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5.1 Selection and Application


Pressure detection devices can be classified on the basis of
the pressure ranges they can measure, on the basis of the
design principle involved in their operation, or on the basis
of their application. In this chapter, the various categories are
not separated in any strict manner. Industrial instruments are
discussed in detail, with emphasis on the most commonly used
devices; laboratory instruments are covered in less detail.

INTRODUCTION

Each section starts with a brief summary of basic features
applicable to the group of instruments discussed in that sec-
tion. This information allows readers to quickly determine
whether that category of instrumentation is suitable for their
application.

This chapter covers a wide range of pressure sensors,
which can measure pressures from ultrahigh vacuums, such
as $10^{-13}$ mmHg, to ultrahigh gauge pressures approaching
400,000 PSIG (2,800 MPa).

The range of the costs and inaccuracies of these instru-
ments are equally broad. A simple, 1.5 in. diameter, 5% inac-
curate gauge might cost only $10, while a fused-quartz helix
sensor with an error of 0.01% and a digital readout could cost
$6000. The cost of pressure transmitters range from a few
hundred dollars or less for the disposable models that have
limited features, to $2000 for smart models with built-in
digital PID control algorithms and/or digital networking
capabilities.

Silicon microchip technology continues steadily to reduce
the cost of advanced features, reducing the size and weight
of hardware and improving their availability and accuracy,
while extending the long-term stability their calibration.
Many of the sensors are available with digital communication
capability, which can serve calibration, adjustment, and
reporting of process variables, allowing for complete plant-
wide integration.

With so many types of sensors, it might seem that making
the proper selection for a particular installation would be
difficult and time consuming. Actually, this is not the case.
A multitude of devices are covered here for the purpose of
completeness, but for a typical industrial installation, the
selection is fairly simple, and often repetitive.

Orientation Table

The reader should find Table 5.1a, the Orientation Table for
Pressure Detectors, of value in narrowing the choices. For each
category of sensors, this table indicates the overall pressure
range that the category is capable of detecting. The table also
notes whether the unit is available for industrial on-line instal-
lation or for laboratory use only. Although any transmitting
instrument can easily be provided with an inexpensive analog
or digital local indicator, the table differentiates those sensor
categories, which primarily serve as local gauges or indicators.
Also distinguished are the sensor categories, which are com-
monly available in microprocessor-based smart configurations.

The table also indicates the type of pressure reference used.
When the environmental pressure surrounding the instrument

Partial List of Suppliers:
ABB Instrumentation (www.abb.com/us/instrumentation)
Barton Instruments (www.barton-instruments.com)
Brooks Instrument (www.brooksinstrument.com)
Dresser Instrument (www.dresserinstruments.com)
Endress + Hauser Inc. (www.us.endress.com)
Fisher controls (www.fisher.com)
Foxboro/Invensys (www.foxboro.com)
Honeywell (www.iac.honeywell.com)
Marsh Bellofram (marshbellofram.com)
Moore Industries (www.miinet.com)
Omega Engineering (www.omega.com)
Rosemount/Emerson (www.rosemount.com)
Siemens (www.sea.siemens.com)
United Electric (www.ueonline.com)
Youkogawa Corp. of America (www.yca.com)
### TABLE 5.1a
Orientation Table for Pressure Detectors

