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Testing Protocol for Pressure, Differential Pressure, and Temperature Measuring Devices

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Introduction

This document defines the testing protocol and reporting protocols for families of devices used to measure differential pressure, pressure, and temperature for the purpose of determining fluid quantities and qualities. This testing protocol is designed to supply industry with capabilities of these devices that can be compared when they are used under similar operating conditions. The objectives of this testing protocol are to:

a) Ensure that the user of any differential pressure, pressure, and temperature device knows its performance characteristics under the prescribed Chapter 22.4 testing conditions (units should only be compared when tested at the same time),

b) Facilitate both the understanding and the introduction of new technologies,

c) Provide information about relative performance characteristics of the differential pressure, pressure, and temperature devices under standardized API 22.4 testing protocol, and

d) Provide a standardized process for reporting transmitter API 22.4 tested performance.

To accomplish these objectives, this testing protocol defines the test limits for operating conditions of the devices, the requirements of the facility or facilities to perform the tests and encompasses any device capable of measuring differential pressure, pressure, and temperature.

Testing Protocol for Pressure, Differential Pressure, and Temperature Measuring Devices

1 Scope

This testing protocol documents the method for testing the performance characteristics specific to pressure, differential pressure, and temperature sensors and transmitters used in petroleum measurement. The testing protocol includes a listing of parameters affecting the performance of the devices, a description of the tests required, requirements for the test facility, a data reporting format, and an uncertainty determination methodology.

2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC 17025:2005, *General requirements for the competence of testing and calibration laboratories*

IEC 60770-2: 2010, *Transmitters for use in industrial-process control systems—Part 2: Methods for inspection and routine testing*

ISO/IEC Guide 98-3 (GUM:1995): 2008, *Uncertainty of measurement—Part 3: Guide to the expression of uncertainty in measurement*

3 Terms and Definitions

3.1
Hysteresis
The difference between the indications of a measuring instrument when the same value of the quantity measured is reached by increasing or decreasing the quantity.

3.2
Combined Repeatability and Hysteresis (CRH)
The combined effect of repeatability and hysteresis. Due to the manner in which the API 22.4 baseline accuracy is determined, it may be impossible to differentiate between repeatability and hysteresis, therefore, the two effects are combined into one test.

3.3
API 22.4 baseline accuracy
A measure of the accuracy at a near ambient temperature determined by the testing procedure defined in this document. The API 22.4 baseline accuracy is calculated from the combination of the linearity and CRH data calculations. API 22.4 baseline accuracy is used to compare the result to other transmitters tested at the same time and is also used in the calculation of influence factor effects.

3.4
Analog signal
A signal that varies continuously in amplitude rather than in discrete steps.

3.5
Digital signal
A signal that varies in discrete steps rather than continuously.

3.6
Dp pressure limit
The maximum working pressure that can be applied to one side of a differential pressure device as defined by the manufacturer.

3.7
Linearity
The degree to which a response function describing the input-output relationship between a measured quantity and the signal produced by the measuring device can be described by a straight line.

3.8
Rangeability
The capability of a measuring device to measure between a minimum and maximum input within an acceptable tolerance. Rangeability is generally expressed as the ratio of the maximum to the minimum.

3.9
Repeatability
Measure of the agreement between the results of successive measurements of the same variable carried out by the same method, with the same instrument, at the same location, and within a short period of time.

3.10
Uncertainty (of measurement)
The amount by which an observed or calculated value may depart from the true value.

3.11
Zero Measurand Output
Zero
The signal of a sensor with zero measurand applied.

3.12
Slope
The ratio of the output signal to the measured variable between the zero value and the span value of a transmitter.

4 Field of Application

The field of application for this testing protocol is limited to devices that are used in the measurement of fluids in the petroleum, energy, and petrochemical industries.

5 Parameter Variations Affecting Device Performance

5.1 API 22.4 Baseline Tests

In order to identify the performance changes resulting from changes in the operating condition, the baseline test is required, see 6.4. The following measures of performance are calculated from the baseline test:

— Accuracy

— Linearity

— Combined Repeatability and Hysteresis

5.2 Influence Testing

Influence testing quantifies the environmental effect and the dynamic performance of pressure, differential pressure, and temperature measuring devices including:

— Ambient Operating Temperature Influence

— Pressure Operating Influence on Differential Pressure Transmitter Maximum Pressure/Differential Pressure Testing

  — Pressure Maximum Operating Pressure for Pressure Transmitter

  — Pressure Maximum Operating Pressure for Differential Pressure Transmitter

  — Differential Pressure Maximum Operating Differential Pressure for Differential Pressure Transmitter

5.3 Special Testing

Special testing quantifies the effect of external mechanical and electrical conditions that may affect the performance of pressure, differential pressure, and temperature measuring devices. These tests are covered in 6.6.

6 Tests

The following sections describe API 22.4 testing requirements for pressure, differential pressure, and temperature transmitters. Test applicability is indicated in the test name and in Table 1.

Table 1—Matrix of API 22.4 Testing Requirements for Transmitters

Baseline and Non-ideal Condition Testing Requirements	Device Type		
	Pressure	Differential Pressure	Temperature
6.4.1 API 22.4 Baseline Accuracy	Required	Required	N/A
6.4.2 API 22.4 Temperature Transmitter Testing	N/A	N/A	Required
6.5.1 Ambient Operating Temperature Influence—Zero and Slope	Required	Required	N/A
6.5.2 Day/Night Cycle Test—Pressure and Differential Pressure	Required	Required	N/A
6.5.3 Pressure Operating Effect on Differential Pressure Transmitter	N/A	Required	N/A
6.5.4 Pressure and Differential Maximum Operating Pressure Testing	Required	Required	N/A

6.1 Test Conditions

Written testing procedures should be developed and agreed to by the party requesting the test and the test facility prior to the start of any testing. The sequence of tests should be considered and any tests that can alter device performance should be completed last. All deviations from written procedures or standards shall be documented.

Care should be taken to ensure that influence factors not being tested are held as constant as possible to minimize their effect on the test results. Influence parameters shall be maintained per IEC 60770-2, Section 5.1. The major influence factors are ambient temperature, pressure, and humidity. Care should also be taken to eliminate or minimize the factors listed in 6.6. The average operating value and range of temperature, relative humidity and atmospheric pressure of the tests shall be measured and reported.

If a transmitter is tested for both digital and analog outputs, the tests should be performed simultaneously but shall be reported separately. If the digital protocol provides an indication of the analog output for a given input, this should be used in addition to an actual analog output measurement. See Section 7 for test facilities and test equipment requirements.

6.2 Transmitter and Data Acquisition Conditioning and Installation

Unless otherwise noted in the individual test requirements, the transmitter shall be installed and adjusted (mounting position, etc.) based on the manufacturer's installation and commissioning procedures. Figure 1 shows typical test setups for transmitters with digital or analog outputs, or a combination thereof.

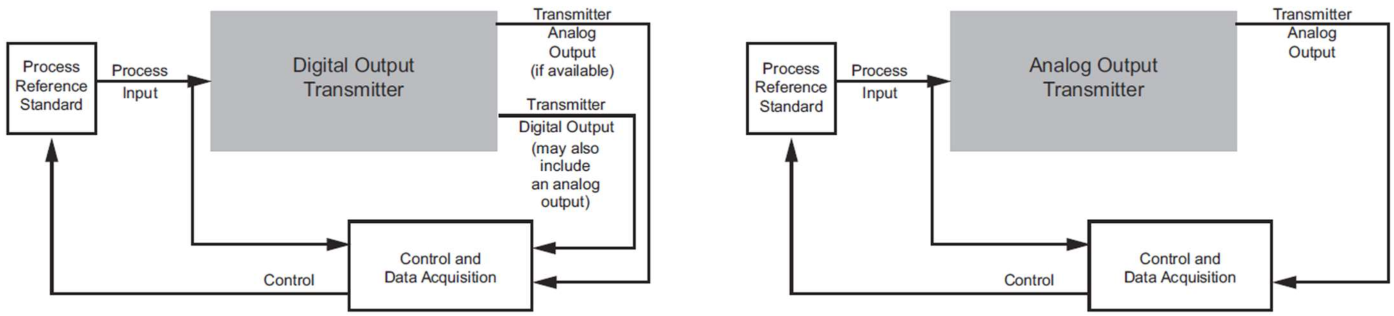


Figure 1—Typical Test Installation for Digital and Analog Output Transmitters

The transmitter shall be preconditioned by:

a) Placing the transmitter in the environment and under the conditions it will be tested (e.g. with the covers removed) for at least 24 hours.

b) Powering up the transmitter for at least one hour prior to testing.

c) Cycling the transmitter (differential and pressure transmitters only) over the range it will be tested as specified in 6.4.1, a minimum of three times.

d) Adjusting the transmitter by (differential and pressure transmitters only):

   1) Adjusting the zero of the transmitter.

   2) Adjusting the slope trim per Annex D if the device has not been factory calibrated.

For a bi-directional differential pressure transmitter, each direction shall be treated as a separate device for the purposes of this testing.

The transmitter filters and damping adjustments shall be set for minimum effect per manufacturers' recommendation. Tapping of the transmitter during testing or evaluation is not allowed and the transmitter installation shall minimize the transfer of vibrations and mechanical shock.

It is important to use measured atmospheric pressure when testing gauge pressure transmitters with absolute pressure reference standards. Changes in weather can cause atmospheric pressure differences up to ±0.5 psi (3.45 kPa) which at a 10 psia (68.95 kPa) operating pressure could result up to a 5 % error if an assumed atmospheric pressure is used Consideration should be given to record the atmospheric pressure at hourly intervals during any of the testing processes.

6.3 Test Data and Calculated Results

All test data, calculated test results, and anomalies shall be recorded along with approximate start and end times of the test. The test operator shall calculate and report the results as described in 6.4, 6.5, and 9. Examples for all of the calculations can be found in Annex B.

There are two ways to view the test results:

1) An individual device could be tested and the performance viewed/studied.

2) Multiple devices can be compared using the results of this protocol, but only if the testing was performed simultaneously and under the same conditions.

The performance of an individual device shall not be compared to another device tested to this protocol that was not tested at the same time and under the same conditions.

6.4 API 22.4 Baseline Testing

6.4.1 API 22.4 Baseline Accuracy

API 22.4 Baseline Accuracy is the combination of linearity and CRH.

Testing requires a minimum of three upscale/downscale test cycles for the test points shown in Table 2. Additional test points may be added.

Table 2—Minimum Required Test Points

Test Points (% of Maximum Test Value)
0% – 2% – 4% – 6% – 8% – 10% – 20% – 40% – 60% – 80% – 100%

6.4.1.1 API 22.4 Baseline Accuracy Calculation

API 22.4 Baseline Accuracy shall be calculated for each required test point in Table 2 as root mean square of linearity and the maximum CRH values:

$$API\ 22.4 BaselineAccuracy = \sqrt{(Linearity)^2 + (max(CRH))^2} \quad (1)$$

(See Annex B.1 for an example of linearity, CRH, and API 22.4 Baseline Accuracy calculations.)

6.4.1.2 Linearity Calculation

Linearity shall be calculated for each test point in Table 2 as the average of all test upscale and downscale values: (See Annex B.1.1 for an example of linearity calculations.)

$$Linearity = \Sigma \frac{DUT - Ref}{Number\ of\ Test\ Points} \quad (2)$$

where

DUT is the Device Under Test Value;

Ref is the Reference Standard Value.

6.4.1.3 CRH Calculation

CRH shall be calculated for each test point in Table 2 as the maximum minus the minimum of all repeat test upscale and downscale values:

$$CRH = \left(max\left([DUT - Ref]_{downscaleorupscale}\right) - \min\left([DUT - Ref]_{upscaleordownscale}\right)\right)/2 \quad (3)$$

Due to the limited number of test points, the transmitter repeatability error shall be reported as the maximum of these calculated values. (See Annex B.1.2 for an example of CRH calculations.)

6.4.2 Temperature Transmitter Testing

Performance of the temperature measurement in an Electronic Flow Measurement (EFM) system is dependent on two factors: 1) the performance of the temperature sensor (typically a Resistance Temperature Detector (RTD)), and 2) the performance of the sensor to temperature conversion electronics of either the EFM or the temperature transmitter.

