APPLICATION NOTE

Measurement Accuracy
Quick guide

A quick guide to calculating the accuracy of measurement devices

Measurement made easy.

—
01 ABB products in the field

Introduction
When measuring, accuracy is a critical factor for deciding what device to choose. Unfortunately, the accuracy of devices is not always clear, as there are different methods to specify accuracy. The two primary methods for specifying accuracy are “% of Reading” and “% of Full Scale”.

Datasheets
Datasheets provide a multitude of technical details for a specific device. From datasheets, accuracy will typically be listed in designated sections. Below is a list of shortcuts to ABB datasheets, for their respective device.

Product
µflo 6213
XFC 6200/6201 EX
XFC^{G5}
266CST
266JST

Definitions

Throughout this document, the terms listed below will be used. They have been defined for the reader's understanding.

Limits*

URL

Upper Range Limit is the the upper pressure limit of the sensor used in the device.

LRL

Lower Range Limit is the lower pressure limit of the sensor used in the device.

*It is important to note that these limits are set at the factory, and cannot be changed by the end user. Measurements above the URL or below the LRL are come with no accuracy specification and are not recommended by the manufacturer.

Values**

URV

Upper Range Value is the factory calibrated pressure of the finished device. Upper Range Value can also be referred to as "Full Scale" or "Factory Calibrated Span (FCS)".

LRV

Lower Range Value is the lowest pressure the device is specified to measure. Lower Range Value can also be referred to as "Span Limit". It is typically specified as a percentage of the Upper Range Limit (URL).

**It is important to note that these values are set at the factory, but unlike limits, these values can be changed, within the specified limits.

** For the µFlo 6213, XFC, and 266 JST the Upper Range Limit (URL) is the Upper Range Value (URV). Accordingly, the Lower Range Limit (LRL) is the Lower Range Value (LRV). This is not true for the 266CST. The 266CST's URL, LRL, and LRV are based on the type of sensor ordered with the device.

Turndown

Turndown or "Turndown Ratio", is a way to specify the LRV of a device. As an example, a 1500 PSI device, specified from 1:1 to 5:1 , states that the highest possible URV is 1500 PSI (1:1) and the lowest possible LRV is 300 PSI (1500 ÷ 5).

Base Accuracy

Base Accuracy is typically specified in a ± percentage, and is specified from the Upper Range Value (URV) to the Lower Range Value (LRV). An example of base accuracy would be ±.05%.

% Full Scale (% of Span)
% Full Scale specifies a percentage of the URV to define a ± band in pressure (PSI), from the URV to the LRV.

With % Full scale, each pressure point from URV to LRV has the same error in PSI.

As an example, the datasheet states the device has an URV of 1500 PSI, with a base accuracy of .05% of full scale, from 100% to 20% of full scale. This means that from 1500 PSI through 300 PSI (20% of your URV), there will be a (1500 x .05% = .75 PSI) error at each point.

Table 1: % Full Scale

Lower -.75 PSI	Measurement	Upper +.75 PSI
1499.25	1500	1500.75
1349.25	1350	1350.75
1199.25	1200	1200.75
1049.25	1050	1050.75
899.25	900	900.75
749.25	750	750.75
599.25	600	600.75
449.25	450	450.75
299.25	300	300.75

% Reading (% Value)
% Reading specifies a ± percentage from the URV to the LRV.

With % Reading, each pressure point from URV to LRV has the same error %.

As an example, the datasheet states the device has an URV of 1500 PSI, with a base accuracy of .05% of reading, from 100% to 20% of full scale. This means that from 1500 PSI through 300 PSI (20% of your URV), there will be a .05% error at each point.

Table 2: % Reading

Lower -.50%	Measurement	Upper +.05%
1499.25	1500	1500.75
1349.325	1350	1350.675
1199.4	1200	1200.6
1049.475	1050	1050.525
899.55	900	900.45
749.625	750	750.375
599.7	600	600.3
449.775	450	450.225
299.85	300	300.15

Comparing a % Full Scale Device to a % Reading Device
The easiest approach to comparing % Full Scale to % Reading is by converting the % Full scale into % Reading. To do this, we use Table 1 above, but we add another column to the left.

