FLUKE ®

Calibration

Uncertainty analysis for pressure defined by a PG7601, PG7102, PG7202 or PG7302 Piston Gauge

Technical Note

7920TN10E

Many users consider the single most important specification of a high performance piston gauge to be the uncertainty claimed on pressure defined by the piston gauge. At the low levels of uncertainty available today, the final uncertainty budget is highly dependent on influences that vary with conditions of operation, many of which are beyond the control of the instrument manufacturer. Therefore, uncertainty specifications provided without documenting the assumptions made in deriving them are of little use. They cannot be used to compare one instrument to another or to reliably predict the actual global uncertainty in pressure that will be obtained in the final application.

For this reason, in providing specifications for the PG7000 line of piston gauges, Fluke Calibration has developed instrumental measurement uncertainty specifications. These are intended to provide easy-to-use figures for overall uncertainty in pressure that can be applied with confidence by the typical user under typical operating conditions. They include all significant sources of uncertainty and are intentionally rounded up to convenient values that can be used over each pressure range.

This document is intended to provide a detailed analysis of PG7000 uncertainty specifications for each piston-cylinder range in each of its operating modes. The components that are included in the uncertainty, the sensitivities assigned to each component and how the components are combined into a global uncertainty in defined pressure, are covered. The uncertainty analysis provides the PG7000 user with a documented validation of uncertainty values. It can also be used to estimate the pressure measurement uncertainty that will be obtained if the uncertainty in one or more components is different from the typical values. The new component uncertainty values can be substituted and combined following the uncertainty analysis to arrive at a new value of overall uncertainty in pressure definition. For example, the uncertainty in piston-cylinder effective area might be lowered by direct calibration by a national metrology institute or local gravity might be known to better than the typical ± 2 ppm, resulting in lower overall uncertainty in pressure definitions.

This revision takes a slightly different approach to some of the uncertainties described based on knowledge gained since the last revision in 2005 and to be more in line with the PG9000 uncertainty technical note. This revision also includes technical note 4050TN08, which is a summary of the PG7000 specifications listed by the piston-cylinder model number and is provided at the end of this document. Also not included here are 10 kPa/kg ceramic piston-cylinders that have not been available for over 10 years.

Like the previous revision, this technical note considers the use of the PG7000 AMH™, (Automatic Mass Handling) option. AMH can be used with all of the PG7000 platforms, piston-cylinder sizes and measurement modes. All benefit from improved stability over time of the components that make up the mass load and lower uncertainty in the mass of the mass loading bell and the piston. These reduced uncertainties are covered in the sections that describe the standard uncertainties for all piston-cylinder sizes. For the final pressure instrumental measurement uncertainty, only the gas operated, gas lubricated PG7601/PG7102 piston-cylinders are significantly affected due to the significance of other uncertainties such as pressure head corrections and piston-cylinder sensitivity on the other models. All instrumental measurement uncertainty tables include a table considering the use of AMH automated mass handling, but in some cases, the instrumental measurement uncertainty is the same with or without AMH.

NOTE: The designation ppm means parts per million or 1 part in 10^6 as a relative uncertainty.

Basis of the uncertainty analysis

All uncertainties in this analysis are calculated using the methods described in ISO "*Guide to the Expression of Uncertainty in Measurement*," June, 1992 (GUM).

Many of the uncertainties described are typical for PG7601, PG7102, PG7202 and PG7302 piston gauges rather than applying to a specific system. The Type A component, the statistical result based on a series of observations, cannot be calculated until a set of data is acquired by the PG7000 user with a specific instrument under specific conditions. Since many unpredictable factors may affect the statistical result (i.e. air drafts, vibration, ancillary hardware), only a typical Type A uncertainty based under typical operating conditions can be provided.

Type B values may also be described as typical because the uncertainties are based on assumptions regarding the type of use and limits of environmental conditions typically encountered by PG7000 users. The environmental condition limits assumed in the analysis are:

Ambient temperature: 19 to 23 °C

Ambient humidity: 5 to 95 % RH

Ambient pressure: 70 to 110 kPa

The uncertainties are listed in two categories:

(i) Uncertainties common in using all PG7000 piston-cylinders types and sizes such as ambient conditions, fluid heads, and piston-cylinder temperature measurement;

(ii) Uncertainties whose values are specific to piston cylinder size such as sensitivity and effective area value.

Both uncertainties (i) and (ii) may be developed either as relative or absolute uncertainties. Some uncertainties are intrinsically relative to pressure such as effective area and gravity. Others should be expressed as constants in units of pressure such as incompressible fluid heads, surface tension and individual masses. Therefore, the relative uncertainties and the absolute uncertainties are combined and expanded separately and expressed as a two-part uncertainty in the typical uncertainty specifications. However, this does not mean they are correlated. If a PG7000 user wants to determine an uncertainty in pressure at a specific pressure point, it is acceptable to convert relative uncertainties to pressure uncertainties and root sum square (square root of the sum of the squares) all standard uncertainties that are not correlated.

For each uncertainty component, an explanation of the variable or parameter is provided along with the value of one standard uncertainty, its sensitivity with pressure and the type of distribution associated with the uncertainty. After each of the uncertainty components has been considered, they are combined to provide global uncertainty values in pressure for measurements made by all of the PG7000 piston-cylinder sizes and measurement modes.

If the PG7000 user's conditions are different from those assumed in this document or the uncertainties have been improved for a specific component, e.g. piston-cylinder effective area, it is possible to replace the typical uncertainty listed in the table with the new uncertainty. The final uncertainty can then be obtained by root sum squaring and multiplying by the appropriate coverage factor.

Pressure calculations

The following equations are used in the PG7000 for calculating the reference pressure at the test instrument's reference level. These variables are identified in the following sections during the discussion of each variable's uncertainty.

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- Gauge Pressure =

$$\frac{M g_l \left(1 - \rho_{(air)}/\rho_{(mass)}\right) + \pi D T}{A_{(20,0)} \left[1 + (\alpha_p + \alpha_c)(\theta - 20)\right](1 + \lambda P)} - (\rho_{(fluid)} - \rho_{(air)})\, g_l h$$

- Absolute Pressure by Application of Vacuum Reference (PG7601 only) =

$$\frac{M g_l}{A_{(20,0)} \left[1 + (\alpha_p + \alpha_c)(\theta - 20)\right](1 + \lambda P)} - \rho_{(fluid)}\, g_l h + Vac$$

- Absolute Pressure by Addition of Atmospheric Pressure =

$$\frac{M g_l \left(1 - \rho_{(air)}/\rho_{(mass)}\right) + \pi D T}{A_{(20,0)} \left[1 + (\alpha_p + \alpha_c)(\theta - 20)\right](1 + \lambda P)} - \rho_{(fluid)}\, g_l h + Baro$$

where:

M = Total true mass load .... [kg]
gl = Local acceleration due to gravity ... [m/s^2]
ρ(air) = Ambient air density .... [kg/m^3]
ρ(mass) = Average density of mass load ..... [kg/m^3]
T = Surface tension (considered 0 with gas) .... [N/m]
D = Diameter of piston .... [m]
ρ(fluid) = Density of the test medium (gas or oil) .... [kg/m^3]
h = Difference in height between PG700 reference level and test reference level .... [m]
Vac = Back pressure in bell jar (absolute with Vacuum) .... [Pa]
Baro = Atmospheric pressure read by barometer .... [Pa]
A(20,0) = Piston-cylinder effective area at 20 °C and 0 pressure .... [m^2]
αp = Linear thermal expansion coefficient of piston .... [$°C^{-1}$]
αc = Linear thermal expansion coefficient of cylinder .... [$°C^{-1}$]
θ = Temperature of the piston-cylinder .... [°C]
λ = Elastic deformation coefficient of the piston-cylinder .... [Pa^{-1}]
P = Pressure applied to the piston-cylinder .... [Pa]

Uncertainties common to all PG7000 piston-cylinder sizes

When using a PG7000 system, the source of the values used for certain variables of the pressure equation may be chosen from a variety of sources. This document assumes that "internal" measurements, i.e. the sensors on board the PG7000, are always used when available. These include vacuum, barometric pressure measurement, piston-cylinder temperature and ambient conditions. The uncertainties described for these sensors include the basic specification and any other uncertainty contributions due to position or data acquisition. An exception to this is in B7 – Back Pressure where a lower uncertainty is provided for a typical capacitance diaphragm gauge used with a PG7601 enhanced with AMH in place of the internal Vacuum gauge delivered with a standard PG7601.

B1 – Mass (m)

The true mass values that are stored in PG7000 memory are determined by Fluke Calibration using the substitution method by comparison to reference masses traceable to the SI. The PG7000 mass set consists of a main mass set comprised mostly of 5, 6.2 or 10 kg masses, a supplementary set broken down into submultiples of the kg, or a binary set for AMH, and trim mass set providing resolution to 10 mg.

Considering that all the masses used with a PG7000 are measured using the same procedure, the same references and the same comparators, the uncertainty in each individual mass is considered correlated with other masses and must be added instead of root sum squaring all or any part of the individual mass uncertainties. This gives a global true mass value uncertainty of ± 5 ppm with a coverage factor of 2 of the total mass load (excluding the piston and bell mass which are expressed as absolute uncertainties later). This uncertainty also includes influences from slight possible unquantified magnetic forces since the main masses are made of 304L non-magnetic stainless steel, which is not at the level of magnetic susceptibility as 316 or 310 used in mass metrology.

The estimation of uncertainty in mass described in the previous paragraph includes changes in mass over a period of one year. Masses used with the PG7000 AMH (Automated Mass Handler) are preserved from the day to day contamination and wear to which masses loaded manually are exposed. Because of this, the uncertainty in mass when using AMH is kept at ± 5 ppm with a coverage factor of 2 of the total mass load but is considered valid for a three year period. For AMH, this specification includes the mass loading bell mass.

Type of uncertainty: Relative type B

Sensitivity: 1 ppm/ppm

Distribution: Considered normal

Standard uncertainty: 2.5 ppm

B2 – Local Gravity (gl)

The value of local gravity and the uncertainty in that value cannot be provided with the PG7000 since local gravity is specific to the location of use. However, it is well known that local gravity for a specific location in the United States can be obtained from the US Geodetic Survey for most locations with a typical uncertainty of ± 2 ppm with a coverage factor of 2.

Type of uncertainty: Relative type B

Sensitivity: 1 ppm/ppm

Distribution: Considered normal

Standard uncertainty: 1 ppm

B3 – Air Density (ρ(air))

For Gauge and Absolute by Addition of Atmospheric Pressure Measurement Modes.

The density of air is calculated real time as PG7000 updates the calculated pressure. Air density is used with the average mass density, B4, to correct for air buoyancy as is shown in the pressure calculation equations. Air density is a function of ambient pressure, temperature and humidity. As mentioned in the beginning of this section, it is assumed that the internal sensors on board the PG7000 are used to measure ambient conditions. The uncertainties shown in this section are based on the specifications of the on-board sensors.

The equation used for calculating air density is:

$$\frac{P}{Pn} \cdot \frac{Tn}{T} \cdot \frac{Zn}{Z} \cdot \textit{Normal Air Density} + \textit{Humidity Correction}$$

where:

- P = Ambient pressure .... [Pa]
- Pn = Normal pressure.......................... [101325 Pa]
- Tn = Normal temperature .... [273.15 K]
- T = Ambient temperature (measured in°C [K] and added to Tn)
- Zn = Normal compressibility of air ...... [0.99941]
- Z = Compressibility of air at P and T.. [-]
- Normal density of air................... [1.2928 kg/m³]
- Humidity correction..................... [-]

The table below provides uncertainties in air density resulting from the specification of the on-board sensors used to measure ambient conditions (no uncertainty is necessary for normalized values).

Measurement	Uncertainty in measurement 1 Std Unc	Uncertainty in air density kg/m³ (1 Std Unc)
T	0.5 °C	0.0019
P	0.1 kPa	0.0012
$Z_{(p,t)}$	0.1 %	0.0012
Humidity	5.0 %RH	0.0005

Root sum squaring the standard uncertainties in air density provides a one standard uncertainty in air density equal to 0.00259 kg/m³.

