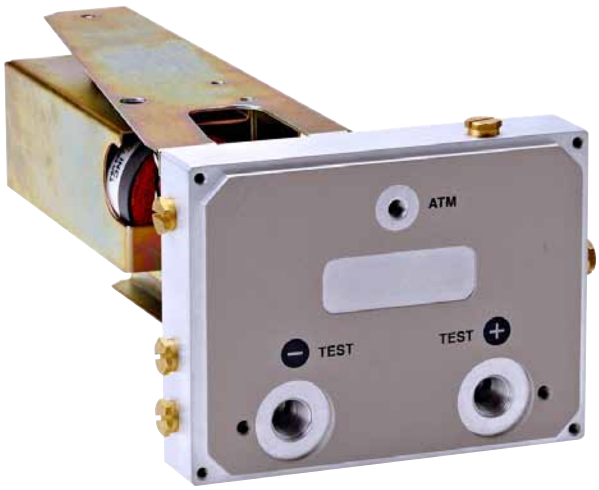
FLUKE®

Calibration

Guide to determining pressure measurement uncertainty for Q-RPT based products

Technical Note



This technical note is a product uncertainty analysis of the Q-RPT based products which include PPC3, PPC4, PPCH, PPCH-G, RPM4 and E-DWT. A separate uncertainty analysis for RPM4-AD, a Q-RPT based air data calibration reference, can be found in technical note 7020TN10[1].

The products listed in the previous paragraph use Q-RPTs to measure pressure. A Q-RPT is a quartz reference pressure transducer that uses a mechanism to convert fluid pressure applied force to an output frequency. Though Q-RPTs are some of the most precise pressure measuring instruments available, they are transfer standards and therefore must be calibrated to output a correct pressure. This guide focuses on the calibration references used, the Q-RPT's ability to reproduce the output of the reference, and its ability to maintain that reproduceability over a specified calibration interval.

This technical note is divided into three main sections. The first section provides all the information to create typical pressure measurement uncertainties by listing all the uncertainties with their sensitivities and the reasoning behind the application of those uncertainties. The second examines the different measurement modes available in Q-RPT based products. The final section is a description of the ppc4 live uncertainty settings.

At the end of this document are tables that identify uncertainties and their values for the classes available with Q-RPT products based on measurement mode, whether or not autozero is used, or if used in parallel.

In this technical note, measurement specifications of the Q-RPTs are supported by an uncertainty analysis based on the recommendations of "*Guide To the Expression of Uncertainty in Measurement*"[2]. All influences are discussed individually to help metrologists using Q-RPT based products to evaluate whether or not the uncertainties are valid for their application. The final portion of this technical note combines all the uncertainties into tables categorized by range, mode and class.

It is important to note that, although this uncertainty analysis is appropriate for the population of Q-RPTs, it is likely that the uncertainty of an individual Q-RPT will be less than that of the population. It is our hope that this technical note will suffice as a guide for users of Q-RPT based products to calculate uncertainties for individual Q-RPTs. Available by request from Fluke Calibration is an Excel spreadsheet that may aid the user while referencing this technical note.

Uncertainty considerations

Because of the possible variances in use and calibration, it is necessary to define the boundaries on conditions that affect the final uncertainty of the Q-RPT.

- Operating mode
- Fluid media
- Environment
- Orientation
- Reference uncertainty
- Calibration and AutoZero frequency
- Control precision
- Dwell

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Operating mode

The operating modes supported by this uncertainty analysis are:

- Absolute
- Gauge
- Negative gauge
- Parallel/differential

The operating modes will have some influence on the final uncertainty published in this document. For the most part the differences in the final uncertainties are small, but not negligible.

Fluid media

The fluid used to transmit pressure has some influence on the final uncertainty calculated for the Q-RPT. This is primarily due to head corrections made by the user of the Q-RPT. The fluids used with Q-RPTs are:

- Nitrogen
- Air (clean and dry)
- Helium
- Di-2-Ethylhexyl Sebacate
- Water
- Other

The above listed fluids are selectable from menus of Q-RPT products. For hydraulic RPM4 and for PPCH the category 'other' allows for liquid densities other than sebacate or water. For an RPM4 the fluid can be any fluid compatible with RPM4 internal pressure components. For PPCH this must be a fluid recommended by Fluke Calibration due to control dependencies. Please contact Fluke Calibration for a list of available hydraulic fluids for PPCH.

For this uncertainty analysis the assumption is that either nitrogen or Sebacate are used. Deviations from these uncertainties are insignificant when considering air, helium or water.

Environment

As long as humidity is such that it is non-condensing, the only limits required are for vibration, temperature and the rate at which the temperature changes. The limits for temperature for this uncertainty analysis are:

- Temperature: 50 °F to 104 °F (10 °C to 40 °C)
- Temperature change: Less than 9 °F (5 °C) per hour
- Vibration: Meets MIL-T-28800D

Note that most Q-RPT based products have an operating temperature range from 59 °F to 95 °F (15 °C to 35 °C). Since E-DWT specifies 50 °F to 104 °F (10 °C to 40 °C), and since the increase in uncertainty for the expanded range of the other products is insignificant, this analysis uses 50 °F to 104 °F (10 °C to 40 °C).

Orientation

There is no sensitivity to orientation of a Q-RPT as long as it is calibrated and used in the same position. Though not quantified, changes due to orientation which may occur are considered to be an offset that is eliminated with use of AutoZero.

Reference uncertainty

The reference uncertainty chosen for this analysis is intended to be as conservative as possible to allow the managers of the equipment to have flexibility with available references. However, it is assumed that a piston gauge is used as the reference.

Other devices could be used as references for Q-RPT's, such as mercury manometers, but piston gauges are recommended based on their ability to calibrate all Q-RPT spans and also based on their inherent repeatability. In many cases for piston gauges, even though the relative uncertainty may be high compared to Q-RPT specifications, the repeatability and linearity are much better. This allows for much greater confidence in curve fitting and analysis of the conformance of a Q-RPT well inside the uncertainty in pressure supplied by the piston gauge.

Calibration and AutoZero frequency

This analysis assumes a recalibration interval of 1 year. Estimates and uncertainty analysis are presented for both a regular AutoZero with enough frequency to eliminate the zero drift of a Q-RPT [3] and without the use of AutoZero between calibrations. For gauge mode calculations use of AutoZero is always assumed.

Control precision

For pressure control products such as PPC3, PPC4, PPCH and PPCH-G an additional uncertainty can be included to account for control precision. This additional uncertainty is only needed when the controller is in dynamic mode and the operator is using the front panel display only, or when the nominal target pressure is used for the measurement. When queried remotely, regardless of control mode, the value of pressure returned by the controller is the actual measured pressure, not the requested pressure.

Dwell (short term stability)

All pressure systems and components have an inherent time to achieve equilibrium or stabilize. This is particularly important for high level calibration applications and is the reason why a dwell time is recommended between setting pressure and making comparisons. In the case of a Q-RPT a stabilization time of 30 seconds is required after any significant instantaneous pressure change to ensure stability of the Q-RPT and the system for comparisons within the stated uncertainty. For Q-RPTs in automated controllers following a normal calibration sequence, the time it takes to control to a point is sufficient dwell time. For manual pressure control, while the control time may also be sufficient, it is recommended that a 30 second dwell time be incorporated after setting pressure before taking a reading.

Q-RPT classifications

Q-RPTs are initially characterized using piston gauges to determine and to correct deviations in linearity as well as possible. The results of these characterizations are used to classify Q-RPTs by uncertainty categories. The class and product uncertainty categories available for Q-RPTs are:

- Premium (p class): ± (0.008 % of reading or 0.0024 % of AutoRanged span, whichever is greater)
- Standard (s class): ± (0.01 % of reading or 0.003 % of Q-RPT span, whichever is greater)
- Standard Mid (s class): ± (0.013 % of reading or 0.0039 % of Q-RPT span, whichever is greater) A20M through A140M
- Standard High (s class): ± (0.018 % of reading or 0.0054 % of Q-RPT span, whichever is greater) A200M and A280M
- Full scale (f class): ± (0.015 % of AutoRanged span)
- EDWT (e class): ± 0.02 % of reading or 0.002 % of Q-RPT span, whichever is greater)

The uncertainties for Premium and Full Scale classes apply to AutoRanged spans 30 % to 100 % of Q-RPT span for all Q-RPTs. The only exceptions to this are BG15K and G15K Full Scale class where the uncertainty above applies to AutoRanged spans as low as 10 % of Q-RPT span. Premium BA100K Q-RPTs are not AutoRanged below 100 % of Q-RPT span.