This column calculates the % Reading at each point
(1-(Lower ÷ Measurement))%
OR
(1-(Measurement ÷ Upper))%

Table 3: Converting % Full Scale to % Reading

% Reading	Lower -.75 PSI	Measurement	Upper +.75 PSI
0.05%	1499.25	1500	1500.75
0.06%	1349.25	1350	1350.75
0.06%	1199.25	1200	1200.75
0.07%	1049.25	1050	1050.75
0.08%	899.25	900	900.75
0.10%	749.25	750	750.75
0.12%	599.25	600	600.75
0.17%	449.25	450	450.75
0.25%	299.25	300	300.75

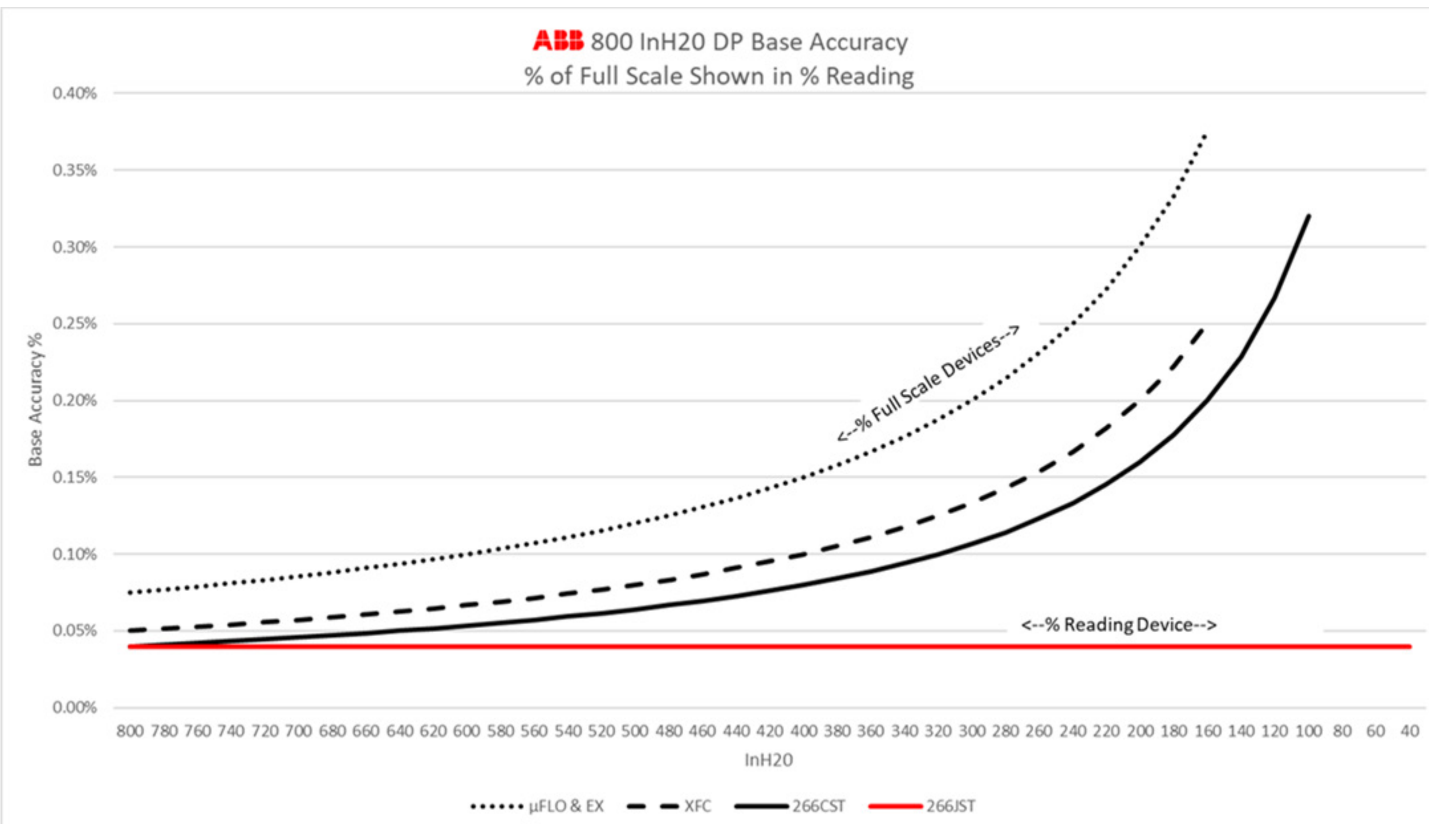
How Does the Base Accuracy of ABB Devices Compare to Each Other?

