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A thick-film pressure transducer for cars propelled by natural gas

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Abstract

The development of a thick-film pressure sensor on a stainless steel substrate for application in cars propelled by compressed methane gas is presented. The development is based on the classic model of a circular diaphragm on which four thick-film resistors are screen-printed. They are connected in a Wheatstone bridge configuration. The sensor response between 0 and 400 bar shows a sensitivity of 11.31 mV/V with a 0.1% FS linearity, 0.2% FS hysteresis and 2 μV/V/°C zero thermal drift. The constant-temperature zero shift due to the creep effect is minimized by annealing the samples.

Introduction

One of the main properties of thick-film resistors is their reversible piezoresistive effect, which has been studied since the early 1970s, although its utilization for the development of pressure sensors started around 1980. Thick-film strain gauges, their long-term stability and the influence of temperature on their properties have been studied since then. Different types of thick-film pressure transducers on alumina substrates have been developed for different applications, particularly for the automobile industry [1].

Automotive industries require low-cost and rugged sensors, which means inexpensive and non-brittle materials, capable of operating in extreme conditions of temperature, vibration and humidity. Although traditionally alumina has been used almost exclusively as the transducer substrate, new technological requirements demand a suitably insulated metallic substrate for certain applications [2]. Machinability, which allows the sensor body and diaphragm to be obtained in one piece, is the most appreciated advantage of a metallic substrate. This makes it a safe and easily manufactured component. In particular, the use of stainless steel substrates renders higher sensitivity and better mechanical properties in terms of bending stress and maximum allowed strain.

The development of a thick-film pressure sensor on a stainless steel substrate is presented in this work. The sensor was developed for application in compressed methane gas-propelled cars, which represent a cleaner alternative to gasoline-propelled ones in terms of environmental protection.

Transducer design

The classic model of a circular diaphragm with an embedded border, where four thick-film resistors are connected in a Wheatstone bridge configuration, was used for the pressure-sensor development. In order for the maximum bridge imbalance to be obtained, two resistors were placed around the centre and the other two close to the embedded border, with their lengthwise axis parallel to the diaphragm radius.

In the mechanical design of the body and diaphragm a 0–200 bar range was considered, as well as compliance with standards of usage that require hydraulic pressure testing at 0–400 bar working ranges. Space restraints also required the device to be small.

Figure 1 shows an outline of the transducer mounting, the 3.6 mm thick diaphragm has an effective radius of 9 mm. These parameters were carefully selected in order to remain within the diaphragm elastic limit and

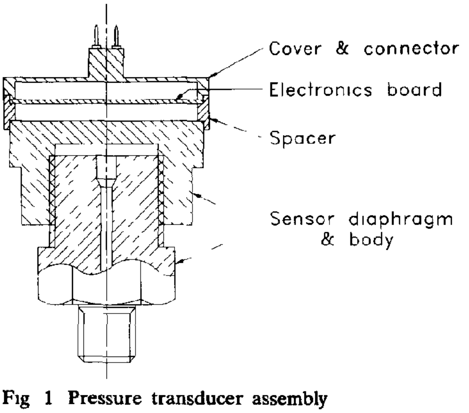

Fig. 1. Pressure transducer assembly.

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avoid breakage A stress level of 1015 kg/cm^2 was obtained for this diaphragm design

The one-piece transducer was machined in AISI 316 stainless steel In order to obtain the four thick-film strain-sensitive resistors, the following steps were performed with a standard screen-printing, drying and firing cycle

(i) two layers of thick-film dielectric paste (Heraeus IP 211) fired at 950 °C for 10 min,

(ii) one layer of thick-film dielectric paste (Heraeus IP 9117) fired at 920 °C for 10 min,

(iii) one conductive layer of thick-film paste (Heraeus H 1214B) fired at 850 °C for 10 min,

(iv) one resistive layer of thick-film paste (Heraeus R 8041) fired at 850 °C for 10 min

The electronic design was based on an instrumentation amplifier circuit with controlled supply voltage and over-pressure detection, which was mounted on the sensor body As the sensor has to be located close to the combustion gases, the associated electronics were designed following intrinsic safety rules [3]