Type of uncertainty: Relative type B

Sensitivity: 125 ppm/kg/m³

Distribution: Considered normal

Standard uncertainty: 0.00259 kg/m³

B4 – Average Mass Density (ρ(mass))

For Gauge and Absolute by Addition of Atmospheric Pressure Measurement Modes.

The average mass density is calculated for each mass load on the PG7000. The equation used for calculation of average density of a PG mass load is:

$$\frac{M(p) + M(b) + M(8)}{\left(M_{(p)}/\rho_{(p)}\right) + \left(M_{(b)}/\rho_{(b)}\right) + \left(M_{(8)}/\rho_{(8)}\right)}$$

where:

- M(p) = True mass of the piston assembly........................... [kg]
- ρ(p) = Average density of the piston assembly........................... [kg/m³]
- M(p) = True mass of the carrying bell .... [kg]
- ρ(b) = Average density of the bell......... [kg/m³]
- M(8) = True mass of all masses with a density........................... [kg] of 7 920 kg/m³]
- ρ(8) = Density of main masses..... [7 920 kg/m³]

In the past revisions of this document the density of the main masses was 8000 kg/m³. Recently a study was performed to show that the main masses have a density of 7920 kg/m³ with an uncertainty of ±40 kg/m³ using a coverage factor of 2 and are being reported as such in calibration certificates. This is 4 times better than previously documented.

Also this revision changes where the uncertainty of this influence applies. In the past the uncertainty would apply to both gauge and absolute modes. In this revision it is realized that the uncertainty only applies when the condition for air buoyancy is significantly different from the calibration condition of the masses, i.e. when the air is removed from around the masses in absolute by application of vacuum modes.

The density of bell assemblies, including the AMH bell assembly, and pistons, are based on the average density of the different pieces that make these up and may include titanium, tungsten or steel. Because of this the uncertainty in density is considered separately as a constant at the bottom of the uncertainty budgets. This additional uncertainty is already included for manual mass bells and all pistons, but is added as a new uncertainty for this revision for AMH bell assemblies and is listed as B4a. Since it is considered a constant it is described in the section for constant mass uncertainties (B1a and B1b).

Type of uncertainty: Relative type B

Sensitivity: 0.019 ppm/kg/m^3

Distribution: Considered normal

Standard uncertainty: 20 kg/m^3

B5 – Fluid Head Height (h)

In order to determine the contribution of uncertainty in a fluid head correction, a typical uncertainty in the height difference between the reference level of the PG7000 and a test instrument needs to be chosen.

Gas Media – PG7601, PG7102 and PG7202

Generally, the height can easily be measured ± 5 mm with a coverage factor of 2 using inexpensive apparatus available in most laboratories. This also includes the uncertainty in the piston position sensor on board the PG7000 for which the height is corrected and the uncertainty in the calculation of the reference level offset. The uncertainty in the density is based on perfect compressibility of the gas. Though the compressibility of N2/Air and He reach 2.0 and 1.5 respectively at 100 MPa, the assumption of the uncertainty calculation in perfect compressibility becomes a conservative estimate.

Type of uncertainty: Relative type B

Sensitivity: 0.12 ppm/mm

Distribution: A priori rectangular

Standard uncertainty: 2.9 mm

Oil Media – PG7302

When using oil media, the fluid is considered incompressible. Also the density is much larger relative to gas density which means the uncertainty is an absolute uncertainty and will be the most significant at the lowest pressures defined by the piston gauge. For the lowest (worst case) oil pressures measured, it may be necessary to determine the height between the reference level and the test to within ± 1 mm. This also includes the uncertainty in the piston position sensor on board the PG7000 for which the height is corrected.

Type of uncertainty: Absolute type B

Sensitivity: 8.98 Pa/mm

Distribution: A priori rectangular

Standard uncertainty: 0.58 mm

B6 – Medium Density (ρ(fluid))

Gas Media – PG7601, PG7102 and PG7202

Referencing the table in B3, Air Density, the same equation without the humidity correction is used for calculating medium density. The pressure is known to within the specifications of the PG7000 pressure and compressibility is known to within ± 0.2 % (k=2). One standard uncertainty in N2 gas medium then becomes dependent on the temperature of the medium. Once pressure is stable in any gas piston gauge, it is assumed the gas temperature is stable and is equal to ambient temperature, ± 1 °±C (k=2).

Measurement	**Uncertainty in measurement** 1 Std Unc	**Uncertainty in N_2 density medium density**
T	0.17 %	0.17 %
P	0.01 %	0.01 %
$Z_{(p,t)}$	0.1 %	0.1 %

One relative standard uncertainty in medium density (using N_2) becomes 0.20 % of the density calculated by the PG7000. This uncertainty is calculated using a maximum typical head correction of one meter and assuming the density changes proportionally to the pressure over the full range of the PG7000.

Type of uncertainty: Relative type B

Sensitivity: 1.2 ppm/% density/m

Distribution: Considered normal

Standard uncertainty: 0.20 % (of density)

Oil Media - PG7302

A PG7302 Piston Gauge uses Di-2-Ethylhexyl Sebacate as the pressure medium. This hydraulic fluid is known to have a density of 916 kg/m^3 at ambient conditions with an uncertainty of ± 1 % with a coverage factor of 2. Since the compressibility of the fluid is most significant at low pressure, changes of density with pressure need not be considered throughout the range of the PG7302. The limit chosen for the total head correction is ± 5 cm.

Type of uncertainty: Absolute type B

Sensitivity (for 5 cm): 0.49 Pa/kg/m^3

Distribution: A priori rectangular

Standard uncertainty: 5.2 kg/m^3

Note: The change of density with pressure is considered insignificant because of the relative insignificance as pressure increases. For instance, the change in density with pressure is approximately 0.4 kg/m^3 per 1 MPa. At 1 MPa this is a change in pressure of 0.2 Pa or 0.2 PPM. The higher the pressure, the less significant the change in density.

B7 – Residual Vacuum

For Absolute by Application of Vacuum Measurement Mode (PG7601)

The vacuum sensor on board the PG7601 has an uncertainty of ± (10 % of reading or 0.1 Pa, whichever is greater) with a coverage factor of 2. The PG7601 is designed to allow a vacuum of 2 Pa to be reached within a reasonable amount of time using a conventional rotary vane pump. If 2 Pa is reached one standard uncertainty may be calculated as 0.1 Pa.

When the PG7601 is used in absolute by application of vacuum mode with the AMH (Automated Mass Handler) option, the reference vacuum does not have to be broken and reestablished to manipulate masses between pressure increments. This makes it practical to use a turbo molecular vacuum pumping system to establish typical residual vacuum pressure of 0.1 Pa (0.75 mTorr) or less.

The AMH vacuum chamber also includes a larger diameter (KF40) suitable for connecting an alternative vacuum gauge. The PG7000 software has the capability to read measurements from any vacuum gauge with an RS232 interface and use the measurements in the calculations of the pressure defined by the piston gauge. Typically, when using AMH, a 13.3 Pa (0.1 Torr) range, unheated, capacitance diaphragm gauge (CDG) can be used. Properly calibrated, this instrument can provide uncertainty in residual vacuum pressure of ± (0.25 % of reading + 0.1 % FS) using a coverage factor of 2 which gives one standard uncertainty of 0.006 mPa at 0.1 Pa residual vacuum.

Note: The selection of the 133 Pa (1 Torr), unheated CDG is somewhat arbitrary and is not intended to be a system requirement. Other ranges or types of Vacuum sensors may be used. For instance, a heated capacitance diaphragm gauge with a range of 13 Pa (100 mTorr) may offer a significantly lower uncertainty in residual Vacuum measurement, but a thermal transpiration correction may have to be applied due to the fact it is heated.

Manually operated PG7601 using on-board vacuum gauge and rotary vane pump

Type of uncertainty: Absolute type B

Sensitivity: 1 Pa/Pa

Distribution: Considered normal

Standard uncertainty: 0.1 Pa

PG7000 with AMH using external CDG as vacuum gauge and turbo molecular pumping system

Type of uncertainty: Absolute type B

Sensitivity: 1 Pa/Pa

Distribution: Considered normal

Standard uncertainty: 0.006 Pa

B8 – Barometric Pressure

For Absolute by Addition of Atmospheric Pressure Only

When using a PG7000 to measure absolute pressure by addition of atmospheric pressure, an uncertainty in the barometer used to measure atmospheric pressure must be included. This analysis assumes the use of a Fluke Calibration barometric range RPM interfaced with the PG7000. The uncertainty in this barometer output is ± 10 Pa. One standard uncertainty is 5 Pa.

Type of uncertainty: Absolute type B

Sensitivity: 1 Pa/Pa

Distribution: Considered normal

Standard uncertainty: 5 Pa

B9 – Resolution

Because PG7000 provides a digital output of pressure, the resolution must be accounted for in this uncertainty analysis. Display of pressure for all units is a minimum of seven places. This provides a worse case resolution of 1 ppm.

Type of uncertainty: Relative type B

Sensitivity: 1 ppm/ppm

Distribution: Rectangular

Standard uncertainty: 0.29 ppm

Note: There are exceptions to the above for some units at low pressure. For instance, the resolution for a PG7601 and PG7102 can be as large as 100 ppm when using a 10 kPa/kg piston-cylinder at the lowest pressure and MPa as the pressure unit of measure, or 10 ppm when using bar. For the PG7302 and PG7202 the resolution can be as high as 7 ppm at the lowest range and pressure when using MPa. To eliminate this uncertainty one need only choose kPa instead of MPa.

B10 – Piston-Cylinder Temperature (θ)

The uncertainty in the prediction of the change of effective area with temperature is affected by the ability of the platinum resistance thermometer (PRT) in the PG7000 mounting post to measure the piston cylinder temperature and also uncertainty in that temperature. The combined uncertainty in both these parameters are ± 0.1 °C with a coverage factor of 2.

The thermal expansion coefficient of all of the PG7000 tungsten carbide piston-cylinders is 9 x 10^{-6} °C-1 which defines a sensitivity of 9 ppm/°C.

Type of uncertainty: Relative type B

Sensitivity: 9 ppm/°C

Distribution: Considered normal

Standard uncertainty: 0.045 °C

B11 – Verticality

The uncertainty in the pressure calculated by the PG7000 system includes the deviation of verticality of the piston-cylinder axis relative to the direction of acceleration with gravity. All PG7000 systems have a precision bubble level adjusted to the piston cylinder mounting post with an uncertainty of ± 3 minutes with a coverage factor of 2. Two minutes of non-verticality represents ± 0.19 ppm on pressure.

Type of uncertainty: Relative type B

Sensitivity: 1 ppm/ppm

Distribution: Asymmetrical

Standard uncertainty: 0.08 ppm

Uncertainties specific to piston cylinder size

The six piston-cylinder sizes available with PG7601 and PG7102 systems are:

- 10 kPa/kg (35.3 mm diameter) tungsten-carbide piston
- 10 kPa/kg (35.3 mm diameter) ceramic piston
- 20 kPa/kg (25 mm diameter)
- 50 kPa/kg (15.8 mm diameter)
- 100 kPa/kg (11.2 mm diameter)
- 200 kPa/kg (7.9 mm diameter)

The six piston-cylinder sizes available with PG7302 systems are:

- 100 kPa/kg (11.2 mm diameter)
- 200 kPa/kg (7.9 mm diameter)
- 500 kPa/kg (5.0 mm diameter)
- 1 MPa/kg (3.5 mm diameter)
- 2 MPa/kg (2.5 mm diameter)
- 5 MPa/kg (1.6 mm diameter)

The five piston-cylinder sizes available with PG7202 systems are:

- 100 kPa/kg (11.2 mm diameter)
- 200 kPa/kg (7.9 mm diameter)
- 500 kPa/kg (5.0 mm diameter)
- 1 MPa/kg (3.5 mm diameter)
- 2 MPa/kg (2.5 mm diameter)

Uncertainties specific to each size are given in the Type B uncertainties that follow.

