Development of Capacitance Diaphragm Gauge

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In the deposition process or an etching process that made to be used for the fabrication of LEDs, semiconductors, FPDs and solar cells, various gases are used and the process pressure gives large effect on product quality, so the excellent corrosion resistance, and without gas dependent, and high accuracy are required to vacuum gauge . To provide solutions to these requests, HORIBA STEC has developed the Capacitance Diaphragm Gauge “VG-200 Series”, and the results of the performance evaluation were superior reproducibility and long term stability. Here, we describe the product features and performance evaluation results of the VG-200.

Introduction

Recently, it is becoming very important to measure and control pressure in the manufacturing processes for maintaining and control product quality in all kinds of industries. For example, in the manufacture of semiconductors, there is a process that requires control of small changes in pressure in a low-vacuum region, and vacuum meters are required to be able to measure a small pressure change with high precision. In addition, product manufacturing processes utilizing vacuum are sometimes used in the renewable energy, display, and MEMS industries. Therefore, vacuum meters are used in a wide range of industries as described above. From this, it is apparent that vacuum instrumentation with precision and stability will be more important in the future.

To meet such requirements of the marketplace, we independently developed a sensor structure and signal-processing algorithm. In addition, we succeeded in the development of self-temperature-regulating, small-sized, and high-precision VG-200 series of capacitance manometers through the development of a manufacturing technology for precision welding in house as introduced below.

Measurement principle of capacitance manometer

The measurement principle of capacitance manometer is as follows (Figure 1):

The sensor body is divided into standard chamber and measurement chamber by a diaphragm. The standard chamber, which is equipped with a fixed electrode, is maintained in the vacuum state by a getter material[*1]. On the other hand, in the measurement chamber, if a distance between the electrode and the diaphragm changes because of a deflection of the diaphragm caused by a change in pressure, the capacitance generated between them also changes. Measuring the change in capacitance and converting it into a pressure value determines the pressure value in the measurement chamber. In addition, since the force (pressure) applied to the diaphragm can be directly converted into an output, the product performance is not dependent on the type of gas, and it is possible to measure pressure with high precision.

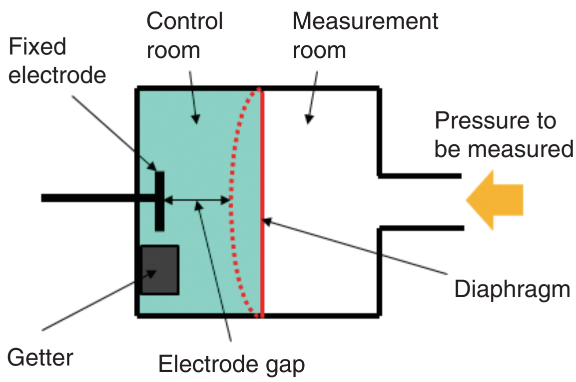

Figure 1 Diagram of Capacitance Diaphragm Gauge

*1: Getter material: A material that absorbs excessive gas to maintain a vacuum.

Figure 2 Appearance of VG-200 series

Features of VG-200 series capacitance manometers

Product specifications

Figure 2 and Table 1 show the external appearance and specifications of VG-200 series products, respectively.

As a self-temperature-regulating capacitance manometer, this series achieved high precision and resolution although small in size. In addition, since its production process is also automated, we succeeded in establishing a stable production system with little variation in product quality.

Table 1 Specification of VG-200 series

Model	VG-200
Pressure range	10, 100, 1000 Torr
Sensor temperature	55°C/100°C
Precision	0.25%R.S.
Zero point coef.	0.0025%F.S./°C
Span coef.	0.02%R.S./°C
Available temp. range	10°C to 45°C (55°C) 10°C to 50°C (100°C)
Warm-up time	60 min (55°C) 120 min (100°C)
Withstand pressure	350 kPa (A)
Signal output	Analog 0-10 V >10 kΩ load
Power source	±15 VDC ±5% or 24VDC±5% @0.6 Amax

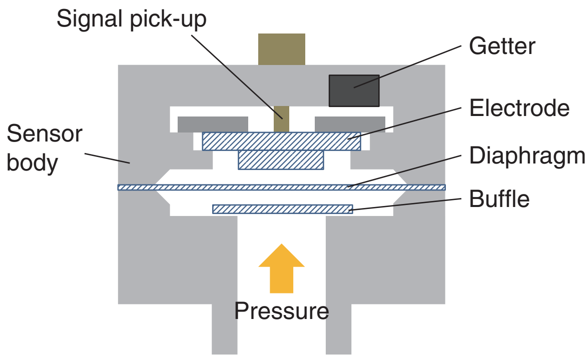

Figure 3 Cross section view of sensor package

Sensor structure

The sensor structure of VG-200 series capacitance manometers is as follows (Figure 3):

The electrode is fixed to the sensor body in a way that a constant force is applied to the entire electrode in the same direction on a consistent basis without being jointed to the sensor body directly. Using this electrode structure that we independently developed allowed us to minimize the impact of thermal stress generated in the event of a significant change in temperature, such as when temperature regulation is started after power activation, achieving excellent stability.