µFLO 6213 & XFC 6200/6201EX
DP - ± 0.075% of user calibrated span from 20% to 100% of URL
SP - ± 0.075% of user calibrated span from 20% to 100% of URL

XFC G5
DP - ± 0.05% of user calibrated spans from 20% to 100% of URL
SP - ± 0.05% of user calibrated spans from 20% to 100% of URL

266CST
DP - ± 0.04 % of calibrated span from 1:1 to 10:1 of calibrated span
SP -± 0.04 % of calibrated span from 1:1 to 10:1 of calibrated span

266JST
DP - ± 0.04% Value from 5% to 100% of full scale
SP - ± 0.05% Value from barometric to 100% of full scale



Other Factors That Affect Device Accuracy

Temperature (Ambient Temperature Effect)
Deviations in the ambient temperature will affect your readings. As an example, you calibrate your device in the morning and the ambient temperature is 50 °F. When you return in the afternoon, the ambient temperature has increased to 100 °F. This difference in ambient temperature, will affect accuracy. This effect varies between products.

µFLO 6213 & XFC 6200/6201EX
± 0.075% of URL ± 0.06% of reading

XFCG5
± 0.075% of URL ± 0.06% of reading

266CST
± 0.03 % URL + 0.045 % measuring span

266JST
± 0.05% reading from 10 to 100% FCS,
± 0.125% reading from 0 to 10% FCS

Age (Stability)
As a device ages, the measurement accuracy can be affected. This effect also varies between products.

µFLO 6213 & XFC 6200/6201EX
12 months – ± 0.1% of URL

XFCG5
12 months – ± 0.1% of URL

266CST
± 0.15 % of URL over a period of 10 years

266JST
± 0.15% of FCS over a period of 24 months

Total Probable Error (TPE)

Total Probable Error (TPE) is a method of calculating a hypothetical "worst case scenario" for each device. The calculation is performed by using the "Sum of Squares" method, where three metrics are squared, and the result has its square root taken. The formula is as follows: $\sqrt{(\text{Base Accuracy Error})^2 + (\text{Temperature Error})^2 + (\text{Age Error})^2}$.

As an example, consider the following scenario of a 266CST with the following parameters:

- Factory calibrated to 800 InH2O.
- Base accuracy of ± 0.04 % of calibrated span from 1:1 to 10:1 of calibrated span.
- Ambient temperature effect of ± 0.03 % of the Upper Rate Limit (URL) + 0.045 % measuring span.
- Age (stability) of ± 0.15 % of the URL, over a period of 10 years.

With a 266CST, we first have to look up the sensor URL. While we're at it, we'll also grab the turndown for later.
The images below are from the datasheet.

