Application Note

Baratron® Capacitance Manometer Selection and Installation

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PROBLEM Capacitance manometers are an ideal choice for measuring pressure and vacuum in many industrial, medical, semiconductor, LED, and critical thin film applications such as CVD, ALD sputtering, optical coating, flat panel display and solar cell manufacturing processes. They are typically constructed from corrosion-resistant materials, are insensitive to the type of process gas being measured, and are extremely accurate and stable over long periods of time. In order to get the maximum performance from installed capacitance manometers, it is critical that appropriate design techniques be used for the selection and installation of these devices.

BACKGROUND Accurate and precise measurements at the maximum and minimum expected process pressures are critical for successful process monitoring and control. For example, if a process set point lies between 5.0 and 6.0 mTorr and the required pressure reading precision is ±0.5 mTorr, the required measurement accuracy is 10% of the reading or, in the case of a 100 mTorr capacitance manometer, 0.5% of Full Scale. If the selected manometer cannot achieve this level of precision, the process cannot be controlled within the desired process "window".

Capacitance manometer signals that are used as input for closed-loop pressure control must have sufficient resolution to discriminate very small pressure changes in a process. Additionally, the pressure controller and control valve in the loop must have the resolution necessary to effectively use this data to control small changes in pressure.

Early capacitance manometers experienced issues with fluctuation in their readings that were caused by changes in ambient temperature. This problem has been minimized through improved sensor design. However, the movement of the sensor diaphragm in response to a pressure change is so minute (typically less than 10^{-6} inch), that even small temperature changes can cause enough thermal expansion to change the output signal and produce a false indication of pressure change.

Pressure and materials compatibility issues are important in some capacitance manometer applications. For example, users sometimes are uncertain as to whether a valve is required to isolate it from "high" pressures (normally this implies atmospheric pressure). While valving protocols exist for certain applications (see below), there is no general need for isolating a capacitance manometer from atmospheric pressure.

The design of a capacitance manometer is such that the device is relatively resistant to chemical damage of the wetted surfaces. Some instances do exist, however, where materials compatibility has to be considered in the selection of a particular manometer. Halogen-based processes and processes using oxidizing gases such as ozone and fluorine in particular need to be carefully investigated.

In addition, capacitance manometers are electronic devices and strong electromagnetic fields can affect their performance. All manometer manufacturers provide some degree of shielding in their products, both to prevent interference with the manometer electronics and to prevent the manometer electronics from affecting outside equipment. If high electromagnetic fields exist in the vicinity of the manometer it is important to ensure that the shielding is adequate.

Finally, while the mounting position of a capacitance manometer is not normally an issue, there are certain instances in which constraints may be placed on the mounting configuration.

This Applications Note provides a detailed discussion of these issues and MKS Instruments' recommendations for the proper selection and installation of Baratron® capacitance manometers in most process equipment configurations.

SOLUTION

Accuracy and Precision

The first consideration in the selection of a capacitance manometer is Full Scale pressure range. For good measurement accuracy, the device range should be matched to the expected pressure or vacuum range to be measured. Ideally, the manometer range should encompass the highest expected pressure, which maximizes the output signal (analog) and increases the signal-to-noise ratio. Consider a vacuum process that operates between 5 mTorr (5.0×10^{-3} Torr) and 80 mTorr (8.0×10^{-2} Torr). The best capacitance manometer for this process would have a Full Scale range of 100 mTorr. This device would have an analog output of 5% of Full Scale at the minimum expected pressure, providing good accuracy and high signal-to-noise at low pressure while maintaining sufficient range to measure high system pressures. While a capacitance manometer with a Full Scale of 1 Torr would also work in this application, the analog output at 5 mTorr would be reduced by a factor of 10. This change in signal strength would greatly reduce the signal-to-noise ratio, degrading the reading accuracy.