In addition, using Ni alloy with superior corrosion resistance as a diaphragm material enabled resistance to corrosive gases and stable output even in a harsh environment.

Precision welding technology

Since capacitance manometers need to detect even slight pressures, the metal diaphragms used in them are as thin as 100 μm or less. In welding such a thin-film metal diaphragm, a precisely controlled welding technology is required to prevent unequal pressure from being applied to the diaphragm from the influence of welding heat input. We introduced a semiconductor laser welding technology several years ago and now mass-produce small-sized and high-performance capacitance type pressure sensors that can be installed in mass flow controllers. Therefore, utilizing this technology enabled us to establish a precision welding technology like this.

Signal processing technology

Synchronous demodulators that are generally used are designed to detect the partial pressure applied to a detection capacitor using an operational amplifier (first-stage amplifier). However, this method has the potential problem that an environmental impact or a fluctuation in power-supply voltage generates a phase or potential shift between an inverting circuit and a non-inverting circuit, causing measurement error. We have solved this problem by implementing a unique circuit, which is designed to use a sampling circuit whose phase is synchronized with the output pulse from a sensor to detect a pulse amplitude always in the same phase. This circuit lowers the factors for measurement error and reduces the effects of disturbances that occur during analog computing that achieved higher resolution. In addition, we changed the structure of this circuit based on the premise of eliminating inverting and non-inverting electric circuits, which had been the root cause of the problem, and succeeded in reducing the size of the substrate.

Power source specifications

Table 2 shows the inter face pin assignment of VG-200.

The VG-200 is designed to operate with the power of +/- 15 VDC as well as 24 VDC so that it can be driven by the power supplied from various kinds of vacuum devices used in a wide range of industries.

Table 2 Interface pin assignment of VG-200 series

Pin No.	Signal
1	Re Zero input (+)
2	Output pressure signal 0-10VDC / 0-F.S. pressure Load resistance should be 10 kΩ more
3	Re Zero input (-)
4	NPN open-collector output for warming-up Open collector turns on after warm-up
5	Source common
6	Source input -15 VDC *1)
7	Source input +15 VDC / +24 VDC
8	Set point relay 1 normally close
9	Set point relay 1 normally open
10	Set point relay 1 common
11	Set point relay 2 normally close
12	Common for pressure signal output
13	Set point relay 2 normally open
14	Set point relay 2 common
15	No connection

*1 No.6 pin should be free for 24 VDC power source

Zero adjustment function

This product is designed to perform zero adjustment both directly and remotely by pressing the Zero Adjustment switch on the top surface of the main unit, by using a dedicated software, or by connecting pins on the interface.

Setpoint relay

The VG-200 has two independent relay functions as standard. In addition, the contact “a” or contact “b” can be chosen for each relay, and the upper and lower thresholds can be set individually. Users can set the thresholds freely using a dedicated software to cope with various event settings.

Evaluation result

Figure 4 shows the environmental temperature dependence of the output of the sensor whose pressure output and temperature characteristics measurement ranges are 1.3 kPa (abs) and temperature is regulated at 100°C. The operating environmental temperature range of the sensor with these specifications is between 10°C and 50°C, and this sensor was confirmed to be stable with little influence from the temperature in this temperature range.

Zero point stability

Figure 5 shows the result of measuring the zero point stability for approximately 100 days.
The output was confirmed to be stable for a long period of time.

Repeated and excessive pressure reproducibilities

Figure 6 shows the output stability when a vacuum and an atmospheric pressure are applied repeatedly for 10,000