<table>
<thead>
<tr>
<th>Features</th>
<th>Applicable Pressure Ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mmHg absolute (1 mmHg = 133 Pa)</td>
</tr>
<tr>
<td></td>
<td>&quot;H_2O (1&quot;H_2O = 250 Pa)</td>
</tr>
<tr>
<td></td>
<td>PSIG (1 PSIG = 6.9 kPa)</td>
</tr>
<tr>
<td></td>
<td>10^-14</td>
</tr>
<tr>
<td>Type of Design</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Bellows</td>
<td></td>
</tr>
<tr>
<td>Abs. Press. Motion Balance</td>
<td>✔</td>
</tr>
<tr>
<td>Abs. Press. Force Balance</td>
<td>✔</td>
</tr>
<tr>
<td>Atm. Press. Ref. Motion Bal.</td>
<td>✔</td>
</tr>
<tr>
<td>Aneroid Manostats</td>
<td>✔</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Bourdon</td>
<td></td>
</tr>
<tr>
<td>C-Bourdon</td>
<td>✔</td>
</tr>
<tr>
<td>Spiral Bourdon</td>
<td>✔</td>
</tr>
<tr>
<td>Helical Bourdon</td>
<td>✔</td>
</tr>
<tr>
<td>Quartz Helix</td>
<td>✔</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Diaphragm</td>
<td></td>
</tr>
<tr>
<td>Abs. Press. Motion Balance</td>
<td>✔</td>
</tr>
<tr>
<td>Abs. Press. Force Balance</td>
<td>✔</td>
</tr>
<tr>
<td>Atm. Press. Ref. Motion Bal.</td>
<td>✔</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Electronic</td>
<td></td>
</tr>
<tr>
<td>Strain Gage</td>
<td>✔</td>
</tr>
<tr>
<td>Capacitive Sensors</td>
<td>✔</td>
</tr>
<tr>
<td>Potentiometric</td>
<td>✔</td>
</tr>
<tr>
<td>Resonant Wire</td>
<td>✔</td>
</tr>
<tr>
<td>Piezoelectric</td>
<td>✔</td>
</tr>
<tr>
<td>Magnetic</td>
<td>✔</td>
</tr>
<tr>
<td>Optical</td>
<td>✔</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>High-Press. Sensors</td>
<td></td>
</tr>
<tr>
<td>Dead Weight Piston Gauge</td>
<td>✔</td>
</tr>
<tr>
<td>Bulk Modulus Cell</td>
<td>✔</td>
</tr>
<tr>
<td>Manganin Cell</td>
<td>✔</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Manometers</td>
<td></td>
</tr>
<tr>
<td>Inverted Bell</td>
<td>✔</td>
</tr>
<tr>
<td>Ring Balance</td>
<td>✔</td>
</tr>
<tr>
<td>Float Manometer</td>
<td>✔</td>
</tr>
<tr>
<td>Barometers</td>
<td>✔</td>
</tr>
<tr>
<td>Visual Manometers</td>
<td>✔</td>
</tr>
<tr>
<td>Micrometers</td>
<td>✔</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Pressure Replicators</td>
<td></td>
</tr>
<tr>
<td>D/P Cell</td>
<td>✔</td>
</tr>
<tr>
<td>Std. Diaphragm</td>
<td>✔</td>
</tr>
<tr>
<td>Button Diaphragm</td>
<td>✔</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Ionization</td>
<td></td>
</tr>
<tr>
<td>Hot Cathode</td>
<td>✔</td>
</tr>
<tr>
<td>Cold Cathode</td>
<td>✔</td>
</tr>
</tbody>
</table>
TABLE 5.1a Continued
Orientation Table for Pressure Detectors

<table>
<thead>
<tr>
<th>Features</th>
<th>Applicable Pressure Ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type of Design</strong></td>
<td><strong>Features</strong></td>
</tr>
<tr>
<td>Plant/Device</td>
<td></td>
</tr>
<tr>
<td>Laboratory or Pilot</td>
<td>- Indicates that the device uses full-vacuum reference in its operation.</td>
</tr>
<tr>
<td>Remote Reader/Trans.</td>
<td>- Indicates that the device uses atmospheric pressure reference.</td>
</tr>
<tr>
<td>Local Reader (Gauge)</td>
<td>- Indicates that the operating principle used does not involve the use of reference pressure.</td>
</tr>
<tr>
<td>Smart Unit/Available</td>
<td></td>
</tr>
<tr>
<td>mmHg absolute</td>
<td>- <strong>Thermocouple</strong></td>
</tr>
<tr>
<td></td>
<td><em>(1 mmHg = 133 Pa)</em></td>
</tr>
<tr>
<td></td>
<td>- <strong>Thermopile</strong></td>
</tr>
<tr>
<td></td>
<td>- <strong>Resistance Wire-Pirani</strong></td>
</tr>
<tr>
<td></td>
<td>- <strong>Convection</strong></td>
</tr>
<tr>
<td></td>
<td>- <strong>Quartz Helix</strong></td>
</tr>
<tr>
<td></td>
<td>- <strong>McLeod</strong></td>
</tr>
<tr>
<td></td>
<td>- <strong>Molecular Momentum</strong></td>
</tr>
<tr>
<td></td>
<td>- <strong>Capacitance</strong></td>
</tr>
<tr>
<td></td>
<td>- <strong>Spinning Ball</strong></td>
</tr>
<tr>
<td></td>
<td><strong>H₂O</strong> <em>(1 H₂O = 250 Pa)</em></td>
</tr>
<tr>
<td></td>
<td>PSIG *(1 PSIG = 6.9 kPa)</td>
</tr>
<tr>
<td></td>
<td>μmHg absolute</td>
</tr>
<tr>
<td></td>
<td><em>(1 μmHg = 133 Pa)</em></td>
</tr>
<tr>
<td></td>
<td>μmHg absolute</td>
</tr>
<tr>
<td></td>
<td><em>(1 μmHg = 133 Pa)</em></td>
</tr>
<tr>
<td></td>
<td>μmHg absolute</td>
</tr>
<tr>
<td></td>
<td><em>(1 μmHg = 133 Pa)</em></td>
</tr>
</tbody>
</table>
Reference Pressures

Reliable reference pressures are important, because they can be a source of error just as much as an error on the measurement side can. In the case of absolute pressure sensors, the reference chamber cannot be fully evacuated to absolute zero pressure, but full vacuum is only approached within a few thousands of a millimeter of mercury (torr). This means that a nonzero value is being treated as zero, which, when measuring higher vacuums, can cause significant errors. The other potential error source is the possibility of in-leakage of atmospheric air into the vacuum reference chamber of absolute pressure detector.