RPM4 reference pressure monitors can use two Q-RPTs to measure the same pressure. In this operation, called parallel mode, Q-RPT uncertainties are uncorrelated and are reduced by a factor of the square root of two. Parallel mode results in product uncertainties lower than those of individual Q-RPTs.

Uncertainties

This section defines the influences of uncertainties that apply to all Q-RPTs. A brief explanation of each uncertainty is provided along with the uncertainty at k=2, its sensitivity to pressure, the type of distribution and the value at K=1, one standard uncertainty.

Reference

The uncertainty in pressure contributed by the reference is dependent upon the Q-RPT span. Table 1 provides a list of reference uncertainties required for all ranges. Generally calibrations performed at Fluke Calibration will have reference uncertainties that are lower than what is shown in Table 1, but the values in Table 1 are expanded to allow for other references to be used without having to modify the uncertainties calculated.

For Premium and Full Scale class Q-RPTs, the absolute uncertainties in the Q-RPT uncertainty tables at the end of this document are listed as % of AutoRanged span. To be conservative the Absolute uncertainties listed in Table 1 are applied to the lowest AutoRanged span to which the uncertainties can apply, i.e. 30 % of Q-RPT span for all Premium and all Full Scale class Q-RPTs and 10 % of Q-RPT span for Full Scale BG15K and G15K.

Type of uncertainty: relative and absolute
Sensitivity: 1 % of rdg/% of rdg or 1 Pa/Pa
Distribution: considered normal
Standard uncertainty: See Table 1

Q-RPT	Relative @ 95 % (% rdg)	Absolute @ 95 % (Pa)	Relative K=1 (% rdg)	Absolute K=1 (Pa)
A280M, A200M	0.005	100	0.0025	50
A140M, A100M, A70M	0.004	50	0.002	25
A40M, A20M	0.004	25	0.002	12.5
A14M, A10M, A7M, A3.5M	0.003	20	0.0015	10
A2M, A1.4M	0.003	3	0.0015	1.5
A700K, A350K	0.003	1	0.0015	0.5
A200K, A160K, A100K, BA100K	0.003	0.2	0.0015	0.1
G200K, G100K	0.003	0.1	0.0015	0.05
BG15K, G15K	0.003	0.005	0.0015	0.0025

Table 1. Reference uncertainties

Linearity, hysteresis and repeatability (precision)

One of the most important characteristics of a Q-RPT as a transfer standard is precision. Precision is the combination of linearity, hysteresis and repeatability. The combination of linearity and hysteresis without repeatability is called conformance. Conformance is used as a Q-RPT adjustment specification and is listed separately from repeatability in this uncertainty analysis. Precision normally includes resolution as one of the characteristics, but with Q-RPTs resolution does not limit the final product uncertainty.

Linearity
Linearity is the uncertainty from deviations from a perfectly linear output of a Q-RPT. Q-RPT linearity is adjusted using a proprietary model determined by extensive characterization using a piston gauge as a reference. The linearity of each Q-RPT is quantified from the characterization results and used for grading into Q-RPT classes. For the most part Q-RPTs can be made to have similar linearity considering the extensive number of points in the characterization test and the ability of the model to 'straighten out' non-linearities. However, repeatability, hysteresis and undetected non-linear sections in the range can limit the degree of resulting linearity.

It is important to note that the contribution of linearity to uncertainty is estimated for the beginning and ending characterized range plus approximately 0.5 % of the Q-RPT span above and below that characterized range. For example if an A350K Q-RPT (350 kPa [50 psi] absolute range) is characterized from 10 kPa to 350 kPa (1.25 psi to 50 psi), then it would not be guaranteed to be within specification less than 8.25 kPa (1.2 psi) absolute without verification with a reference. For the most part the characterization range is the same as the calibrated range shown in the calibration report from Fluke Calibration. There are some deviations to this such as an A700K Q-RPT that is characterized to 800 kPa (116 psi) absolute to account for use in gauge mode.

Table 2 lists the span of Q-RPT calibrations performed at Fluke Calibration. Note that these calibration spans are current procedural guidelines and can change with customer specific requests or future improvements.

Linearity is considered independent from one Q-RPT to the next, but is consistent for a single Q-RPT from one calibration to the next. It is possible that the linearity of a Q-RPT may change as the Q-RPT ages, but this has not been prevalent since the time that Fluke Calibration began calibrating Q-RPTs. If there is a change in linearity the characterization process can be repeated at any time. It is possible that there are changes in linearity with large changes in temperature. However it is not expected to be significant inside of the 50 °F to 104 °F (10 °C to 40 °C) temperature range, as long as the temperature is stable. If it is predicted that a Q-RPT is going to be operated at a temperature that is significantly different than the temperature that it was calibrated, it may be necessary to add additional uncertainty for linearity.

Q-RPT span	Calibration span
A280M	ATM – 280000 kPa (ATM to 40000 psi)
A200M	ATM – 200000 kPa (ATM to 30000 psi)
A140M	ATM – 140000 kPa (ATM to 20000 psi)
A100M	ATM – 100000 kPa (ATM to 15000 psi)
A70M	ATM – 70000 kPa (ATM to 10000 psi)
A40M	ATM – 40000 kPa (ATM to 6000 psi)
A20M	ATM – 20000 kPa (ATM to 3000 psi)
A14M	ATM – 14000 kPa (ATM to 2000 psi)
A10M	ATM – 10000 kPa (ATM to 1500 psi)
A7M	ATM – 7000 kPa (ATM to 1000 psi)
A3.5M	70 kPa to 3500 kPa (10 psi to 500 psi)
A2M	70 kPa to 2000 kPa (10 psi to 300 psi)
A1.4M	35 kPa to 1400 kPa (5 psi to 200 psi)
A700K	18 kPa to 700 kPa (2.6 psi to 100 psi)
A350K	350 kPa to 10 kPa (50 psi to 1.5 psi)
A200K	200 kPa to 10 kPa (30 psi to 1.5 psi)
A160K	160 kPa to 6 kPa (23 psi to 0.9 psi)
A116K	116 kPa to 6 kPa (16.8 psi to 0.9 psi)
A100K	110 kPa to 6 kPa (16 psi to 0.9 psi)
BA100K	70 kPa to 110 kPa (10 psi to 16 psi)
G200K	0 to 200 kPa (0 to 30 psi)
G100K	0 to 100 kPa (0 to 14.5 psi)
G15K	0 to 15 kPa (0 to 2.2 psi)
BG15K	-15 kPa to 15 kPa (-2.2 psi to 2.2 psi)

Table 2. Q-RPT span of calibration

Repeatability
Repeatability is the ability of the Q-RPT to repeat a pressure when subjected to the same pressure and conditions. Repeatability can only be measured by reproducing a test point in the same manner more than once. Usually this means that full pressure cycles performed the same way must be used to measure repeatability at individual points throughout the calibrated range.

Like linearity, repeatability of a Q-RPT is evaluated during characterization and used to determine Q-RPT class.

Hysteresis
Hysteresis is the uncertainty from an influence that is dependent upon the mechanical memory of the Q-RPT and depends upon the direction, duration and magnitude of the change in pressure. Because of the dependency of on the magnitude of pressure change a Q-RPT experiences during a test, hysteresis is considered scalable. This means, for a Q-RPT, the magnitude of the effect of hysteresis is usually relative to the total amount of pressure change during a calibration cycle.

Unlike linearity, hysteresis is not always consistent. However it is usually consistent if the same test is performed again. Some Q-RPTs will be more susceptible to changes in pressure and variant dwell times than others.

Like linearity and repeatability, hysteresis is tested during a Q-RPT characterization. This test includes a measure of the total hysteresis and the scalability of the Q-RPTs hysteresis.

Combining precision characteristics

Table 3 provides information describing the precision specifications for each class. In the table hysteresis and linearity are combined and called conformance. Repeatability is separated and is an uncertainty, but is not included in the conformance specification and is not used for the as left tolerance in the calibration of a Q-RPT. Since the conformance is used as the as left tolerance of a Q-RPT when it is calibrated, this really ensures that very close to 100 % of Q-RPTs that are delivered are within this specification. However there is no emphasis in probability density of the deviations for a specific Q-RPT inside of the tolerance limits. This means that the conformance specification is given at k=3 and is considered a rectangular distribution. To express k=1 the tolerance (conformance) is divided by the square root of six (approximately 2.5).

