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Calibration

Guide to determining pressure measurement uncertainty for 6270A Pressure Controller/ Calibrator pressure modules

Technical Note

6140TN01

This technical note is a product uncertainty analysis of the PM200 and PM600 modules delivered with the 6270A pressure controller calibrator. The purpose of this document is to help provide the user of a 6270A controller with information to be able to calculate measurement uncertainty based on the specifications defined for the PM200 and PM600 pressure measurement modules (PMM).

PM600 modules are a version of Q-RPT (Quartz Reference Pressure Transducers) that are primarily addressed in the technical note "*Guide to determining pressure measurement uncertainty for Q-RPT based products*"[1] found on the Fluke Calibration website. However they only have a specification that is equal to the "standard class" specification. No other specification options are available for the PM600 modules (not premium, standard mid or standard high). There are a few differences between the PM600s and the Q-RPT based products defined in the technical note. These are:

- Mounting of the transducer is different to be able to accommodate the 6270A PMM form.
- Absolute mode AutoZero by reference is not a feature of the 6270A. 6270A introduces a new automated zeroing process used to limit the amount of absolute mode zero drift (offset).
- Absolute sensors used in gauge mode have higher uncertainty, but this only affects the two lowest absolute ranges.
- BRM600-BA100K barometric modules have a lower uncertainty based on a large population study of recalibrated BA100K barometers.
- The PM600-A20M is specified as standard class, not standard mid as in[1].

Since the differences are minimal for PM600 modules and Q-RPT standard class products, only the differences are discussed here for PM600 modules. A full description of their influences can be found in[1].

PM200 modules are lower cost/accuracy modules that are new to the Fluke Calibration pressure product line. PM200s are silicone based strain gauge transducers that are highly characterized to meet the specifications claimed. Unlike PM600 their specifications are of full scale.

This technical note is divided into three main sections. The first section provides all the information to create instrumental measurement uncertainties by listing all the uncertainties with their sensitivities and the reasoning behind the application of those uncertainties. The second takes the information from the first section and defines specifications based on an uncertainty budget table. The third section shows how the specifications can be applied to the 6270A uncertainty settings for onboard uncertainty calculations.

It is important to note that, although this uncertainty analysis is appropriate for the population of PMMs, it is likely that the uncertainty of an individual PMM will be less than that of the population. It is our hope that this technical note will suffice as a guide for users of 6270A to calculate uncertainties for individual PMMs.

NOTE: Overall compliance of the PMM is determined by review of the overall 1-year specification in pressure. There may be situations where, for example, one influence is more than the uncertainty shown in this document, but other influences are less than uncertainties listed in this document. But as long as the PMM meets the overall 1-year pressure measurement specification presented in this document, it is considered compliant.

General 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 PMMs.

- Operating mode
- Fluid media
- Environment
- Orientation
- Reference uncertainty
- Calibration frequency
- Dwell
- Zeroing

Operating mode

The operating modes supported by this uncertainty analysis are:

- Absolute
- Gauge
- Negative gauge (vacuum)

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 modules. This is primarily due to head corrections made by the user of the 6270A controller. The fluids used with a 6270A are:

- Nitrogen
- Air (clean and dry)

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: 15 °C to 35 °C (59 °F to 95 °F)
- Temperature change: Less than 5 °C (9 °F) per hour
- Vibration: Meets MIL-T-28800E

Orientation

The PM200's sensitivity to orientation has been found to be insignificant. This is also true for PM600 as long as it is calibrated and used in approximately the same orientation.

Reference uncertainty

The reference uncertainty requirement for this analysis is intended to be as conservative as possible to allow the operators of the equipment to have flexibility with available references. However, it is assumed that a piston gauge is used as the reference for PM600s as stated in[1].

For all PMMs it is not necessary to choose a reference that has an uncertainty four times lower than the PMM specification since it is included as an influence in this uncertainty analysis. The reference uncertainty only needs to be equal to or less than what is specified for that uncertainty influence.

Calibration frequency

This analysis assumes a recalibration interval of 1-year. There is not extensive data or information that other intervals will prorate the uncertainties due to drift over time to be proportional to the interval. Studies have been performed on PM200 and PM600s to justify the uncertainties from drift based on 1 year. That does not mean that PMMs will be not be better in six months or less, but there is not a guarantee for anything other than 1 year.

