A New High-Precision Low-Range Bi-Directional Gauge Pressure Sensor

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Description:

The Model 202BG is a bi-directional gauge pressure sensor that offers unparalleled precision over the range of –15 to +15 kPa (-2 to +2 psig). The sensor is ideally suited for use in high-precision gas calibrators and in portable transfer standards. The transducer provides pressure and temperature frequency outputs and is fully characterized over a temperature range of 0 to 40 deg C and ambient static pressure of 80 to 110 kPa.

The 202BG provides sub-micron resolution (sensitivity) of 0.007 Pa (Pascal) and a total accuracy band better than 3 Pa (0.0004 psig) including repeatability, hysteresis, and conformance. Careful linearity tests against low-pressure primary standards have shown conformance is better than 0.2 Pa (rms). Temperature effects and common-mode sensitivity are eliminated with a dynamic compensation equation that is provided by Paroscientific, Inc.

Typical Application:

A typical low-pressure manifold is shown in Appendix A. The 202BG can serve as a high-precision monitor and calibration reference for direct input of bi-directional gauge pressure. In conjunction with a pressure source and pressure control, it is the ideal solution for a reference standard in a high-precision pressure calibrator. For optimal performance, the static pressure should be monitored by an absolute pressure sensor with a range of 80 to 110 kPa, and the data should be processed with the provided temperature and common-mode compensation equation. For overpressure protection, a dynamic shunt valve should open outside the specified limits (overpressure above/below 120 % of full scale). For shock protection, the 202BG sensor is provided with a protective housing and flexible buffer-tubes.

Pressure Equation:

Appendix B shows the pressure algorithm. Each sensor is individually characterized. Coefficients are provided by Paroscientific. The basic pressure algorithm with temperature compensation is identical to other Paroscientific instruments. In addition, a common-mode correction is supplied.

The sensor is originally calibrated at a static pressure of 100 kPa at the negative port of the device. Static or line pressures are also referred to as common-mode pressures. The sensor measures positive and negative differential (gauge) pressure relative to the static pressure. Even though the measured gauge pressure is largely independent of static pressure, careful tests have revealed that the indicated pressure has a small dependence to ambient (or controlled) static pressure. This dependence is referred to as common-mode sensitivity. The compensation equation models the dependence as quadratic zero and span common-mode corrections. For optimal performance, we recommend using an absolute static pressure sensor with an accuracy of 1 hPa and applying the common-mode correction as supplied. We also recommend taring the sensor output prior to measurements at 0 psig (both ports at static pressure) regardless of the quality of the static pressure sensor.

There are some other feasible alternative common-mode corrections. If the testing takes place at ambient atmospheric static pressure, this local value can be calculated from sea-level readings obtained from nearby weather stations or airports. This would be sufficient to characterize the span common-mode sensitivity. The sensor should be zeroed prior to measurements to eliminate the residual zero common-mode sensitivity.

For highest precision and for applications that require prolonged sensitivity in the parts per million range (0.01 Pa), a Paroscientific Barometric Standard or 216B sensor with an intrinsic accuracy of 0.1 hPa is recommended for common-mode correction. With such a setup, we have demonstrated stability of better than 0.1 Pa per week under varying atmospheric pressure.

Calibration Equipment:

The Calibration Laboratory at Paroscientific, Inc., uses a PG7601 Differential Primary Standard from DH Instruments. The principle of operation and the uncertainty analysis of the device can be obtained from the manufacturer. The instrument is uniquely capable of maintaining the static pressure while applying absolute pressure in the positive and negative direction around the common-mode pressure. The stated standard accuracy of the instrument is ± (0.3 Pa + 20 ppm) in differential mode. The introduction of the Paroscientific Model 202BG presents a novel way to monitor and check the accuracy and operation of the primary standard. Initial results have shown that the intrinsic precision of the 202BG can successfully be used to detect measurement scatter of the standard.