Rangeability refers to the lowest AutoRange, in percent of Q-RPT span, where the uncertainties are the same as the Q-RPT span. The lower limit in the last column of Table 2 is for Q-RPTs that are percent of reading and is where the percent of reading becomes a fixed value of either Q-RPT span, or the AutoRanged span for rangeable Q-RPTs.

For example, if you consider an A700K premium Q-RPT, which has a 700 kPa Q-RPT span, you can AutoRange to 210 kPa, 30 % of 700 kPa, and still expect the same conformance specification as 700 kPa. In this case the lower limit where percent of reading specifications become fixed is 30 % of 210 kPa or 63 kPa. One way of describing the lower limit, for conformance only, is to use the expression:

± (0.005 % of reading or 0.0015 % of AutoRanged span, whichever is greater). *For Premium*

For those Q-RPTs that are not rangeable, such as standard and E-DWT class, the same rule applies for the lower limit and the expression is changed to:

± (0.008 % of reading or 0.0024 % of Q-RPT span, whichever is greater). *For Standard*

Or :

± (0.018 % of reading or 0.0018 % of Q-RPT span, whichever is greater). *E-DWT*

For the latter case note that the lower limit is 10 % of the Q-RPT span as compared to 30 % for standard, but there is little difference in the second part of the expression (0.0018 % of Q-RPT span versus 0.0024 % Q-RPT span).

Type of uncertainty: relative and absolute
Sensitivity: 1
Distribution: rectangular for conformance and considered normal for repeatability
Standard uncertainty: See Table 2

Temperature

Q-RPTs are compensated for changes in temperature using an on-board temperature measurement device. But there is an uncertainty in that compensation that is equal to or less than ± 0.0001 percent of Q-RPT span per °C at k=2. This value is based on a manufacturer's specification for all Q-RPTs and is considered to be an estimate. Since it is apriori the distribution is rectangular and is primarily applied as a percent of Q-RPT span with a small component applied as uncertainty in percent of reading.

The value of uncertainty accounts for changes in temperature in a range of 50 °F to 104 °F (10 °C to 40 °C). If a Q-RPT is calibrated and/or AutoZeroed at 25 °C then the uncertainty applies to a maximum change of ± 15 °C or an uncertainty at k=2 of ± 0.0015 percent of Q-RPT span. An additional ± 0.001 percent of reading, at k=2, is added to account for small changes in slope caused by changes in temperature in the 50 °F to 104 °F (10 °C to 40 °C) range. However, if the temperature is stable and the Q-RPT is AutoZeroed, the constant part of this uncertainty is reduced to the effect of total change of ± 5˚ C, a conservative estimate of total temperature change during a calibration, or in between AutoZeros.

The uncertainties in temperature only apply when the temperature of the Q-RPT has had sufficient time to stabilize. The amount of time required for stability would depend on the amount of change of temperature. As a rough estimate approximately one hour per 41 °F (5 °C) change should be observed. There is no quantification of uncertainties when there is not a temperature soak time observed. Uncertainties may be as high as 0.01 % of Q-RPT span with large temperature changes and without waiting for temperature stability of the Q-RPT product.

Q-RPT class [all values at k=1]	**Conformance (tolerance)**	**Conformance**	**Repeatability**	**Rangeability**	**Lower limit**
Premium [% of reading, ±]	0.005	0.0020	0.0015	30 %	30 %
Standard [% of reading, ±]	0.008	0.0033	0.002	100 %	30 %
Standard MID [% of reading, ±]	0.012	0.0050	0.003	100 %	30 %
Standard HI [% of reading, ±]	0.015	0.0060	0.004	100 %	30 %
Full scale [% of AutoRanged Span, ±]	0.010	0.0041	0.003	30 %	100 %
Full scale (BG15K and G15K) [% of AutoRanged Span, ±]	0.010	0.0041	0.003	10 %	100 %
EDWT [% of reading, ±]	0.020	0.0082	0.004	100 %	10 %

Table 3. Precision Uncertainties, tolerance and @ k=1.

Type of uncertainty: absolute and relative
Sensitivity: 1 %/% Q-RPT span or reading
Distribution: triangular
Standard uncertainty: 0.0005 % of reading and 0.00075 % Q-RPT span with AutoZero off and 0.00025 % of Q-RPT Span with AutoZero on.

Head pressure

It is always possible to place devices being calibrated by Q-RPTs at the reference level of the Q-RPT. For this reason this uncertainty is not included for the typical pressure measurement uncertainty. However in support of a specific Q-RPT or calibration uncertainty a short description is given here and a row is reserved in the Q-RPT Uncertainty spreadsheet for the head pressure.

The uncertainty in head pressure depends on how well the head height is measured and also what media is being used and how well the density of the media is known. The amount of uncertainty from the height measurement should be the same whether or not a device is used in oil or gas, but the influence will be different considering the density will be different.

If the uncertainty in the height measurement is ± 0.04 in (± 1 mm), at k=2, the uncertainty in gas is approximately ± 0.1 parts in 106 of the measured pressure. If the media is oil then the same uncertainty in height is approximately ± 0.008 kPa. This considers both the uncertainty in height and the density used by the Q-RPT products that calculate density.

Type of uncertainty: absolute (oil) or relative (gas)
Sensitivity: 9 Pa/mm for oil and 0.1 parts in 106 for gas
Distribution: rectangular
Standard uncertainty: 0.02 in (0.5 mm)

Line pressure

There are two configurations where an uncertainty in pressure with respect to line pressure is relevant. In RPM4 differential mode dual Q-RPTs in parallel measure differential pressures at line pressure within the span of the Q-RPTs. In addition, G15K and BG15K Q-RPTs have a moderate sensitivity to changes in barometric pressure.

For RPM4 Q-RPTs in parallel, the uncertainty results from the repeatability of the low side of the differential pressure measurement. The added uncertainty is shown as repeatability in Table 3.

G15K and BG15K Q-RPTs are compensated for line pressures from 70 kPa to 110 kPa (10 psi to 16 psi). Most of the influence of line pressure is eliminated when the G15K or BG15K is zeroed, however there is some slight relative line pressure effect equal to ± 0.002 % of reading at k=2.

Type of uncertainty: relative
Sensitivity: 1% or rdg/% of rdg
Distribution: normal
Standard uncertainty: 0.001 % of reading

Stability

Stability is defined in two separate categories: change in slope of the Q-RPT and change in offset. Change in offset can be corrected using the AutoZero function or calibration. Change in slope can only be corrected in calibration. The effect of changes in both offset and slope is reduced in parallel mode where two Q-RPTs of the same range read the same pressure.

There are three separate uncertainties when considering changes in offset. The uncertainty when AutoZero is on (same for all gauge and differential modes), the uncertainty when AutoZero is off considering one Q-RPT reading absolute pressure, and the uncertainty when AutoZero is off and reading absolute pressure in parallel mode.

When AutoZero is on in gauge and differential modes there is no additional uncertainty required except for absolute Q-RPTs used in gauge mode. In this case the uncertainty due to resolution and repeatability of the internal barometer is considered because the barometer is used to detect changes in barometric pressure since the time a Q-RPT was AutoZeroed in gauge mode. The internal barometer resolution is 0.1 Pa and repeatability is ± 1 Pa using a coverage factor of 2. This uncertainty is considered to be rectangular. Because this is an uncertainty in pressure and not percent of reading or span, it is not included in the uncertainty tables. The influence will vary with Q-RPT or AutoRanged span, but worse case is approximately ± 0.001 % when used with an A100K, at k=2.

When AutoZero is on for absolute Q-RPTs measuring absolute pressure, the uncertainty is the uncertainty of the reference used to determine the Zoffset and the change of offset in between AutoZeros. An AutoZero reference can always be another Q-RPT with lower uncertainty. In this case the reference uncertainty is what is determined for that Q-RPT. If a piston gauge is used as an AutoZero reference, Table 1 provides the uncertainty.

The uncertainty for stability of slope is ± 0.005 % of reading for one Q-RPT for one year. For parallel mode the uncertainty is ± 0.0035 % of reading for one year. Uncertainty due to changes in offset (with AutoZero off) are ± 0.005 % Q-RPT span for single Q-RPTs and ± 0.0035 % Q-RPT span for parallel mode for 1 year using a coverage factor of 2.