Dwell (stabilization time)

All static pressure measuring 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 PM600 a stabilization time of thirty seconds is required after any significant instantaneous pressure change to ensure stability of the PMM and the system for comparisons within the stated uncertainty. For PM200s it is assumed a ten-second dwell is observed.

Zeroing

It is assumed that all PMMs that are in gauge mode are zeroed before each use. It may be found that this is not necessary depending on the zero stability of each PMM. For all absolute PMMs it is not assumed they are zeroed between calibrations.

Abbreviations

Throughout this document, some abbreviations are used. To clarify...

% FS = Percent full scale (maximum indication)

% Span = Maximum – minimum pressure range

RSS = root-sum-square

PM200 uncertainties

This section defines the uncertainty influences that apply to all PM200s. A brief explanation of each uncertainty is given. All uncertainties for PM200s are expressed as a %FS and at 95 % confidence. The influences discussed are:

- Reference
- Precision
  - -Conformance
  - -Repeatability
- Temperature
- Zero drift
- Stability
- Pressure head
- Absolute mode uncertainty using a G or BG PM200

Reference

The uncertainty in pressure contributed by the reference is dependent upon the PM200 range. Most PM200 ranges have an instrumental measurement uncertainty of ± 0.02 % FS for one year at 95 % confidence. For these PM200s the uncertainty for the reference is set to ± 0.0075 % of FS at 95 % confidence. For other ranges the reference uncertainty requirement is expanded due to the magnitude of the other uncertainty contributions.

Precision

One of the most important characteristics of a PMM as a secondary 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 an adjustment specification and is listed separately from repeatability in this uncertainty analysis. Resolution is ± 0.0001 % FS, which is also considered separately and becomes insignificant when combined with other precision characteristics.

Conformance

Conformance is the combination of linearity and hysteresis since they both influence deviations from a perfect fit. This combination is used as an uncertainty and also a tolerance for an as left state for PM200s.

Hysteresis is the uncertainty from an influence that is dependent upon a pressure transducer's mechanical memory. For example, if a pressure measurement is made at one pressure, then increased to a higher pressure, it might be in error by a little less coming from the lower pressure. The reverse may happen in decreasing pressures. The influence may be dependent on the amount of time the transducer was at the previous pressure, or the amount of the pressure change.

Linearity is an uncertainty from deviations from a perfectly linear output over its pressure/temperature range. PM200s are well characterized over the given temperature specification. Since the model of the fit is the same over the temperature range the characterization is applied, the linearity is assumed to be the same at different temperatures. However there is still an uncertainty for temperature to account for overall changes in zero or span throughout the temperature range.

Conformance for PM200s is no less than ± 0.01 % FS. It is important to note that the conformance tolerance used for as left results in a calibration is at the approximate ambient temperature during the calibration. If there is a significant temperature change from where the PM200 met this tolerance, but still within limits, the PM200 may not be within the conformance tolerance. However it should still be well within the 1-year specification.

Repeatability

Repeatability is the ability of the PM200 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. Repeatability is no less than ±0.005 % FS.

Temperature

PM200s are characterized when they are new over the full scale pressure range and a temperature range greater than the temperature range given. For PM200s there is an overall uncertainty of no less than ± 0.005 % of FS from 18 °C to 28 °C (64.4 °F to 82.4 °F). If used outside of this ambient operating temperature range an additional ± 0.003 % of FS/°C should be added for all ranges, but should not go outside of the specified temperature range of 15 °C to 35 °C (59 °F to 95 °F).

Zero drift

PM200s that measure bi-directional gauge (BG) or gauge (G) are assumed to be zeroed before use. However the zero can drift during use. An uncertainty of ± 0.002 % FS is assigned to zero drift during a test, i.e. before there is the opportunity to zero again. Absolute PM200 modules are not zeroed. Zero drift for these are considered to be ± 0.05 % FS for 1 year.