Results and discussion

Sensitivity, linearity and hysteresis tests were carried out on a Degranges et Hout 5300 pressure balance, an HP 6282A power supply and a Keithley 197 digital voltmeter of 5 1/2 digits

The sensor temperature performance was tested in a Heraeus HC4020 climatic chamber

Figure 2 shows the sensor response between 0 and 400 bar The maximum measured sensitivity was 11 31 mV/V with a 0 1% full-scale (FS) linearity and 0 2% FS hysteresis The calculated gauge factor was 16 The temperature coefficient of resistance (*TCR*) was also measured for each resistor and the value of 320 ppm/°C in the range 25–100 °C was obtained

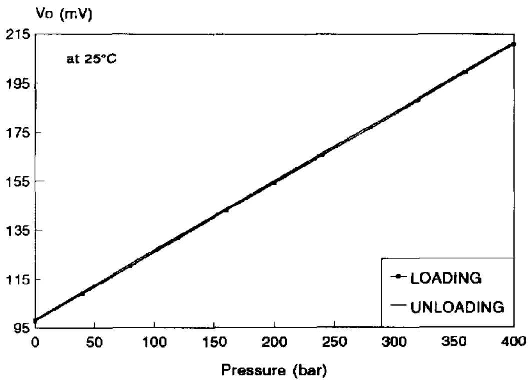

Fig 2 Pressure sensor response with unbalanced bridge at 10 V supply

In order to study the sensor stability in unloaded conditions, the output of the bridge was measured at constant temperature for four weeks Results are shown in Fig 3 The registered zero drift was 0 6%, which is rather high for industrial applications Such a drift at constant temperature is a typical phenomenon in metallic substrates, which accumulate residual stresses during heating It is well known that these stresses can be relieved by an appropriate heat treatment, which in this case was an annealing at 230 °C for 24 h The constant-temperature zero drift after heat treatment is also shown in Fig 3

Like ceramic pressure sensors, metallic ones show a zero drift with temperature In order to determine this drift, the sensor was subjected to a thermal sweep from 0 to 100 °C and the bridge output was measured unloaded Results can be seen in Fig 4, which shows a zero thermal drift of 2 μV/V/°C This value is similar to that obtained in commercial ceramic-substrate pressure sensors

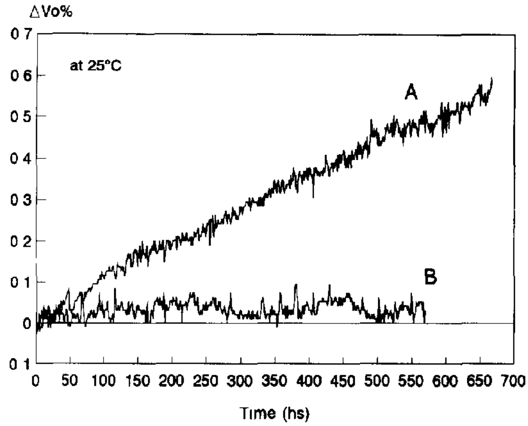

Fig 3 Zero drift response (A) before heat treatment, (B) after heat treatment

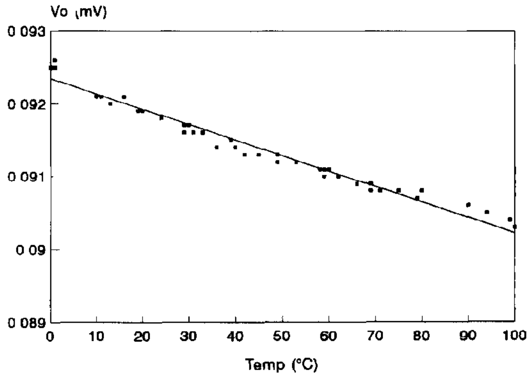

Fig 4 Zero thermal drift of pressure sensor

Conclusions

The sensor described showed the following characteristics sensitivity, 11 31 mV/V FS, linearity, 0 1% FS, hysteresis, 0 2% FS, zero thermal drift, 2 μV/V/°C

The sensor proved to be robust, reliable and safe and it can be produced at competitive prices A pilot production of these sensors is currently under field testing The results encourage its application in methane gas-propelled cars, where intrinsically safe devices are needed

References

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