For all Q-RPTs the uncertainty from stability can be expanded to increase the period of calibration intervals. One recommended approach is to use an AutoZero reference for absolute Q-RPTs and expand only the relative uncertainty for stability.

Type of uncertainty: relative and absolute
Sensitivity: 1 % of rdg/% of rdg or % of span/% of span
Distribution: rectangular
Standard uncertainty: 0.0029 % of rdg, or 0.0029 % Q-RPT span

Internal Barometer

Type of uncertainty: absolute
Sensitivity: 1 Pa/Pa
Distribution: rectangular
Standard uncertainty: 0.58 Pa

Control precision

For Q-RPT based products that control pressure, PPC3, PPC4, PPCH and PPCH-G, an additional uncertainty may be included for dynamic control. For the most part this is not necessary because the only time this applies is when the displayed front panel pressure is used in lieu of the pressure output remotely by the controller.

The additional uncertainty in pressure from dynamic control is solely dependent upon the pressure hold setting. The default setting is 0.005 % of the active range (0.01 % of active range for PPCH and PPCH-G) but may be reduced or increased. This uncertainty can be treated like resolution because when a controller is within the hold limits it displays the requested pressure and the operator does not know where inside the limit the pressure really is. This means it is a rectangular distribution that is equal to two times the hold limit set, since the hold limit is applied as plus or minus.

Considerations of measurement modes

All absolute Q-RPTs can be used to measure gauge pressure. Also dual absolute and gauge Q-RPTs can measure differential pressures at a line pressure other than atmosphere (gauge). However since gauge Q-RPT spans are no greater than 200 kPa (29 psi), only absolute Q-RPTs are typically used for measuring differential pressure. Absolute, gas only Q-RPTs that have ranges that are low enough can measure pressure in both gauge and negative gauge modes but may be limited in range because of the absolute span available. In some of these cases the product uncertainty specification may not be intuitive. This section explains how the product uncertainty specification applies to A350K, A200K, A160K and A100K Q-RPTs and AutoRanges for premium Q-RPTs below 700 kPa (102 psi) in gauge and negative gauge, differential pressure for all absolute Q-RPTs, and the use of parallel mode to measure gauge, negative gauge and absolute pressures for all Q-RPTs.

Absolute Q-RPT measuring gauge pressure

All Q-RPT based products that use absolute Q-RPTs have an on board barometer that monitors changes in barometric pressure and compensates the absolute Q-RPT for those changes. This allows them to measure real time gauge pressure without having to re-zero when atmospheric pressure changes during a test.

For all Q-RPTs with spans from 700 kPa (102 psi) and above, there is no difference in the span between absolute, gauge and negative gauge. For all Q-RPTs, there is no difference in the span between absolute and negative gauge. When AutoRanging in negative gauge for A350K, A200K, A160K and A100K Q-RPTs, the value entered is considered gauge mode and atmospheric pressure is added on to complete the negative gauge range. It is not an asymmetrical span between gauge and negative gauge. For instance an A350K Q-RPT used in negative gauge mode is 250 kPa in gauge and approximately 100 kPa (15 psi) in negative gauge. If this is AutoRanged to 50 kPa (7 psi) then the gauge span is 50 kPa (7 psi) and negative gauge span is still 100 kPa (15 psi). This means that negative gauge mode ends up using the same span as absolute mode. The uncertainties for negative gauge mode would be exactly the same as absolute mode if not for the AutoZero that must occur for an absolute Q-RPT to be put into gauge or negative gauge mode. What occurs is that repeatability, linearity and hysteresis combine in a different way than in absolute mode.

The main difference is that when AutoZeroing a Q-RPT of these ranges, the repeatability and hysteresis are the same as with absolute, whereas the linearity is changed because it is perfect at zero gauge pressure and is no longer based on a least squares fit of all the pressures. Uncertainties in linearity as well as with uncertainties in changes in slope over time will increase as pressure moves from zero gauge. Whereas uncertainties in repeatability, and depending upon the pressure sequence uncertainties in hysteresis, will be identical as if it was being used in absolute. A similar scenario exists in absolute mode with a Q-RPT that has been AutoZeroed at atmospheric pressure in these ranges.

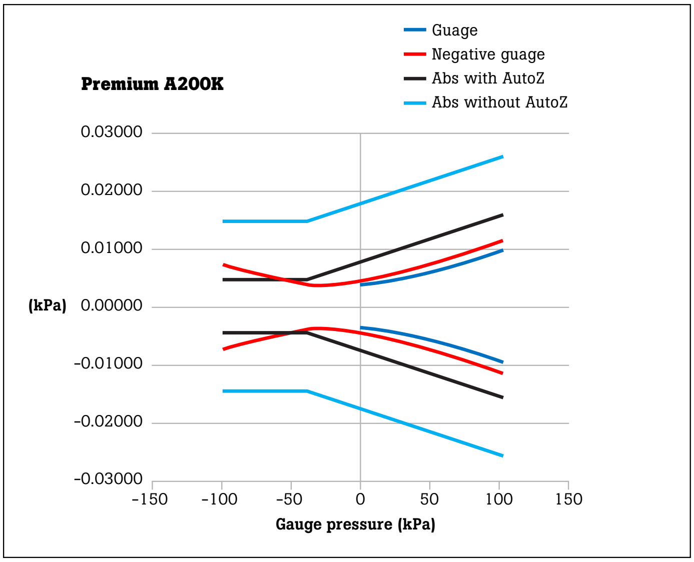

Figure 1. Chart showing the difference in calculated gauge and negative gauge uncertainties compared to typical pressure measurement uncertainty in absolute mode for an A200K premium Q-RPT range.

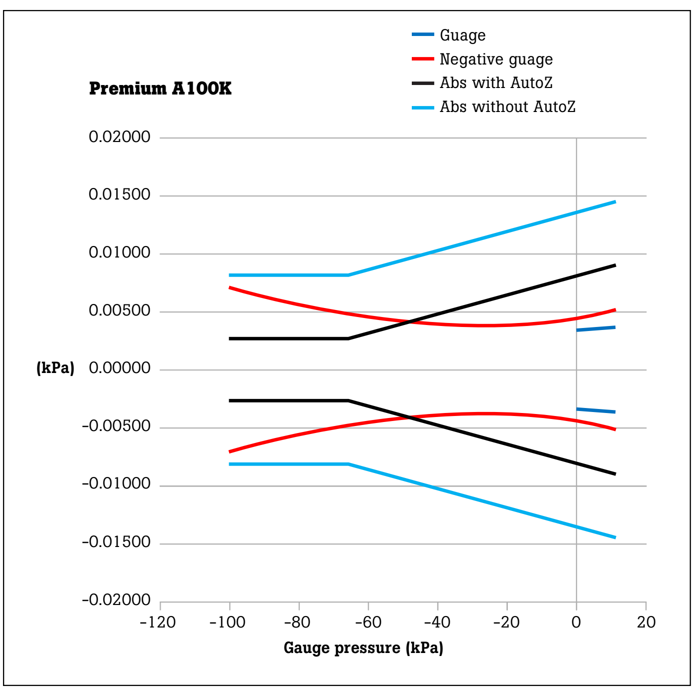

Figure 2. Chart showing the difference in calculated gauge and negative gauge uncertainties compared to typical pressure measurement uncertainty in absolute mode for an A100K premium Q-RPT range.

The difficulty in calculating a product uncertainty for premium Q-RPTs in negative gauge mode in these ranges is that the result is different for every AutoRange available. Figures 1 and 2 present the differences in uncertainty between absolute, gauge and negative gauge measurement modes for an A100K and A200K premium Q-RPT. The calculations assume a barometric pressure of 100 kPa and are scaled in gauge pressure that corresponds to the absolute pressure range of the Q-RPT. As can be seen in these charts the uncertainty in negative gauge is larger than absolute at low absolute or negative gauge pressures. For this reason the absolute typical pressure measurement uncertainty should not be used. Figure 3 shows the same calculation for an A700K premium Q-RPT. This chart shows that the uncertainties are very similar between Absolute with AutoZero on and gauge and negative gauge modes.