RTD sensors are manufactured to specific tolerances based on their performance classification. For example, Class A and Class B RTDs have the following manufacturing tolerance:

$$Class A \Delta T_{o_F} = \pm(0.27 + 0.0036 \times |T_{o_F}|) or \Delta T_{o_C} = \pm(0.15 + 0.002 \times |T_{o_C}|) \quad (4)$$

$$Class B \Delta T_{o_F} = \pm(0.54 + 0.009 \times |T_{o_F}|) or \Delta T_{o_C} = \pm(0.30 + 0.005 \times |T_{o_C}|) \quad (5)$$

where

$|T_{o_F}|$ is the absolute value of temperature $T_{°F}$ in °F;

$|T_{o_C}|$ is the absolute value of temperature $T_{°C}$ in °C;

$\Delta T_{°F}$ is the maximum temperature error at temperature T_{o_F};

$\Delta T_{°C}$ is the maximum temperature error at temperature T_{o_C}.

NOTE 1 For RTD sensor measuring electronics that are calibrated to a precision input resistance source, this manufacturing specification can be used to estimate the additional temperature performance uncertainty of the RTD. For example, a Class B RTD operating at 68 °F (20 °C) will add approximately ± 0.7 °F (± 0.4 °C) temperature measurement uncertainty to the measuring electronics uncertainty. A Class A RTD will have approximately half the uncertainty of a Class B RTD.

NOTE 2 To minimize the impact of sensor uncertainty, the sensor can be characterized and the characterized sensor used during calibration of the EFM/transmitter electronics.

The measuring electronics shall be calibrated prior to the start of testing and the combined performance of the input (RTD or other) sensor through to the output of the measuring electronics shall be tested at four ambient temperatures and the test temperatures shown in Table 3. If the temperature difference is within the appropriate Class specification, the uncertainty of the Class as stated in Equation (5) may be utilized. If the temperature difference is outside the appropriate Class specification, the manufacturer should be contacted to determine the cause of the discrepancy.

The electronics shall be allowed to stabilize at the ambient temperature prescribed for each test at a minimum of one hour prior to commencing. The RTD/Sensor temperature shall be calculated from the reference standard temperature if a characterized sensor is used. The temperature difference shall be calculated from the RTD/Sensor temperature, if available.

Table 3—Electronics Ambient Temperature and Sensor Temperature Test Points

1. Baseline Test—Electronics Ambient Temperature Approximately 70 °F/21 °C						
Test Temperature	Temperature of Reference Standard	RTD/Sensor Characterized Temperature (If Available)	EFM/ Transmitter Reading	Temperature Difference	Class A Spec	Class B Spec
	°F/°C	°F/°C	°F/°C	°F/°C	°F/°C	°F/°C
0 °F/–18 °C						
32 °F/0 °C						
68 °F/20 °C						
104 °F/40 °C						
140 °F/60 °C						
2. Hot Test—Electronics Ambient Temperature Approximately 140 °F/60 °C						
Test Temperature	Temperature of Reference Standard	RTD/Sensor Characterized Temperature (If Available)	EFM/ Transmitter Reading	Temperature Difference	Class A Spec	Class B Spec
	°F/°C	°F/°C	°F/°C	°F/°C	°F/°C	°F/°C
32 °F/0 °C						
68 °F/20 °C						
104 °F/40 °C						
3. Cold Test—Electronics Ambient Temperature Approximately 40 °F/40 °C						
Test Temperature	Temperature of Reference Standard	RTD/Sensor Characterized Temperature (If Available)	EFM/ Transmitter Reading	Temperature Difference	Class A Spec	Class B Spec
	°F/°C	°F/°C	°F/°C	°F/°C	°F/°C	°F/°C
32 °F/0 °C						
68 °F/20 °C						
104 °F/40 °C						
4. Baseline Repeat—Electronics Ambient Temperature Approximately 70 °F/21 °C						
Test Temperature	Temperature of Reference Standard	RTD/Sensor Characterized Temperature (If Available)	EFM/ Transmitter Reading	Temperature Difference	Class A Spec	Class B Spec
	°F/°C	°F/°C	°F/°C	°F/°C	°F/°C	°F/°C
0 °F/–18 °C						
32 °F/0 °C						
68 °F/20 °C						
104 °F/40 °C						
140 °F/60 °C						

6.5 Influence Testing

This section describes the transmitter testing protocol for the influence factors (see 5.2) affecting flow rate measurement of petroleum products.

6.5.1 Ambient Operating Temperature Influence—Zero and Slope

The ambient operating temperature influence shall be tested by measuring the change when the transmitter is cycled twice through the test points in Table 4. (Test points in Table 4 that exceed the transmitter operating range shall be replaced with the operating limit of the transmitter.) At each temperature, the zero and maximum test value shall be recorded.

No adjustment of the transmitter shall be done between changes to the ambient temperature and sufficient time shall be allowed for the transmitter core temperature to stabilize to the test chamber temperature at each test point. If the transmitter has an internal temperature sensor, it should be used to confirm that the transmitter temperature has stabilized, and the values shall be reported. Due to the uncertainty of this sensor, there may be an offset from the chamber ambient temperature and the rate of change should be used to determine stabilization. For transmitters without internal temperature measurement, the output of the transmitter should be monitored for a trend change after allowing a minimum of one hour for the temperature to stabilize.

Transmitter zero effect is the change in the zero reading between Test Point 1 and any of the other required test points in Table 4. Transmitter span effect is the change in the span reading between Test Point 1 and any of the other required test points in Table 4.

Table 4—Ambient Temperature Test Cycle

Temperature	Test Point 1	Test Point 2	Test Point 3	Test Point 4	Test Point 5	Test Point 6	Test Point 7	Test Point 8	Test Point 9	Test Point 10
°F	68	86	104	140	68	50	32	–4	–40	68
°C	20	30	40	60	20	10	0	–20	–40	20

6.5.2 Day/Night Cycle Test—Pressure and Differential Pressure

Transmitters are often installed outdoors and may be exposed to radiant heat from the sun or other sources which may significantly affect the transmitter zero. By measuring the effect of these conditions on transmitter zero the user of this document can estimate these effects and any requirement they may have on installation and maintenance practices.

The day/night cycle test is designed to measure the temperature effect on zero when the transmitter is cycled over a 24-hour period. To quantify the effect of temperature on zero, the temperature shall be varied over two temperature tests: 1) one starting at approximately 70 °F (21 °C) and varying ±18 °F (10 °C), and 2) another starting at approximately 70 °F (21 °C) and varying ±35 °F (19.5 °C), and each test shall be for one 24-hour sinusoidal cycle. The transmitter will be zeroed at the start of the test, and the test chamber temperature and transmitter zero recorded at 30-second intervals for the duration of the test. Figure 8 shows an example of the logged data and graphical representation of the test data. This example assumes a transmitter with a Maximum Test Value (MTV) of 100 units. No adjustments shall be done for the duration of each test. Transmitter zero effect is the change in the zero reading between the initial zero and any of the other values collected.

6.5.3 Pressure Operating Effect on Differential Pressure Transmitter

Differential pressure transmitters shall be tested for the effect of changes in operating pressure on both the transmitter zero and the transmitter slope.

The pressure zero and span effect shall be tested by measuring the change when the transmitter is cycled twice through the test points in Table 5. At each pressure, the zero and maximum test value shall be recorded.

No adjustment of the transmitter shall be done between changes to the pressure, the pressure ramp rate shall be controlled to minimize any impact on the transmitter calibration and sufficient time shall be allowed for the transmitter zero reading to stabilize at each test point.

Transmitter zero effect is the change in the zero reading between Test Point 1 and any of the other required test points in Table 5. Transmitter span effect is the change in the span reading between Test Point 1 and any of the other required test points in Table 5. If the measured transmitter slope effect is less than the transmitter repeatability, the pressure slope effect may be reported as not measurable.

Table 5—Differential Pressure Transmitter—Operating Pressure Test Cycle

Percentage of Pressure Operating Range	0 %	1 %	2 %	3 %	4 %	5 %	10 %	20 %	40 %	60 %	80 %	100 %	60 %	20 %	0 %

6.5.4 Pressure and Differential Maximum Operating Pressure Testing

6.5.4.1 Pressure—Pressure Transmitter

The transmitter shall be tested for changes in zero and slope caused when the transmitter is cycled from atmospheric pressure to its maximum operating pressure limit and then returned to atmospheric pressure as shown in Table 6.

Transmitter zero effect is the change in the zero reading at each zero point between the initial and the final test cycle. Transmitter span effect is the change in the reading at each non-zero test point between the initial and the final test cycle.

Table 6—Pressure Maximum Operating Pressure Test Cycle

	Test Point 1	**Test Point 2**	**Test Point 3**	**Test Point 4**	**Test Point 5**	**Test Point 6**	**Test Point 7**	**Test Point 8**	**Test Point 9**
Initial Test Cycle	0 %	25 %	50 %	75 %	100 %	75 %	50 %	25 %	0 %
Transmitter Cycled to Maximum Operating Pressure									
Final Test Cycle	0 %	25 %	50 %	75 %	100 %	75 %	50 %	25 %	0 %

6.5.4.2 Pressure—Differential Pressure Transmitter

The transmitter shall be tested for changes in zero and slope caused when the transmitter is cycled from atmospheric pressure to its DP Pressure Limit and then returned to its normal operating/calibration pressure range as shown in Table 7. The test shall be repeated for the three pressure conditions of:

— Both differential pressure high and low pressure sides exposed to maximum operating pressure.

— The differential pressure high pressure side exposed to maximum operating pressure (not to exceed DP PRESSURE LIMIT) and the low pressure side exposed to atmospheric pressure.

— The differential pressure low pressure side exposed to maximum operating pressure (not to exceed DP PRESSURE LIMIT) and the high pressure side exposed to atmospheric pressure.

Transmitter zero effect is the change in the zero reading at each zero point between the initial and the final test cycle. Transmitter span effect is the change in the reading at each non-zero test point between the initial and the final test cycle.

Table 7—Differential Pressure Maximum Pressure Test Cycles

Initial Test Cycle	0 %	25 %	50 %	75 %	100 %	75 %	50 %	25 %	0 %
Transmitter Cycled to:	— High and Low Side Maximum Operating Pressure — High Side Maximum DP Static Pressure Limit/Low Side Atmosphere Pressure — Low Side Maximum DP Static Pressure Limit/High Side Atmospheric Pressure								
Final Test Cycle	0 %	25 %	50 %	75 %	100 %	75 %	50 %	25 %	0 %

6.5.4.3 Operating Over-range—Differential Pressure Transmitter

The transmitter shall be tested for changes in zero and slope caused when the differential pressure is cycled from its normal calibrated range to 150 % of the highest test point and then returned to its normal calibration pressure range as shown in Table 8.

Transmitter zero effect is the change in the zero reading at each zero point between the initial and the final test cycle. Transmitter span effect is the change in the reading at each non-zero test point between the initial and the final test cycle.

If the change to either zero or slope is significant, the manufacturer shall report either the time to return to normal operation and the residual zero and slope effect or the permanent zero and slope effect.

Table 8—150 % Over-range Test Cycle

Initial Test Cycle	0 %	25 %	50 %	75 %	100 %	75 %	50 %	25 %	0 %
Transmitter Cycled to 150 % of Highest Test Point									
Final Test Cycle	0 %	25 %	50 %	75 %	100 %	75 %	50 %	25 %	0 %

6.6 External Interference Testing

There are a number of conditions that can affect the performance of the transmitter in specific applications in addition to the predominant influence factors tested in 6.5. The testing in this section is outside of the scope of this chapter, but the testing can be useful for a user with specific application requirements. The manufacturer may test and report specifications for these conditions some of which are listed below. If the user is interested in this information the manufacturer should be consulted. There are several IEC documents that cover many of the interference conditions below.

- Mounting Position
- Stability and Drift
- Dynamic Response
- Dead Band
- Mechanical Vibration
- Power Frequency Magnetic Field
- Radiated Electromagnetic Interference

— Electrostatic Discharges

— Effect of Medium

— Drop and Topple

— Diaphragm Seal

— Wiring Disturbances

— Power Supply

— Relative Humidity

The general reporting requirements of this chapter may be used as a guideline.