Measuring range limits and span limits

		Measuring range lower limit (LRL)		Minimum measuring span	
Sensor Code	Measuring range upper limit (URL)	Models 26CSH/ CST	Models 266JSH/ JST	Models 266HSH/ CST	Models 266JSH/JST
A	1 kPa	0	-1 kPa	0.05 kPa	0.05 kPa
	10 mbar		-10 mbar	0.5 mbar	0.5 mbar
	4 inH2O		-4inH2O	0.2 inH2O	0.2 inH2O
C	6 kPa	0	-6 kPa	0.2kPa	0.2 kPa
	60 mbar		-60 mbar	2 mbar	2 mbar
	24 inH2O		-24 inH2O	0.8 inH2)	0.8 inH2O
F	40 kPa	0	-40 kPa	0.4 kPa	0.4 kPa
	400 mbar		-400 mbar	4 mbar	4 mbar
	160 inH2O		-160 inH2O	1.6 inH2O	1.6 inH2O
L	250 kPa	0	-250 kPa	2.5 kPa	2.5 kPa
	2500 bar		-2500 bar	25 mbar	25 mbar
	1000 inH2O		-1000 inH2O	10 inH2O	10 inH2O
N	2000 kPa	0	-2000 kPa	20 kPa	20 kPa
	20 bar		-20 bar	0.2 mbar	0.2 mbar
	290 psi		-290 psi	2.9 psi	2.9 psi
R	10000 kPa	-	-10000 kPa	-	100 kPa
	100 bar		-100 bar		1 bar
	1450 psi		-1450 psi		14.5 psi

Measuring error
% of calibrated span, consisting of terminal-based nonlinearity, hysteresis, and non-repeatability.

Model	DP Sensor	For TD Range	Measuring error
266CSH, 266JST	A to R 1)	From 1:1 to 10:1	±0.075 %
	A	From 10:1 to 20:1	±(0.075 + 0.005 X TD =0.05)%
	C	From 10:1 to 30:1	±(0.075 + 0.005 X TD =0.05)%
	F to R 1)	From 10:1 to 100:1	±(0.075 + 0.005 X TD = 0.05)%
266CST, 266JST	A to R 1)	From 1:1 to 10:1	±0.04%
	A	From 10:1 to 20:1	±(0.04 + 0.005 X TD = 0.05)%
	C	From 10:1 to 30:1	±(0.04 + 0.005 X TD = 0.05)%
	F to R 1)	From 10:1 to 100:1	±(0.04 + 0.005 X TD = 0.05)%

We select sensor code "L" (highlighted in yellow) since it's closest to the 800 InH2O target. The URL for our calculations will be 1000 InH2O.

Next, calculate the base accuracy over the measurement range (span). From the Scenario Outline, the base accuracy is ± 0.04% of the calibrated span (URV) and the calibrated pressure is 800 InH2O. With these values, the following formula is used: 0.04% of 800 InH2O = 0.32 InH2O

After that, the calculation for the Ambient Temperature Effect is needed. From the Scenario Outline, it is stated to be 0.03 % of the Upper Rate Limit (URL) + 0.045 % measuring span. With these values, the follow-ing formula is used: (0.03 % of 1000 InH2O) + (0.045 % of 800 InH2O) = 0.66 InH2O

Then, calculate the error due to age, using the stated stability. From the Scenario Outline, the Age (Stability) is ± 0.15 % of URL over a period of 10 years; the URL is 1000 InH2O. With this information provided, the following formula is used: (0.15% of 1000 InH2O) / 10 years = 0.15 InH2O.

Finally, the calculations are combined as follows:

TPE = $\sqrt{(\text{Base Accuracy Error})^2 + (\text{Temperature Error})^2 + (\text{Age Error})^2}$.

Below is a step-by-step breakdown of each calculation:

TPE $= \sqrt{(0.32)^2 + (0.66)^2 + (0.15)^2}$

$= \sqrt{(0.1024) + (0.4356) + (0.0225)}$

$= \sqrt{(0.5605)}$

= .748665 InH2O

TPE ≈ .75 InH2O

Total Probable Error (TPE)… Continued

From the previous page we know that he Total Probable Error (TPE) throughout the measurement range, is .75 InH2O.