Note that in Figure 3 the range is actually 800 kPa (116 psi) absolute. Realistically an A700K Q-RPT is characterized to 800 kPa (116 psi) in absolute, but only calibrated to 700 kPa (102 psi). Because of the range of characterization the 100 kPa (15 psi) extrapolation when put into gauge mode is not considered to be a significant source of uncertainty.

A conservative estimate for a typical pressure measurement uncertainty of an absolute Q-RPT measuring gauge or negative gauge pressure is calculated as the percent of reading specification multiplied by the absolute value of the gauge (or negative gauge) pressure with a limitation of the threshold uncertainty from absolute mode with AutoZero on. Using figure 1 as an example the A200K premium Q-RPT has an absolute pressure threshold uncertainty of ± 4.8 Pa when AutoRanged to 200 kPa (29 psi) absolute. The uncertainty in gauge mode would be ± (0.008 % of absolute value of indicated pressure or 4.8 Pa, whichever is greater)

+1 Pa for dynamic barometric compensation]. Figure 4 shows this typical pressure measurement uncertainty in a chart compared with the calculations.

Dual absolute Q-RPTs measuring differential pressure for RPM4

A feature available with RPM4 is the ability to measure differential pressure at an elevated line pressure. This is only applicable for RPM4s that have Q-RPTs of the same range.

As with negative gauge the uncertainties are not necessarily intuitive nor equal to the absolute pressure specification because of taring at a given line pressure. Because there are so many combinations of line/differential pressures, it is not realistic to define typical pressure measurement uncertainties for differential mode. A conservative estimate would be the percent of reading

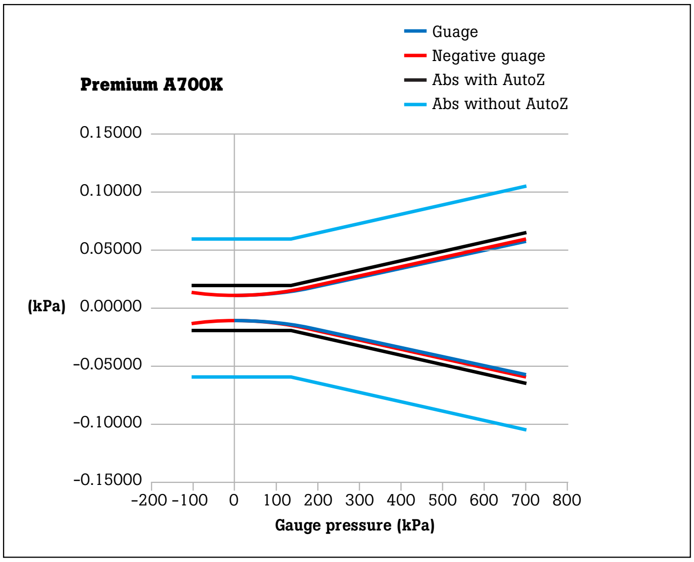

Figure 3. Chart showing the difference in calculated gauge and negative gauge uncertainties compared to typical pressure measurement uncertainty in absolute mode for an A700K premium Q-RPT.

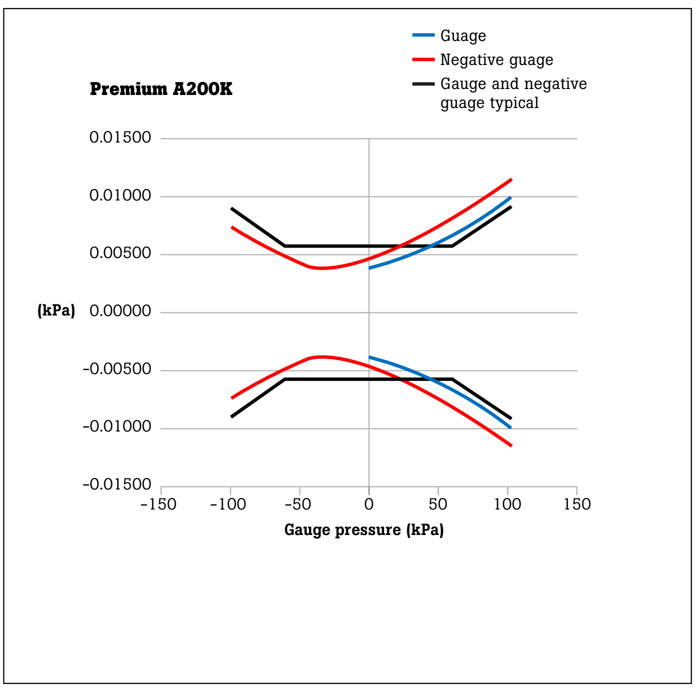

Figure 4. Chart showing the difference in calculated gauge and negative gauge uncertainties compared to typical pressure measurement uncertainty in gauge and negative gauge mode for an A200K premium Q-RPT range.

specification with a limit of the threshold uncertainty of a Q-RPT in absolute mode with regular use of AutoZero. For example, considering the case of using a 7 M standard measuring 100 kPa (15 psi) differential at a line pressure of 3500 kPa (508 psi). The threshold uncertainty is ± 0.21 kPa (0.03 psi) (0.003 % of Q-RPT span), or approximately ± 0.21 % of the 100 kPa (15 psi) differential.

For the same example described in the previous paragraph, but with a premium Q-RPT, the applicable AutoRanged span the specifications are held to is the line pressure plus the differential pressure. In this example the AutoRanged span is 3600 kPa (522 psi) and would have a threshold uncertainty of ± 0.08 kPa (0.01 psi).

Dual Q-RPTs in parallel mode for RPM4

Two Q-RPTs of the same range can be used to read the same gauge or absolute pressure in parallel. In this case all the uncertainties that are uncorrelated, which in this case all uncertainties that are randomly distributed, are reduced by factor of the square root of 2.

The uncertainties that are considered uncorrelated are:

- Repeatability
- Conformance
- Temperature
- Stability

The typical pressure measurement uncertainties at the end of this technical note includes a table for parallel mode where the influences listed above are reduced by the square root of 2 (1.41).

It is important to note that the random nature of conformance, temperature and offset stability are with the population of Q-RPTs. This is to say that that a single Q-RPT’s influence of these parameters will be consistent and somewhat systematic, whereas these influences will be independent from one Q-RPT to the next. The theory of a reduction of uncertainty in these influences has been proven extensively in the verification of calibration of an extensive amount of Q-RPTs in RPM4-AD A160Ka/A160Ka [1] that offer the parallel measurement mode. This is also shown in [3] with dual barometric ranges.

Guard banding Q-RPT calibrations

Guard banding is an adjustment of a tolerance to minimize or eliminate the risk for false accept and to help improve reliability in use. The scheme of using a conformance as a tolerance for as left data when calibrating a Q-RPT is, in effect, a method of guard banding. If only the conformance is used to determine compliance, then the uncertainties left out; reference, repeatability and temperature are what would be used to calculate calibration uncertainty, which is what is used to determine false accept risk or TURs (Test Uncertainty Ratios). So as long as all points are within the conformance tolerance, and the reference and ambient temperature requirements follow this guidelines of this technical note, then the reliability is equal to the reliability that would be achieved if the full, 1 year pressure measurement uncertainty was used as a tolerance and reverse guard banding was applied.

It is a recommendation that with every calibration, as long as a reference is used with sufficient performance characteristics such as a piston gauge, the Q-RPT is adjusted by least squares fit. In the case of gauge mode only Q-RPTs, a least squares fit forced to zero is recommended. However, as long as the points fall within the conformance tolerance there is no need for adjustment. However, experience suggests that this is possible only after adjustment. Recommendations on calibration points and procedures can be found in the respective Q-RPT product operator's manual.

Calculating real time uncertainty for PPC4

The previous sections provide specifications and uncertainties that apply to the entire product lines that use Q-RPTs. These are important for normalizing the expectations of Q-RPT based products. They also provide the information needed for other uncertainty analysis when required. This section uses the information from the previous section and outlines the steps to take to enter uncertainty parameters available with a PPC4.

The available parameters for uncertainty in pressure for a PPC4 are:

- Relative uncertainty
- Threshold uncertainty
- Scaling factor
- Head
- Zerot sability
- Control uncertainty

Relative uncertainty

Relative uncertainty is entered as a percent value and is multiplied by the current pressure when Ready to determine the relative uncertainty. The relative uncertainty default value is determined from the upper portion of the typical pressure measurement uncertainty tables at the end of this document. For Full Scale (f) class Q-RPT's this is always zero and the product uncertainty is defined by Threshold Uncertainty below.