B12 – Effective Area ($A_{(20,0)}$)

Fluke Calibration maintains reference piston cylinders that are directly traceable to the SI and have known valid relationships to various national metrology institutes through the Fluke Calibration Piston-Cylinder Pressure Calibration Chain. Calibration chain references are used to determine the PG7000 piston-cylinder effective areas through a process called a “base ratio crossfloat”. Although the actual calculated uncertainties in the PG7000 piston cylinder effective areas are always lower, the following tables list the worst case uncertainty in each piston-cylinder size supplied:

PG7601 and 7102 Piston-Cylinders	Uncertainty (k=2) [± ppm]	Uncertainty 1 Std Unc
10 kPa/kg (t.c. piston)	10	5.0
20 kPa/kg	11	5.5
50 kPa/kg	11	5.5
100 kPa/kg	16	8.0
200 kPa/kg	16	8.0

PG7302 Piston-Cylinders	Uncertainty (k=2) [± ppm]	Uncertainty 1 Std Unc
100 kPa/kg	14	7.0
200 kPa/kg	14	7.0
500 kPa/kg	15	7.5
1 MPa/kg	18	9.0
2 MPa/kg	25	12.5
5 MPa/kg	30	15.0

PG7302 Piston-Cylinders	Uncertainty (k=2) [± ppm]	Uncertainty 1 Std Unc
100 kPa/kg	14	7.0
200 kPa/kg	14	7.0
500 kPa/kg	16	8.0
1 MPa/kg	20	10.0
2 MPa/kg	30	15.0

The effective areas and their uncertainties are determined using nitrogen or Sebacate as the pressurized medium. For PG7601 they are valid for both gauge and absolute operating modes.

As is mentioned earlier in this document, global uncertainties may be improved by determining better uncertainties in specific parameters and replacing the typical or "worst case" uncertainties with improved values.

Type of uncertainty: Relative type B

Sensitivity: 1 ppm/ppm

Distribution: Considered normal

Standard uncertainty: See tables

B13 – Sensitivity

One of the intrinsic characteristics of a piston cylinder is its sensitivity. Sensitivity is defined as the minimum change in input (mass load) that causes a detectable change in output (defined pressure). The sensitivity of a piston-cylinder is itself an uncertainty. Sensitivity is similar to resolution because it has a rectangular probability distribution.

Because sensitivity is not strictly relative to pressure it is best described by both a relative uncertainty and an absolute uncertainty.

The following tables list the uncertainty in sensitivity for both the relative and absolute component of each piston cylinder size in both relative and absolute values. One standard uncertainty is then equal to the full width sensitivity for each piston cylinder size divided by the square root of twelve.

PG7601 and 7102 Piston-Cylinders	Sensitivity [ppm]	1 Std Unc [ppm]	Sensitivity [Pa]	1 Std Unc [Pa]
10 kPa/kg	0.5	0.14	0.01	0.003
20 kPa/kg	0.5	0.14	0.04	0.012
50 kPa/kg	0.5	0.14	0.1	0.029
100 kPa/kg	0.5	0.14	0.2	0.057
200 kPa/kg	0.5	0.14	0.4	0.115

PG7302 Piston-Cylinders	Sensitivity [ppm]	1 Std Unc [ppm]	Sensitivity [Pa]	1 Std Unc [Pa]
100 kPa/kg	1	0.29	2	0.58
200 kPa/kg	1	0.29	4	1.15
500 kPa/kg	1	0.29	10	2.88
1 MPa/kg	1	0.29	20	5.77
2 MPa/kg	1	0.29	40	11.55
5 MPa/kg	1	0.29	100	28.87

PG7202 Piston-Cylinders	Sensitivity [ppm]	1 Std Unc [ppm]	Sensitivity [Pa]	1 Std Unc [Pa]
100 kPa/kg	1	0.29	2	0.58
200 kPa/kg	1	0.29	4	1.15
500 kPa/kg	1	0.29	10	2.88
1 MPa/kg	1	0.29	20	5.77
2 MPa/kg	1	0.29	40	11.55

Type of uncertainty: Relative and absolute type B

Sensitivity: 1 ppm/ppm and 1 Pa/Pa

Distribution: Rectangular

Standard uncertainty: See tables

B14 – Linearity

Another intrinsic characteristic of a piston-cylinder is the degree to which the change of its effective area with pressure over its pressure range follows the mechanical theory. PG7000 piston-cylinders are characterized by a linear model with an uncertainty that depends upon range, size, type of mounting system, materials and piston-cylinder annular space. The following table lists the uncertainties attributable to the assumption of a linear model with a coverage factor of 2 and one standard uncertainty.

Though there are various sizes of mass sets available from 35 to 100 kg for PG7000 systems, the uncertainty in effective area linearity for each piston-cylinder size are only given at 35 kg and 100 or 55 kg mass loads.

PG7601 and 7102 Piston-Cylinders Mass Sets	**10 kPa/kg t.c piston** [ppm]	**10 kPa/kg ceramic piston** [ppm]	**20 kPa/kg** [ppm]	**50 kPa/kg** [ppm]	**100 kPa/kg** [ppm]	**200 kPa/kg** [ppm]
35 kg U_L	1.0	2.0	1.0	3.0	4.0	5.0
1 std unc	0.5	1.0	0.5	1.5	2.0	2.5
55 kg U_L	2.0	3.0	2.0	5.0	6.0	7.0
1 std unc	1.0	1.5	1.0	2.5	3.0	3.5

PG7302 Piston-Cylinders Mass Sets	**100 kPa/kg** [ppm]	**200 kPa/kg** [ppm]	**500 kPa/kg** [ppm]	**1 MPa/kg** [ppm]	**2 MPa/kg** [ppm]	**5 MPa/kg** [ppm]
35 kg U_L	3	3	3	4	5	6
1 std unc	1.5	1.5	1.5	2	2.5	3
100 kg U_L	8	9	10	10	14	16
1 std unc	4	4.5	5	5	7	8

PG7202 Piston-Cylinders Mass Sets	**100 kPa/kg** [ppm]	**200 kPa/kg** [ppm]	**500 kPa/kg** [ppm]	**1 MPa/kg** [ppm]	**2 MPa/kg** [ppm]
35 kg U_L	3	3	3	6	10
1 std unc	1.5	1.5	1.5	3	5
100 kg U_L	8	9	10	16	16*
1 std unc	4	4.5	5	5	8*

*Limited to 50 kg (100 MPa)

Type of uncertainty: Relative type B

Sensitivity: 1 ppm/ppm

Distribution: Considered normal

Standard uncertainty: See tables

B15 – Elastic Deformation (λ)

The effective area of a PG7000 piston-cylinder is a function of the applied pressure and the theoretical elastic deformation coefficient. The theoretical deformation coefficient is calculated knowing the type of mounting post in which the piston-cylinder is contained and the piston-cylinder size and materials. It is well accepted that an uncertainty in theoretical elastic deformation coefficients of the free deformation mounting post is ± 10 % with a coverage factor of 2.

The following tables list the elastic deformation coefficient, one standard uncertainty, full scale pressure for minimum and maximum mass loads, sensitivity of uncertainty and the uncertainty in pressure, given in ppm, for each piston-cylinder size.

Piston-Cylinder size	**Deformation Coefficient** (λ) [MPa^{-1}]	**1 Std Unc** [MPa^{-1}]	**Sensitivity** [ppm/MPa]
10 kPa/kg	4.20×10^{-6}	2.10×10^{-7}	0.210
10 kPa/kg L	5.19×10^{-6}	3.0×10^{-7}	0.300
20 kPa/kg	2.65×10^{-6}	1.32×10^{-7}	0.132
50 kPa/kg	-1.67×10^{-6}	8.3×10^{-8}	0.083
100 kPa/kg	-2.47×10^{-6}	1.23×10^{-7}	0.123
200 kPa/kg	-2.35×10^{-6}	1.17×10^{-7}	0.117

Piston-Cylinder size	**35 kg 1 Std Unc** [ppm]	**55 kg 1 Std Unc** [ppm]
10 kPa/kg	0.07	0.11
10 kPa/kg L	0.11	0.17
20 kPa/kg	0.09	0.15
50 kPa/kg	0.15	0.23
100 kPa/kg	0.43	0.68
200 kPa/kg	0.82	1.29

PG7302

Piston-Cylinder size	**Deformation Coefficient** (λ) [MPa^{-1}]	**1 Std Unc** [MPa^{-1}]	**Sensitivity** [ppm/MPa]
100 kPa/kg	17.9×10^{-7}	8.95×10^{-8}	0.089
200 kPa/kg	12.6×10^{-7}	6.30×10^{-8}	0.063
500 kPa/kg	10.6×10^{-7}	5.30×10^{-8}	0.053
1 MPa/kg	8.14×10^{-7}	4.07×10^{-8}	0.041
2 MPa/kg	7.92×10^{-7}	3.96×10^{-8}	0.039

Piston-Cylinder size	**35 kg 1 Std Unc** [ppm]	**100 kg 1 Std Unc** [ppm]
100 kPa/kg	0.31	0.90
200 kPa/kg	0.44	1.26
500 kPa/kg	0.90	2.7
1 MPa/kg	1.43	4.1
2 MPa/kg	2.77	7.92
5 MPa/kg	6.81	19.47

PG7202

Piston-Cylinder size	Deformation Coefficient (λ) [MPa^{-1}]	1 Std Unc [MPa^{-1}]	Sensitivity [ppm/MPa]
100 kPa/kg	-2.91 x 10^{-7}	1.45 x 10^{-7}	0.145
200 kPa/kg	-2.48 x 10^{-6}	1.24 x 10^{-7}	0.124
500 kPa/kg	-2.31 x 10^{-7}	1.15 x 10^{-7}	0.115
1 MPa/kg	-2.25 x 10^{-6}	1.12 x 10^{-7}	0.112

Piston-Cylinder size	35 kg 1 Std Unc [ppm]	100 kg 1 Std Unc [ppm]
100 kPa/kg	0.51	1.45
200 kPa/kg	0.87	2.48
500 kPa/kg	2.01	5.75
1 MPa/kg	3.92	11.2
2 MPa/kg	7.77	11.1*

*Limited to 50 kg (100 MPa)

It should be noted that the uncertainty shown in the table above is worst case considering the maximum pressure is used to determine the value shown. When the piston gauge is calibrated to a lower pressure, the uncertainty contributed by elastic deformation could be recalculated using the sensitivity coefficient.

It should also be mentioned that these uncertainties are based on theoretical values of distortion. For the 500 kPa/kg, 1 and 2 MPa/kg PG7202 ranges and the 2 and 5 MPa/kg PG7302 ranges the piston-cylinder assemblies have measured distortion coefficients that may significantly reduce the uncertainty in elastic deformation.

Type of uncertainty: Relative type B

Sensitivity: See tables

Distribution: Considered normal

Standard uncertainty: See tables

B16 – Thermal Expansion ($\alpha_p+\alpha_c$)

The effective area of a piston-cylinder changes with temperature depending on the thermal expansivity of the piston-cylinder materials. The magnitude of this change with temperature is the thermal expansion coefficient. This coefficient has an uncertainty of ± 5 % with a coverage factor of 2. Assuming a typical laboratory temperature of 21 °C, resulting in a correction of 1 °C, the table below lists the thermal expansion coefficient of the piston-cylinder, one standard uncertainty, and relative effect on pressure.