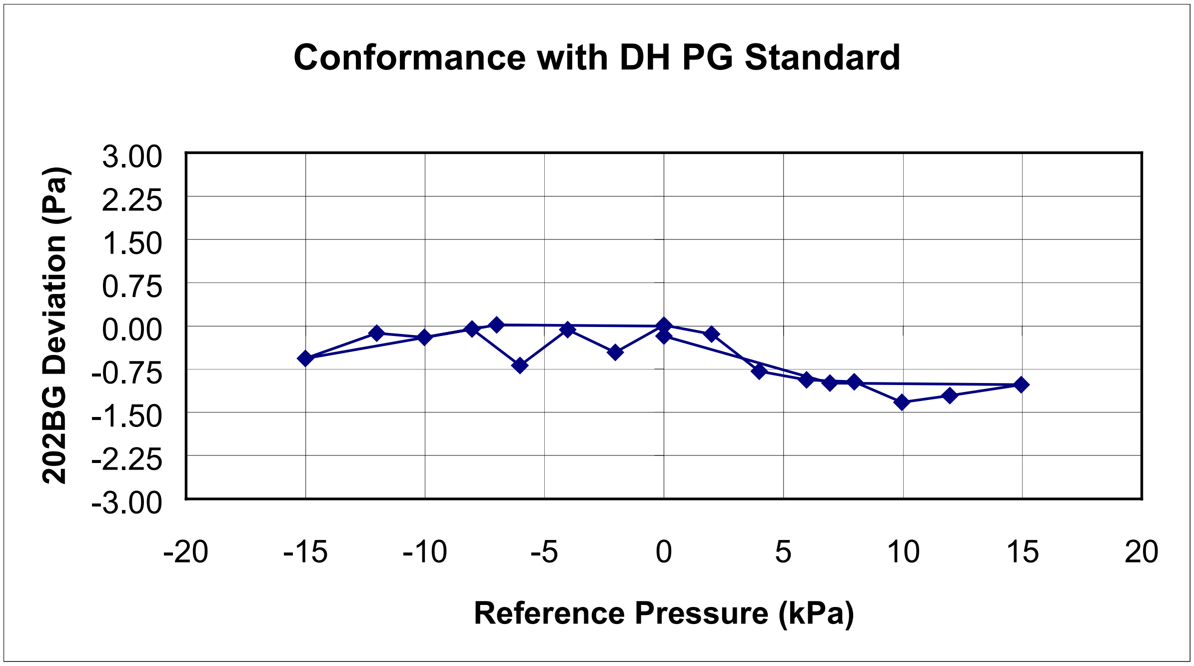
The basic factory calibration of the 202BG is done with the PG7601 in three steps. First, the coefficients of the pressure equation are evaluated at several temperatures over the full pressure range. This step is done at a static pressure of 100 kPa. Next, the common-mode correction is measured over the static pressure range 80 to 110 kPa. Lastly, the pressure conformance (linearity) is measured in steps of 2 kPa from –15 to +15 kPa at a nominal static pressure of 100 kPa.

The recalibration procedure of the 202BG follows the guidelines of other Paroscientific instruments. We recommend taking a conformance run at ambient static pressure (or 100 kPa) and ambient temperature over the full bi-directional gauge pressure range in steps of

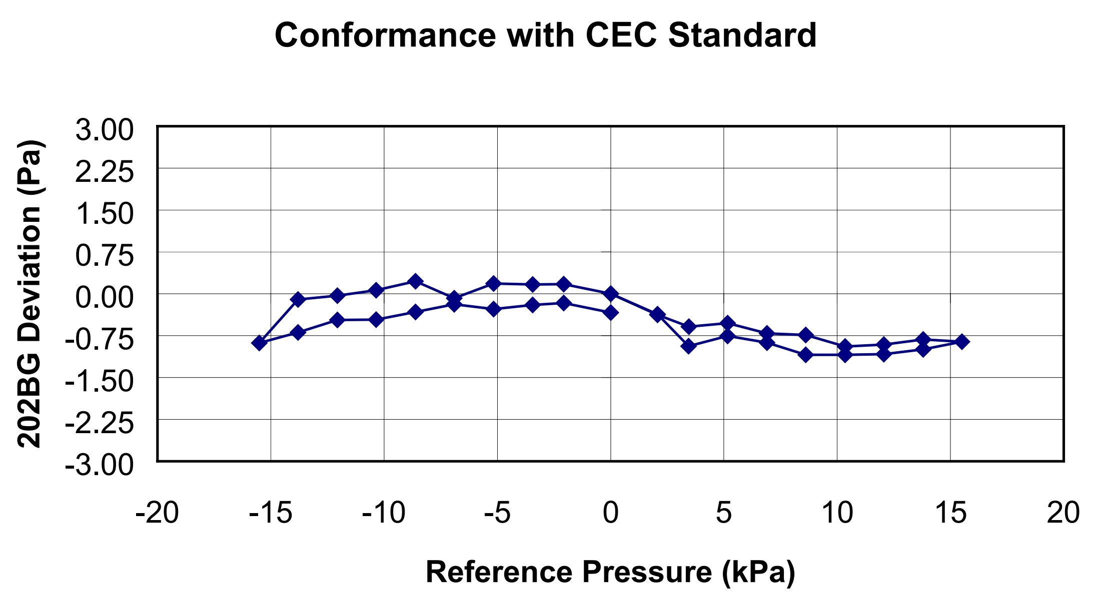
2 kPa. Offset and linearity adjustments can be made as outlined in Doc. 8140-001 (Recalibration of Paroscientific Transducers). Suggested calibration interval is one year.