Threshold uncertainty

Threshold uncertainty defines the limit at which product uncertainty becomes a constant value instead of percent of measured pressure. This uncertainty is comprised of the uncertainties on the lower half of the typical pressure measurement uncertainty tables, or all the uncertainties for Full Scale class, with the exception of Zero Stability whih is entered separately. It is used with Relative Uncertainty to create the basic product uncertainty where the larger of the two is always used.

Scaling factor

The Scaling Factor is the rangeability of the product uncertainty and is entered as a percent of Q-RPT Calculations span. There are two default Scaling Factor's, 30% Measured pressure uncertainty: for Premium (p) and Full Scale (f) class Q-RPTs, and 10% for BG15K and G15K Full scale class. When the Scaling Factor is less than 100%, the assumption is that an AutoRange set that is equal to or greater than the Scaling Factor will have a product uncertainty that is equal to what is shown in the uncertainty tables. AutoRanged spans that are lower than this percent will have an uncertainty lower limit that is defined by the Scaling Factor multiplied by the Threshold Uncertainty. Note that rangeability in Table 2 for conformance characteristics follow these same default guidelines.

Head

Head is simply the uncertainty in the height of the head correction in either centimeters or inches. The PPC4 will use this height and combine with a gas density calculation to provide an uncertainty in pressure.

Zero stability

Zero stability can be entered for two situations, AutoZero on and AutoZero off. Zero stability is not scalable and is a percent of Q-RPT span. For 'AutoZero on' the uncertainty is either zero for gauge and negative gauge modes, or the uncertainty in the reference to AutoZero combined with the predicted amount of drift in between corrections (Zoffset) for absolute mode. For 'AutoZero off' it is the predicted zero drift between calibrations.

Control Uncertainty

All the components up to this point calculate measured pressure uncertainty. The PPC4 has the option of displaying either measured pressure uncertainty or delivered pressure uncertainty. Delivered pressure uncertainty combines the measured pressure uncertainty with control settings and/or pressure stability. If set to delivered pressure uncertainty in dynamic pressure mode the displayed uncertainty will be the measured pressure uncertainty root sum squared with the hold limit. One standard uncertainty of the hold limit is the hold limit divided by the square root of three. This is because when in dynamic mode, as long as the pressure is inside the hold limit, only the requested pressure is displayed, so there is no information to know where the measured pressure is inside the requested pressure plus or minus the hold limit.

When delivered pressure uncertainty is selected and control is in static mode, the uncertainty is the measured pressure uncertainty root sum squared with a pressure stability calculation based on the change in pressure from one update to the next.

References

[1] M. Bair, M. Giriard, *Guide To Determining Pressure Measurement Uncertainty Defined By An RPM4-AD For Air Data Calibrations*, 18 Sep 2007.

[2] ISO/TAG4/WG3, *Guide to the Expression of Uncertainty in Measurement*.

[3] M. Bair, *Evaluating the Contribution of Stability in the Measurement Uncertainty of Resonant Quartz Pressure Transfer Standards*, NCSLI 2005 Workshop & Symposium.

[4] Fluke Calibration, *PPC4™ Pressure Controller/ Calibrator Operation and Maintenance Manual*.

Calcuations

Measured pressure uncertainty

$$U_{meas} = 2 \times \sqrt{\left(\frac{U_{prod}}{2}\right)^2 + \left(\frac{U_{head} \times \rho_{gas} \times g_{std}}{2}\right)^2 + \left(\frac{U_{Autoz} \times S_{QRPT}}{\sqrt{3}}\right)^2}$$

Where:

U_{meas}: Measured pressure uncertainty.
U_{prod}: Product uncertainty = Max [(U_{read} x P_{curr}), (U_{span} x AutoRange Span)].
P_{curr}: Current measured pressure.
U_{span}: Threshold uncertainty component. Allowable scaling is defined by "Scale" which specifies the extent to which the uncertainty can be downranged.
U_{head}: Uncertainty of head height measurement in centimeters or inches.
ρ_{gas}: Density of the test gas. In gauge mode replaced with ($\rho_{gas} - \rho_{air}$), where ρ_{air} is standard air density, 1.2 kg/m^3.
g_{std}: Standard gravity 9.80665 m/s^2.
U_{Autoz}: Uncertainty associated with zero drift of the Q-RPT, specified with AutoZ on and separately with AutoZ off.
S_{QRPT}: Q-RPT span.

Delivered pressure uncertainty

$$U_{del} = 2 \times \sqrt{\left(\frac{U_{meas}}{2}\right)^2 + \left[\left(\frac{HL}{\sqrt{3}}\right)^2 \textit{ or } \left(\frac{P_{Stab} \times UpdateRate}{\sqrt{12}}\right)^2\right]}$$

Where:

U_{del}: Delivered pressure uncertainty.
UL: Dynamic mode hold limit.
P_{curr}: Current pressure stability.
UpdateRate: Fixed value in seconds.

Product uncertainity tables

The tables that follow list the uncertainties defined in the previous sections of this document for all types of QRPTs and all measurement modes. 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 percent of reading are combined separately from those in percent of Q-RPT span or of AutoRanged span. Finally, the relative and absolute combined uncertainty are each multiplied by a coverage factor of 2 and listed.

Note: If it is required to calculate a confidence level for 95 % for this uncertainty analysis, greater knowledge of the effective degrees of freedom for each standard uncertainty must be obtained. However, it should be noted that because all rectangular distributions are conservatively chosen and can be considered to have a high effective degree of freedom, and many of the dominant standard uncertainties are considered to have normal distributions, a coverage factor of 2 (k=2) should sufficiently approximate a confidence level of 95 %.

Typical pressure measurement uncertainty for Q-RPT ranges: G100K, G200K, BA100K, A100K, A160K, A200K, A350K, A700K, A1.4M, A2M, A3.5M, A7M, A10M AND A14M

Premium class

± (0.008% of reading or 0.0024 % of AutoRanged span, whichever is greater) with regular use of AutoZero
± [(0.008% of reading or 0.0024 % of AutoRanged span, whichever is greater) +0.005 % of Q-RPT span] without use of AutoZero

		Premium		
Variable or parameter	**Distribution**	**Absolute with AutoZ**	**Absolute without AutoZ**	**Gauge**
Relative uncertainties		**% of reading**		
Reference	Normal	0.0015 %	0.0015 %	0.0015 %
Conformance	Rectangular	0.0020 %	0.0020 %	0.0020 %
Repeatability	Normal	0.0015 %	0.0015 %	0.0015 %
Temperature	Rectangular	0.0006 %	0.0006 %	0.0006 %
Stability	Rectangular	0.0000 %	0.0029 %	0.0029 %
Combined		**0.004 % of rdg or 0.0008 % AutoRanged span**	**(0.004 % of rdg or 0.0008 % AutoRanged span) + 0.003 % Q-RPT span**	**0.004 % of rdg or 0.0008 % AutoRanged span**
Combined and expanded for (k=2)		**0.008 % of rdg or 0.0016 % AutoRanged span**	**(0.008 % of rdg or 0.0015 % AutoRanged span) + 0.006 % Q-RPT span**	**0.008 % of rdg or 0.0016 % AutoRanged span**
Absolute uncertainties		**% AutoRanged span**		
Reference	Normal	0.00003 %	0.00003 %	0.00003 %
Resolution	Rectangular	0.00003 %	0.00003 %	0.00003 %
Precision	Normal	0.0008 %	0.0008 %	0.0008 %
		% Q-RPT span		
Temperature	Rectangular	0.0003 %	0.0029 %	0.0003 %
Stability	Rectangular	0.0000 %	0.0029 %	0.0000 %

Note: Because of the limited range of a premium BA100K Q-RPT (70 kPa to 110 kPa) the AutoRanged span is never considered different from the Q-RPT span.