PG7601 or PG7102 Piston-Cylinders size	(αp+αc) [$°C^{-1}$]	1 Std Unc [$°C^{-1}$]	Unc in Pressure 1 Std Unc [ppm]
10 kPa/kg	9 x 10^{-6}	2.2 x 10^{-7}	0.22
20 kPa/kg	9 x 10^{-6}	2.2 x 10^{-7}	0.22
50 kPa/kg	9 x 10^{-6}	2.2 x 10^{-7}	0.22
100 kPa/kg	9 x 10^{-6}	2.2 x 10^{-7}	0.22
200 kPa/kg	9 x 10^{-6}	2.2 x 10^{-7}	0.22

PG7302 or PG7202 Piston-Cylinders size	(αp+αc) [$°C^{-1}$]	1 Std Unc [$°C^{-1}$]	Unc in Pressure 1 Std Unc [ppm]
100 kPa/kg	9 x 10^{-6}	2.2 x 10^{-7}	0.22
200 kPa/kg	9 x 10^{-6}	2.2 x 10^{-7}	0.22
500 kPa/kg	9 x 10^{-6}	2.2 x 10^{-7}	0.22
1 MPa/kg	9 x 10^{-6}	2.2 x 10^{-7}	0.22
2 MPa/kg	9 x 10^{-6}	2.2 x 10^{-7}	0.22
*5 MPa/kg	9 x 10^{-6}	2.2 x 10^{-7}	0.22

*PG7302 only

Type of uncertainty: Relative type B

Sensitivity: 1.0000000/°C-1

Distribution: Considered normal

Standard uncertainty: See tables

B18 (PG7302 only) – Surface Tension (πDT)

Surface tension for gas operated piston-cylinders (PG7601, PG7102 and PG7202) is considered insignificant. For oil lubricated, oil operated piston cylinders (PG7302) there is a constant force applied by the physical attraction between the fluid and the piston. Since the effect is constant, the uncertainty is an absolute uncertainty. The value used for Sebacate is 0.031 N/m from 19 to 23 °C with an uncertainty of ± 0.0093 N/m using a coverage factor of 2. Because the correction is a function of the size of the piston the uncertainty is expressed as an absolute value for each piston-cylinder size. The following table lists the size, sensitivity for that range and one standard uncertainty in each size expressed in pressure.

PG7302 Piston-Cylinder size	Sensitivity [Pa / N/m]	1 Std Unc [Pa]
100 kPa/g	352	1.89
200 kPa/kg	506	2.71
500 kPa/kg	801	4.30
1 MPa/kg	1 132	6.17
2 MPa/kg	1 602	8.60
5 MPa/kg	2 563	13.76

In the equation for calculating surface tension, π is a constant and does not require an uncertainty in the resolution used for π in the PG7302 calculations. Also the effective area is used to calculate the diameter of the piston. The uncertainty in the effective area, including the piston-cylinder gap, is very small with respect to the significance of this correction and does not need to be included.

Type of uncertainty: Absolute type B

Sensitivity: See table

Distribution: A priori rectangular

Standard uncertainty: 0.0054 N/m

B1a and B1b – Bell and Piston Mass, B4a

AMH Bell Density and B19 AMH Lubrication The mass of the mass loading bell and the mass of the pistons have uncertainty specifications that are separate from the other PG7000 masses. These uncertainty specifications are ± 3 mg for each piston, ± 5 mg for the tungsten-carbide 10 kPa/kg piston, ± 4 mg for the 20 kPa/kg, ± 5 mg for the 300 gram PG7601 mass loading bell and ± 8 mg for the 800 gram PG7X02 mass loading bell all with a coverage factor of 2.

As was mentioned in B1 - Mass, the PG7000 AMH mass handling system preserves the masses from contamination and wear. Therefore the uncertainty specifications are reduced to the global mass specification of ± 5 ppm at k=2 for the AMH bell assembly. However, there is an additional uncertainty due to a larger uncertainty in average density of the mass carrying bell.

For the AMH bell assembly there are threads that connect the stem to the binary spindle that holds the smaller binary masses. Because they are made of the same material, 6AL4V titanium, the threads require lubrication. Fluke uses a krytox grease for this that can be used in a vacuum for use with a PG7601. The process for lubricating the threads happens after as found data is taken and before the as left mass measurement is taken. The threads are completely cleaned out of the previous lubrication and a small amount of krytox grease is applied to the threads and then wiped lightly with a paper towel until no excess is apparent on the threads but a thin film exists. In this process the amount of lubricant added is approximately 15-20 mg. During the calibration interval of the mass set it is likely that some of that grease will be inadvertently removed, either from depletion from being under a vacuum, or from rubbing off when the assembly is removed and replaced during the change of piston-cylinder ranges. Statistically this is around -5 mg of mass. Though this uncertainty is asymmetrical it is shown as a normally distributed uncertainty as uncertainty B19.

In regards to the previous paragraph it may be beneficial to combine the uncertainty from B19 with the AMH bell assembly uncertainty as a full specification for that piece. The uncertainties may be considered correlated and if combined would provide an uncertainty specification of, k=2:

500 gram AMH-38 Bell Assembly: ±7.5 mg

800 gram AMH-100 Bell Assembly: ±9 mg

Note that this does not include the uncertainty due to the larger uncertainty in density of the bell assembly because that only applies to absolute by vacuum mode.

Because the mass uncertainties result in a different pressure value for each piston-cylinder size they are listed separately for each size available in the tables below.

PG7601 and PG7102

Piston-Cylinder size	**Sensitivity** [Pa / N/m]	**Piston 1 Std Unc** [Pa]	**Bell PG7601 1 Std Unc** [Pa]	**Bell PG7102 1 Std Unc** [Pa]
10 kPa/g	0.01	0.025	0.025	0.040
20 kPa/kg	0.02	0.04	0.05	0.08
50 kPa/kg	0.05	0.075	0.125	0.20
100 kPa/kg	0.1	0.15	0.25	0.4
200 kPa/kg	0.2	0.3	0.5	0.8

PG7302 and PG7202

Piston-Cylinder size	**Sensitivity** [Pa / N/m]	**Piston 1 Std Unc** [Pa]	**Bell PG7601 1 Std Unc** [Pa]
100 kPa/g	0.1	0.15	0.4
200 kPa/kg	0.2	0.3	0.8
500 kPa/kg	0.5	0.75	2.0
1 MPa/kg	1	1.5	4.0
2 MPa/kg	2	3.0	8.0
5 MPa/kg	5	7.5	20

AMH bell assembly density and lubrication

Piston-Cylinder size	Sensitivity [Pa / N/m]	AMH 38 Bell Density 1 Std Unc [Pa]	AMH 100 Bell Density 1 Std Unc [Pa]	AMH Lub 1 Std Unc [Pa]
10 kPa/g	0.01	0.008	0.014	0.025
20 kPa/kg	0.02	0.016	0.029	0.05
50 kPa/kg	0.05	0.041	0.072	0.125
100 kPa/kg	0.1	0.082	0.144	0.25
200 kPa/kg	0.2	0.164	0.289	0.5
500 kPa/kg	0.5	0.410	0.721	1.25
1 MPa/kg	1.0	0.82	1.44	2.5
2 MPa/kg	2.0	1.64	2.89	5

Type of uncertainty: Absolute type B
Sensitivity: See tables
Distribution: Considered normal
Standard uncertainty: See tables

B17 – Stability (Reproducibility with time)

To help PG7000 users define initial calibration intervals and to predict contributions of uncertainty based on the natural changes of the materials, we have included known values for an interval of one year.

There are three issues to consider when identifying stability of the PG7000 system. The effective area of the piston-cylinder, the masses and all the sensors on board a PG7000 system.

The specifications for the sensors on-board a PG7000 system include stability for one year.

As long as they are inside their specifications then there is no additional uncertainty retained from drift.

Masses can change with time due to contamination or wear. Because the PG7000 systems are generally used carefully in a laboratory environment the change of mass with time is minimal. The uncertainty of ± 5 ppm or 1 mg, whichever is greater includes the stability of the masses over a 1 year period for standard masses and 3 years for AMH masses.

The stability of effective area of a piston-cylinder is a function of the material, size and manufacturing. Fluke Calibration has many years of documented evidence of the stability of tungsten carbide. This clearly evidences stability better than 1 to 5 ppm per year, depending on the range.

Piston-Cylinder size	Stability 1 year [ppm]	1 Std Unc [ppm]
10 kPa/g	1	0.5
20 kPa/kg	1	0.5
50 kPa/kg	1	0.5
100 kPa/kg	1	0.5
200 kPa/kg	2	1.0
5 MPa/kg	2	1.0
1 MPa/kg	2	1.0
2 MPa/kg	3	1.5
5 MPa/kg	5	2.5

Type of uncertainty: Relative type B
Sensitivity: 1 ppm/ppm
Distribution: Considered normal
Standard uncertainty: See table

A1 – Type A Contribution

Because this uncertainty analysis covers a population of instruments, a specific Type A uncertainty cannot be assigned from a set of data. Generally, a Type A uncertainty will be determined when a customer uses the piston gauge to calibrate another instrument to be used in the uncertainty analysis of that instrument. The specific Type A uncertainties depend upon the system configuration, the environment, the pressure connections and hardware between the piston gauge and the test, and also any contributions from the piston gauge. Since it is impossible to know what Type A influences a given PG7000 user will have in a specific situation, we have only included the contribution of Type A from the piston gauge. This is done for each piston-cylinder size.

To determine the contribution of Type A by an instrument, there must be another instrument with performance characteristics that exceed the instrument being evaluated. For piston gauges no such instrument is available except for other piston gauges with documented performance. The best known source of this information comes from the Type A uncertainties determined in the Fluke Calibration Piston-Cylinder Calibration Chain. This is the only source where all systematic influences are corrected well enough to allow a normal distribution to be observed for a population of piston-cylinders. The values listed in the table below show nominal Type A uncertainties that are slightly larger than the Type A uncertainties determined in the Fluke Calibration Piston-Cylinder Calibration Chain.

One exception to the values shown in the following tables is the case where a PPCH-G is used to control the piston float position of a gas piston gauge. It is necessary for the controller to be actively maintaining piston float position even while in its free floating band setting. In this case it is expected to experience an additional contribution to type A uncertainty during a test of approximately ±10 ppm at k=2.

PG7601 or PG7102 Piston-Cylinder size	**Type A (k=2)** [± ppm]	**Unc in Pressure 1 Std Dev** [ppm]
10 kPa/kg (t.c. piston)	1	0.5
10 kPa/kg (ceramic piston)	2	1.0
20 kPa/kg	2	1.0
50 kPa/kg	2	1.0
100 kPa/kg	2	1.0
200 kPa/kg	2	1.0

PG7302 Piston-Cylinder size	**Type A (k=2)** [± ppm]	**Unc in Pressure 1 Std Dev** [ppm]
100 kPa/kg	3	1.5
200 kPa/kg	3	1.5
500 kPa/kg	4	2.0
1 MPa/kg	5	2.5
2 MPa/kg	5	2.5
5 MPa/kg	6	3.0

PG7202 Piston-Cylinder size	**Type A (k=2)** [± ppm]	**Unc in Pressure 1 Std Dev** [ppm]
100 kPa/kg	2	1.0
200 kPa/kg	3	1.5
500 kPa/kg	4	2.0
1 MPa/kg	5	2.5
2 MPa/kg	5	2.5

Type of uncertainty: Relative type A

Sensitivity: 1 ppm/ppm

Distribution: Normal

Standard uncertainty: See tables

Combining uncertainties

The tables that follow list the uncertainties defined in the previous sections of this document for all piston-cylinder sizes, for minimum and maximum mass loads and for the three different pressure measurement modes offered by PG7000 systems (separate uncertainty analyses cover differential and high line differential modes (see Technical Notes 9940TN02, 0080TN03)). All individual uncertainties are categorized into relative or absolute uncertainties and listed as one standard uncertainty. The uncertainties are then combined by root sum squaring the individual uncertainties. Values shown in ppm or pressure (Pa or kPa) are combined separately. Finally, the relative and absolute combined uncertainty are each multiplied by a coverage factor of 2 and listed. These define the instrumental measurement uncertainty for each piston-cylinder range.

Only the gas operated/gas lubricated piston-cylinder ranges (PG7601 and PG7102) have a separate section for the AMH™ uncertainty due to some slight differences in the final uncertainty. The final instrumental measurement uncertainty for PG7302 and PG7202 piston-cylinder when used with AMH is not different enough to warrant showing these, so it is the same as for manual mass sets.