Stability (1-year span drift)

The output of PM200s can change over time due to natural material changes of the transducer and supporting electronics from age or use. Extensive studies were performed during the development of PM200 sensor technology on the drift of those pressure transducers over time. The uncertainty for 1 year drift is no better than ± 0.01 % FS. This uncertainty is conservatively given in % of FS for G and BG PM200 modules but is actually a percentage of reading since these are zeroed when vented, so realistically is always span drift.

Head pressure

Because of the possibility that a device being calibrated by a 6270A pressure controller/calibrator can be at a height that is significantly different than the controller, the uncertainty contributed by head pressure is not included in this analysis when considering the 1-year specification. If an uncertainty for head height is needed to be included, it is fairly easy to do for a 6270A since the media is limited to air and nitrogen gas (N_2). For air and N_2 a close approximation to head height is 0.0003 % of reading (gauge or absolute) per inch of head height (approximately 0.00012 % per centimeter). The uncertainty in head height, in terms of height (centimeter or inches) is an influence captured by the 6270A on board pressure uncertainty calculator. This includes the uncertainty in head when units are used in system mode and is simply the addition of the device under test (DUT) height uncertainty and the uncertainty of the head height from auxiliary to primary platform.

Measuring absolute pressure with a G or BG PM200

The 6270A gauge or bi-directional gauge PM200s can measure absolute pressure if there is an absolute PM200 installed. The uncertainty in this case is simply the RSS of the uncertainty of the gauge or bidirectional gauge PM200 and the absolute PM200 or PM600 at ATM.

PM600 uncertainties

As stated earlier in this document PM600s are Q-RPTs with a “Standard” 1-year specification as described in the Technical Note “*Guide to the uncertainty of Q-RPT pressure based products*”[1]. This section only covers the differences in PM600s from other Q-RPT based products.

Zero stability (drift over 1 year)

For PM600 absolute modules there is an uncertainty associated with zero drift over the 1-year calibration interval. For each absolute range an additional uncertainty of ± 0.007 % of span is root sum squared (RSS) with the one year specification of ± (0.01 % of reading or 0.003 % Q-RPT span, whichever is greater).

The zero drift uncertainty component can be reduced significantly using a 6270A automated feature that allows the user to designate and use a different PMM as an AutoZero reference. This can be any absolute PMM, but the idea is to use the PMM that is the most stable. By definition, lower range absolute PM600s should be more stable with the BRM600-BA100K being the most stable of all. This feature is enabled by turning on AutoZero and specifying the module to use as the AutoZero reference. The correction happens when vented much like the automated gauge zero when at vent. If AutoZero is off then there is the option to manually enter a reference value for barometric pressure that will be used to correct all absolute PMMs when vented. The uncertainty used is the uncertainty that is stored with the atmospheric pressure value in the instrument settings menu.

Figure 1 shows the uncertainty at atmospheric pressure for four examples of PM600s in a 6270A at the same time with AutoZero off and AutoZero on. The values for AutoZero off are the standard class specification RSS with 0.007 % Q-RPT span of each range. The values for AutoZero on are the standard class specification RSS with 10 Pa since 10 Pa is the uncertainty of the BRM600-BA100K when reading barometric pressure.

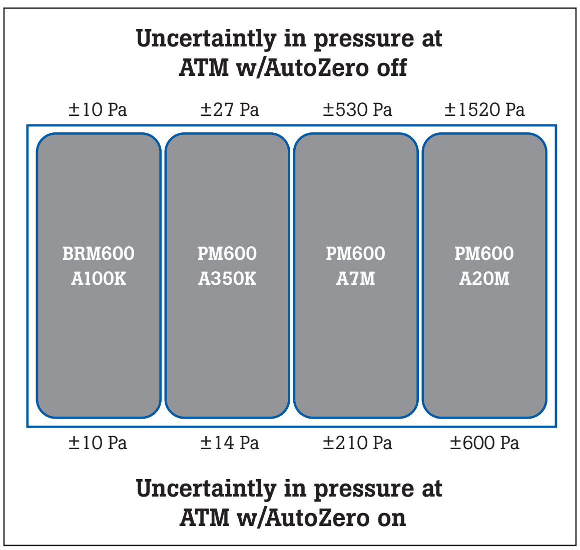

Figure 1. Uncertainty of PM600 modules in absolute mode at atmospheric pressure with AutoZero off and AutoZero on.