In case of positive pressure detectors, if the barometric pressure is the reference, atmospheric pressure variations cause a problem. As the atmospheric pressure can vary, by about 1 in. of mercury (13.6 in. or 0.345 m of water), the resulting error can be significant if the process pressure is near atmospheric. In addition, the output signal of the sensor can change even when the process pressure is constant. The resulting error might not be significant when detecting high gauge pressures, but it can be a problem with compound detectors.

A compound pressure sensor is one that operates at near atmospheric pressures and can detect the pressures on both above and below atmospheric. In controlling the pressure in sealed rooms (clean rooms, biohazard containment chambers, ordinary tight buildings, etc.) where the ventilation systems may purposely hold the pressure above or below atmospheric pressure, this variable reference can be a source of problems. In selecting pressure measurement devices for such applications, the design engineer must not ignore this and must either determine that the effect of barometric pressure variation can be safely neglected, or must measure and correct for this variation in the measurement and control systems.

An Example

Take the example of a chemical reactor that has to be evacuated to 10 mmHg before being purged at 1 in. (25.4 mm) H₂O positive pressure. After purging, when the reaction starts, this reactor operates at a higher positive pressure.

Due to the problem with the references, there is no single pressure transmitter that can detect all these pressures. If a vacuum reference is used, the purge pressure of 1 in. (25.4 mm) H₂O over atmospheric cannot be reliably detected. If an atmospheric reference is used, the 10 mmHg vacuum cannot be accurately detected, because it could be subject to a 25 mmHg error. In the past, the logical solution was to use multiple sensors. Today, we can also use intelligent transmitters, which are provided with multiple references and are capable of switching them on the basis of the batch sequence of the reactor.
SELECTING THE PRESSURE DETECTOR

When local pressure indication is required and the process pressure range is between 0 to 10 in. H<sub>2</sub>O (2.6 kPa) and 0 to 100,000 PSIG (690 MPa), the conventional pressure sensors, which are described in Sections 5.3, 5.4, 5.5, and 5.11 can be considered. The local pressure gauges, described in Section 5.11, can have ranges from 10 in. H<sub>2</sub>O up to 100,000 PSIG.

For the measurement of near-atmospheric pressures, the bellows diaphragm sensors and manometers (Sections 5.3, 5.4, and 5.9) are the most likely choices. Similarly, for local vacuum measurement down to 1 mmHg (0.13 kPa), the diaphragm, the bellows-type, and the vacuum manometers (Sections 5.3, 5.5, and 5.9) will give satisfactory performance. Vacuum sensors, ranging from 10<sup>−12</sup> to 760 mmHg, are discussed in Section 5.14. See Figure 5.14a for a summary of all the available vacuum sensors and their ranges.

Where remote transmission is required, the force balance or motion balance transmitters (Sections 5.3, 5.4, 5.5, and 5.7) will handle most applications. They can detect vacuums down to 1 mmHg (0.13 kPa) absolute and gauge pressures up to 100,000 PSIG (690 MPa). When small, near-atmospheric or high pressures up to 200,000 PSIG (1,400 MPa) are to be transmitted, the differential pressure or the electronic sensors described in Sections 5.6 and 5.7 should be considered. The high-pressure sensors, described in Section 5.8, are the recommended choices for pressures from 20,000 PSIG (140 MPa) up to 400,000 PSIG (2,800 MPa).

Multiple pressure sensors, including scanners and multiplexers, are discussed in Section 5.10. Pressure repeaters capable of repeating pressures from full vacuum to 10,000 PSIG (69 MPa) are described in Section 5.12. Pressure and differential pressure switches for applications at up to 20,000 PSIG (138 MPa) pressures can be found in Section 5.13.