Conformance:

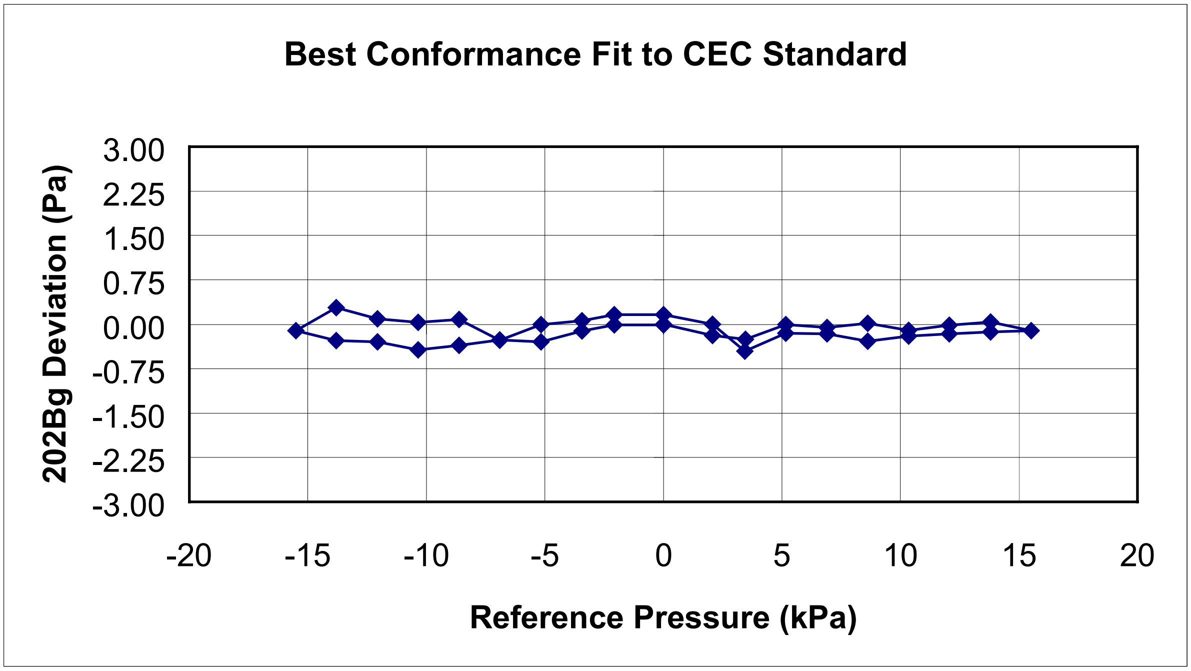
The graph below shows an example of a conformance calibration taken with the DH PG7601 Primary Standard in the course of the factory calibration. Since the coefficients of the pressure equation are evaluated in a previous sequence, the conformance data allows us to view pressure performance "as found" after the calibration. The rms deviation of this particular sensor was 0.7 Pa, including repeatability and pressure hysteresis. The conformance of other units is similar.



We also tested the same unit later on the calibration bench against a more conventional gauge primary dead weight tester. The standard used was a CEC tester with a 5 psig piston/cylinder. The traceable accuracy of the device is 0.015 %. The testing of positive gauge pressure is straightforward. We used a Paroscientific 216B for common-mode corrections. The testing of negative gauge pressure was done by applying positive gauge pressure to the negative port. The common-mode correction is applied using the absolute pressure of the negative port, which is the ambient pressure measured by the 216B, minus the applied gauge pressure of the standard. The rms deviation of the sensor was 0.6 Pa, including repeatability and pressure hysteresis. The agreement with the previous test is very good, and the linearities of the two primary standards agree well. Generally, the point-by-point scatter was less with the conventional tester; however, we noted that with the incredible precision of the new 202BG, piston height and speed dependence are easily detected. Variations of outputs as large as 1.5 Pa at 15 kPa differential pressure were measured over the range of operational piston heights and speeds. In principle, one could use a conventional gauge dead weight tester to calibrate the 202BG, but only if the common-mode corrections are known beforehand.