Premium class: parallel mode

± (0.006 % of reading or 0.0018 % of AutoRanged span, whichever is greater) with regular use of AutoZero
± [(0.006 % of reading or 0.0018 % of AutoRanged span, whichever is greater) + 0.004 % of Q-RPT span] without use of AutoZero

		Premium: parallel mode		
Variable or parameter	**Distribution**	**Absolute with AutoZ**	**Absolute without AutoZ**	**Gauge**
Relative uncertainties		**% of reading**		
Reference	Normal	0.0015 %	0.0015 %	0.0015 %
Conformance	Rectangular	0.0014 %	0.0014 %	0.0014 %
Repeatability	Normal	0.0011 %	0.0011 %	0.0011 %
Temperature	Rectangular	0.0004 %	0.0004 %	0.0004 %
Stability	Rectangular	0.0021 %	0.0021 %	0.0021 %
Combined		**0.003 % of rdg or 0.0006 % span**	**0.003 % of rdg or 0.0005 % AutoRanged span) + 0.0019 % Q-RPT span**	**0.003 % of rdg or 0.0006 span**
Combined and expanded for (k=2)		**0.006 % of rdg or 0.0011 % span**	**(0.006 % of rdg or 0.0011 % AutoRanged span) + 0.004 % Q-RPT span**	**0.006 % of rdg or 0.0012 % span**
Absolute uncertainties		**% AutoRanged span**		
Reference	Normal	0.00003 %	0.00003 %	0.00003 %
Resolution	Rectangular	0.00003 %	0.00003 %	0.00003 %
Precision	Normal	0.0005 %	0.0005 %	0.0005 %
		% Q-RPT span		
Temperature	Rectangular	0.0002 %	0.0006 %	0.0002 %
Stability	Rectangular	0.0000 %	0.0018 %	0.0000 %

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Typical pressure measurement uncertainty for Q-RPT ranges: G100k, G200k, BA100K, A100k, a160K, A200K, A350K, A700K, A1.4M, A2M, A3.5M, A7M, A10M AND A14M

Standard class

± (0.01 % of reading or 0.003 % of Q-RPT span, whichever is greater) with regular use of AutoZero
± (0.01 % of reading or 0.007 % of Q-RPT span, whichever is greater) without use of AutoZero

		Standard		
Variable or parameter	**Distribution**	**Absolute with AutoZ**	**Absolute without AutoZ**	**Gauge**
Relative uncertainties		**% of reading**		
Reference	Normal	0.0015 %	0.0015 %	0.0015 %
Conformance	Rectangular	0.0033 %	0.0033 %	0.0033 %
Repeatability	Normal	0.0020 %	0.0020 %	0.0020 %
Temperature	Rectangular	0.0006 %	0.0006 %	0.0006 %
Stability	Rectangular	0.0029 %	0.0029 %	0.0029 %
Combined		**0.005 % of rdg or 0.0012 % Q-RPT span**	**(0.005 % of rdg or 0.0012 % Q-RPT span**	**0.005 % of rdg or 0.0012 % Q-RPTspan**
Combined and expanded for (k=2)		**0.010 % of rdg or 0.0024 % Q-RPT span**	**0.010 % of rdg or 0.0065 % Q-RPT span**	**0.010 % of rdg or 0.0024 % Q-RPT span**
Absolute uncertainties		**% Q-RPT span**		
Reference	Normal	0.00003 %	0.00003 %	0.00003 %
Resolution	Rectangular	0.00003 %	0.00003 %	0.00003 %
Precision	Normal	0.0012 %	0.0012 %	0.0012 %
Temperature	Rectangular	0.0003 %	0.0009 %	0.0003 %
Stability	Rectangular	0.0000 %	0.0029 %	0.0000 %

Standard class: parallel mode

± (0.008% of reading or 0.0024% of Q-RPT span, whichever is greater) with regular use of AutoZero
± (0.008% of reading or 0.005% of Q-RPT span, whichever is greater) without use of AutoZero

		Standard: parallel mode		
Variable or parameter	**Distribution**	**Absolute with AutoZ**	**Absolute without AutoZ**	**Gauge**
Relative uncertainties		**% of reading**		
Reference	Normal	0.0015 %	0.0015 %	0.0015 %
Conformance	Rectangular	0.0023 %	0.0023 %	0.0023 %
Repeatability	Normal	0.0014 %	0.0014 %	0.0014 %
Temperature	Rectangular	0.0004 %	0.0004 %	0.0004 %
Stability	Rectangular	0.0021 %	0.0021 %	0.0021 %
Combined		**0.004 % of rdg or 0.0008 % span**	**0.004 % of rdg or 0.0020 % span**	**0.004 % of rdg or 0.0008 % span**
Combined and expanded for (k=2)		**0.008 % of rdg or 0.0017 % span**	**0.008 % of rdg or 0.0041 % span**	**0.008 % of rdg or 0.0017 % span**
Absolute uncertainties		**% Q-RPT span**		
Reference	Normal	0.00002 %	0.00002 %	0.00002 %
Resolution	Rectangular	0.00003 %	0.00003 %	0.00003 %
Precision	Normal	0.0008 %	0.0008 %	0.0008 %
Temperature	Rectangular	0.0002 %	0.0006 %	0.0002 %
Stability	Rectangular	0.0000 %	0.0018 %	0.0000 %

Typical pressure measurement uncertainty for Q-RPT ranges: A20M, A40M, A70, A100M, A140M

Standard class

± (0.013% of reading or 0.0039 % of Q-RPT span, whichever is greater) with regular use of AutoZero
± (0.013% of reading or 0.007 % of Q-RPT span, whichever is greater) without use of AutoZero

		Standard		
Variable or parameter	**Distribution**	**Absolute with AutoZ**	**Absolute without AutoZ**	**Gauge**
Relative uncertainties		% of reading		
Reference	Normal	0.0020 %	0.0020 %	0.0020 %
Conformance	Rectangular	0.0049 %	0.0049 %	0.0049 %
Repeatability	Normal	0.0025 %	0.0025 %	0.0025 %
Temperature	Rectangular	0.0006 %	0.0006 %	0.0006 %
Stability	Rectangular	0.0029 %	0.0029 %	0.0029 %
Combined		**0.007 % of rdg or 0.0017 % Q-RPT span**	**0.013 % of rdg or 0.0034 % Q-RPT span**	**0.007 % of rdg or 0.0017 % Q-RPT span**
Combined and expanded for (k=2)		**0.013 % of rdg or 0.0034 % Q-RPT span**	**0.013 % of rdg or 0.0069 % Q-RPT span**	**0.013 % of rdg or 0.0034 % Q-RPT span**
Absolute uncertainties		% Q-RPT span		
Reference	Normal	0.00002 %	0.00002 %	0.00002 %
Resolution	Rectangular	0.00003 %	0.00003 %	0.00003 %
Precision	Normal	0.0017 %	0.0017 %	0.0017 %
Temperature	Rectangular	0.0003 %	0.0009%	0.00093%
Stability	Rectangular	0.0000 %	0.0029 %	0.0000 %

Standard class: parallel mode

± (0.01% of reading or 0.003 % of Q-RPT span, whichever is greater) with regular use of AutoZero
± (0.01% of reading or 0.005 % of Q-RPT span, whichever is greater) without use of AutoZero

		Standard: parallel mode		
Variable or parameter	**Distribution**	**Absolute with AutoZ**	**Absolute without AutoZ**	**Gauge**
Relative uncertainties		% of reading		
Reference	Normal	0.0020 %	0.0020 %	0.0020 %
Conformance	Rectangular	0.0035 %	0.0035 %	0.0035 %
Repeatability	Normal	0.0018 %	0.0018 %	0.0018 %
Temperature	Rectangular	0.0004 %	0.0004 %	0.0004 %
Stability	Rectangular	0.0021 %	0.0021 %	0.0021 %
Combined		**0.005 % of rdg or 0.0012 % Q-RPT span**	**0.005 % of rdg or 0.0024 % Q-RPT span**	**0.005 % of rdg or 0.0012 % Q-RPT span**
Combined and expanded for (k=2)		**0.010 % of rdg or 0.0024 % Q-RPT span**	**0.010 % of rdg or 0.0049 % Q-RPT span**	**0.010 % of rdg or 0.0024 % Q-RPT span**
Absolute uncertainties		% Q-RPT span		
Reference	Normal	0.00002 %	0.00002 %	0.00002 %
Resolution	Rectangular	0.00003 %	0.00003 %	0.00003 %
Precision	Normal	0.0012 %	0.0012 %	0.0012 %
Temperature	Rectangular	0.0002 %	0.0006 %	0.0002 %
Stability	Rectangular	0.0000 %	0.0021 %	0.0000 %

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Typical pressure measurement uncertainty for Q-RPT ranges: A200M AND A280M