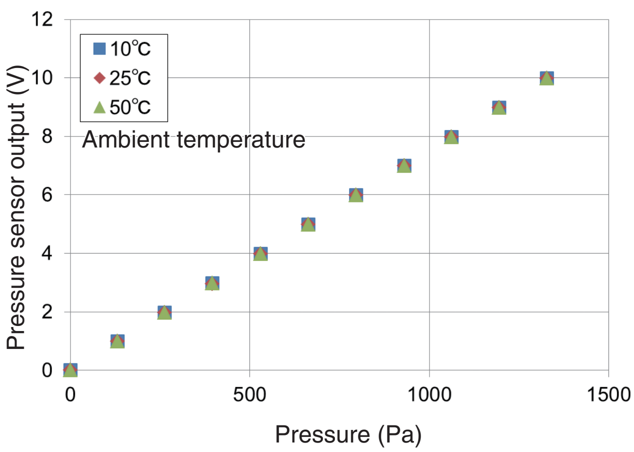

Figure 4 Ambient temperature characteristics

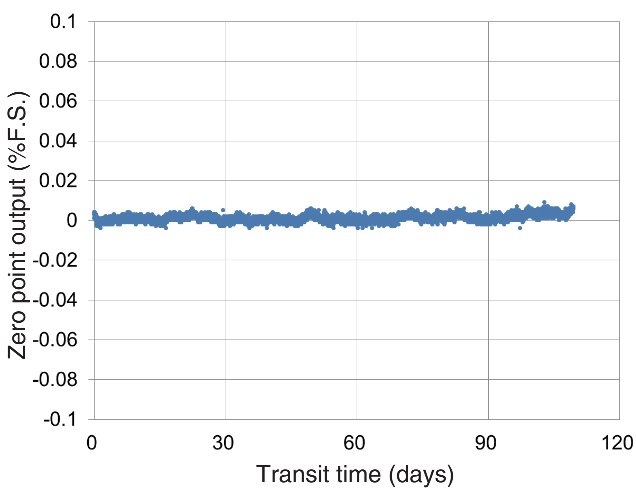

Figure 5 Long term Zero stability

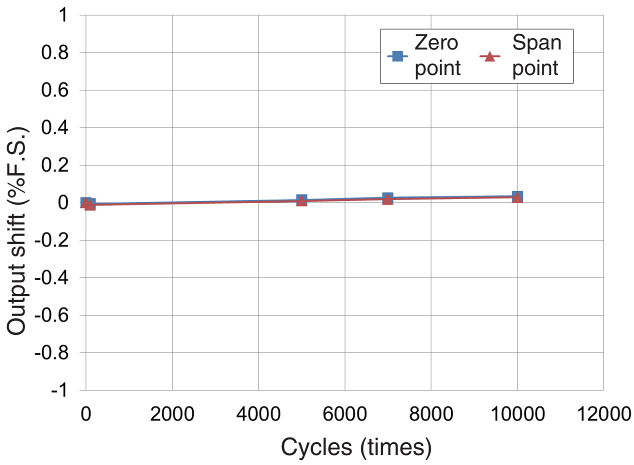

Figure 6 Test result of pressure cycle

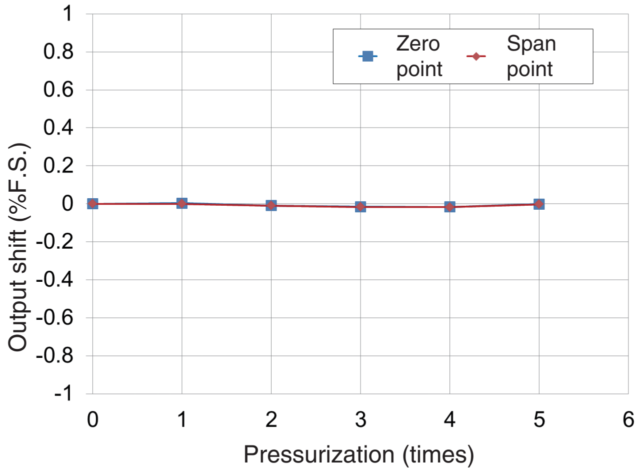

Figure 7 Test result of proof pressure

times, and Figure 7 shows the output stability when an excessive pressure (350 kPa [abs]) is continuously applied for an hour.

With the use of a metal diaphragm with superior mechanical properties, it was confirmed that the output shift could be minimized even when an excessive pressure was applied to the sensor and was very small even when the sensor was exposed to the atmosphere repeatedly.

Conclusion

We succeeded in the development of a small-sized, high-precision, and corrosion-resistant all-metal capacitance manometer using the technologies we developed independently. In the future, we hope to promote the development of a vacuum meter that can measure lower pressures with higher sensitivity in processes at higher temperatures.

HORIBA STEC, Co., Ltd., has been selling mass flow controllers in the semiconductor manufacturing device market as one of the top fluid control device suppliers. We hope to contribute to global development by offering wider range of process chamber-controlling products, including the manometer we developed this time, to provide solutions to a wide variety of customer requirements.

References

[1] Larry K. Baxter, *CAPACITIVE SENSORS*, IEEE Press (1997).
[2] Takehisa Hataita, *Readout*, **36**, 10 (2010).

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