Note: If it is required to calculate a specific confidence level for this uncertainty analysis (such as 95 %), greater knowledge of the effective degrees of freedom for each standard uncertainty must be obtained. However, it should be noted that as all the dominant standard uncertainties are considered to have normal distributions with a high degree of confidence, and observing the Central Limit Theorem, a coverage factor of 2 (k=2) should sufficiently approximate a confidence level of 95 %.

PG7601/PG7102

10 KPA/KG Piston-cylinder range (tungsten carbide piston) PC-7100/7600-10, 10L

Instrumental measurement uncertainty ± (0.2 Pa + 12 ppm)

Variable or Parameter	Type Unc	Absolute w/application of vacuum	Absolute by/addition of atmospheric pressure		Gauge	
Full Mass Load	—	35 kg	35 kg	55 kg	35 kg	55 kg
(Relative Unc's)	—	ppm	ppm	ppm	ppm	ppm
Mass (M)	B1	2.50	2.50	2.50	2.50	2.50
Local G	B2	1.00	1.00	1.00	1.00	1.00
Air Density	B3	n/a	0.32	0.32	0.32	0.32
Mass Density	B4	0.38	n/a	n/a	n/a	n/a
Head (height)	B5	0.35	0.35	0.35	0.35	0.35
Head (density)	B6	0.23	0.23	0.23	0.23	0.23
Resolution	B9	0.29	0.26	0.26	0.29	0.29
PC Temp	B10	0.50	0.50	0.50	0.50	0.50
Verticality	B11	0.10	0.10	0.10	0.10	0.10
Effective area	B12	5.00	5.00	5.00	5.00	5.00
Linearity	B14	0.50	0.50	1.00	0.50	1.00
Elastic deformation	B15	0.07	0.07	0.11	0.07	0.11
Thermal expansion	B16	0.22	0.22	0.22	0.22	0.22
Stability Ae	B17	0.50	0.50	0.50	0.50	0.50
Sensitivity	B13	0.14	0.14	0.14	0.14	0.14
Type A	A1	0.50	0.50	0.50	0.50	0.50
Combined		5.9 ppm + 5.00 Pa	5.9 ppm + 5.00 Pa	6.0 ppm + 5.00 Pa	5.9 ppm + 0.04 Pa	6.0 ppm + 0.05 Pa
Combined and expanded for (K=2)		12 ppm + 0.2 Pa	12 ppm + 10 Pa	12 ppm + 10 Pa	12 ppm + 0.07 Pa	12 ppm + 0.09 Pa
(Absolute Unc's)	—	Pa	Pa	Pa	Pa	Pa
Barometric pressure	B8	n/a	5.00	5.00	n/a	n/a
Residual vacuum	B7	0.1	n/a	n/a	n/a	n/a
Surface tension	n/a	n/a	n/a	n/a	n/a	n/a
Sensitivity	B13	0.003	0.003	0.003	0.003	0.003
Bell mass	B1a	0.025	0.025	0.040	0.025	0.040
Piston mass	B1b	0.025	0.025	0.025	0.025	0.025

10 KPA/KG Piston-cylinder range (tungsten carbide piston) with AMH™

Instrumental measurement uncertainty ± (0.08 Pa + 12 ppm)

Combined		5.8 ppm + 0.037 Pa	5.9 ppm + 5.00 Pa	6.0 ppm + 5.00 Pa	5.9 ppm + 0.035 Pa	6.0 ppm + 0.035 Pa
Combined and expanded for (K=2)		12 ppm + 0.07 Pa	12 ppm + 10 Pa	12 ppm + 10 Pa	12 ppm + 0.07 Pa	12 ppm + 0.07 Pa
(Absolute Unc's)	—	Pa	Pa	Pa	Pa	Pa
Barometric pressure	B8	n/a	5.00	5.00	n/a	n/a
Residual vacuum	B7	0.006	n/a	n/a	n/a	n/a
Surface tension	n/a	n/a	n/a	n/a	n/a	n/a
Sensitivity	B13	0.003	0.003	0.003	0.003	0.003
Bell mass density	B4a	0.008	n/a	n/a	n/a	n/a
Piston mass	B1b	0.025	0.025	0.025	0.025	0.025
Bell lubrication	B18	0.025	0.025	0.025	0.025	0.025

PG7601/PG7102
20 KPA/KG Piston-cylinder range

Instrumental measurement uncertainty ± (0.2 Pa + 13 ppm)

Variable or Parameter	**Type Unc**	**Absolute w/application of vacuum**	**Absolute by/addition of atmospheric pressure**		**Gauge**	
Full Mass Load	—	35 kg	35 kg	55 kg	35 kg	55 kg
(Relative Unc's)	—	ppm	ppm	ppm	ppm	ppm
Mass (M)	B1	2.50	2.50	2.50	2.50	2.50
Local G	B2	1.00	1.00	1.00	1.00	1.00
Air Density	B3	n/a	0.32	0.32	0.32	0.32
Mass Density	B4	0.38	n/a	n/a	n/a	n/a
Head (height)	B5	0.35	0.35	0.35	0.35	0.35
Head (density)	B6	0.23	0.23	0.23	0.23	0.23
Resolution	B9	0.29	0.26	0.26	0.29	0.29
PC Temp	B10	0.50	0.50	0.50	0.50	0.50
Verticality	B11	0.10	0.10	0.10	0.10	0.10
Effective area	B12	5.50	5.50	5.50	5.50	5.50
Linearity	B14	0.50	0.50	1.00	0.50	1.00
Elastic deformation	B15	0.09	0.09	0.15	0.09	0.15
Thermal expansion	B16	0.25	0.25	0.25	0.25	0.25
Stability Ae	B17	0.50	0.50	0.50	0.50	0.50
Sensitivity	B13	0.14	0.14	0.14	0.14	0.14
Type A	A1	1.00	1.00	1.00	1.00	1.00
Combined		6.3 ppm + 0.12 Pa	6.3 ppm + 5.00 Pa	6.4 ppm + 5.00 Pa	6.3 ppm + 0.07 Pa	6.4 ppm + 0.09 Pa
Combined and expanded for (K=2)		12 ppm + 0.2 Pa	13 ppm + 10 Pa	13 ppm + 10 Pa	14 ppm + 0.14 Pa	13 ppm + 0.2 Pa
(Absolute Unc's)	—	Pa	Pa	Pa	Pa	Pa
Barometric pressure	B8	n/a	5.00	5.00	n/a	n/a
Residual vacuum	B7	0.1	n/a	n/a	n/a	n/a
Surface tension	n/a	n/a	n/a	n/a	n/a	n/a
Sensitivity	B13	0.012	0.012	0.012	0.012	0.012
Bell mass	B1a	0.050	0.050	0.080	0.050	0.080
Piston mass	B1b	0.040	0.040	0.040	0.040	0.040

20 KPA/KG Piston-cylinder range (tungsten carbide piston) with AMH™

Instrumental measurement uncertainty ± (0.13 Pa + 13 ppm)

Combined		6.3 ppm + 0.067 Pa	6.3 ppm + 5.00 Pa	6.4 ppm + 5.00 Pa	6.3 ppm + 0.065 Pa	6.4 ppm + 0.065 Pa
Combined and expanded for (K=2)		13 ppm + 0.13 Pa	13 ppm + 10 Pa	13 ppm + 10 Pa	13 ppm + 0.13 Pa	13 ppm + 0.13 Pa
(Absolute Unc's)	—	Pa	Pa	Pa	Pa	Pa
Barometric pressure	B8	n/a	5.00	5.00	n/a	n/a
Residual vacuum	B7	0.006	n/a	n/a	n/a	n/a
Surface tension	n/a	n/a	n/a	n/a	n/a	n/a
Sensitivity	B13	0.012	0.012	0.012	0.012	0.012
Bell mass density	B4a	0.016	n/a	n/a	n/a	n/a
Piston mass	B1b	0.04	0.04	0.04	0.04	0.04
Bell lubrication	B18	0.05	0.05	0.05	0.05	0.05

PG7601/PG7102
50 KPA/KG Piston-cylinder range

Instrumental measurement uncertainty ± (0.5 Pa + 14 ppm)

Variable or Parameter	Type Unc	Absolute w/application of vacuum	Absolute by/addition of atmospheric pressure		Gauge	
Full Mass Load	—	35 kg	35 kg	55 kg	35 kg	55 kg
(Relative Unc's)	—	ppm	ppm	ppm	ppm	ppm
Mass (M)	B1	2.50	2.50	2.50	2.50	2.50
Local G	B2	1.00	1.00	1.00	1.00	1.00
Air Density	B3	n/a	0.32	0.32	0.32	0.32
Mass Density	B4	0.38	n/a	n/a	n/a	n/a
Head (height)	B5	0.35	0.35	0.35	0.35	0.35
Head (density)	B6	0.23	0.23	0.23	0.23	0.23
Resolution	B9	0.29	0.26	0.26	0.29	0.29
PC Temp	B10	0.50	0.50	0.50	0.50	0.50
Verticality	B11	0.10	0.10	0.10	0.10	0.10
Effective area	B12	5.50	5.50	5.50	5.50	5.50
Linearity	B14	1.50	1.50	2.50	1.50	2.50
Elastic deformation	B15	0.15	0.15	0.23	0.15	0.23
Thermal expansion	B16	0.25	0.25	0.25	0.25	0.25
Stability Ae	B17	0.50	0.50	0.50	0.50	0.50
Sensitivity	B13	0.14	0.14	0.14	0.14	0.14
Type A	A1	1.00	1.00	1.00	1.00	1.00
Combined		6.5 ppm + 0.18 Pa	6.5 ppm + 5.00 Pa	6.8 ppm + 5.00 Pa	6.5 ppm + 0.15 Pa	6.8 ppm + 0.22 Pa
Combined and expanded for (K=2)		13 ppm + 0.4 Pa	13 ppm + 10 Pa	14 ppm + 10 Pa	13 ppm + 0.3 Pa	14 ppm + 0.3 Pa
(Absolute Unc's)	—	Pa	Pa	Pa	Pa	Pa
Barometric pressure	B8	n/a	5.00	5.00	n/a	n/a
Residual vacuum	B7	0.1	n/a	n/a	n/a	n/a
Surface tension	n/a	n/a	n/a	n/a	n/a	n/a
Sensitivity	B13	0.029	0.029	0.029	0.029	0.029
Bell mass	B1a	0.075	0.075	0.075	0.075	0.075
Piston mass	B1b	0.125	0.125	0.125	0.125	0.125

50 KPA/KG Piston-cylinder range (tungsten carbide piston) with AMH™

Instrumental measurement uncertainty ± (0.3 Pa + 14 ppm)

Combined		6.5 ppm + 0.15 Pa	6.5 ppm + 5.00 Pa	6.8 ppm + 5.00 Pa	6.5 ppm + 0.15 Pa	6.8 ppm + 0.15 Pa
Combined and expanded for (K=2)		13 ppm + 0.3 Pa	13 ppm + 10 Pa	13 ppm + 10 Pa	13 ppm + 0.3 Pa	13 ppm + 0.3 Pa
(Absolute Unc's)	—	Pa	Pa	Pa	Pa	Pa
Barometric pressure	B8	n/a	5.00	5.00	n/a	n/a
Residual vacuum	B7	0.006	n/a	n/a	n/a	n/a
Surface tension	n/a	n/a	n/a	n/a	n/a	n/a
Sensitivity	B13	0.029	0.029	0.029	0.029	0.029
Bell mass density	B4a	0.041	n/a	n/a	n/a	n/a
Piston mass	B1b	0.075	0.075	0.075	0.075	0.075
Bell lubrication	B18	0.125	0.125	0.125	0.125	0.125

PG7601/PG7102
100 KPA/KG Piston-cylinder range

Instrumental measurement uncertainty ± (1 Pa + 20 ppm)