Figure 1 shows the significant reduction of uncertainty using the BRM600-BA100K as a PMM zeroing reference. This is among the best results that one could obtain without using a primary standard and manual AutoZero. It is important to note that the calibration certificates for recalibrations on absolute PM600 from Fluke Calibration will use the full 1-year specification including the RSS of the 0.007 % of Q-RPT span since it is unknown what was used as the AutoZero reference.

Absolute PM600 used in gauge and negative gauge mode

In the Q-RPT uncertainty technical note there is a section on using absolute Q-RPTs to measure gauge pressure. In this section it describes the uncertainty as the normal standard class specifications, but the absolute value of the pressure is used in case the pressure being measured is negative gauge, then 1 Pa is added. For absolute PM600 modules used in gauge or negative gauge it is a similar calculation but 7 Pa is RSS with the threshold uncertainty. This only significantly affects the two lowest ranges; A100K and A200K. These end up with a specification in gauge mode that is ± (0.01 % of the absolute value of reading or 0.0074 % of span, whichever is greater) for the A100K, and ± (0.01 % of absolute value of reading or 0.0043 % of span, whichever is greater) for A200K with span being the full absolute range (full negative to positive gauge range). Figure 2 shows these specifications graphically.

BRM600 BA100K uncertainty

A reliability study was performed on a significant sample of BA100K Q-RPTs from RPM4 in the field. As suggested in[2] the stability of the barometric Q-RPTs are better than Q-RPTs that are continuously cycled through their range. Reliability was very good using a 1-year specification of 0.01 % of reading for the range of 70 to 110 kPa. The uncertainties are given in upper part of Table 3 as relative uncertainties, but these are close to being % of FS since the range is limited to 70 to 110 kPa.

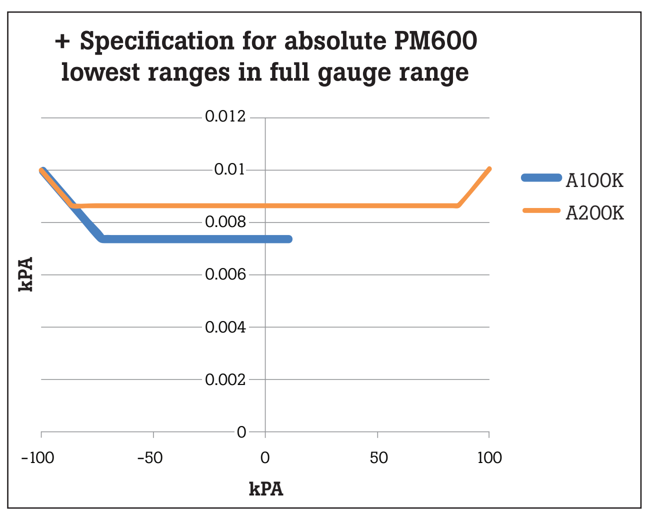

Figure 2. Absolute PM600 used in gauge mode, two lowest ranges.

Resolution (All PMMs)

The best resolution available from the front panel of the 6270A and from a remote query is 0.0001 % of span of the module. For all models this is insignificant so is not included. The user should be careful when decreasing the resolution to a higher percent of span if they are using the displayed value. For instance, if 0.1 % of FS is selected the displayed value would have a much higher uncertainty than the PMMs at normal resolution. The on-board uncertainty calculator described at the end of this document is a good way to make sure the user has selected sufficient resolution. If the resolution decreases on the displayed value, so does the displayed uncertainty. If there are two significant digits shown on the displayed uncertainty, then it is at an appropriate resolution based on the current PMM uncertainty.

Uncertainty budget tables

Table 1 gives the range in psi and kPa for all PM200 modules and their 1-year specification. Tables 2 and Table 3 provide the uncertainty budgets for the PM200 and PM600 respectively.

Both Tables 2 and 3 show the influence, type of distribution, standard uncertainty reduced by either 2, for normal, or by the square root of 3 for rectangular distributions, and the combined and expanded uncertainty. The expansion was based on a factor of 2. With the conservative approach in determining the influences described for the population of the PMMs, effective degrees of freedom is estimated to be large enough to assume that the expansion is a good representation of 95 % confidence.