7 Test Facility Requirements

7.1 Lab/Facility Qualification

a) The laboratory/facility measurements shall:

1) be traceable to NIST (National Institute of Standards and Technology) or

2) other national metrology standards.

b) The laboratory/facility shall also have:

1) ISO/IEC 17025: “General Requirements for the Competence of Testing and Calibration Laboratories” accreditation or

2) equivalent documentation and uncertainty calculations.

If the facility has ISO/IEC 17025 accreditation, then items a) or b) above are satisfied, otherwise the facility shall provide the documentation as listed as requested by the user.

7.2 Audit Process

In order to assure validity of tests performed following the testing protocols defined in this chapter, the laboratory or testing facility performing the tests shall provide evidence that the tests are performed in accordance with this standard. This evidence shall be provided at the request of any user/customer of the facility.

Providing validity that the tests were performed in accordance with the applicable test procedure is the responsibility of the facility performing the tests. The user/customer of the facility can request an audit of the laboratory or the testing facility to ensure the validity of the tests. The depth of the audit is determined by the user/customer of the facility and should be consistent with relevant national or international standards. A user/customer of the facility wanting a detailed analysis of the performance of the lab/facility, can request a review of all its procedures and processes.

8 Uncertainty Analysis and Calculation

8.1 Types of Uncertainty Calculations

8.1.1 How to Calculate Uncertainty

The uncertainty associated with the measured value shall be calculated following the guidelines of ISO/IEC Guide 98-3:2008 “Uncertainty of measurement—Part 3: Guide to the expression of uncertainty in measurement”. All uncertainties shall be reported with a confidence level of k = 2 (95 %).

8.1.2 Device Specifications

This testing protocol is limited to API 22.4 testing and as such cannot be used to establish transmitter specifications.

8.1.3 Presentation of Test Report Uncertainty

Section 6 and Section 9 specify how the tests are to be conducted and reported. The reported uncertainty cannot be interpreted as a transmitter type uncertainty statement because the tests are specific to an individual transmitter.

9 Test Report

If the test facility meets all the user requirements and any additional requirements defined in this testing protocol, then the results of the test shall be considered valid. The uncertainty of the testing equipment shall be recorded, reported, and used in the uncertainty calculations outlined in Section 8.

The test report shall contain:

— the name of the test facility and personnel responsible for test quality;

— copies or references to the test procedures used;

— make, model and serial number of the device under test along with the manufacturer's specifications;

— make, model and serial number of test equipment along with uncertainty statements, the last calibration date and the calibration facility;

— a commentary on the test results including any test observations or anomalies, or both, and a summary for the test findings;

— reports for each test conducted;

  — a statement of the national metrology standards body to which the measurement is traceable; and

  — the uncertainty statements of all test equipment used and in which testing procedure they were used.

The uncertainty associated with the test equipment shall be included in the uncertainty calculation for each test.

Table 9 summarizes tests with specific calculation and reporting requirements. The referenced figures show the minimum reporting requirements for recording of the raw test data and reporting of the calculated test results.

NOTE The tables in Figure 2 through Figure 4 and Figure 6 through Figure 12 have been color coded with the test results shown as blue fields and the calculations shown as red fields. The values in the tables are rounded for display purposes, however unrounded values are used in the calculations. This may result in a variation of +/- 1 in the last decimal place when recreating the data.

The format of the reporting may be changed as long as all of the required test data and calculations are provided. Units of Measure (UOM) shall be reported for all measurements.

Table 9—Required Tests and Example Test Reports

Test	Example Reports
6.4.1 API 22.4 Baseline Accuracy	Figure 2, Figure 3, Figure 4, and Figure 5
6.4.2 API 22.4 Temperature Transmitter Testing	Figure 6
6.5.1 Ambient Operating Temperature Influence—Zero and Slope	Figure 7
6.5.2 Day/Night Cycle Test—Pressure and Differential Pressure	Figure 8
6.5.3 Pressure Operating Effect on Differential Pressure Transmitter	Figure 9
6.5.4 Pressure and Differential Maximum Operating Pressure Testing	Figure 10, Figure 11, and Figure 12

Figure 2—Section 6.4.1, API 22.4 Baseline Accuracy—Test Data and Calculations

Test Cycle		1			2			3			Ref. Std.	
Test Point		Ref. Value	DUT Value	Difference	Ref. Value	DUT Value	Difference	Ref. Value	DUT Value	Difference	% Reading	
1	0%	0.0003	0.0267	0.0263	-0.0027	-0.0033	-0.0007	-0.0010	-0.0333	-0.0323		
2	2%	2.0003	1.9733	-0.0270	2.0000	1.9933	-0.0067	2.0020	2.0100	0.0080	+/-	0.025%
3	4%	4.0013	4.0000	-0.0013	3.9993	3.9667	-0.0327	4.0013	3.9933	-0.0080	+/-	0.025%
4	6%	5.9970	6.0000	0.0030	5.9980	6.0267	0.0287	5.9977	6.0100	0.0123	+/-	0.025%
5	8%	8.0020	8.0233	0.0213	7.9983	8.0200	0.0217	8.0017	7.9833	-0.0183	+/-	0.025%
6	10%	9.9983	10.0200	0.0217	9.9990	9.9700	-0.0290	9.9973	10.0333	0.0360	+/-	0.025%
7	20%	20.0027	20.0267	0.0240	19.9977	19.9733	-0.0243	19.9980	20.0133	0.0153	+/-	0.025%
8	40%	39.9967	40.0067	0.0100	40.0013	39.9833	-0.0180	40.0007	40.0167	0.0160	+/-	0.025%
9	60%	60.0030	59.9700	-0.0330	59.9973	60.0233	0.0260	59.9987	59.9900	-0.0087	+/-	0.025%
10	80%	80.0007	79.9933	-0.0073	80.0003	79.9733	-0.0270	80.0010	80.0167	0.0157	+/-	0.025%
11	100%	100.0020	99.9833	-0.0187	99.9970	99.9667	-0.0303	99.9987	100.0233	0.0247	+/-	0.025%
12	80%	80.0003	80.0133	0.0130	79.9967	79.9833	-0.0133	79.9967	79.9733	-0.0233	+/-	0.025%
13	60%	60.0000	60.0133	0.0133	59.9967	60.0167	0.0200	60.0023	59.9733	-0.0290	+/-	0.025%
14	40%	40.0000	40.0233	0.0233	40.0003	39.9733	-0.0270	40.0010	39.9733	-0.0277	+/-	0.025%
15	20%	19.9973	20.0300	0.0327	19.9967	20.0133	0.0167	20.0027	20.0167	0.0140	+/-	0.025%
16	10%	9.9967	9.9800	-0.0167	9.9993	10.0133	0.0140	10.0027	10.0033	0.0007	+/-	0.025%
17	8%	7.9973	7.9967	-0.0007	7.9997	8.0100	0.0103	8.0020	8.0167	0.0147	+/-	0.025%
18	6%	6.0023	6.0267	0.0243	6.0020	6.0067	0.0047	5.9977	6.0033	0.0057	+/-	0.025%
19	4%	3.9983	4.0333	0.0350	3.9967	4.0300	0.0333	3.9967	3.9767	-0.0200	+/-	0.025%
20	2%	1.9983	2.0267	0.0283	2.0020	1.9900	-0.0120	1.9977	1.9967	-0.0010	+/-	0.025%
21	0%	0.0013	0.0333	0.0320	0.0010	-0.0100	-0.0110	0.0033	-0.0200	-0.0233		

Linearity/CRH for Each Test Cycle											
Test Cycle	1			2			3			Ref. Std.	
Test Point	Ref. Value		Linearity	Ref. Value		Linearity	Ref. Value		Linearity	% Reading	
0%	0.0		0.0292	0.0		-0.0058	0.0		-0.0278		
2%	2.0		0.0007	2.0		-0.0093	2.0		0.0035	+/-	0.025%
4%	4.0		0.0168	4.0		0.0003	4.0		-0.0140	+/-	0.025%
6%	6.0		0.0137	6.0		0.0167	6.0		0.0090	+/-	0.025%
8%	8.0		0.0103	8.0		0.0160	8.0		-0.0018	+/-	0.025%
10%	10.0		0.0025	10.0		-0.0075	10.0		0.0183	+/-	0.025%
20%	20.0		0.0283	20.0		-0.0038	20.0		0.0147	+/-	0.025%
40%	40.0		0.0167	40.0		-0.0225	40.0		-0.0058	+/-	0.025%
60%	60.0		-0.0098	60.0		0.0230	60.0		-0.0188	+/-	0.025%
80%	80.0		0.0028	80.0		-0.0202	80.0		-0.0038	+/-	0.025%
100%	100.0		-0.0187	100.0		-0.0303	100.0		0.0247	+/-	0.025%

Key

Input Value

Calculated Value

Figure 3—Section 6.4.1, API 22.4 Baseline Accuracy—Repeatability/Hysteresis Calculations

CRH Calculation		
Test Point	CRH	
0%	+/-	0.0322
2%	+/-	0.0277
4%	+/-	0.0338
6%	+/-	0.0128
8%	+/-	0.0200
10%	+/-	0.0325
20%	+/-	0.0285
40%	+/-	0.0255
60%	+/-	0.0295
80%	+/-	0.0213
100%	+/-	0.0275
Max CRH	+/-	0.0338

Figure4—Section 6.4.1, API 22.4 Baseline Accuracy—Summary Calculations

Summary Calculations											
Test Point		Linearity			CRH			API 22.4 Baseline Accuracy			Ref. Std.
	Ref. Value		% URL	% Reading		% URL	% Reading		% URL	% Reading	% Reading
0%	0.0	-0.0015	-0.002%		+/- 0.0338	+/- 0.034%		+/- 0.0339	+/- 0.034%		
2%	2.0	-0.0017	-0.002%	-0.086%	+/- 0.0338	+/- 0.034%	+/- 1.692%	+/- 0.0339	+/- 0.034%	+/- 1.694%	+/- 0.025%
4%	4.0	0.0011	0.001%	0.026%	+/- 0.0338	+/- 0.034%	+/- 0.846%	+/- 0.0338	+/- 0.034%	+/- 0.846%	+/- 0.025%
6%	6.0	0.0131	0.013%	0.219%	+/- 0.0338	+/- 0.034%	+/- 0.564%	+/- 0.0363	+/- 0.036%	+/- 0.605%	+/- 0.025%
8%	8.0	0.0082	0.008%	0.102%	+/- 0.0338	+/- 0.034%	+/- 0.423%	+/- 0.0348	+/- 0.035%	+/- 0.435%	+/- 0.025%
10%	10.0	0.0044	0.004%	0.044%	+/- 0.0338	+/- 0.034%	+/- 0.338%	+/- 0.0341	+/- 0.034%	+/- 0.341%	+/- 0.025%
20%	20.0	0.0131	0.013%	0.065%	+/- 0.0338	+/- 0.034%	+/- 0.169%	+/- 0.0363	+/- 0.036%	+/- 0.181%	+/- 0.025%
40%	40.0	-0.0039	-0.004%	-0.010%	+/- 0.0338	+/- 0.034%	+/- 0.085%	+/- 0.0341	+/- 0.034%	+/- 0.085%	+/- 0.025%
60%	60.0	-0.0019	-0.002%	-0.003%	+/- 0.0338	+/- 0.034%	+/- 0.056%	+/- 0.0339	+/- 0.034%	+/- 0.056%	+/- 0.025%
80%	80.0	-0.0071	-0.007%	-0.009%	+/- 0.0338	+/- 0.034%	+/- 0.042%	+/- 0.0346	+/- 0.035%	+/- 0.043%	+/- 0.025%
100%	100.0	-0.0081	-0.008%	-0.008%	+/- 0.0338	+/- 0.034%	+/- 0.034%	+/- 0.0348	+/- 0.035%	+/- 0.035%	+/- 0.025%
Maximum - Minimum Linearity				0.305%							

NOTE Reference Standard Accuracy at zero points only apply to devices where the zero is determined by using a reference standard.