Many modern capacitance manometers send their output as an analog signal to a host computer, process controller, or data-recording device. The signal has various formats; 0-10 VDC, 0-5 VDC, 0-1 VDC, and 4-20 mA are common. The output is linear with pressure in most of the formats, making a manometers' output easy to scale in software.

Analog/digital (A/D) conversion of the pressure signal at the destination must have sufficient resolution to distinguish the signal from the manometer's normal background noise. For example, 12-bit A/D conversion of the manometer signal will discriminate a minimum signal of 0.02% of the manometer's Full Scale analog output. For a 1 Torr Full Scale manometer, this means that pressure or a pressure change of less than 2×10^{-4} Torr cannot be detected. Table 1 shows the minimum resolvable pressure vs. A/D conversion accuracy for various manometers, assuming that the analog output of the manometer is 0-10 VDC.

It is very important to match the output of the manometer and desired process measurement accuracy with the resolution of the host computer, data logger, or controller. For example, if a process operates at 1.0% of the Full Scale range and the manometer's Full Scale output is 10.000 VDC, the host must be able to reliably discriminate a 100 mV analog signal. An A/D data acquisition system thus requires at least 12-bit resolution to use the manometer over most of its measurement range. Higher bit resolutions allow improved resolution of the manometer measurements at the lowest pressures. Table 1 shows the minimum resolvable analog signals at different A/D resolutions. MKS pressure controllers all offer A/D conversion of at least 16 bits and are capable of resolving signals as low as 0.4 mV.

		Minimum Resolvable Pressure			
A/D Resolution	Minimum Detectable Signal - mV	100 PSIA FS (PSIA)	1000 Torr FS (Torr)	10 Torr FS (Torr)	0.1 Torr FS (Torr)
8-bit	39.22	3.92E-01	3.92	3.92E-02	3.92E-04
9-bit	19.61	1.96E-01	1.96	1.96E-02	1.96E-04
10-bit	9.81	9.81E-02	9.81E-01	9.81E-03	9.81E-05
11-bit	4.90	4.90E-02	4.90E-01	4.90E-03	4.90E-05
12-bit	2.45	2.45E-02	2.45E-01	2.45E-03	2.45E-05
13-bit	1.23	1.23E-02	1.23E-01	1.23E-03	1.23E-05
14-bit	0.61	6.13E-03	6.13E-02	6.13E-04	6.13E-06
15-bit	0.31	3.06E-03	3.06E-02	3.06E-04	3.06E-06
16-bit	0.15	1.53E-03	1.53E-02	1.53E-04	1.53E-06
18-bit	0.04	3.83E-04	3.83E-03	3.83E-05	3.83E-07
20-bit	0.01	9.58E-05	9.58E-04	9.58E-06	9.58E-08

Table 1:
Minimum Resolvable Pressure at Common A/D Resolutions

Instruments that employ digital communications using protocols such as EtherCAT®, DeviceNet™, Profibus®, Ethernet, and serial communications are also available. These devices send a digital signal representing the measured pressure to a host on command. This eliminates the need for A/D conversion within the control system. Digital communications also allows sensor networking and the collection of data that can be used for statistical process control (SPC). This can have a significant benefit for optimizing process yields. The use of digital communications also facilitates the implementation of the powerful diagnostic and troubleshooting features built into advanced digital capacitance manometers. These features drastically reduce the time necessary for process development, implementation, and repair.

Closed Loop Pressure Control

The need to discriminate small pressure changes for closed loop pressure control limits the range selection for a capacitance manometer by at least one full decade. Consider the case in which a manometer is to be used to control a process at 5 mTorr. A 100 mTorr Full Scale manometer is the maximum pressure range that can be employed. Indeed, lower Full Scale range devices would be a better option since they offer higher output signals that are more easily detected and resolved and this would improve the accuracy of the pressure control. Table 2 presents the minimum recommended control pressures for some common capacitance manometer vacuum ranges.