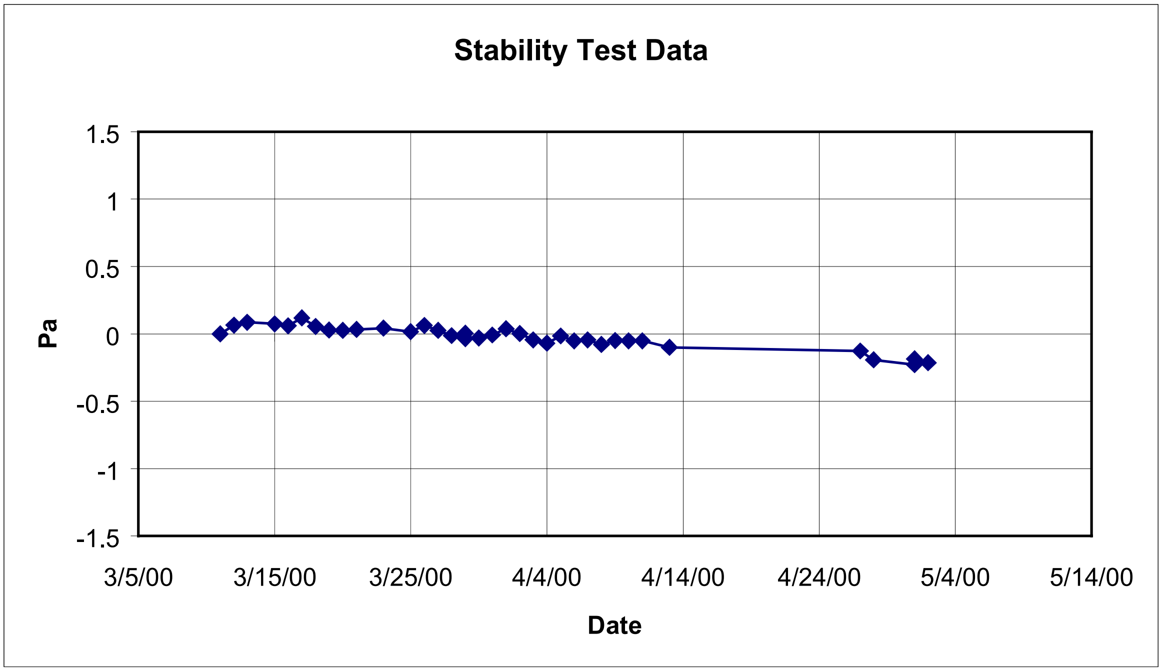


The standard pressure equation is a quadratic polynomial in frequency squared. We noted a somewhat systematic deviation between the test unit and the reference pressure that looks like an S-curve. We added a small cubic term to the pressure equation to best model the sensor. The residual rms error was 0.2 Pa, including repeatability and hysteresis. The shown data is the same as in the previous plot.



Stability:

Even though long-term stability is generally not important in calibration equipment that can be zeroed easily, as is the case with the 202BG, we perform routine longer-term stability tests at 0 psig to identify anomalies. Stability test data is shown below.



In the stability test setup, a Paroscientific 216B is used to correct the common-mode sensitivity for atmospheric pressure variations of up to 4 kPa. As shown in the data, a resolution of better than 0.01 Pa and week-long stability of better than 0.1 Pa can be achieved.