Variable or Parameter	Type Unc	Absolute w/application of vacuum	Absolute by/addition of atmospheric pressure		Gauge	
Full Mass Load	—	35 kg	35 kg	55 kg	35 kg	55 kg
(Relative Unc's)	—	ppm	ppm	ppm	ppm	ppm
Mass (M)	B1	2.50	2.50	2.50	2.50	2.50
Local G	B2	1.00	1.00	1.00	1.00	1.00
Air Density	B3	n/a	0.32	0.32	0.32	0.32
Mass Density	B4	0.38	n/a	n/a	n/a	n/a
Head (height)	B5	0.35	0.35	0.35	0.35	0.35
Head (density)	B6	0.23	0.23	0.23	0.23	0.23
Resolution	B9	0.29	0.29	0.29	0.29	0.29
PC Temp	B10	0.50	0.50	0.50	0.50	0.50
Verticality	B11	0.10	0.10	0.10	0.10	0.10
Effective area	B12	8.00	8.00	8.00	8.00	8.00
Linearity	B14	2.00	2.00	3.00	2.00	3.00
Elastic deformation	B15	0.43	0.43	0.68	0.43	0.68
Thermal expansion	B16	0.22	0.22	0.22	0.22	0.22
Stability Ae	B17	0.50	0.50	0.50	0.50	0.50
Sensitivity	B13	0.14	0.14	0.14	0.14	0.14
Type A	A1	1.00	1.00	1.00	1.00	1.00
Combined		8.8 ppm + 0.3 Pa	8.8 ppm + 5.0 Pa	9.1 ppm + 5.0 Pa	8.8 ppm + 0.3 Pa	9.1 ppm + 0.4 Pa
Combined and expanded for (K=2)		18 ppm + 0.6 Pa	18 ppm + 10 Pa	18 ppm + 10 Pa	19 ppm + 0.6 Pa	18 ppm + 0.9 Pa
(Absolute Unc's)	—	Pa	Pa	Pa	Pa	Pa
Barometric pressure	B8	n/a	5.00	5.00	n/a	n/a
Residual vacuum	B7	0.1	n/a	n/a	n/a	n/a
Surface tension	n/a	n/a	n/a	n/a	n/a	n/a
Sensitivity	B13	0.058	0.058	0.058	0.058	0.058
Bell mass	B1a	0.250	0.250	0.400	0.250	0.400
Piston mass	B1b	0.150	0.150	0.150	0.150	0.150

100 KPA/KG Piston-cylinder range (tungsten carbide piston) with AMH™

Instrumental measurement uncertainty ± (0.6 Pa + 20 ppm)

Combined		8.8 ppm + 0.3 Pa	8.8 ppm + 5.00 Pa	9.1 ppm + 5.00 Pa	8.8 ppm + 0.03 Pa	9.1 ppm + 0.3 Pa
Combined and expanded for (K=2)		18 ppm + 0.6 Pa	18 ppm + 10 Pa	18 ppm + 10 Pa	18 ppm + 0.6 Pa	18 ppm + 0.6 Pa
(Absolute Unc's)	—	Pa	Pa	Pa	Pa	Pa
Barometric pressure	B8	n/a	5.00	5.00	n/a	n/a
Residual vacuum	B7	0.006	n/a	n/a	n/a	n/a
Surface tension	n/a	n/a	n/a	n/a	n/a	n/a
Sensitivity	B13	0.058	0.058	0.058	0.058	0.058
Bell mass density	B4a	0.041	n/a	n/a	n/a	n/a
Piston mass	B1b	0.150	0.150	0.150	0.150	0.150
Bell lubrication	B18	0.250	0.250	0.250	0.250	0.250

PG7601/PG7102
200 KPA/KG Piston-cylinder range

Instrumental measurement uncertainty ± (2 Pa + 20 ppm)

Variable or Parameter	**Type Unc**	**Absolute w/application of vacuum**	**Absolute by/addition of atmospheric pressure**		**Gauge**	
Full Mass Load	—	35 kg	35 kg	55 kg	35 kg	55 kg
(Relative Unc's)	—	ppm	ppm	ppm	ppm	ppm
Mass (M)	B1	2.50	2.50	2.50	2.50	2.50
Local G	B2	1.00	1.00	1.00	1.00	1.00
Air Density	B3	n/a	0.32	0.32	0.32	0.32
Mass Density	B4	0.38	n/a	n/a	n/a	n/a
Head (height)	B5	0.35	0.35	0.35	0.35	0.35
Head (density)	B6	0.23	0.23	0.23	0.23	0.23
Resolution	B9	0.29	0.29	0.29	0.29	0.29
PC Temp	B10	0.50	0.50	0.50	0.50	0.50
Verticality	B11	0.10	0.10	0.10	0.10	0.10
Effective area	B12	8.00	8.00	8.00	8.00	8.00
Linearity	B14	2.50	2.50	3.50	2.50	3.50
Elastic deformation	B15	0.43	0.43	0.68	0.43	0.68
Thermal expansion	B16	0.22	0.22	0.22	0.22	0.22
Stability Ae	B17	0.50	0.50	0.50	0.50	0.50
Sensitivity	B13	0.14	0.14	0.14	0.14	0.14
Type A	A1	1.00	1.00	1.00	1.00	1.00
Combined		9.0 ppm + 0.6 Pa	9.0 ppm + 5.0 Pa	9.4 ppm + 5.1 Pa	9.0 ppm + 0.6 Pa	9.4 ppm + 0.9 Pa
Combined and expanded for (K=2)		18 ppm + 1.2 Pa	18 ppm + 10 Pa	19 ppm + 10 Pa	18 ppm + 1.2 Pa	19 ppm + 1.7 Pa
(Absolute Unc's)	—	Pa	Pa	Pa	Pa	Pa
Barometric pressure	B8	n/a	5.00	5.00	n/a	n/a
Residual vacuum	B7	0.1	n/a	n/a	n/a	n/a
Surface tension	n/a	n/a	n/a	n/a	n/a	n/a
Sensitivity	B13	0.115	0.115	0.115	0.115	0.115
Bell mass	B1a	0.500	0.500	0.800	0.500	0.800
Piston mass	B1b	0.300	0.300	0.300	0.300	0.300

200 KPA/KG Piston-cylinder range (tungsten carbide piston) with AMH™

Instrumental measurement uncertainty ± (1.2 Pa + 20 ppm)

Combined		9.0 ppm + 0.3 Pa	9.0 ppm + 5.00 Pa	9.4 ppm + 5.00 Pa	9.0 ppm + 0.3 Pa	9.4 ppm + 0.3 Pa
Combined and expanded for (K=2)		18 ppm + 1.2 Pa	18 ppm + 10 Pa	19 ppm + 10 Pa	18 ppm + 1.2 Pa	18 ppm + 1.2 Pa
(Absolute Unc's)	—	Pa	Pa	Pa	Pa	Pa
Barometric pressure	B8	n/a	5.00	5.00	n/a	n/a
Residual vacuum	B7	0.006	n/a	n/a	n/a	n/a
Surface tension	n/a	n/a	n/a	n/a	n/a	n/a
Sensitivity	B13	0.115	0.115	0.115	0.115	0.115
Bell mass density	B4a	0.164	n/a	n/a	n/a	n/a
Piston mass	B1b	0.300	0.300	0.300	0.300	0.300
Bell lubrication	B18	0.500	0.500	0.500	0.500	0.500

PG7302
100 KPA/KG Piston-cylinder range – Manual and AMH™

Instrumental measurement uncertainty ± (16 Pa + 17 ppm)

Variable or Parameter	Type Unc	Gauge	Absolute by/addition of atmospheric pressure	Gauge	Absolute by/addition of atmospheric pressure
Full Mass Load	–	35	35	100	100
(Relative Unc's)	–	(ppm)	(ppm)	(ppm)	(ppm)
Mass (M)	B1	2.50	2.50	2.50	2.50
Local G	B2	1.00	1.00	1.00	1.00
Air Density	B3	0.32	0.32	0.32	0.32
Mass Density	B4	n/a	n/a	n/a	n/a
Resolution	B9	0.29	0.29	0.29	0.29
PC Temp	B10	0.50	0.50	0.50	0.50
Verticality	B11	0.10	0.10	0.10	0.10
Effective area	B12	7.00	7.00	7.00	7.00
Linearity	B14	1.50	1.50	4.00	4.00
Elastic deformation	B15	0.31	0.31	0.90	0.90
Thermal expansion	B16	0.22	0.22	0.22	0.22
Stability Ae	B17b	0.50	0.50	0.50	0.50
Sensitivity	B13	0.29	0.29	0.29	0.29
Type A	A1	1.50	1.50	1.50	1.50
Combined		7.9 ppm + 6.1 Pa	7.9 ppm + 7.9 Pa	8.7 ppm + 6.1 Pa	8.7 ppm + 7.9 Pa
Combined and expanded for (K=2)		16 ppm + 12 Pa	16 ppm + 16 Pa	17 ppm + 12 Pa	17 ppm + 16 Pa
(Absolute Unc's)	–	Pa	Pa	Pa	Pa
Head (height)	B5	5.20	5.20	5.20	5.20
Head (density)	B6	2.50	2.50	2.50	2.50
Surface tension	B7	1.89	1.89	1.89	1.89
Sensitivity	B13b	0.58	0.58	0.58	0.58
Barometer	B8	n/a	5.00		5.00
Bell mass	B1a	0.40	0.40	0.40	0.40
Piston mass	B1b	0.15	0.15	0.15	0.15

PG7302

200 KPA/KG Piston-cylinder range – Manual and AMH™

Instrumental measurement uncertainty ± (16 Pa + 20 ppm)

Variable or Parameter	Type Unc	Gauge	Absolute by/addition of atmospheric pressure	Gauge	Absolute by/addition of atmospheric pressure
Full Mass Load	–	35	35	100	100
(Relative Unc's)	–	(ppm)	(ppm)	(ppm)	(ppm)
Mass (M)	B1	2.50	2.50	2.50	2.50
Local G	B2	1.00	1.00	1.00	1.00
Air Density	B3	0.32	0.32	0.32	0.32
Mass Density	B4	n/a	n/a	n/a	n/a
Resolution	B9	0.29	0.29	0.29	0.29
PC Temp	B10	0.50	0.50	0.50	0.50
Verticality	B11	0.10	0.10	0.10	0.10
Effective area	B12	7.00	7.00	7.00	7.00
Linearity	B14	1.50	1.50	4.50	4.50
Elastic deformation	B15	0.44	0.44	1.26	1.26
Thermal expansion	B16	0.22	0.22	0.22	0.22
Stability Ae	B17b	1.00	1.00	1.00	1.00
Sensitivity	B13	0.29	0.29	0.29	0.29
Type A	A1	1.50	1.50	1.50	1.50
Combined		7.9 ppm + 6.5 Pa	7.9 ppm + 8.2 Pa	9.1 ppm + 6.5 Pa	9.1 ppm + 8.2 Pa
Combined and expanded for (K =2)		16 ppm + 13 Pa	16 ppm + 16 Pa	19 ppm + 13 Pa	19 ppm + 16 Pa
(Absolute Unc's)	–	Pa	Pa	Pa	Pa
Head (height)	B5	5.20	5.20	5.20	5.20
Head (density)	B6	2.50	2.50	2.50	2.50
Surface tension	B7	2.71	2.71	2.71	2.71
Sensitivity	B13b	1.15	1.15	1.15	1.15
Barometer	B8	n/a	5.00	n/a	5.00
Bell mass	B1a	0.80	0.80	0.80	0.80
Piston mass	B1b	0.30	0.30	0.30	0.30

PG7302
500 KPA/KG Piston-cylinder range – Manual and AMH™

Instrumental measurement uncertainty ± (20 Pa + 20 ppm)