Figure 5—Section 6.4.1, API 22.4 Baseline Accuracy—Test Results

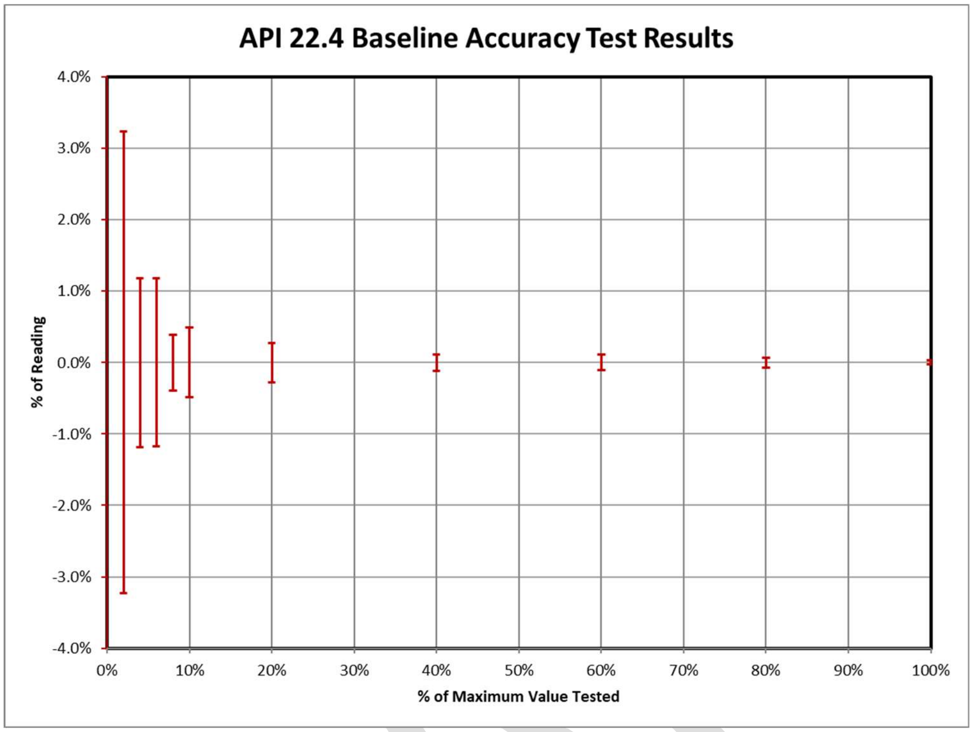


Figure 6—Section 6.4.2, API 22.4 Temperature Transmitter Testing

Test Temperature	Temperature of Reference Standard	RTD/Sensor Characterized Temperature (If Available)	EFM/Transmitter Reading	Temperature Difference	Class A Spec	Class B Spec
1. Baseline Test - Electronics Ambient Temperature ~70ºF/21ºC						
	°F	°F	°F	°F	°F	°F
0°F	-0.002	0.09	0.04	0.04	0.2700	0.5400
32°F	32.170	32.17	31.88	-0.29	0.3858	0.8295
68°F	68.107	68.05	68.08	-0.03	0.5152	1.1530
104°F	104.260	104.15	103.81	-0.45	0.6453	1.4783
140°F	139.669	139.96	140.07	0.40	0.7728	1.7970
2. Hot Test - Electronics Ambient Temperature ~140ºF/60ºC						
Test Temperature	Temperature of Reference Standard	RTD/Sensor Characterized Temperature (If Available)	EFM/Transmitter Reading	Temperature Difference	Class A Spec	Class B Spec
	°F	°F	°F	°F	°F	°F
32°F	31.866	32.15	32.21	0.35	0.3847	0.8268
68°F	67.843	68.10	68.16	0.32	0.5142	1.1506
104°F	103.786	104.04	103.90	0.12	0.6436	1.4741
3. Cold Test - Electronics Ambient Temperature ~-40ºF/-40ºC						
Test Temperature	Temperature of Reference Standard	RTD/Sensor Characterized Temperature (If Available)	EFM/Transmitter Reading	Temperature Difference	Class A Spec	Class B Spec
	°F	°F	°F	°F	°F	°F
32°F	31.806	31.93	32.06	0.25	0.3845	0.8263
68°F	68.086	68.12	68.15	0.07	0.5151	1.1528
104°F	103.995	104.03	103.99	0.00	0.6444	1.4760
4. Baseline Repeat - Electronics Ambient Temperature ~70ºF/21ºC						
Test Temperature	Temperature of Reference Standard	RTD/Sensor Characterized Temperature (If Available)	EFM/Transmitter Reading	Temperature Difference	Class A Spec	Class B Spec
	°F	°F	°F	°F	°F	°F
0°F	0.002	-0.03	0.09	0.09	0.2700	0.5400
32°F	32.018	31.80	32.08	0.06	0.3853	0.8282
68°F	67.943	67.87	67.80	-0.14	0.5146	1.1515
104°F	103.773	103.95	103.85	0.08	0.6436	1.4740
140°F	139.938	139.67	140.38	0.45	0.7738	1.7994

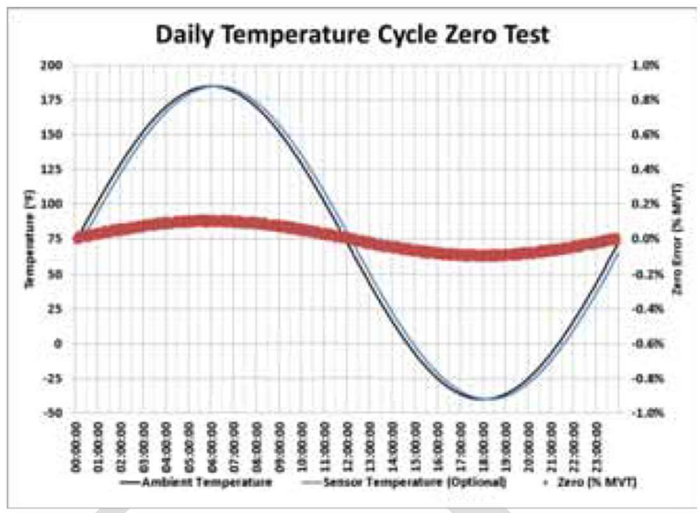
Figure 7—Section 6.5.1, Ambient Operation Temperature Influence—Zero and Slope

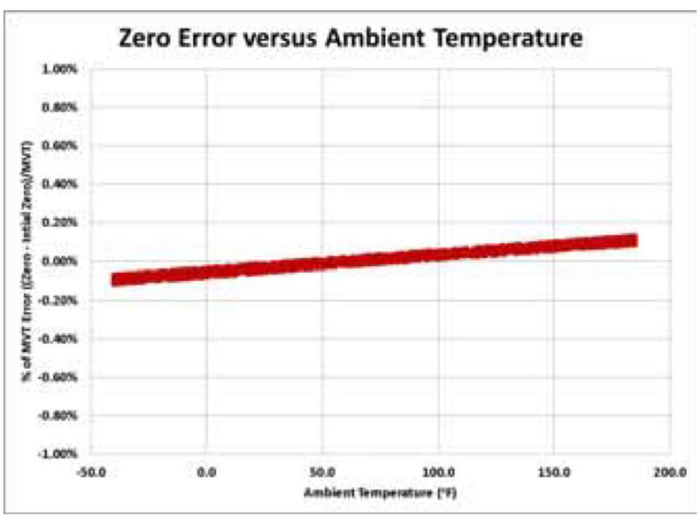
Ambient Operating Temperature Test											
Temperature	Test Point 1	Test Point 2	Test Point 3	Test Point 4	Test Point 5	Test Point 6	Test Point 7	Test Point 8	Test Point 9	Test Point 10	Ref. Std. Accuracy
°F	68	86	104	140	68	50	32	-4	-40	68	
°C	20	30	40	60	20	10	0	-20	-40	20	
Transmitter Zero Reading	0.010	-0.030	-0.050	-0.100	0.000	0.000	0.050	0.050	0.080	0.010	
Zero Difference		-0.040	-0.060	-0.110	-0.010	-0.010	0.040	0.040	0.070	0.000	
Zero Error (% MVT)		-0.04%	-0.06%	-0.11%	-0.01%	-0.01%	0.04%	0.04%	0.07%	0.00%	
Transmitter MVT Reading	100.000	100.002	99.956	99.928	99.970	99.978	100.011	100.005	100.105	100.052	+/- 0.25% Reading
URL Difference (Zero Corrected)	99.990	100.032	100.006	100.028	99.970	99.978	99.961	99.955	100.025	100.042	
Slope Error (% Reading)		0.04%	0.02%	0.04%	-0.02%	-0.01%	-0.03%	-0.04%	0.04%	0.05%	

Figure 8—Section 6.5.2, Day/Night Cycle Test—Pressure and Differential Pressure

Day/Night Cycle Test—Pressure and Differential Pressure

Time	Ambient Temperature	Sensor Temperature (Optional)	Zero	Zero (% MVT)
00:00:00	72.5	72.5	-0.018	0.000%
00:00:30	72.7	72.5	-0.005	0.013%
00:01:00	73.0	72.5	-0.023	-0.005%
00:01:30	73.2	72.5	0.023	0.041%
00:02:00	73.5	72.5	0.015	0.034%
00:02:30	73.7	72.5	0.019	0.037%
00:03:00	74.0	72.5	0.010	0.028%
00:03:30	74.2	72.5	-0.022	-0.004%
00:04:00	74.5	72.5	0.021	0.039%
00:04:30	74.7	72.5	-0.012	0.006%
00:05:00	75.0	72.5	0.015	0.033%
00:05:30	75.2	72.5	0.003	0.021%





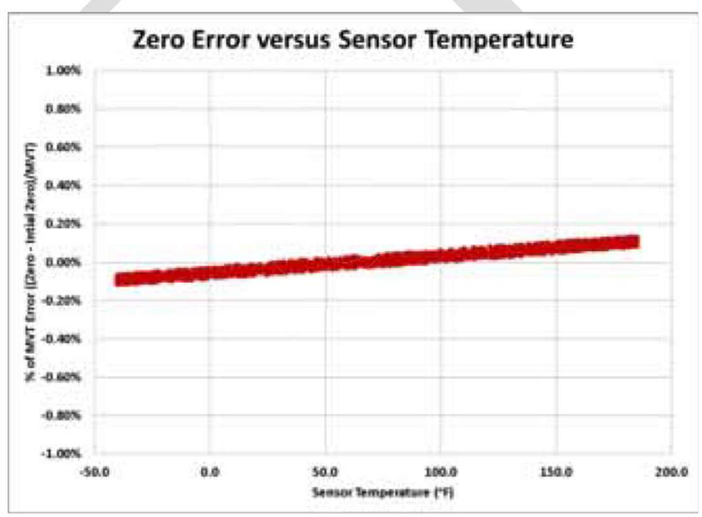
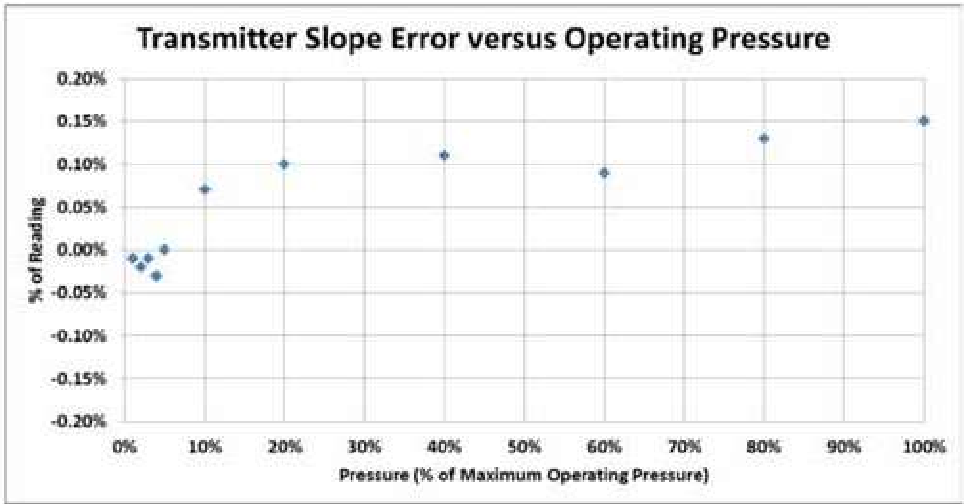