Full Scale Range – Torr	Minimum Detectable Pressure – Torr	Minimum Control Pressure - Torr
1000	1.00E-01	5.00
100	1.00E-02	0.50
20	2.00E-03	0.10
10	1.00E-03	5.00E-02
2.0	2.00E-04	1.00E-02
1.0	1.00E-04	5.00E-03
0.1	1.00E-05	5.00E-04
0.05	5.00E-06	2.50E-04

Table 2:
Lowest Control Pressures for Full Scale Manometer Ranges

Heated vs. Unheated Capacitance Manometers

The problem of degraded accuracy due to ambient temperature variations has been solved by the advent of heated manometers. These devices have the sensor enclosed in a volume that is maintained at a constant temperature typically 45°C. This solution improves the manometer's accuracy and repeatability and minimizes drift by reducing or eliminating process contamination within the manometer. Higher temperature manometers are available for where the process gas temperature is higher and where an increased temperature will prevent or reduce process byproduct condensation in the manometer. Heated manometers with operating temperatures of up to 200°C are commercially available and are employed in semiconductor manufacturing, optical fiber production, freeze drying of biopharmaceuticals and food, and in advanced materials processing. Heated manometers are thus the most accurate and repeatable option for pressure sensing and they are recommended for applications that require maximum accuracy and repeatability, operate above ambient temperature and for those processes that employ hot gases or process gases that would otherwise condense in the manometer. Less accurate, unheated capacitance manometers continue to be used in less demanding applications where gas temperatures are close to ambient (72°F or 23°C), and/or contamination by process byproducts is less likely.

Selection of the correct operating temperature for a heated manometer requires knowledge of all of the operating conditions of the process. This includes process gas pressure or vacuum, gas composition, process gas temperature, accuracy requirements for the process, and cycle times for the equipment. Some basic rules for the selection of a heated manometer include:

- Manometer operating temperatures should be at least 5°C higher than that of the process gas. This is particularly important at pressures above 100 Torr (132 mbar). For example, an atmospheric pressure annealing process operating at 95°C requires a manometer operating temperature of at least 100°C.

- Thin film deposition processes, particularly chemical vapor deposition (CVD and ALD), require operating temperatures of at least 45°C, and can require 200°C or higher for certain chemistries. Deposition of conducting and insulating/wear films typically require high temperatures,

Capacitance Manometers
Heated version (left); Unheated version (right)

while dielectric and optical films commonly operate at lower temperatures. The manometer manufacturer should be contacted for advice in the selection of a manometer for these applications.

- Thin film removal or cleaning processes, such as dry etching, sterilization, or plasma cleaning require that manometers be heated to at least 45°C. The composition of the cleaning gas determines the best temperature; typically oxygen or argon etching use manometers that are heated to 45°C while halogen-based or steam-based processes normally require manometers that operate at 100°C or higher.

- Analytical equipment like automated leak testers and electron microscopes do not normally require heated products, but the improved accuracy of heated manometers can improve the analytical instrument's performance and accuracy.

Isolation Valves and Capacitance Manometers

When configuring the installation of a capacitance manometer it is important to adhere to the following recommendations:

- An isolation valve is almost never needed between a capacitance gauge and atmosphere to prevent damage by exposure to atmospheric pressure. All MKS Baratron manometers have burst pressures of at least 10x their Full Scale pressure range.

- A manometer that may be exposed to pressures greater than 45 PSIA should be configured with an isolation valve between the manometer and the system. Above 45 PSIA, the manometer's diaphragm may experience a span shift that will affect its accuracy.

- MKS recommends that an isolation valve be used when a heated vacuum manometer is used for process control and the process chamber is expected to be exposed to atmospheric pressure. This recommendation isn't due to any potential for damage to the manometer; rather, it maintains the output accuracy of the device. Ambient air or gas entering the inlet port can lower the manometer temperature by a few degrees (depending on the gas temperature), which slightly shifts its output. An isolation valve programmed to close when the pressure increases to more than the Full Scale range of the manometer helps preserve the device accuracy.