Standard class

± (0.018 % of reading or 0.0054 % of Q-RPT span, whichever is greater) with regular use of AutoZero
± (0.018 % of reading or 0.008 % of Q-RPT span, whichever is greater) without use of AutoZero

		Standard		
Variable or parameter	**Distribution**	**Absolute with AutoZ**	**Absolute without AutoZ**	**Gauge**
Relative uncertainties		% of reading		
Reference	Normal	0.0025 %	0.0025 %	0.0025 %
Conformance	Rectangular	0.0060 %	0.0060 %	0.0060 %
Repeatability	Normal	0.0050 %	0.0050 %	0.0050 %
Temperature	Rectangular	0.0006 %	0.0006 %	0.0006 %
Stability	Rectangular	0.0029 %	0.0029 %	0.0029 %
Combined		**0.009 % of rdg or 0.0024 % Q-RPT span**	**0.009 % of rdg or 0.0038 % Q-RPT span**	**0.009 % of rdg or 0.0024 % Q-RPT span**
Combined and expanded for (k=2)		**0.017 % of rdg or 0.0047 % Q-RPT span**	**0.017 % of rdg or 0.0077 % Q-RPT span**	**0.017 % of rdg or 0.0047 % Q-RPT span**
Absolute uncertainties		% Q-RPT span		
Reference	Normal	0.00002 %	0.00002 %	0.00002 %
Resolution	Rectangular	0.00003 %	0.00003 %	0.00003 %
Precision	Normal	0.0023 %	0.0023 %	0.0023 %
Temperature	Rectangular	0.0003 %	0.0003 %	0.0009 %
Stability	Rectangular	0.0000 %	0.0000 %	0.0029 %

Standard class: parallel mode

± (0.013 % of reading or 0.0039 % of Q-RPT span, whichever is greater) with regular use of AutoZero
± (0.013 % of reading or 0.006 % of Q-RPT span, whichever is greater) without use of AutoZero

		Standard: parallel mode		
Variable or parameter	**Distribution**	**Absolute with AutoZ**	**Absolute without AutoZ**	**Gauge**
Relative uncertainties		% of reading		
Reference	Normal	0.0025 %	0.0025 %	0.0025 %
Conformance	Rectangular	0.0042 %	0.0042 %	0.0042 %
Repeatability	Normal	0.0035 %	0.0035 %	0.0035 %
Temperature	Rectangular	0.0004 %	0.0004 %	0.0004 %
Stability	Rectangular	0.0020 %	0.0020 %	0.0020 %
Combined		**0.006 % of rdg or 0.0017 % Q-RPT span**	**0.006 % of rdg or 0.0027 % Q-RPT span**	**0.006 % of rdg or 0.0017 % Q-RPT span**
Combined and expanded for (k=2)		**0.013 % of rdg or 0.0033 % Q-RPT span**	**0.013 % of rdg or 0.0054 % Q-RPT span**	**0.013 % of rdg or 0.0033 % Q-RPT span**
Absolute uncertainties		% Q-RPT span		
Reference	Normal	0.00002 %	0.00002 %	0.00002 %
Resolution	Rectangular	0.00003 %	0.00003 %	0.00003 %
Precision	Normal	0.0017 %	0.0017 %	0.0017 %
Temperature	Rectangular	0.0002 %	0.0006 %	0.0002 %
Stability	Rectangular	0.0000 %	0.0021 %	0.0000 %

Typical pressure measurement uncertainty for Q-RPT ranges: G15K, BG15K

Premium and standard class

± (0.008% of reading or 0.0024% of AutoRanged span, whichever is greater) Premium Class
± (0.006% of reading or 0.0018% of AutoRanged span, whichever is greater) Parallel Mode Premium Class
± (0.01% of reading or 0.003% of Q-RPT span, whichever is greater) Standard Class
± (0.008% of reading or 0.0024% of Q-RPT span, whichever is greater) Parallel Mode Standard Class

				Parallel mode	
Variable or Parameter	**Distribution**	**Premium (p)**	**Standard (s)**	**Premium (p)**	**Standard (s)**
Relative uncertainties		% of reading			
Reference	Normal	0.0015%	0.0015%	0.0015%	0.0015%
Conformance	Rectangular	0.0020%	0.0033%	0.0014%	0.0023%
Repeatability	Normal	0.0015%	0.0020%	0.0011%	0.0014%
Line pressure	Normal	0.0005%	0.0005%	0.0005%	0.0005%
Temperature	Rectangular	0.0006%	0.0006%	0.0004%	0.0004%
Stability	Rectangular	0.0029%	0.0029%	0.0021%	0.0021%
Combined		**0.004% of rdg or 0.0008% AutoRanged span**	**0.005% of rdg or 0.0012% Q-RPT span**	**0.003% of rdg or 0.0006% AutoRanged span**	**0.004% of rdg or 0.0008% Q-RPT span**
Combined and expanded for (k=2)		**0.008% of rdg or 0.0016% AutoRanged span**	**0.010% of rdg or 0.0024% Q-RPT span**	**0.006% of rdg or 0.0011% AutoRanged span**	**0.008% of rdg or 0.0017% Q-RPT span**
Absolute uncertainties		**% AutoRanged span**	**% of Q-RPT span**	**% AutoRanged span**	**% of Q-RPT span**
Reference	Normal	0.00003%	0.00003%	0.00003%	0.00003%
Conformance	Rectangular	0.00003%	0.00003%	0.00003%	0.00003%
Repeatability	Normal	0.0008%	0.0012%	0.0005%	0.0008%
Line pressure	Normal	0.0002%	0.0002%	0.0002%	0.0002%
Temperature	Rectangular	0.0003%	0.0003%	0.0002%	0.0002%
Stability	Rectangular	0.0000%	0.0000%	0.0000%	0.0000%

[1] For BG, span is the difference between the lowest and highest pressure.

Typical pressure measurement uncertainty for Q-RPT ranges: BG15K[1], G15K[1], G100K, G200K, A100K, A160K, A200K, A350K, A700K, A1.4M, A2M, A3.5M, A7M, A10M AND A14M

Full scale class

± (0.015% of AutoRanged span) with regular use of AutoZero
± [(0.015% of AutoRanged span) + 0.005% Q-RPT span] without use of AutoZero

		Full scale
Variable or parameter	**Distribution**	**Absolute with AutoZ and gauge**
Relative uncertainties		% AutoRanged span
Reference	Normal	0.0015%
Conformance	Rectangular	0.0041%
Repeatability	Normal	0.0030%
Line pressure	Normal	0.0005%
Temperature	Rectangular	0.0003%
Stability	Rectangular	0.0043%
Combined		**0.0069% of AutoRanged span**
Combined and expanded for (k=2)		**0.014% of AutoRanged span**

[1] Scaling factor is 10% of Q-RPT span (30 kPa for BG15K), all other Q-RPTs scaling factor is 30% of Q-RPT span.

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Calibration

Typical pressure measurement uncertainty for E-DWT-H, Q-RPT ranges: A7M, A14M, A20M, A40M, A70M, A100M, A140M, A200M, A280M

Gauge only

± (0.02 % of reading or 0.002 % of Q-RPT span, whichever is greater) for one year
± (0.025 % of reading or 0.0025 % of Q-RPT span, whichever is greater) for two years

		Gauge only	
Variable or parameter	**Distribution**	**2 years**	**1 year**
Relative uncertainties		% of reading	
Reference	Normal	0.0025 %	0.0025 %
Conformance	Rectangular	0.0082 %	0.0082 %
Repeatability	Normal	0.0040 %	0.0040 %
Resolution	Rectangular	0.0029 %	0.0029 %
Temperature	Rectangular	0.0009 %	0.0009 %
Stability	Rectangular	0.0075 %	0.0038 %
Combined		**0.0124 % of rdg or 0.0010 % Q-RPT span**	**0.01 % of rdg or 0.0010 % Q-RPT span**
Combined and expanded for (k=2)		**0.025 % of rdg or 0.0021 % Q-RPT span**	**0.02 % of rdg or 0.0021 % Q-RPT span**
Absolute uncertainties		% span	
Reference	Normal	0.0003 %	0.0003 %
Resolution	Rectangular	0.0003 %	0.0003 %
Precision	Normal	0.0009 %	0.0009 %
Temperature	Rectangular	0.0003 %	0.0003 %

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Printed in U.S.A. 9/2011 4058234A A-EN-N
Pub-ID 11806-eng