Figure 9—Section 6.5.3, Pressure Operating Effect on Differential Pressure Transmitter

	Pressure Sensor Slope Operating Effect – Differential Pressure															Ref. Std Accuracy
Test Point	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
% of Pressure Operating Range	0%	1%	2%	3%	4%	5%	10%	20%	40%	60%	80%	100%	60%	20%	0%	
Transmitter Zero	0	0.025	0.05	0.075	0.1	0.125	0.15	0.175	0.2	0.225	0.25	0.275	0.225	0.175	0	
Zero Error (%MVT)		0.025	0.05	0.075	0.1	0.125	0.15	0.175	0.2	0.225	0.25	0.275	0.225	0.175	0	
Transmitter MVT Reading	100.00	99.99	99.98	99.99	99.97	100.00	100.07	100.10	100.11	100.09	100.03	100.15	100.09	100.10	100.01	+/- 0.25% Reading
MVT Difference (Zero Corrected)		-0.01	-0.02	-0.01	-0.03	0.00	0.07	0.10	0.11	0.09	0.03	0.15	0.09	0.10	0.01	
Slope Error (% Reading)		-0.01%	-0.02%	-0.01%	-0.03%	0.00%	0.07%	0.10%	0.11%	0.09%	0.03%	0.15%	0.09%	0.10%	0.01%	



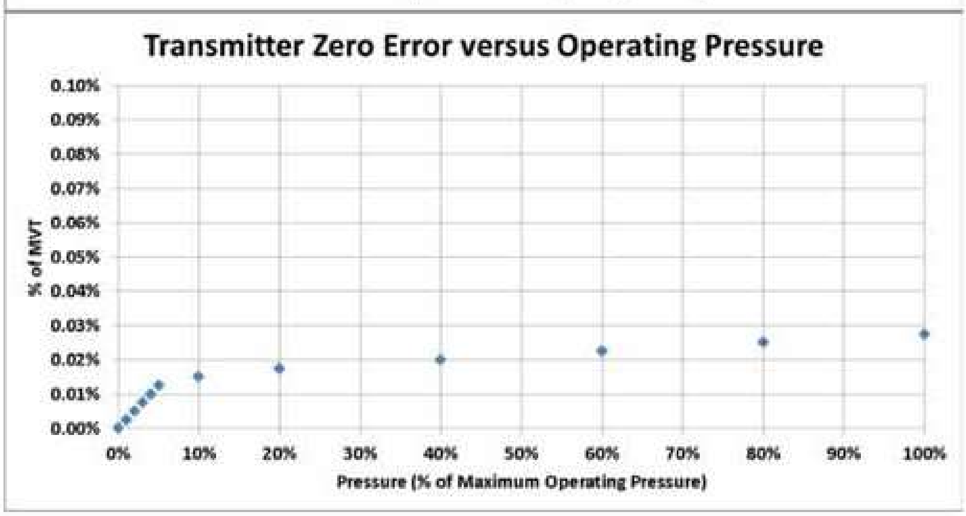


Figure 10—Section 6.5.4.1, Pressure—Pressure Transmitter

Maximum Working Pressure Limit Test - Pressure Transmitter									
	Test Point 1 0%	Test Point 2 25%	Test Point 3 50%	Test Point 4 75%	Test Point 5 100%	Test Point 6 75%	Test Point 7 50%	Test Point 8 25%	Test Point 9 0%
Intial Calibration Cycle	0.013	24.997	50.052	75.026	99.989	74.997	50.001	25.014	0.010
Transmitter Cycled to Maximum Working Pressure									
Final Calibration Cycle	0.140	25.202	50.301	75.188	100.123	75.306	50.247	25.217	0.150
Zero Error (% URL)	0.13%								
Span Error (% Reading)		0.21%	0.25%	0.16%	0.13%	0.31%	0.25%	0.20%	
Ref. Std. Accuracy		0.025%	0.025%	0.025%	0.025%	0.025%	0.025%	0.025%	

Figure 11—Section 6.5.4.2, Pressure—Differential Pressure Transmitter

Maximum Working Pressure Limit Test - Differential Pressure Transmitter									
	Test Point 1 0%	Test Point 2 25%	Test Point 3 50%	Test Point 4 75%	Test Point 5 100%	Test Point 6 75%	Test Point 7 50%	Test Point 8 25%	Test Point 9 0%
Intial Calibration Cycle	0.013	25.035	50.128	75.114	99.602	75.098	49.922	25.052	0.010
Transmitter Cycled - High and Low Side to Maximum Working Pressure									
Final Calibration Cycle	0.100	25.063	50.170	75.182	99.705	75.190	49.983	25.074	0.096
Zero Error (% URL)	0.09%								0.09%
Span Error (% Reading)		0.03%	0.04%	0.07%	0.10%	0.09%	0.06%	0.02%	
Transmitter Cycled - High Side to Maximum Working Pressure and Low Side Atmospheric Pressure									
Final Calibration Cycle	0.001	25.015	50.102	75.063	99.511	75.053	49.884	25.038	0.002
Zero Error (% URL)	-0.01%								-0.01%
Span Error (% Reading)		-0.02%	-0.03%	-0.05%	-0.09%	-0.05%	-0.04%	-0.01%	
Transmitter Cycled - Low Side to Maximum Working Pressure and High Side Atmospheric Pressure									
Final Calibration Cycle	0.122	25.085	50.203	75.242	99.746	75.231	50.025	25.101	0.131
Zero Error (% URL)	0.11%								0.12%
Span Error (% Reading)		0.05%	0.08%	0.13%	0.14%	0.13%	0.10%	0.05%	
Ref. Std. Accuracy		0.025%	0.025%	0.025%	0.025%	0.025%	0.025%	0.025%	

Figure 12—Section 6.5.4.3, Operating Over-range—Differential Pressure Transmitter

150% Over-range Test - Differential Pressure Transmitter									
	Test Point 1 0%	Test Point 2 25%	Test Point 3 50%	Test Point 4 75%	Test Point 5 100%	Test Point 6 75%	Test Point 7 50%	Test Point 8 25%	Test Point 9 0%
Intial Calibration Cycle	0.013	24.883	49.917	75.369	100.016	75.202	49.936	24.995	0.010
Transmitter Cycled to 150% of its URL									
Final Calibration Cycle	0.154	24.931	49.988	75.483	100.239	75.358	50.025	25.046	0.160
Zero Error (% URL)	0.14%								0.15%
Span Error (% Reading)		0.05%	0.07%	0.11%	0.22%	0.16%	0.09%	0.05%	
Ref. Std. Accuracy		0.025%	0.025%	0.025%	0.025%	0.025%	0.025%	0.025%	

Annex A
(informative)

Refinement of Transmitter API 22.4 Baseline Accuracy with Verification Data

A.1 API 22.4 Baseline Accuracy

Baseline accuracy is commonly reported as percent of span. Although percent of span provides a simpler accuracy statement, percent of reading represents the real impact of the transmitter accuracy on the measurement system. The transmitter percent of reading uncertainty can be calculated from the transmitter percent of span uncertainty at any operating point using Equation (A.1):

$$Percentage\ of\ Reading\ Uncertainty = \frac{Percentage\ of\ Span\ Uncertainty \times Span}{Operating\ Point} \qquad \text{(A.1)}$$

For example 0.1 % of span accuracy is shown plotted in Figure A.1 as a percent of span (left side) and a percent of reading (right side) for the calibrated operating range of the transmitter.

For the same value accuracy specification, percent of reading accuracy will require higher accuracies from the instrument except at full span, relative to the same specified accuracy as percent of full span. For example, if a specification calls for an instrument to be accurate within 0.10 % of full scale at 10 in. of differential when the span is 100 in., the instrument must indicate between 9.9 in. and 10.1 in. of differential. For an accuracy stated as 0.10 % of reading for the same span, the instrument must indicate between 9.99 in. and 10.01 in. of differential.

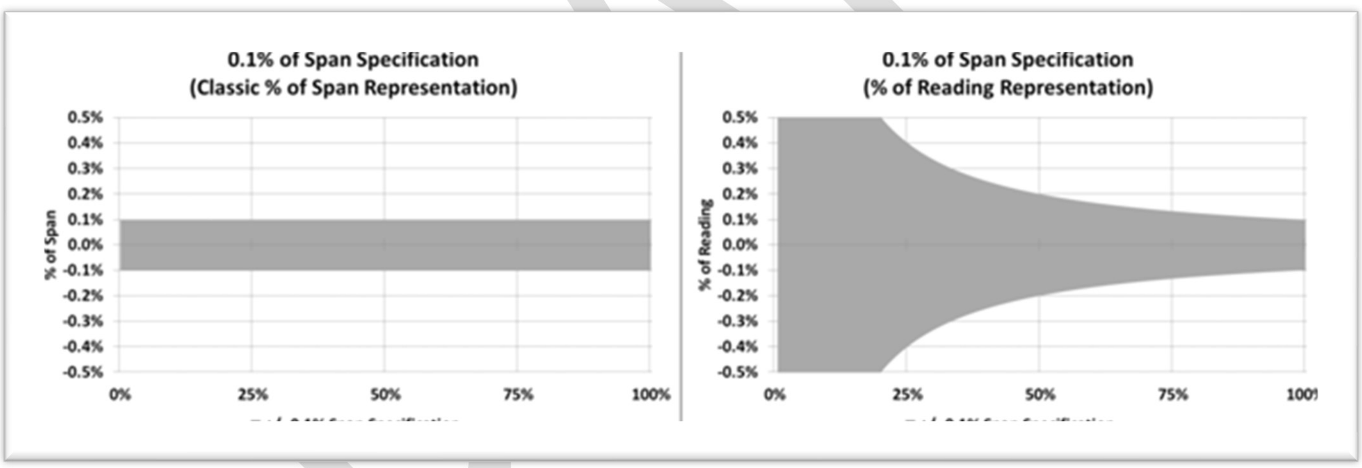


Figure A.1—Percentage of Span and Percentage of Reading Representation of a 0.1 % of Span Accuracy

A.2 Combining Reference Accuracy with Verification Data

Two transmitter characteristics can be combined to provide a better picture of the transmitter performance over its operating range based on verification data and API 22.4 Baseline Accuracy specifications:

— By showing the transmitter API 22.4 Baseline Accuracy specification as error bars at each verification point, the uncertainty range of doing a digital sensor upper trim (slope) adjustment to each verification point is displayed. (See A.2.1)

— By recognizing that when the transmitter verification data is plotted as percent of reading, a percent of reading digital sensor upper trim (slope) adjustment at any point will shift all of the operating points by the same percent of reading across the entire transmitter range. (See A.2.2)

NOTE The term digital sensor upper trim (slope) adjustment is used because the slope adjustment needs to be applied with no transmitter sensor zero interaction. This is typically only possible in transmitters with digital senor trim, using flow computer calibration routines that apply separate zero and slope adjustments or with analog transmitters that have a smart/digital zero and slope trim output modules.

A.2.1 Verification Point Percent of Reading

The percent of span API 22.4 Baseline Accuracy specification can be represented as a percent of reading verification error bar at each verification point. This representation is based on the assumption that if the transmitter was calibrated to the verification point, the verification point would become the span. This change in span makes the percent of span API 22.4 Baseline Accuracy equal to percent of reading at the verification point and the percent of reading uncertainty for verification point can be calculated as shown in Figure A.2. By limiting the percent of reading uncertainty for each verification point to the range between it and the next lower verification point, the expected verification uncertainty can be calculated as shown in Figure A.3.