- The preceding consideration is especially relevant for fast-cycling processes (i.e. shorter than 30 minutes). As noted, exposure of the manometer to atmospheric pressure shifts its output due to temperature changes. The manometer recovers within a few minutes, however, during that time, some small degree of shift is likely to occur; this affects closed-loop pressure control. An isolation valve minimizes this issue to the point that a manometer can be used in processes with cycle times as low as 10 seconds or less.

Chemical Compatibility

The basic capacitance manometer design is well suited to pressure measurement in the presence of corrosive gases since only a limited number of materials are exposed to the process gas. Many commercial products use corrosion-resistant stainless steel or nickel alloys for the diaphragm and other sensor parts.

Electromagnetic Interference

Most capacitance manometers are able to operate normally in the presence of magnetic fields up to 1-3 gauss without additional shielding; with shielding, operations in fields up to 60 gauss may be possible. It is important to measure the strength of local magnetic fields and to check with the manometer manufacturer if field strengths of this magnitude are expected in the application area. Mechanical set point relays can be impacted by magnetic fields. If set point relays are required in a high magnetic field application, solid state relays may be a better option.

Similarly, the electric field strength in the vicinity of the manometer must be measured to determine whether it is compatible with the manometer shielding. CE approval requires that the manometer withstand field strengths of 10 volts/meter with no change in output, but certain applications can subject the device to field strengths of more than 100 volts/meter – and sometimes the presence of standing waves. If very high electric field strengths are determined or suspected in the vicinity of the manometer, contact MKS for specific recommendations.

Mounting

Capacitance manometers are relatively insensitive to mounting positions. MKS recommends that Baratron capacitance manometers be mounted such that the inlet tube is facing either vertically down (i.e. the inlet tube is lower in height than the electronics) or horizontal. This orientation helps to prevent any gravity-induced incursion of particles or condensable gases into the inlet tube and sensor. In low-range (Full Scale < 1.0 Torr) manometers, gravity may affect the deflection of the very thin sensor diaphragms. Differences in orientation during calibration can induce as much as a 5% variation in the zero position of these devices. While it is typically possible to rezero the manometer after installation and remove the gravity induced zero offset, a significant portion of the device allowable zero adjustment can be consumed. For manometers with Full Scale pressures < 1.0 Torr, MKS allows preselection of mounting orientation/factory calibration.

As noted in previous sections, unheated capacitance manometer output can shift if the ambient temperature is higher than about 24°C (75°F). Therefore, always mount a capacitance manometer in a location where the expected temperature will remain as close to ambient as possible.

Heated devices should always be mounted in a location with adequate airflow, as the manometer depends on this airflow to maintain its internal and external temperatures within acceptable ranges. A corollary to this rule is that heated manometers should only be mounted and operated in locations where the ambient temperatures is expected to remain less than the manometer internal temperature. For example, a 45°C heated manometer should not be used in applications where the ambient temperature is higher than 42°C (preferably the ambient should be lower). Operating in higher ambient temperature can cause instability in the manometer output since its heater controller will respond to the ambient temperature rather than to the sensor temperature. This can cause uncontrolled thermal expansion and contraction in the sensor.

CONCLUSION

Capacitance manometers are an ideal choice for pressure/vacuum measurement in many process applications. In order to achieve the maximum performance in terms of accuracy and precision, manometer characteristics must be considered and properly selected. These include electronic characteristics that are innate to the manometer such as range, data resolution and sensitivity to EMI. These must be appropriately matched with the environment and other components in any system that utilizes the manometer data. The physical structure of the manometer must be matched with the process conditions to determine the manometer heating requirements and materials compatibility. Finally, the best mounting orientation for manometers in certain applications must be considered. Once these selection and installation criteria have been properly fulfilled, MKS Baratron capacitance manometers provide the best available technology for pressure measurement in processes in a wide range of industries.

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