### Accessories

The pressure detectors are often provided with various accessory items (discussed in Section 5.2), which serve to protect them from process conditions and environmental effects, are provided to reduce maintenance. The most common causes of failure or maintenance problems include plugging, vibration, freezing, corrosion, excessive temperatures, and hard-to-handle process materials. The various protection devices discussed in Section 5.2 can assist in making the installation

---

**TABLE 5.1c**

Pressure Detector Errors, Ranges, and Costs

<table>
<thead>
<tr>
<th>Type</th>
<th>Range</th>
<th>Inaccuracy</th>
<th>Approx. Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>General-purpose Bourdon-tube</td>
<td>15–10,000 PSIG (1–690 bars)</td>
<td>2%</td>
<td>$100</td>
</tr>
<tr>
<td>indicator</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High-accuracy test gauge</td>
<td>Low vacuum to 3000 PSIG (Low vacuum to 207 bars)</td>
<td>0.1% to 0.01%</td>
<td>$300–$6,000</td>
</tr>
<tr>
<td>Bourdon/spiral case-mounted</td>
<td>Low vacuum to 50,000 PSIG (Low vacuum to 3450 bars)</td>
<td>0.50%</td>
<td>$1,200</td>
</tr>
<tr>
<td>indicator/recorder</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spring-and-bellow case-mounted</td>
<td>Low vacuum to 50 PSIG (Low vacuum to 3.5 bars)</td>
<td>0.50%</td>
<td>$1,600</td>
</tr>
<tr>
<td>recorder</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nested capsular case-mounted</td>
<td>10–90 PSIG, (0.7–6.2 bars)</td>
<td>0.50%</td>
<td>$1,600</td>
</tr>
<tr>
<td>recorder</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low-pressure bell case-mounted</td>
<td>−0.1 to 0.1 in. H&lt;sub&gt;2&lt;/sub&gt;O (−3 to 3 mm H&lt;sub&gt;2&lt;/sub&gt;O)</td>
<td>2%</td>
<td>$2,200</td>
</tr>
<tr>
<td>indicator</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beam-mounted strain gauge</td>
<td>0–1000 PSIG (0–69 bars)</td>
<td>0.25%</td>
<td>$800</td>
</tr>
<tr>
<td>(sensor only) 4–20-mA DC output</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Piezoresistive transducer</td>
<td>0–5000 PSIG (0–365 bars)</td>
<td>0.50%</td>
<td>$500</td>
</tr>
<tr>
<td>4–20-mA DC output</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>“Smart” piezoresistive transmitter</td>
<td>0–6000 PSIG (0–414 bars)</td>
<td>0.10%</td>
<td>$1,200–$2,000</td>
</tr>
<tr>
<td>4–20-mA DC output</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>“Smart” field communicator for</td>
<td></td>
<td></td>
<td>$1000–$3,000</td>
</tr>
<tr>
<td>remote calibration and configuring</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>of “smart” transmitter</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capacitive sensor/transmitter</td>
<td>1 in. H&lt;sub&gt;2&lt;/sub&gt;O–6000 PSIG (25 mm H&lt;sub&gt;2&lt;/sub&gt;O–414 bars)</td>
<td>0.2%</td>
<td>1000</td>
</tr>
</tbody>
</table>

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less sensitive to such effects and can reduce the required tasks of periodic servicing, testing, calibration, and maintenance.

**Intelligent Transmitters**

Microprocessor based pressure and differential pressure transmitters are widely available today. Such a transmitter includes an input circuit referred to as an analog-to-digital (A/D) converter that converts the sensor input into a digital signal before it is sent to the microprocessor. The microprocessor performs the manipulations of ranging, linearization, error checking, and conversion and either transmits the reading digitally or sends the resulting value to the output digital-to-analog converter (D/A), which converts the signal back to an analog signal of 4–20 mA DC, 0–1 V DC, or 0–10 V DC.

Just as microprocessors have evolved in sophistication, so have A/D and D/A converters, increasing their resolution from 8-bit up to the 18-bit, which has been used in the better transmitters since the beginning of 2000. These advanced transmitters also check their own calibration on every measurement cycle and incorporate self-diagnostics, while being configurable by using simple personal computer (PC) software. The reconfiguration process is not only quick and convenient, but also tends to lower inventories by making the transmitters interchangeable.

The benefits of remote setup, configuration, and access to diagnostics has resulted in a dramatic increase in the use of proprietary protocols that are supported by many of the larger manufacturers. A wide variety of intelligent pressure transmitters are available on the market today. Some common features of the leading models include not only digital and analog outputs, but also multiple ranges, remote zero and span settings, configuration push buttons, PC software and Hand Held Configurators. The available bus and network protocols include Highway Addressable Remote Transducer (HART), Foundation Fieldbus, Profibus, Ethernet, or just 4–20 mA. Some field locations will benefit from local indication and this feature is optional with most manufacturers.

**Bibliography**


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