Model	Range (psi)	Range (kPa)	Published 1 year spec. ±
BG2.5K	-0.36 to 0.36	-2.5 to 2.5	0.20 % FS
BG35K	-5 to 5	-35 to 35	0.05 % FS
BG40K	-6 to 6	-40 to 40	0.05 % FS
BG60K	8.7 to 8.7	-60 to 60	0.05 % FS
A100K	0.3 to 15	2 to 100	0.10 % FS
BG100K	-15 to 15	-100 to 100	0.02 % FS
A200K	0.3 to 30	2 to 200	0.10 % FS
BG200K	-15 to 30	-100 to 200	0.02 % FS
BG250K	-15 to 36	-100 to 250	0.02 % FS
G700K	0 to 100	0 to 700	0.02 % FS
G1M	0 to 150	0 to 1000	0.02 % FS
G1.4M	0 to 200	0 to 1400	0.02 % FS
G2M	0 to 300	0 to 2000	0.02 % FS
G2.5M	0 to 360	0 to 2500	0.02 % FS
G3.5M	0 to 500	0 to 3500	0.02 % FS
G4M	0 to 580	0 to 4000	0.02 % FS
G7M	0 to 1000	0 to 7000	0.02 % FS
G10M	0 to 1500	0 to 10000	0.02 % FS
G14M	0 to 2000	0 to 14000	0.02 % FS
G20M	0 to 3000	0 to 20000	0.02 %FS

Table 1. PM200 1-year specifications

		PM200 Modules			
Variable or parameter	**Distribution**	**BG100K through G20M**	**BG35K, BG40K, BG60K**	**A100K, A200K**	**BG2.5K**
Reference	normal	0.0038 %	0.0038 %	0.0100 %	0.0100 %
Resolution	rectangular	0.0001 %	0.0001 %	0.0001 %	0.0001 %
Conformance	normal	0.0050 %	0.0050 %	0.0100 %	0.0250 %
Repeatability	normal	0.0025 %	0.0050 %	0.0125 %	0.0100 %
Temperature	normal	0.0025 %	0.0050 %	0.0050 %	0.0100 %
Zero Drift	rectangular	0.0012 %	0.0023 %	0.0289 %	0.0058 %
Stability	rectangular	0.0058 %	0.0231 %	0.0144 %	0.0866 %
Combined		**0.0093 % FS**	**0.0251 % FS**	**0.0377 % FS**	**0.0920 % FS**
Combined and expanded for (k=2)		**0.019 % FS**	**0.050 % FS**	**0.075 % FS**	**0.18 % FS**

Table 2. PM200 Uncertainty Budget – See Table 1 for 1-year specification

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		PM600 Standard Class Absolute Mode	
Variable or parameter	**Distribution**	**Absolute**	**BRM600 BA100K**
Relative uncertainties			
Reference	normal	0.0015 %	0.0015 %
Conformance	normal	0.0033 %	0.0033 %
Repeatability	normal	0.0020 %	0.0020 %
Temperature	normal	0.0006 %	0.0006 %
Stability	rectangular	0.0029 %	0.0029 %
Combined		**0.005 % of rdgvor 0.0012 % Q-RPT span**	**0.005 % of rdg**
Combined and expanded for (k=2)		**0.010 % of rdg or 0.0024 % Q-RPT span**	**0.010 % of rdg**
% FS uncertainties			
Reference	normal	0.00003 %	
Resolution	rectangular	0.00003 %	
Precision	normal	0.0012 %	
Temperature	rectangular	0.0003 %	
Stability	rectangular	RSS of lowest range PM600 at ATM	