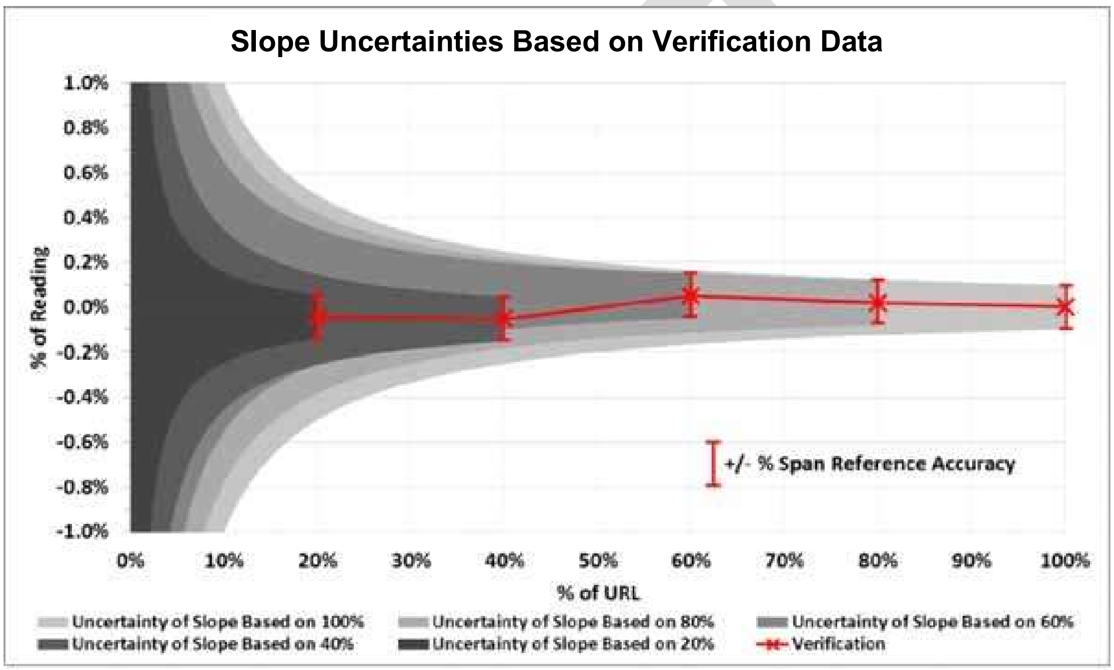


Figure A.2—Verification Data with API 22.4 Baseline Accuracy Error Bars and Percent of Reading Uncertainty

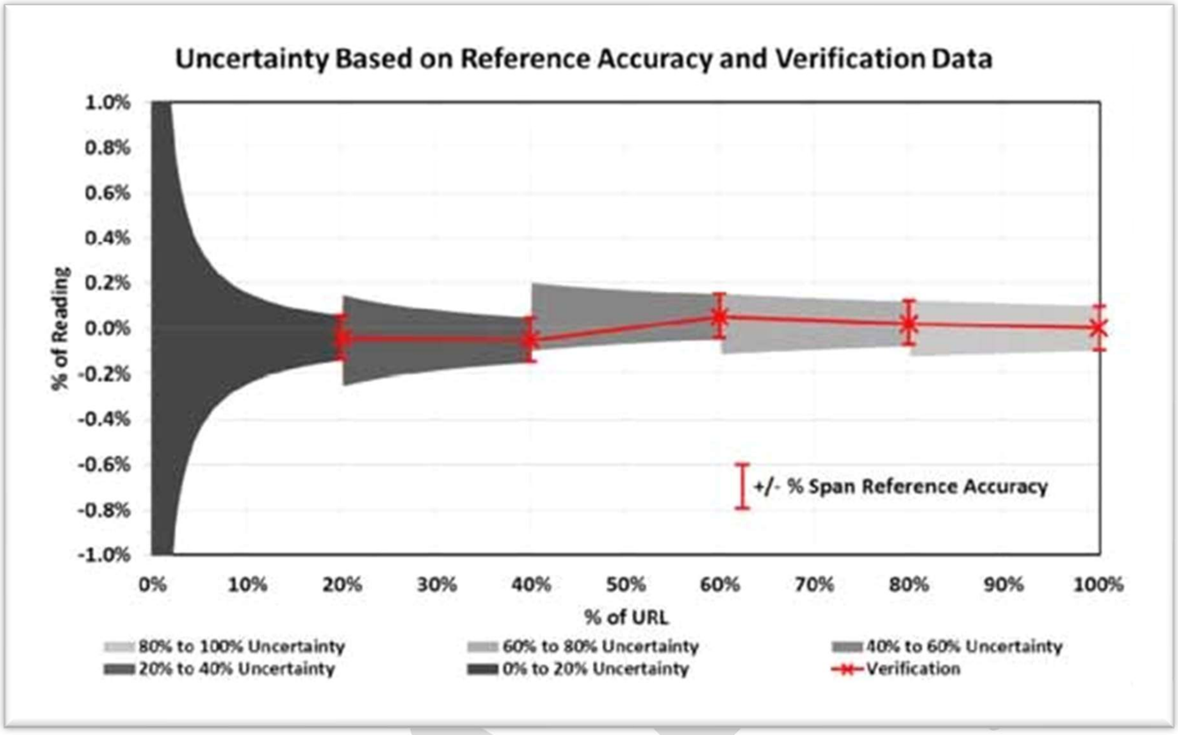


Figure A.3—Uncertainty Calculation Limited by the Next Lower Verification Point

A.2.2 Transmitter Digital Sensor Upper Trim (Slope) Adjustment

To obtain the manufacturer's stated specification over a specified operating range requires applying a digital sensor upper trim (slope) adjustment for that range. If the verification data is presented as percent of reading it is very easy to determine the required digital slope upper trim (slope) adjustment because the percent of reading adjustment at any verification point will result in the same percent of reading adjustment of all verification points.

For example, if the transmitter in Figure A.3 has a digital sensor upper trim (slope) adjusted at the 40 % verification point by +0.05 % of reading, then all of the span verification points shift by +0.05 % of reading as shown in Figure A.4.

A.3 Calculating Performance Accuracy from Verification Data

By presenting the API 22.4 Baseline Accuracy verification data as percent of reading, the estimated performance of the transmitter can be calculated from the verification points within the expected operating range. Using the percent of reading verification error of the points within the expected operating range:

Digital Sensor Upper Trim (Slope) Adjustment

= (Max(Verification Error) – Min(Verification Error))/2 + Min(Verification Error)

Verification Nonlinearity

= (Max(Verification Error) – Min(Verification Error))

Estimated Uncertainty Band

= ± (Max(Verification Error) – Min(Verification Error)) + 2 × % of Span Using a maximum verification error of

0.049% and a minimum verification error of -0.045%:

— Digital Sensor Upper Trim (Slope) Adjustment = ((0.049 %) – (–0.045 %))/2 + (–0.045%) = 0.002 %

— Verification Nonlinearity = ((+0.049 %) – (–0.045%)) = 0.094 %

— Estimated Uncertainty Band = ((+0.049 %) – (–0.045 %)) + 2 × 0.1 % = ± 0.394 %

over the operating range of 20 % to 100 % of span.

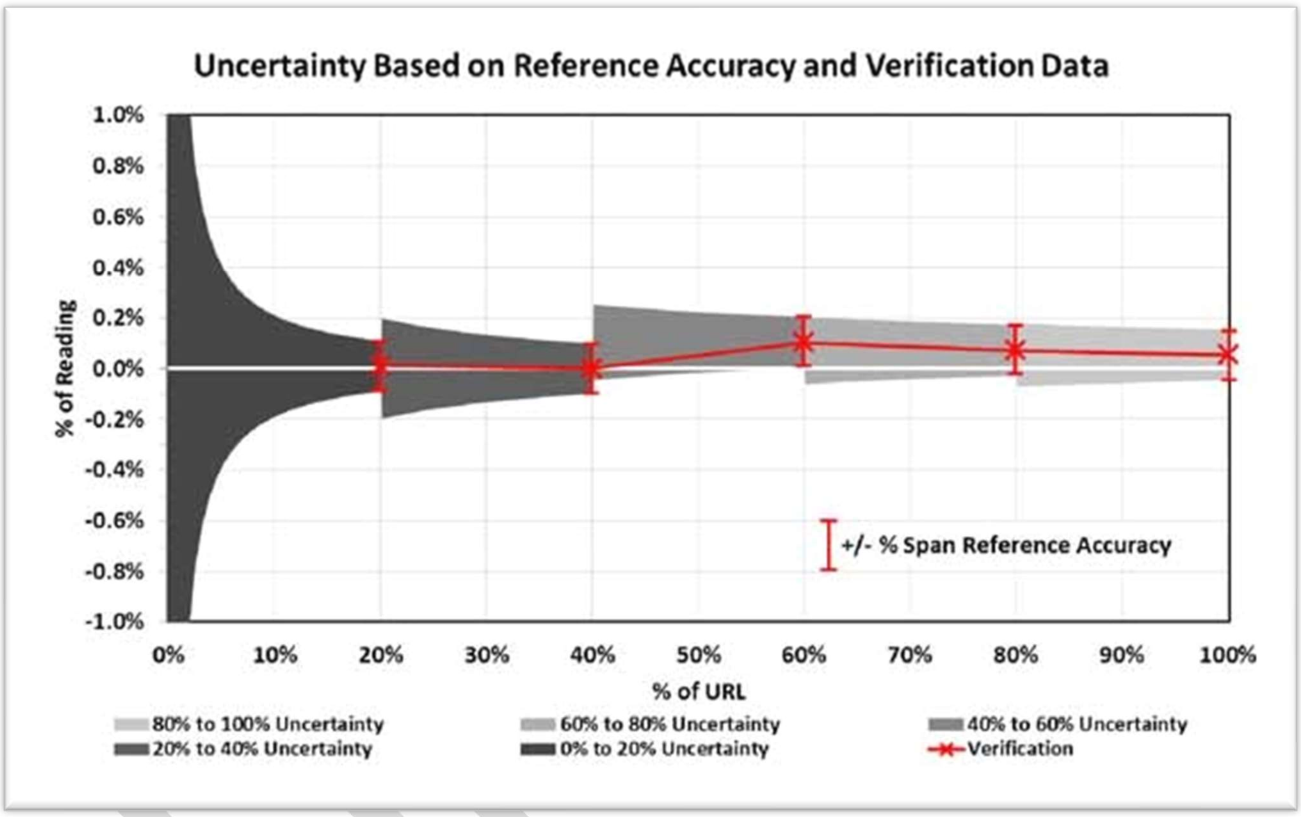


Figure A.4—Slope Trim of the 40 Percent Verification Point and the As-left Verification Results

A.4 Use of Verification Performance Data to Compare Transmitters

The graph in Figure A.5 can be simplified by removing the verification based API 22.4 Baseline Accuracy shading as shown in Figure A.6 and the nonlinearity and nonlinearity plus API 22.4 Baseline Accuracy bands can be used to compare transmitter performance.