800 InH2O is the URV, and 100 InH2O is the the LRV (URL/Turndown = 1000/10).

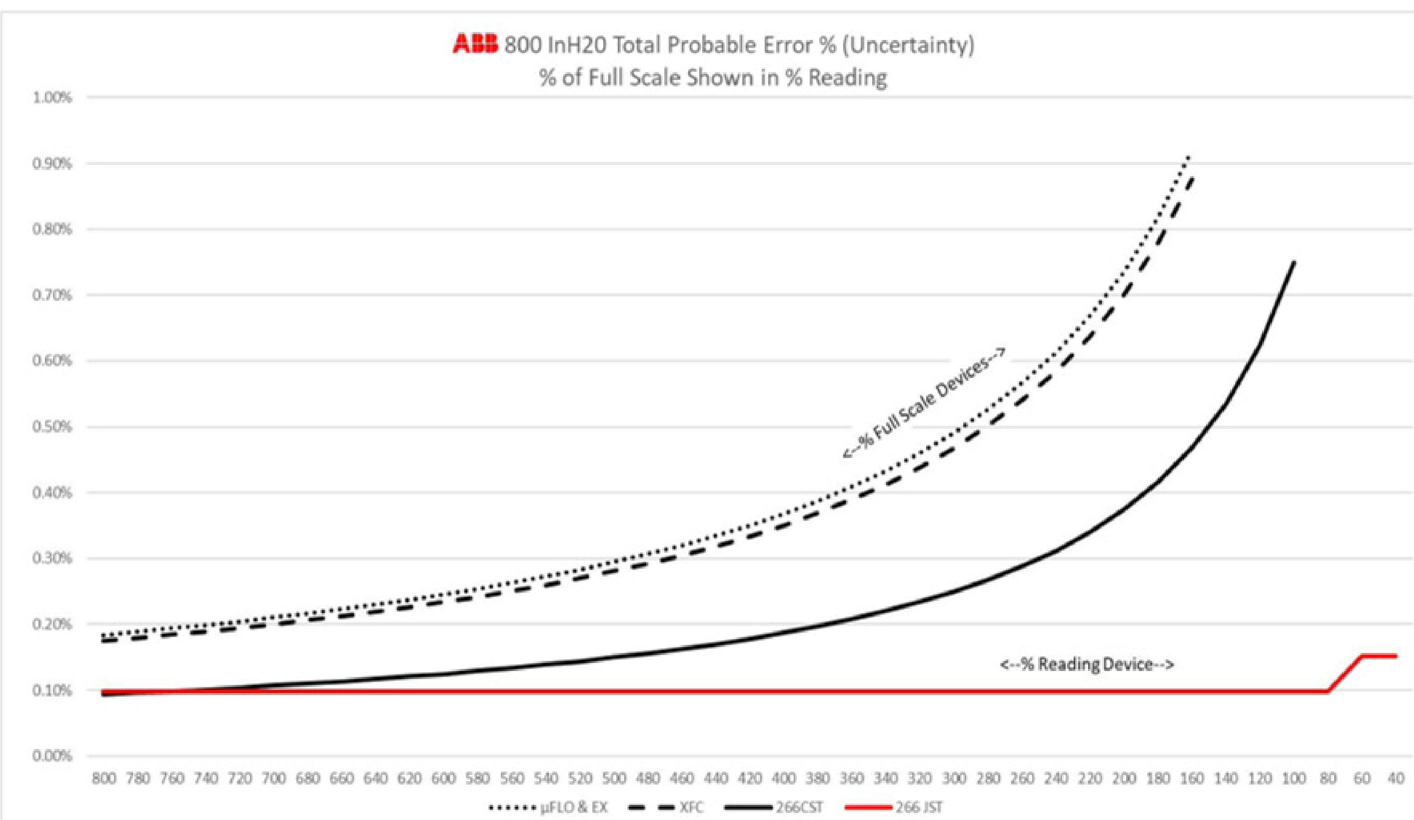
The .75 InH2O is applied at each measurement point, throughout the measurement range (span). We then add the column to the left to convert that to % Reading.