Variable or Parameter	Type Unc	Gauge	Absolute by/addition of atmospheric pressure	Gauge	Absolute by/addition of atmospheric pressure
Full Mass Load	–	35	35	100	100
(Relative Unc's)	–	(ppm)	(ppm)	(ppm)	(ppm)
Mass (M)	B1	2.50	2.50	2.50	2.50
Local G	B2	1.00	1.00	1.00	1.00
Air Density	B3	0.32	0.32	0.32	0.32
Mass Density	B4	n/a	n/a	n/a	n/a
Resolution	B9	0.29	0.29	0.29	0.29
PC Temp	B10	0.50	0.50	0.50	0.50
Verticality	B11	0.10	0.10	0.10	0.10
Effective area	B12	7.50	7.50	7.50	7.50
Linearity	B14	1.50	1.50	5.00	5.00
Elastic deformation	B15	0.93	0.93	2.65	2.65
Thermal expansion	B16	0.22	0.22	0.22	0.22
Stability Ae	B17b	1.00	1.00	1.00	1.00
Sensitivity	B13	0.29	0.29	0.29	0.29
Type A	A1	2.00	2.00	2.00	2.00
Combined		8.5 ppm + 8.0 Pa	8.5 ppm + 9.5 Pa	10.1 ppm + 8 Pa	10.1 ppm + 9.5 Pa
Combined and expanded for (K =2)		17 ppm + 16 Pa	17 ppm + 19 Pa	20 ppm + 16 Pa	20 ppm + 19 Pa
(Absolute Unc's)	–	Pa	Pa	Pa	Pa
Head (height)	B5	5.20	5.20	5.20	5.20
Head (density)	B6	2.50	2.50	2.50	2.50
Surface tension	B7	4.30	4.30	4.30	4.30
Sensitivity	B13b	2.88	2.88	2.88	2.88
Barometer	B8	n/a	5.00	n/a	5.00
Bell mass	B1a	2.00	2.00	2.00	2.00
Piston mass	B1b	0.75	0.75	0.75	0.75

PG7302
1 MPA/KG Piston-cylinder range – Manual and AMH™

Instrumental measurement uncertainty ± (25 Pa + 25 ppm)

Variable or Parameter	Type Unc	Gauge	Absolute by/addition of atmospheric pressure	Gauge	Absolute by/addition of atmospheric pressure
Full Mass Load	–	35	35	100	100
(Relative Unc's)	–	(ppm)	(ppm)	(ppm)	(ppm)
Mass (M)	B1	2.50	2.50	2.50	2.50
Local G	B2	1.00	1.00	1.00	1.00
Air Density	B3	0.32	0.32	0.32	0.32
Mass Density	B4	n/a	n/a	n/a	n/a
Resolution	B9	0.29	0.29	0.29	0.29
PC Temp	B10	0.50	0.50	0.50	0.50
Verticality	B11	0.10	0.10	0.10	0.10
Effective area	B12	9.00	9.00	9.00	9.00
Linearity	B14	2.00	2.00	2.00	2.00
Elastic deformation	B15	1.42	1.42	4.07	4.07
Thermal expansion	B16	0.22	0.22	0.22	0.22
Stability Ae	B17b	1.00	1.00	1.00	1.00
Sensitivity	B13	0.29	0.29	0.29	0.29
Type A	A1	2.50	2.50	2.50	2.50
Combined		10.1 ppm + 11.6 Pa	10.1 ppm + 12.6 Pa	11.7 ppm + 11.6 Pa	11.7 ppm + 12.6 Pa
Combined and expanded for (K =2)		20 ppm + 23 Pa	20 ppm + 25 Pa	23 ppm + 23 Pa	23 ppm + 25 Pa
(Absolute Unc's)	–	Pa	Pa	Pa	Pa
Head (height)	B5	5.2	5.2	5.2	5.2
Head (density)	B6	2.5	2.5	2.5	2.5
Surface tension	B7	7.0	7.0	7.0	7.0
Sensitivity	B13b	5.8	5.8	5.8	5.8
Barometer	B8	n/a	5.00	n/a	5.00
Bell mass	B1a	4.00	4.00	4.00	4.00
Piston mass	B1b	1.5	1.5	1.5	1.5

PG7302
2 MPA/KG Piston-cylinder range – Manual and AMH™

Instrumental measurement uncertainty ± [40 Pa + (25 ppm + 0.04 ppm/MPa)]

Variable or Parameter	Type Unc	Gauge	Absolute by/addition of atmospheric pressure	Gauge	Absolute by/addition of atmospheric pressure
Full Mass Load	–	35	35	100	100
(Relative Unc's)	–	(ppm)	(ppm)	(ppm)	(ppm)
Mass (M)	B1	2.50	2.50	2.50	2.50
Local G	B2	1.00	1.00	1.00	1.00
Air Density	B3	0.32	0.32	0.32	0.32
Mass Density	B4	n/a	n/a	n/a	n/a
Resolution	B9	0.29	0.29	0.29	0.29
PC Temp	B10	0.50	0.50	0.50	0.50
Verticality	B11	0.10	0.10	0.10	0.10
Effective area	B12	12.50	12.50	12.50	12.50
Linearity	B14	2.50	2.50	7.00	7.00
Elastic deformation	B15	2.77	2.77	7.92	7.92
Thermal expansion	B16	0.22	0.22	0.22	0.22
Stability Ae	B17b	1.50	1.50	1.50	1.50
Sensitivity	B13	0.29	0.29	0.29	0.29
Type A	A1	2.50	2.50	2.50	2.50
Combined		13.7 ppm + 17.7 Pa	13.7 ppm + 18.4 Pa	16.9 ppm + 17.7 Pa	16.9 ppm + 18.4 Pa
Combined and expanded for (K =2)		27 ppm + 35 Pa	27 ppm + 37 Pa	34 ppm + 35 Pa	34 ppm + 37 Pa
(Absolute Unc's)	–	Pa	Pa	Pa	Pa
Head (height)	B5	5.2	5.2	5.2	5.2
Head (density)	B6	2.5	2.5	2.5	2.5
Surface tension	B7	8.6	8.6	8.6	8.6
Sensitivity	B13b	11.6	11.6	11.6	11.6
Barometer	B8	n/a	5.0	n/a	5.0
Bell mass	B1a	8.0	8.0	8.0	8.0
Piston mass	B1b	3.0	3.0	3.0	3.0

PG7302
5 MPA/KG Piston-cylinder range – Manual and AMH™

Instrumental measurement uncertainty ± [100 Pa + (35 ppm + 0.04 ppm/MPa)]

Variable or Parameter	Type Unc	Gauge	Absolute by/addition of atmospheric pressure	Gauge	Absolute by/addition of atmospheric pressure
Full Mass Load	—	35	35	100	100
(Relative Unc's)	—	(ppm)	(ppm)	(ppm)	(ppm)
Mass (M)	B1	2.50	2.50	2.50	2.50
Local G	B2	1.00	1.00	1.00	1.00
Air Density	B3	0.32	0.32	0.32	0.32
Mass Density	B4	n/a	n/a	n/a	n/a
Resolution	B9	0.29	0.29	0.29	0.29
PC Temp	B10	0.50	0.50	0.50	0.50
Verticality	B11	0.10	0.10	0.10	0.10
Effective area	B12	15.00	15.00	15.00	15.00
Linearity	B14	3.00	3.00	3.00	3.00
Elastic deformation	B15	6.81	6.81	6.81	6.81
Thermal expansion	B16	0.22	0.22	0.22	0.22
Stability Ae	B17b	2.50	2.50	2.50	2.50
Sensitivity	B13	0.29	0.29	0.29	0.29
Type A	A1	3.00	2.50	3.00	3.00
Combined		17.4 ppm + 38.9 Pa	17.4 ppm + 39.2 Pa	26.3 ppm + 38.9 Pa	26.3 ppm + 39.2 Pa
Combined and expanded for (K =2)		35 ppm + 78 Pa	35 ppm + 78 Pa	53 ppm + 78 Pa	53 ppm + 78 Pa
(Absolute Unc's)	—	Pa	Pa	Pa	Pa
Head (height)	B5	5.2	5.2	5.2	5.2
Head (density)	B6	2.5	2.5	2.5	2.5
Surface tension	B7	13.8	13.8	13.8	13.8
Sensitivity	B13b	28.9	28.9	28.9	28.9
Barometer	B8	n/a	5.0	n/a	5.0
Bell mass	B1a	20.0	20.0	20.0	20.0
Piston mass	B1b	7.5	7.5	7.5	7.5

PG7202

100 KPA/KG Piston-cylinder range – Manual and AMH™

Instrumental measurement uncertainty ± (2 Pa + 20 ppm)

Variable or Parameter	Type Unc	Gauge	Absolute by/addition of atmospheric pressure	Gauge	Absolute by/addition of atmospheric pressure
Full Mass Load	–	35	35	100	100
(Relative Unc's)	–	(ppm)	(ppm)	(ppm)	(ppm)
Mass (M)	B1	2.50	2.50	2.50	2.50
Local G	B2	1.00	1.00	1.00	1.00
Air Density	B3	0.32	0.32	0.32	0.32
Mass Density	B4	n/a	n/a	n/a	n/a
Head (height)	B5	0.35	0.35	0.35	0.35
Head (density)	B6	0.23	0.23	0.23	0.23
Resolution	B9	0.29	0.29	0.29	0.29
PC Temp	B10	0.50	0.50	0.50	0.50
Verticality	B11	0.10	0.10	0.10	0.10
Effective area	B12	7.00	7.00	7.00	7.00
Linearity	B14	1.50	1.50	4.00	4.00
Elastic deformation	B15	0.51	0.51	1.46	1.46
Thermal expansion	B16	0.22	0.22	0.22	0.22
Stability Ae	B17b	0.50	0.50	0.50	0.50
Sensitivity	B13	0.29	0.29	0.29	0.29
Type A	A1	1.00	1.00	1.00	1.00
Combined		7.8 ppm + 0.72 Pa	7.8 ppm + 5.05 Pa	8.7 ppm + 0.72 Pa	8.7 ppm + 5.05 Pa
Combined and expanded for (K =2)		16 ppm + 1.4 Pa	16 ppm + 10 Pa	17 ppm + 1.4 Pa	17 ppm + 10 Pa
(Absolute Unc's)	–	Pa	Pa	Pa	Pa
Head (height)	B5	n/a	n/a	n/a	n/a
Head (density)	B6	n/a	n/a	n/a	n/a
Surface tension	B7	n/a	n/a	n/a	n/a
Sensitivity	B13b	0.58	0.58	0.58	0.58
Barometer	B8	n/a	5.00	n/a	5.00
Bell mass	B1a	0.40	0.40	0.40	0.40
Piston mass	B1b	0.15	0.15	0.15	0.15

PG7202
200 KPA/KG Piston-cylinder range – Manual and AMH™

Instrumental measurement uncertainty ± (3 Pa + 20 ppm)

Variable or Parameter	Type Unc	Gauge	Absolute by/addition of atmospheric pressure	Gauge	Absolute by/addition of atmospheric pressure
Full Mass Load	—	35	35	100	100
(Relative Unc's)	—	(ppm)	(ppm)	(ppm)	(ppm)
Mass (M)	B1	2.50	2.50	2.50	2.50
Local G	B2	1.00	1.00	1.00	1.00
Air Density	B3	0.32	0.32	0.32	0.32
Mass Density	B4	n/a	n/a	n/a	n/a
Head (height)	B5	0.35	0.35	0.35	0.35
Head (density)	B6	0.23	0.23	0.23	0.23
Resolution	B9	0.29	0.29	0.29	0.29
PC Temp	B10	0.50	0.50	0.50	0.50
Verticality	B11	0.10	0.10	0.10	0.10
Effective area	B12	7.00	7.00	7.00	7.00
Linearity	B14	1.50	1.50	4.50	4.50
Elastic deformation	B15	0.87	0.87	0.87	0.87
Thermal expansion	B16	0.22	0.22	0.22	0.22
Stability Ae	B17b	1.00	1.00	1.00	1.00
Sensitivity	B13	0.29	0.29	0.29	0.29
Type A	A1	1.50	1.50	1.50	1.50
Combined		8.1 ppm + 1.43 Pa	8.1 ppm + 5.20 Pa	9.4 ppm + 1.43 Pa	9.4 ppm + 5.20 Pa
Combined and expanded for (K =2)		16 ppm + 2.9 Pa	16 ppm + 10 Pa	19 ppm + 2.9 Pa	19 ppm + 10 Pa
(Absolute Unc's)	—	Pa	Pa	Pa	Pa
Head (height)	B5	n/a	n/a	n/a	n/a
Head (density)	B6	n/a	n/a	n/a	n/a
Surface tension	B7	n/a	n/a	n/a	n/a
Sensitivity	B13	1.2	1.2	1.2	1.2
Barometer	B8	n/a	5.0	n/a	5.0
Bell mass	B1a	0.8	0.8	0.8	0.8
Piston mass	B1b	0.3	0.3	0.3	0.3