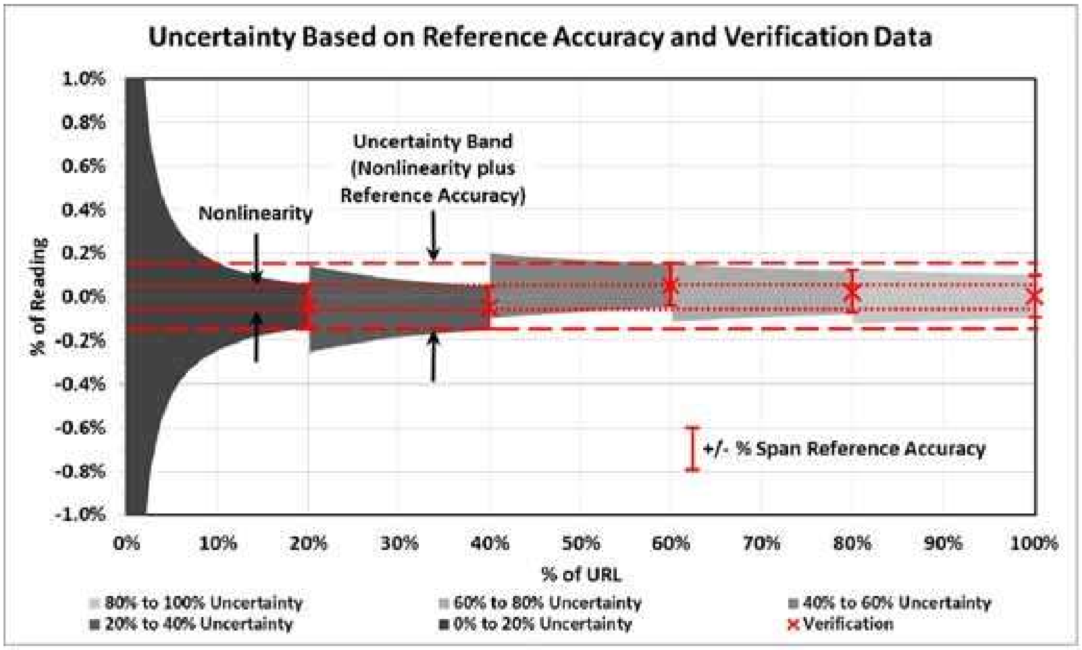


Figure A.5—API 22.4 Baseline Accuracy Nonlinearity and Uncertainty Based on Verification Data

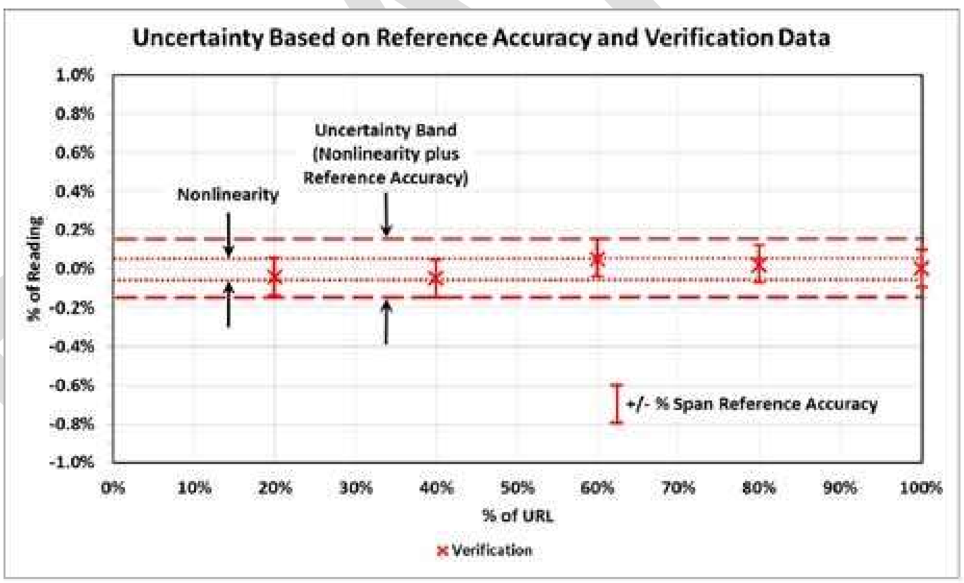


Figure A.6—Simplified API 22.4 Baseline Accuracy Nonlinearity and Uncertainty Based on Verification Data

Annex B
(normative)

Linearity, CRH, API 22.4 Baseline Accuracy and Calculations

B.1 Example Calculations

Figure B.1 shows an example report of the API 22.4 Baseline Accuracy test results including the calculated test error and the reference standard percentage of reading accuracy at each test point. Examples of the calculation of linearity, CRH, and API 22.4 Baseline Accuracy are provided.

Test Cycle		1			2			3			Ref. Std.
Test Point		Ref. Value	DUT Value	Difference	Ref. Value	DUT Value	Difference	Ref. Value	DUT Value	Difference	% Reading
1	0%	-0.0010	-0.0200	-0.0190	-0.0023	0.0033	0.0057	0.0013	0.0300	0.0287	
2	2%	1.9980	1.9800	-0.0180	1.9977	2.0133	0.0157	2.0033	2.0100	0.0067	+/- 0.025%
3	4%	3.9977	3.9700	-0.0277	4.0000	4.0233	0.0233	4.0013	4.0033	0.0020	+/- 0.025%
4	6%	5.9967	6.0200	0.0233	5.9987	6.0100	0.0113	5.9967	6.0100	0.0133	+/- 0.025%
5	8%	7.9993	7.9667	-0.0327	7.9973	7.9667	-0.0307	7.9977	8.0067	0.0090	+/- 0.025%
6	10%	9.9967	10.0200	0.0233	10.0007	10.0133	0.0127	9.9990	10.0100	0.0110	+/- 0.025%
7	20%	20.0023	19.9667	-0.0357	20.0027	20.0300	0.0273	20.0010	19.9800	-0.0210	+/- 0.025%
8	40%	40.0013	39.9733	-0.0280	40.0010	39.9900	-0.0110	40.0020	39.9767	-0.0253	+/- 0.025%
9	60%	59.9970	60.0333	0.0363	60.0023	60.0167	0.0143	59.9990	60.0300	0.0310	+/- 0.025%
10	80%	79.9980	80.0067	0.0087	79.9967	80.0100	0.0133	79.9983	79.9967	-0.0017	+/- 0.025%
11	100%	100.0007	100.0100	0.0093	99.9997	99.9733	-0.0263	100.0013	100.0267	0.0253	+/- 0.025%
12	80%	80.0010	80.0133	0.0123	80.0033	79.9667	-0.0367	79.9973	79.9967	-0.0007	+/- 0.025%
13	60%	60.0007	59.9667	-0.0340	59.9970	59.9800	-0.0170	59.9973	60.0167	0.0193	+/- 0.025%
14	40%	39.9990	39.9700	-0.0290	40.0027	40.0033	0.0007	39.9997	39.9900	-0.0097	+/- 0.025%
15	20%	20.0000	20.0067	0.0067	20.0003	20.0133	0.0130	19.9980	19.9700	-0.0280	+/- 0.025%
16	10%	9.9997	10.0000	0.0003	10.0020	10.0200	0.0180	10.0033	9.9933	-0.0100	+/- 0.025%
17	8%	8.0023	7.9900	-0.0123	8.0017	7.9767	-0.0250	8.0020	8.0100	0.0080	+/- 0.025%
18	6%	5.9997	6.0033	0.0037	5.9993	6.0000	0.0007	6.0007	5.9933	-0.0073	+/- 0.025%
19	4%	3.9997	3.9667	-0.0330	3.9980	4.0167	0.0187	4.0007	3.9900	-0.0107	+/- 0.025%
20	2%	2.0007	1.9700	-0.0307	2.0027	2.0267	0.0240	1.9973	1.9700	-0.0273	+/- 0.025%
21	0%	-0.0013	0.0033	0.0047	-0.0033	-0.0200	-0.0167	-0.0033	-0.0167	-0.0133	

Figure B.1—Example of Transmitter Digital Test Results

B.1.1 Linearity Calculation

Linearity is calculated for each percentage of span point as the average of all test upscale and downscale values:

$$Linearity = \Sigma \frac{DUT - Ref}{Number\ of\ Test\ Points} \tag{B.1}$$

Linearity is calculated at each percentage of Span Test Point using the associated Test Values.

where

DUT is the Device Under Test Value;

Ref is the Reference Standard Value.

Test Cycle		1			2			3			Ref. Std.
Test Point		Ref. Value	DUT Value	Difference	Ref. Value	DUT Value	Difference	Ref. Value	DUT Value	Difference	% Reading
1	0%	-0.0010	-0.0200	**-0.0190**	-0.0023	0.0033	0.0057	0.0013	0.0300	0.0287	
2	2%	1.9980	1.9800	-0.0180	1.9977	2.0133	0.0157	2.0033	2.0100	0.0067	+/- 0.025%
3	4%	3.9977	3.9700	-0.0277	4.0000	4.0233	0.0233	4.0013	4.0033	0.0020	+/- 0.025%
4	6%	5.9967	6.0200	0.0233	5.9987	6.0100	0.0113	5.9967	6.0100	0.0133	+/- 0.025%
5	8%	7.9993	7.9667	-0.0327	7.9973	7.9667	-0.0307	7.9977	8.0067	0.0090	+/- 0.025%
6	10%	9.9967	10.0200	0.0233	10.0007	10.0133	0.0127	9.9990	10.0100	0.0110	+/- 0.025%
7	20%	20.0023	19.9667	-0.0357	20.0027	20.0300	0.0273	20.0010	19.9800	-0.0210	+/- 0.025%
8	40%	40.0013	39.9733	-0.0280	40.0010	39.9900	-0.0110	40.0020	39.9767	-0.0253	+/- 0.025%
9	60%	59.9970	60.0333	0.0363	60.0023	60.0167	0.0143	59.9990	60.0300	0.0310	+/- 0.025%
10	80%	79.9980	80.0067	0.0087	79.9967	80.0100	0.0133	79.9983	79.9967	-0.0017	+/- 0.025%
11	100%	100.0007	100.0100	0.0093	99.9997	99.9733	-0.0263	100.0013	100.0267	0.0253	+/- 0.025%
12	80%	80.0010	80.0133	0.0123	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.0007	+/- 0.025%
13	60%	60.0007	59.9667	-0.0340	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0193	+/- 0.025%
14	40%	39.9990	39.9700	-0.0290	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.0097	+/- 0.025%
15	20%	20.0000	20.0067	0.0067	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.0280	+/- 0.025%
16	10%	9.9997	10.0000	0.0003	10.0020	10.0200	0.0180	10.0033	9.9933	-0.0100	+/- 0.025%
17	8%	8.0023	7.9900	-0.0123	8.0017	7.9767	-0.0250	8.0020	8.0100	0.0080	+/- 0.025%
18	6%	5.9997	6.0033	0.0037	5.9993	6.0000	0.0007	6.0007	5.9933	-0.0073	+/- 0.025%
19	4%	3.9997	3.9667	-0.0330	3.9980	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20	2%	2.0007	1.9700	-0.0307	2.0027	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
21	0%	-0.0013	0.0033	**0.0047**	-0.0033	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	

Linearity (Test Cycle 1)

$$= \frac{-0.019 + 0.0047}{2} = -0.0072$$

Linearity (All Test Cycles)

$$= \frac{-0.0072 + -0.0055 + 0.0077}{3} = -0.0017$$

Linearity/CRH Calculations for Each Test Cycle										
Test Cycle	1			2			3			Ref. Std.
Test Point	Ref. Value		Linearity	Ref. Value		Linearity	Ref. Value		Linearity	% Reading
0%	0.0		**-0.0072**	0.0		**-0.0055**	0.0		**0.0077**	
2%	2.0		-0.0243	2.0		0.0198	2.0		-0.0103	+/- 0.025%
4%	4.0		-0.0303	4.0		0.0210	4.0		-0.0043	+/- 0.025%
6%	6.0		0.0135	6.0		0.0060	6.0		0.0030	+/- 0.025%
8%	8.0		-0.0225	8.0		-0.0278	8.0		0.0085	+/- 0.025%
10%	10.0		0.0118	10.0		0.0153	10.0		0.0005	+/- 0.025%
20%	20.0		-0.0145	20.0		0.0202	20.0		-0.0245	+/- 0.025%
40%	40.0		-0.0285	40.0		-0.0052	40.0		-0.0175	+/- 0.025%
60%	60.0		0.0012	60.0		-0.0013	60.0		0.0252	+/- 0.025%
80%	80.0		0.0105	80.0		-0.0117	80.0		-0.0012	+/- 0.025%
100%	100.0		0.0093	100.0		-0.0263	100.0		0.0253	+/- 0.025%

Figure B.2—Example of Transmitter Digital Test Results Linearity Calculations

B.1.2 CRH Calculation

CRH is calculated for each percentage of span point as the maximum minus the minimum of all repeat test upscale and downscale values:

$$CRH = \left(max\left([DUT - Ref]_{upscaleordownscale}\right) - min\left([DUT - Ref]_{upscaleordownscale}\right)\right)/2 \qquad \text{(B.2)}$$

CRH is calculated at each percentage of Span Point using the associated Upscale and Downscale Test Values.

where

DUT is the Device Under Test Value;

Ref is the Reference Standard Value.