Table: TPE% Throughout the Measuring Range

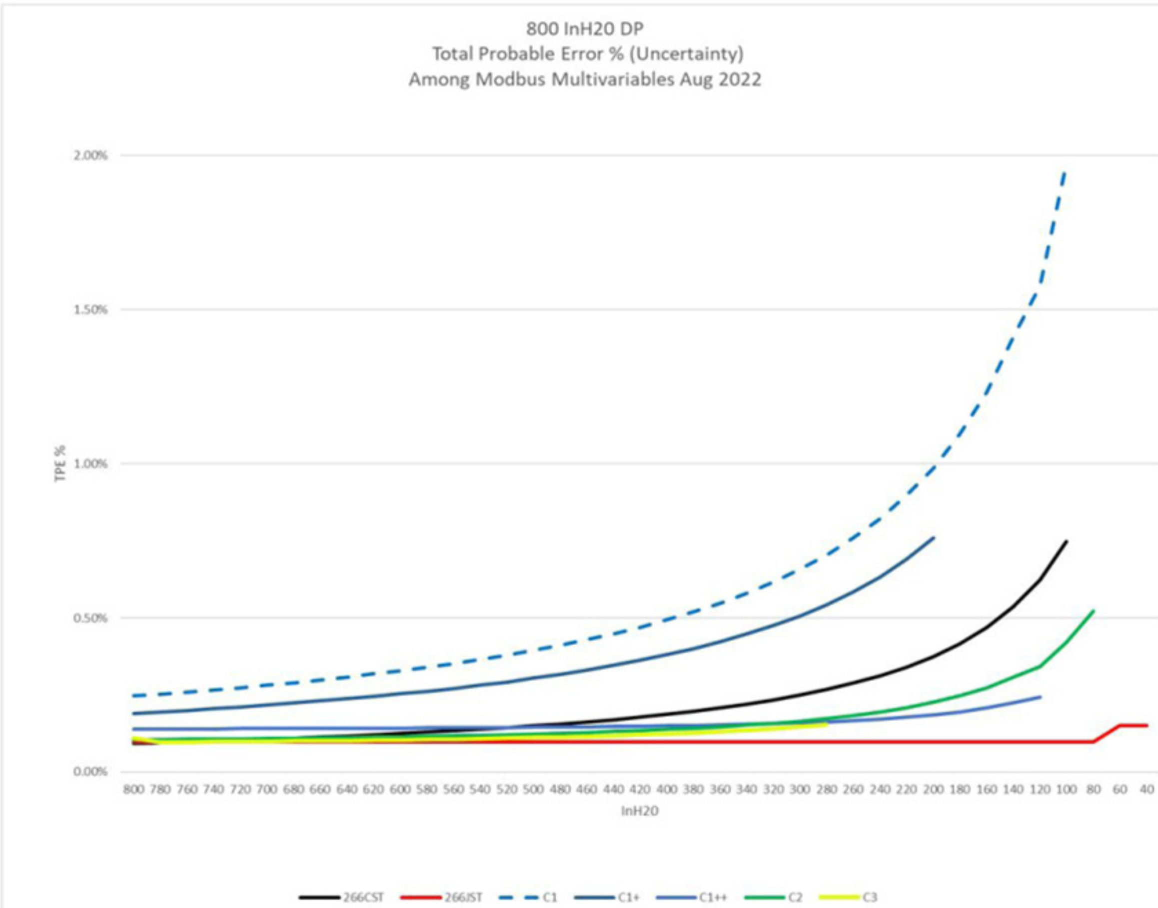
% Reading	Lower -.75 PSI	Measurement	Upper +.75 PSI
0.09%	799.25	800	800.75
0.11%	699.25	700	700.75
0.12%	599.25	600	600.75
0.15%	499.25	500	500.75
0.19%	399.25	400	400.75
0.25%	299.25	300	300.75
0.37%	199.25	200	200.75
0.75%	99.25	100	100.75

This % Reading data is shown in the chart below with the black solid line.
***Note the difference in the %Full Scale devices and the % Reading device.

Comparison of ABB Devices and their Total Probable Error (TPE)



Comparison of ABB and competitor devices and their Total Probable Error (TPE)



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