PG7202
500 KPA/KG Piston-cylinder range – Manual and AMH™

Instrumental measurement uncertainty ± [8 Pa + (18 ppm + 0.15 ppm/MPa)]

Variable or Parameter	Type Unc	Gauge	Absolute by/addition of atmospheric pressure	Gauge	Absolute by/addition of atmospheric pressure
Full Mass Load	—	35	35	100	100
(Relative Unc's)	—	(ppm)	(ppm)	(ppm)	(ppm)
Mass (M)	B1	2.50	2.50	2.50	2.50
Local G	B2	1.00	1.00	1.00	1.00
Air Density	B3	0.32	0.32	0.32	0.32
Mass Density	B4	n/a	n/a	n/a	n/a
Head (height)	B5	0.35	0.35	0.35	0.35
Head (density)	B6	0.23	0.23	0.23	0.23
Resolution	B9	0.29	0.29	0.29	0.29
PC Temp	B10	0.50	0.50	0.50	0.50
Verticality	B11	0.10	0.10	0.10	0.10
Effective area	B12	8.00	8.00	8.00	8.00
Linearity	B14	1.50	1.50	5.00	5.00
Elastic deformation	B15	2.06	2.06	5.88	5.88
Thermal expansion	B16	0.22	0.22	0.22	0.22
Stability Ae	B17b	1.00	1.00	1.00	1.00
Sensitivity	B13	0.29	0.29	0.29	0.29
Type A	A1	2.00	2.00	2.00	2.00
Combined		9.1 ppm + 3.59 Pa	9.1 ppm + 6.15 Pa	11.7 ppm + 3.59 Pa	11.7 ppm + 6.15 Pa
Combined and expanded for (K =2)		19 ppm + 7.2 Pa	19 ppm + 12 Pa	23 ppm + 7.2 Pa	23 ppm + 12 Pa
(Absolute Unc's)	—	Pa	Pa	Pa	Pa
Head (height)	B5	n/a	n/a	n/a	n/a
Head (density)	B6	n/a	n/a	n/a	n/a
Surface tension	B7	n/a	n/a	n/a	n/a
Sensitivity	B13	2.9	2.9	2.9	2.9
Barometer	B8	n/a	5.0	n/a	5.0
Bell mass	B1a	2.0	2.0	2.0	2.0
Piston mass	B1b	0.8	0.8	0.8	0.8

PG7202
1 MPA/KG Piston-cylinder range – Manual and AMH™

Instrumental measurement uncertainty ± [15 Pa + (20 ppm + 0.15 ppm/MPa)]

Variable or Parameter	Type Unc	Gauge	Absolute by/addition of atmospheric pressure	Gauge	Absolute by/addition of atmospheric pressure
Full Mass Load	–	35	35	100	100
(Relative Unc's)	–	(ppm)	(ppm)	(ppm)	(ppm)
Mass (M)	B1	2.50	2.50	2.50	2.50
Local G	B2	1.00	1.00	1.00	1.00
Air Density	B3	0.32	0.32	0.32	0.32
Mass Density	B4	n/a	n/a	n/a	n/a
Head (height)	B5	0.35	0.35	0.35	0.35
Head (density)	B6	0.23	0.23	0.23	0.23
Resolution	B9	0.29	0.29	0.29	0.29
PC Temp	B10	0.50	0.50	0.50	0.50
Verticality	B11	0.10	0.10	0.10	0.10
Effective area	B12	10.00	10.00	10.00	10.00
Linearity	B14	3.00	3.00	8.00	8.00
Elastic deformation	B15	3.97	3.97	11.35	11.35
Thermal expansion	B16	0.22	0.22	0.22	0.22
Stability Ae	B17b	1.00	1.00	1.00	1.00
Sensitivity	B13	0.29	0.29	0.29	0.29
Type A	A1	2.50	2.50	2.50	2.50
Combined		11.8 ppm + 7.2 Pa	11.8 ppm + 8.75 Pa	17.6 ppm + 7.18 Pa	17.6 ppm + 8.75 Pa
Combined and expanded for (K =2)		24 ppm + 14 Pa	24 ppm + 17 Pa	35 ppm + 14 Pa	35 ppm + 17 Pa
(Absolute Unc's)	–	Pa	Pa	Pa	Pa
Head (height)	B5	n/a	n/a	n/a	n/a
Head (density)	B6	n/a	n/a	n/a	n/a
Surface tension	B7	n/a	n/a	n/a	n/a
Sensitivity	B13	5.8	5.8	5.8	5.8
Barometer	B8	n/a	5.0	n/a	5.0
Bell mass	B1a	4.0	4.0	4.0	4.0
Piston mass	B1b	1.5	1.5	1.5	1.5

PG7202
2 MPA/KG Piston-cylinder range – Manual and AMH™

Instrumental measurement uncertainty ± [30 Pa + (30 ppm + 0.15 ppm/MPa)]

Variable or Parameter	Type Unc	Gauge	Absolute by/addition of atmospheric pressure	Gauge	Absolute by/addition of atmospheric pressure
Full Mass Load	–	35	35	50	50
(Relative Unc's)	–	(ppm)	(ppm)	(ppm)	(ppm)
Mass (M)	B1	2.50	2.50	2.50	2.50
Local G	B2	1.00	1.00	1.00	1.00
Air Density	B3	0.32	0.32	0.32	0.32
Mass Density	B4	n/a	n/a	n/a	n/a
Head (height)	B5	0.35	0.35	0.35	0.35
Head (density)	B6	0.23	0.23	0.23	0.23
Resolution	B9	0.29	0.29	0.29	0.29
PC Temp	B10	0.50	0.50	0.50	0.50
Verticality	B11	0.10	0.10	0.10	0.10
Effective area	B12	15.00	15.00	15.00	15.00
Linearity	B14	5.00	5.00	8.00	8.00
Elastic deformation	B15	7.84	7.84	11.20	11.20
Thermal expansion	B16	0.22	0.22	0.22	0.22
Stability Ae	B17b	1.50	1.50	1.50	1.50
Sensitivity	B13	0.29	0.29	0.29	0.29
Type A	A1	2.50	2.50	2.50	2.50
Combined		18.1 ppm + 14.4 Pa	18.1 ppm + 15.2 Pa	20.8 ppm + 14.4 Pa	20.8 ppm + 15.2 Pa
Combined and expanded for (K =2)		36 ppm + 29 Pa	36 ppm + 30 Pa	42 ppm + 29 Pa	42 ppm + 30 Pa
(Absolute Unc's)	–	Pa	Pa	Pa	Pa
Head (height)	B5	n/a	n/a	n/a	n/a
Head (density)	B6	n/a	n/a	n/a	n/a
Surface tension	B7	n/a	n/a	n/a	n/a
Sensitivity	B13	11.6	11.6	11.6	11.6
Barometer	B8	n/a	5.0	n/a	5.0
Bell mass	B1a	8.0	8.0	8.0	8.0
Piston mass	B1b	3.0	3.0	3.0	3.0

FLUKE ®
Calibration

PG7000 Piston-cylinder modules
Summary of pressure measurement specifications

Designator	Uncertainty[1] [±]	Uncertainty[1] with AMH [±]	Sensitivity[1]	Typical drop rate @ pressure[3] [mm/min]	Reproducibility[4] [± ppm]	Type A[5] [± ppm]
PC-7100/7600-10 TC PC-7100/7600-10-L	(0.2 Pa + 12 ppm)	(0.08 Pa + 12 ppm)	(0.01 Pa + 0.5 ppm)	0.2 @ 350 kPa	2	1
PC-7100/7600-20	(0.2 Pa + 13 ppm)	(0.13 Pa + 13 ppm)	(0.04 Pa + 0.5 ppm)	0.3 @ 700 kPa	2	2
PC-7100/7600-50	(0.5 Pa + 14 ppm)	(0.3 Pa + 14 ppm)	(0.1 Pa + 0.5 ppm)	0.5 @ 1750 kPa	3	2
PC-7100/7600-100	(1 Pa + 20 ppm)	(0.6 Pa + 20 ppm)	(0.2 Pa + 0.5 ppm)	0.7 @ 3500 kPa	3	2
PC-7100/7600-200	(2 Pa + 20 ppm)	(1.2 Pa + 20 ppm)	(0.4 Pa + 0.5 ppm)	1.0 @ 7000 kPa	5	2
PC-7302-100	(16 Pa + 17 ppm)	(16 Pa + 17 ppm)	(2 Pa + 1 ppm)	0.02 @ 5 mPa	2	3
PC-7302-200	(16 Pa + 20 ppm)	(16 Pa + 20 ppm)	(4 Pa + 1 ppm)	0.04 @ 10 mPa	3	3
PC-7302-500	(20 Pa + 20 ppm)	(20 Pa + 20 ppm)	(10 Pa + 1 ppm)	0.10 @ 25 mPa	3	4
PC-7302-1	(25 Pa + 25 ppm)	(25 Pa + 25 ppm)	(20 Pa + 1 ppm)	0.2 @ 50 mPa	3	5
PC-7302-2	[40 Pa + (25 ppm + 0.04 ppm/MPa)]	[40 Pa + (25 ppm + 0.04 ppm/MPa)]	(40 Pa + 1 ppm)	0.40 @ 100 mPa	4	5
PC-7302-5	[100 Pa + (35 ppm + 0.04 ppm/MPa)]	[100 Pa + (35 ppm + 0.04 ppm/MPa)]	(100 Pa + 1 ppm)	1.0 @ 250 mPa	6	6
PC-7202-100	(2 Pa + 20 ppm)	(2 Pa + 20 ppm)	(2 Pa + 1 ppm)	0.10 @ 5 mPa	2	2
PC-7202-200	(3 Pa + 20 ppm)	(3 Pa + 20 ppm)	(4 Pa + 1 ppm)	0.15 @ 10 mPa	3	3
PC-7202-500	[8 Pa + (18 ppm + 0.15 ppm/MPa)]	[8 Pa + (18 ppm + 0.15 ppm/MPa)]	(10 Pa + 1 ppm)	0.20 @ 25 mPa	3	4
PC-7202-1	[15 Pa + (20 ppm + 0.15 ppm/MPa)]	[15 Pa + (20 ppm + 0.15 ppm/MPa)]	(20 Pa + 1 ppm)	0.25 @ 50 mPa	3	5
PC-7202-2	[30 Pa + (20 ppm + 0.15 ppm/MPa)]	[30 Pa + (20 ppm + 0.15 ppm/MPa)]	(40 Pa + 1 ppm)	0.50 @ 100 mPa	4	5

[1] Instrumental Measurement Uncertainty: All relevant sources of uncertainty under typical operating conditions are identified, quantified and combined following JCGM 100:2008, *"Guide to the Expression of Uncertainty in Measurement (GUM)"*.

[2] Sensitivity: The smallest variation in input detectable in output. Since sensitivity is considered a rectangular distribution, it is given as 2a per the definition given in the GUM and is not ±.

[3] Typical Drop Rate: Typical drop rate at the pressure given.

[4] Reproducibility: The root sum square of the piston-cylinder stability and using $2x10^{-6}$ for the stability of masses with a coverage factor of 2.

[5] Type A: Predicted typical type A uncertainty contribution due to the variation of piston position from +2 to –2 mm and rotation from 5 to 50 RPM.

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