Test Cycle		1			2			3			Ref. Std.
Test Point		Ref. Value	DUT Value	Difference	Ref. Value	DUT Value	Difference	Ref. Value	DUT Value	Difference	% Reading
1	0%	-0.0010	-0.0200	-0.0190	-0.0023	0.0033	0.0057	0.0013	0.0300	0.0287	
2	2%	1.9980	1.9800	-0.0180	1.9977	2.0133	0.0157	2.0033	2.0100	0.0067	+/- 0.025%
3	4%	3.9977	3.9700	-0.0277	4.0000	4.0233	0.0233	4.0013	4.0033	0.0020	+/- 0.025%
4	6%	5.9967	6.0200	0.0233	5.9987	6.0100	0.0113	5.9967	6.0100	0.0133	+/- 0.025%
5	8%	7.9993	7.9667	-0.0327	7.9973	7.9667	-0.0307	7.9977	8.0067	0.0090	+/- 0.025%
6	10%	9.9967	10.0200	0.0233	10.0007	10.0133	0.0127	9.9990	10.0100	0.0110	+/- 0.025%
7	20%	20.0023	19.9667	-0.0357	20.0027	20.0300	0.0273	20.0010	19.9800	-0.0210	+/- 0.025%
8	40%	40.0013	39.9733	-0.0280	40.0010	39.9900	-0.0110	40.0020	39.9767	-0.0253	+/- 0.025%
9	60%	59.9970	60.0333	0.0363	60.0023	60.0167	0.0143	59.9990	60.0300	0.0310	+/- 0.025%
10	80%	79.9980	80.0067	0.0087	79.9967	80.0100	0.0133	79.9983	79.9967	-0.0017	+/- 0.025%
11	100%	100.0007	100.0100	0.0093	99.9997	99.9733	-0.0263	100.0013	100.0267	0.0253	+/- 0.025%
12	80%	80.0010	80.0133	0.0123	80.0033	79.9667	-0.0367	79.9973	79.9967	-0.0007	+/- 0.025%
13	60%	60.0007	59.9667	-0.0340	59.9970	59.9800	-0.0170	59.9973	60.0167	0.0193	+/- 0.025%
14	40%	39.9990	39.9700	-0.0290	40.0027	40.0033	0.0007	39.9997	39.9900	-0.0097	+/- 0.025%
15	20%	20.00									- 0.025%
16	10%	9.99									- 0.025%
17	8%	8.00									- 0.025%
18	6%	5.99									- 0.025%
19	4%	3.99									- 0.025%
20	2%	2.0007	1.9700	-0.0307	2.0027	2.0267	0.0240	1.9973	1.9700	-0.0273	+/- 0.025%
21	0%	-0.0013	0.0033	0.0047	-0.0033	-0.0200	-0.0167	-0.0033	-0.0167	-0.0133	

CRH Calculation
(Max (0.0363, 0.0143, 0.0310, -0.0340, -0.0170, 0.0193)
- Min (0.0363, 0.0143, 0.0310, -0.0340, -0.0170, 0.0193))/2 = 0.0352

CRH Calculation	
Test Point	CRH
0%	+/- 0.0238
2%	+/- 0.0273
4%	+/- 0.0282
6%	+/- 0.0153
8%	+/- 0.0208
10%	+/- 0.0167
20%	+/- 0.0315
40%	+/- 0.0148
60%	+/- 0.0352
80%	+/- 0.0250
100%	+/- 0.0258
Max CRH	+/- 0.0352

Figure B.3—Example of Transmitter Digital Test Results CRH Calculations

B.1.3 API 22.4 Baseline Accuracy and Summary Calculation

API 22.4 Baseline Accuracy is calculated for each percentage of span point as root mean square of Linearity and the maximum CRH values as shown in Figure B.4. The Reference Standard accuracy for each test point is reported.

$$API\ 22.4\ Baseline\ Accuracy = \sqrt{(Linearity)^2 + (max(CRH))^2} \quad \text{(B.3)}$$

Summary Calculations											
Test Point		Linearity			CRH			API 22.4 Baseline Accuracy			Ref. Std.
	Ref. Value		% URL	% Reading		% URL	% Reading		% URL	% Reading	% Reading
0%	0.0	-0.0017	-0.017%		+/- 0.0352	+/- 0.352%		+/- 0.0352	+/- 0.352%		
2%	2.0	-0.0049	-0.049%	-0.247%	+/- 0.0352	+/- 0.352%	+/- 1.758%	+/- 0.0355	+/- 0.355%	+/- 1.776%	+/- 0.025%
4%	4.0	-0.0046	-0.046%	-0.114%	+/- 0.0352	+/- 0.352%	+/- 0.879%	+/- 0.0355	+/- 0.355%	+/- 0.887%	+/- 0.025%
6%	6.0	0.0075	0.075%	0.125%	+/- 0.0352	+/- 0.352%	+/- 0.586%	+/- 0.0360	+/- 0.360%	+/- 0.599%	+/- 0.025%
8%	8.0	-0.0139	-0.139%	-0.174%	+/- 0.0352	+/- 0.352%	+/- 0.440%	+/- 0.0378	+/- 0.378%	+/- 0.473%	+/- 0.025%
10%	10.0	0.0092	0.092%	0.092%	+/- 0.0352	+/- 0.352%	+/- 0.352%	+/- 0.0364	+/- 0.364%	+/- 0.364%	+/- 0.025%
20%	20.0	-0.0063	-0.063%	-0.031%	+/- 0.0352	+/- 0.352%	+/- 0.176%	+/- 0.0357	+/- 0.357%	+/- 0.179%	+/- 0.025%
40%	40.0	-0.0171	-0.171%	-0.043%	+/- 0.0352	+/- 0.352%	+/- 0.088%	+/- 0.0391	+/- 0.391%	+/- 0.098%	+/- 0.025%
60%	60.0	0.0083	0.083%	0.014%	+/- 0.0352	+/- 0.352%	+/- 0.059%	+/- 0.0361	+/- 0.361%	+/- 0.060%	+/- 0.025%
80%	80.0	-0.0008	-0.008%	-0.001%	+/- 0.0352	+/- 0.352%	+/- 0.044%	+/- 0.0352	+/- 0.352%	+/- 0.044%	+/- 0.025%
100%	10.0	0.0028	0.028%	0.028%	+/- 0.0352	+/- 0.352%	+/- 0.352%	+/- 0.0353	+/- 0.353%	+/- 0.353%	+/- 0.025%
Maximum - Minimum Linearity				0.372%							

Figure B.4—Example Calculations Based on Test Results in Figure B.1

Annex C
(normative)

Rangeability

C.1 Introduction

Rangeability refers to the ratio of maximum to minimum limits. For transmitters, rangeability can be used to describe a transmitter's:

— Span Calibration Turndown Ratio—the ratio of the maximum calibrated span to the minimum calibrated span.

— Operating Range—the ratio of the calibrated span to the minimum transmitter operating value that still meets the minimum operating accuracy requirements.

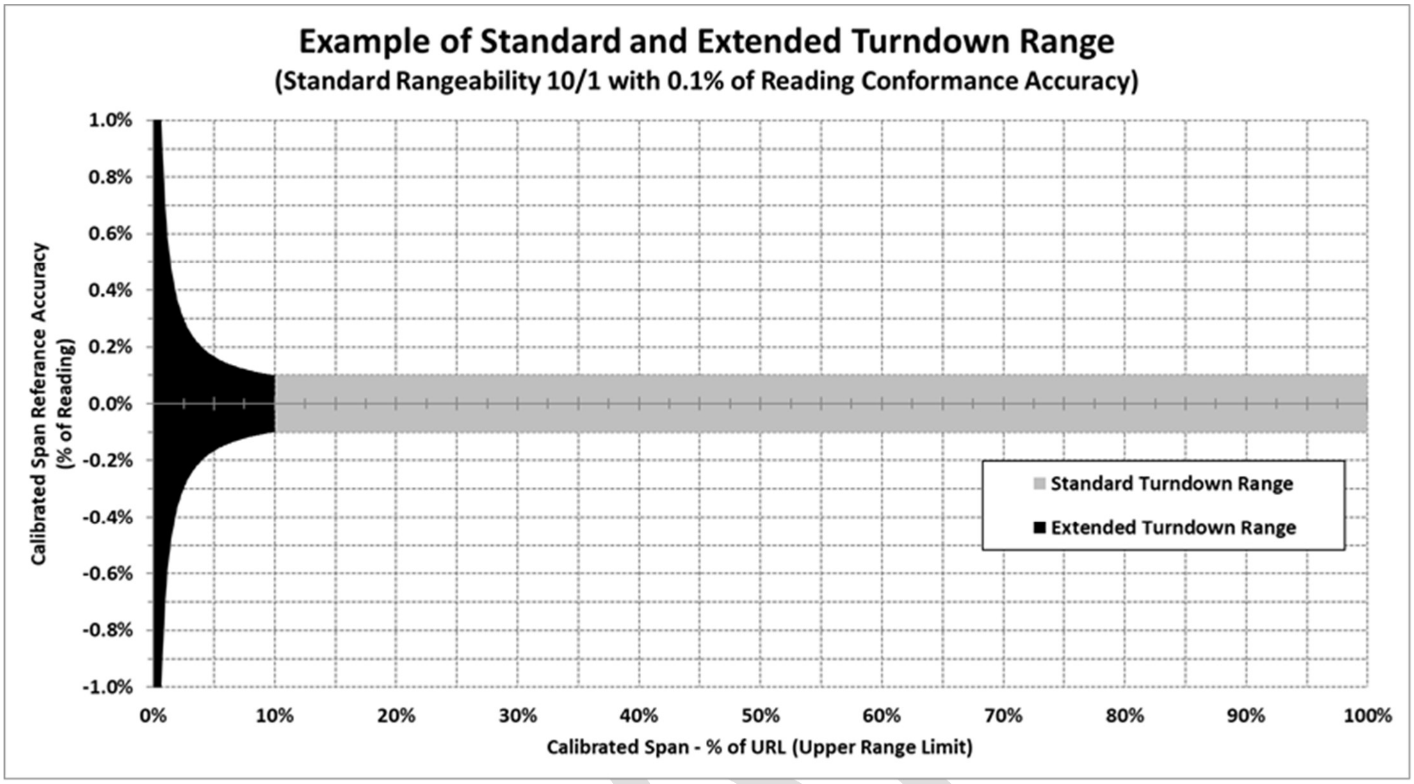
With the increased accuracy of transmitters and the ability to decouple the analog output resolution from the sensor accuracy, the reported transmitter span calibration turndown ratio has been extended by many manufacturers. For the purposes of transmitter testing, this turndown range will be divided into two categories:

1) Standard—The turndown range over which the calibrated span uncertainty is stated as a fixed value.

2) Extended—The turndown range over which the calibrated span uncertainty increases as the calibrated span decreases. Extended rangeability specifications typically make use of percent of span uncertainties when determining the extended turndown range of the transmitter as shown in Figure C.1.

Due to the end user judgment required to determine the allowable combined uncertainty of the transmitter extended turndown ratio and transmitter operating range, span range testing will be limited to the standard turndown range.

NOTE For testing of the transmitter with spans in the extended turndown range, the user should determine the specified operating accuracy limits and required test points prior to the start of the transmitter testing.



Standard Turndown Range = % of Reading Conformance Accuracy
Extended Turndown Range = % of Span of Minimum Turndown Range Conformance Accuracy

Figure C.1—Example of Standard and Extended Calibrated Span Turndown Rangeability

Annex D
(normative)

Field Calibration vs Field Verification

D.1 Introduction

Use of verification data to calculate the conformance tolerance or to perform a slope sensor trim/flow computer linearization described in this annex, requires the use of a verification standard that is four to ten times more accurate than the Baseline Accuracy specification. This requires a verification standard that is more accurate than 0.025 % of reading for a 0.1 % Baseline Accuracy transmitter and 0.0125 % of reading for a 0.05 % Baseline Accuracy transmitter. Calibration equipment of this accuracy is generally limited to factory or laboratory equipment.

D.1.1 Transmitter Slope

Field verification is useful to confirm that the transmitters are operating within the slope accuracy limits of the verification standard and the transmitter. The ability to obtain and transport field verification equipment that is more accurate than transmitters is often impractical and differences between the verification standard and the transmitters are often due to the verification standard. Differences within limits and should not be adjusted.

D.1.2 Transmitter Zero

Transmitter zero adjustments are required due to installation effects such as mounting position, significant changes in operating temperature, operating pressure, etc. The adjustments do not face the same standards limitations as slope verifications because the transmitter zero can either be created without the use of a standard or the barometric pressure can be measured accurately.