		PM600 Standard Gauge Mode				
Variable or parameter	**Distribution**	**PM600-BG15K**	**Gauge PM600-A100K**	**PM600-A200K**	**Gauge > A200K**	**PM600 G100K/ G200K**
Relative uncertainties		% of reading				
Reference	normal	0.0015 %	0.0015 %	0.0015 %	0.0015 %	0.0015 %
Conformance	rectangular	0.0033 %	0.0033 %	0.0033 %	0.0033 %	0.0033 %
Repeatability	normal	0.0020 %	0.0020 %	0.0020 %	0.0020 %	0.0020 %
Temperature	normal	0.0006 %	0.0006 %	0.0006 %	0.0006 %	0.0006 %
Stability	rectangular	0.0029 %	0.0029 %	0.0029 %	0.0029 %	0.0029 %
Line pressure	rectangular	0.0005 %	N/A	N/A	N/A	N/A
Combined		**0.005 % of rdg or 0.0009 % Q-RPT span**	**0.005 % of rdg or 0.0037 % Q-RPT span**	**0.005 % of rdg or 0.0022 % Q-RPT span**	**0.005 % of rdg or 0.0012 % Q-RPT span**	**0.005% of rdg or 0.0012% Q-RPT span**
Combined and expanded for (k=2)		**0.010 % of rdg or 0.0018 % Q-RPT span**	**0.010 % of rdg or 0.0074 % Q-RPT span**	**0.010 % of rdg or 0.0044 % Q-RPT span**	**0.010 % of rdg or 0.0024 % Q-RPT span**	**0.010% of rdg or 0.0024% Q-RPT span**
% FS uncertainties		% Q-RPT span				
Reference	normal	0.00003 %	0.00003 %	0.00003 %	0.00003 %	0.00003 %
Resolution	rectangular	0.00003 %	0.00003 %	0.00003 %	0.00003 %	0.00003 %
Precision	normal	0.0008 %	0.0012 %	0.0012 %	0.0012 %	0.0012 %
Temperature	rectangular	0.0003 %	0.0003 %	0.0003 %	0.0003 %	0.0003 %
Line Pressure	rectangular	0.0002 %	N/A	N/A	N/A	N/A
Dynamic baro compensation	rectangular		0.0035 %	0.0018 %	N/A	N/A

Table 3. PM600 – Q-RPT Standard Class uncertainty budget

Q-RPT ranges: G100K, G200K, A100K, A200K, A350K, A700K, A1.4M, A2M, A3.5M, A7M, A10M, A14M and A20M.

1-year specification ± (0.01 % of reading or 0.003 % of Q-RPT span, whichever is greater) for absolute RSS with absolute AutoZero reference module uncertainty at atmospheric pressure, or 0.007 % of Q-RPT span if an AutoZero reference PMM is not used.

6270A onboard pressure uncertainty calculator

The 6270A Pressure Controller/Calibrator includes the ability to do real time calculation of the estimated uncertainty. This tool is extremely useful due to the flexible configurations allowed by the variety of pressure measurement modules available.

The uncertainty calculation uses a number of variables, some of which are stored in each pressure module and some that are stored in the main chassis.

Uncertainty values stored in the Pressure Measurement Module

These values come pre-loaded from the factory with the default instrument specifications. To view or edit these values from the front panel, press [SETUP][Module Information][Slot x][Uncertainty]. These values are password protected. All uncertainty values entered are treated as 95% confidence level.

U_{THRESH} = Threshold Uncertainty – The uncertainty component of the module that is expressed as a constant pressure value

U_{READ} = Relative Uncertainty – The uncertainty component of the module that is relative to the measured pressure

U_{ABS} = Uncertainty associated with the zero instability over time (absolute mode modules only)

Combination Method = Defines how the Threshold Uncertainty and the Relative Uncertainty are combined together to give the overall uncertainty associated with the module

Uncertainty values stored in the main chassis

These values impact the uncertainty independent of the measurement module used. To view or edit these values from the front panel, press [SETUP][Instrument Setup][Uncertainty].

U_{HEAD} = Uncertainty of head height measurement in millimeters, centimeters, or inches. Default value is 0.

U_{ADDI} = User defined additional Uncertainty Value (value in pressure). Default value is 0.

U_{ADD2} = User defined additional Uncertainty Value (value in % reading). Default value is 0.

Include Control Uncertainty = When set to Yes the additional uncertainty associated with the instability in the control is included. An example of when this should be set to Yes is if the user is observing the ready indicator only, and not observing the actual measured pressure. The default setting is No.

