer case types such as EPX059 and EPX068 include the required diagnostic functions.

The required specification is that the ECU determines an abnormal state if output voltage is over the standard when the ground (GND) line is in open mode (including the wire harness).

The ECU can also determine an abnormal state such as over the standard output voltage of open or short conditions in the voltage source and output line.

One reason for the necessity of diagnosis is legal limitation. In the state of California in the USA, diagnosis of equipment relating to exhaust gas is carried out to reduce air pollution.

The effects of exhaust gas can be ideally reduced by complete fuel combustion in all driving situations of the car.

But as the required air volume for combustion is calculated by related output voltage of the pressure sensor, the gas is affected by the output of optimum control when an abnormal output voltage is generated.

3.6 Reliability

Results of the reliability test were excellent, and one example of the thermal shock test is shown in Fig. 4. The welded parts and soldered parts of the resistor in the case were all superior and no disconnection was found.

4. Conclusion

Due to the addition of the diesel engine car to the gasoline engine car, the pressure range of the sensor has increased. Increased functions for uses are now possible and further growth is expected. In the future, we will expand uses for the car's fuel tank pressure sensor and oil pressure sensor as well as for fuel injection.