APPENDIX A: A Typical Application

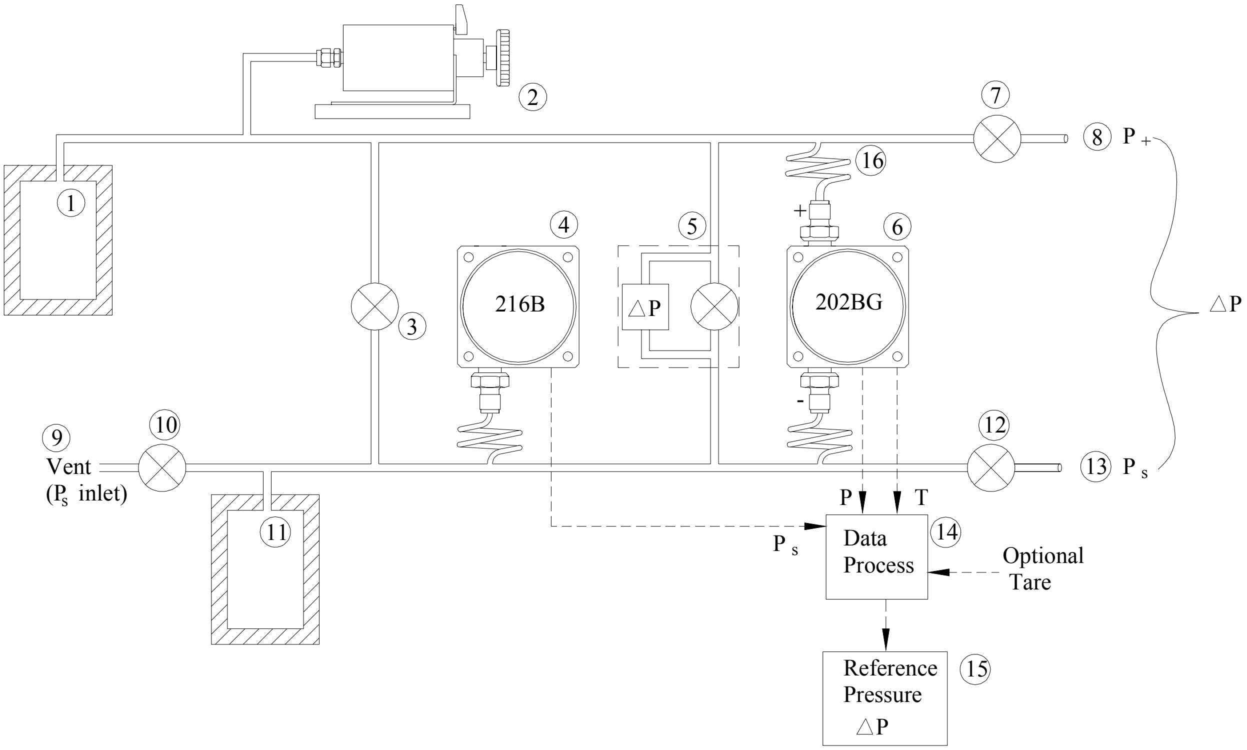


Figure Captions:

1) Optional insulated storage tank for positive reference pressure stability
2) Variable bi-directional volume control for +/- 15 kPa (2 psig) pressure generation; not needed if 202BG is used as a precision monitor only
3) Shunt valve (open to set static pressure, closed to set differential pressure)
4) Static (absolute) static pressure monitor (could be a Paroscientific Model 216B or equivalent; suggested accuracy is 1 hPa or better)
5) Dynamic overpressure shunt valve (low cost pressure monitor that opens shunt valve outside differential pressure range)
6) **High-precision low-pressure transfer standard 202BG**
7) Optional shutoff valve
8) Positive reference pressure outlet (or inlet for monitoring)
9) Vent or static pressure inlet (80 to 110 kPa)
10) Inlet shutoff valve
11) Optional static pressure storage tank for prolonged stability
12) Optional shutoff valve
13) Static pressure outlet (or inlet for monitoring)
14) Signal processing, pressure calculation
15) High-precision output of reference gauge pressure
16) Note buffer-tubes for shock isolation of sensitive sensors

APPENDIX B: Pressure Equation

Definitions:

P_{ind}: Indicated pressure using standard Paroscientific CDT_0 equation
P_s: Static pressure (absolute pressure at negative port; normally ambient pressure)
P_0: Reference static pressure (100 kPa)
P_{corr}: Correct sensor pressure using common mode correction
a_1, a_2: Zero common-mode correction terms
b_1, b_2: Span common-mode correction terms

Correction Equation:

$$P_{corr} = P_{ind} + a_1 * (P_s - P_0) + a_2 * (P_s - P_0)^2 + b_1 * (P_s - P_0) * P_{ind} + b_2 * (P_s - P_0) * P_{ind}^2$$

APPENDIX C: Pressure Units

The SI pressure units are Pascal (Pa), hectoPascal (hPa), and kiloPascal (kPa)

1 kPa = 10 hPa = 1000 Pa

Generally, we use kPa for the differential range and the static pressure range of the device. Barometric pressure is usually expressed in hPa (1 hPa = 1 mbar). We express the residual errors in Pa. Pascals are indeed small pressure values (1 Pa = 7.5 micron).

In English pressure units 1 psig ≈ 7 kPa, or more accurately, 1 psig = 6.894757 kPa.

(Last updated 5/18/00)