Show Uncertainty = Allows the user to turn off the indication of measurement uncertainty. The default setting is Yes.

Other values used in the calculation of pressure

The following values are also used during the calculation of the uncertainty.

ρ_{MEDIA} = Density of the gas media

ρ_{AIR} = Ambient air density

G_{STD} = Standard acceleration of gravity (9.80665 m/s^2)

P_{CURR} = The currently measured pressure (absolute value)

Calculation of uncertainty

The following calculations are performed in order to determine the total estimated uncertainty.

U_{MODULE}

When set to “Greater of Mode”:

$$MAX[(U_{READ} \times P_{CURR}), U_{THRESH}$$

When set to “Addition”:

$$U_{READ} \times P_{CURR} + U_{THRESH}$$

$U_{CONTROL}$ = Uncertainty due to control noise. When Include Control Uncertainty is set to Yes and the controller is in dynamic mode it equals the Ready Tolerance. In all other cases it equals 0.

U_{ABS} = Additional uncertainty component when operating in absolute mode.

When using inherently gauge mode sensors in absolute mode by addition of atmospheric pressure, U_{ABS} equals the uncertainty of the atmospheric pressure measurement. If atmospheric pressure is a manual entry, then it is the value entered on the [SETUP][Measure Setup][Atmosphere] screen. If atmospheric pressure is being read by a barometric reference module, then it is the calculated uncertainty of that measurement.

When using inherently absolute mode modules with AutoZero off, then it is equal to the U_{ABS} value for that module. When AutoZero is off the user has the option to enter a manual AutoZero. In this case the uncertainty used is from the atmospheric manual entry [SETUP][Measure Setup][Atmosphere] screen. The value entered for manual atmospheric pressure AutoZero is also used for the current manual atmospheric pressure.

When using inherently absolute mode modules with AutoZero on, then it is equal to the calculated uncertainty of the selected zeroing reference PMM at atmospheric pressure.

Final uncertainty calculations

Uncertainty in gauge mode

$$U_{TOTAL} = \sqrt{\left(\frac{U_{MODULE}}{2}\right)^2 + \left(\frac{U_{HEAD} \text{ x } G_{STD} \text{ x } \rho_{MEDIA} - \rho_{AIR}}{2}\right)^2 + \left(\frac{U_{CONTROL}}{\sqrt{3}}\right)^2 + \left(\frac{U_{ADD1}}{2}\right)^2 + \left(\frac{U_{ADD2} \text{ x } P_{CURR}}{2}\right)^2} \text{ x } 2$$

Uncertainty in absolute mode (no AutoZero)

$$U_{TOTAL} = \sqrt{\left(\frac{U_{MODULE}}{2}\right)^2 + \left(\frac{U_{ABS}}{\sqrt{3}}\right)^2 + \left(\frac{U_{HEAD} \text{ x } G_{STD} \text{ x } \rho_{MEDIA}}{2}\right)^2 + \left(\frac{U_{CONTROL}}{\sqrt{3}}\right)^2 + \left(\frac{U_{ADD1}}{2}\right)^2 + \left(\frac{U_{ADD2} \text{ x } P_{CURR}}{2}\right)^2} \text{ x } 2$$

Uncertainty in absolute mode (with AutoZero on or when using a gauge mode module with the addition of atmospheric pressure)

$$U_{TOTAL} = \sqrt{\left(\frac{U_{MODULE}}{2}\right)^2 + \left(\frac{U_{ABS}}{\sqrt{2}}\right)^2 + \left(\frac{U_{HEAD} \text{ x } G_{STD} \text{ x } \rho_{MEDIA}}{2}\right)^2 + \left(\frac{U_{CONTROL}}{\sqrt{3}}\right)^2 + \left(\frac{U_{ADD1}}{2}\right)^2 + \left(\frac{U_{ADD2} \text{ x } P_{CURR}}{2}\right)^2} \text{ x } 2$$

References

1. M. Bair, *Guide to Determining Pressure Measurement Uncertainty for Q-RPT Based Products*, August 2009.

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

3. JCGM 100:2008, *Evaluation of Measurement Data – Guide to the Expression of Uncertainty in Measurement.*

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