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Understanding specifications
for process calibrators

Application Note

The initial selection of a calibrator is often based on a specification sheet, a written description of the equipment's performance in quantifiable terms that applies to all calibrators having the same model number. Since specifications are based on the statistics of a large sample of calibrators, they describe the performance of a group rather than a single, specific calibrator. Any single calibrator would meet all the specifications, and usually would significantly exceed most of the various specification details.

Good specifications have the following characteristics:

- They are complete.
- They are easy to interpret and use.
- They include the effects found in normal usage, such as environment and loading.

Completeness requires that sufficient information be provided so the user can determine the bounds of performance for all anticipated outputs (or inputs), all possible and permissible environmental conditions within the listed bounds, and all permissible loads.

Ease of use is also important. Many specifications can be confusing and difficult to interpret, thus causing mistakes in interpretations that can lead to application errors or faulty calibrations.

The requirement for completeness conflicts somewhat with that for ease of use; one can be traded for the other. The challenge of specification design is to mutually satisfy both, which is sometimes accomplished by bundling the effects of many error contributions within a useful and common window of operation. For example, the listed performance may be valid for a period of six months when used in a temperature range of 23 + 5 °C, and in humidity up to 80 percent, and for all loads up to a specified maximum rating. This is a great simplification for the user since the error contributions of time, temperature, humidity, and loads are included in the basic specification and can be ignored as long as operation is maintained within the listed bounds.

The importance of specifications

Comprehensive specifications are essential in maintaining a chain of traceability and in ensuring global uniformity of products, quality and product safety.

Traceability

Traceability is a term that refers to the fact that instruments have been proven to conform with the official standards for the parameters which they measure. This means the measurements made by this equipment are traceable to national standards. A certified instrument is one which itself has been regularly tested by even better-performing certified devices. Specific test procedures are used, and the results are documented and must be repeated at specific intervals of time. This chain sequence of comparing to superior performing certified devices is repeated until, finally, specific comparisons are made with standards maintained by national authorities, such as the National Institute of Standards and Technology (NIST) in the U.S. This unbroken chain of comparisons is often called a "traceability chain."

For a process calibrator, traceability refers to the fact that the process calibrator's test and measurement functions have been verified to perform within its required specifications, and that this usage of the calibrator falls within the appropriate limits of performance, including signal levels, environmental conditions,

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tors will usually outperform their specifications. Other manufacturers may manipulate specifications to make an instrument appear more capable than it really is. Impressive specifications touted in advertisements or brochures may be incomplete and reflect only a small part of the total usable calibrator performance.

Advertisements and product literature often make liberal use of footnotes, asterisks, and superscripts. In general, there are two types of footnotes—those that inform and those that qualify. Always read all footnotes carefully and determine which have a direct effect on the specification.

The buyer should also be aware that a calibrator specification applies to an entire product run of a particular instrument model. For example, the specification for a Fluke 702 applies to all 702s made; it does not describe the actual performance of any individual 702. Since the variation in the performance of individual calibrators from nominal tends to be normally distributed, a large majority of the units of a specific model should perform well within their specification limits. In fact, most individual calibrators can be expected to perform much better than specified, although the performance of an individual calibrator should never be taken as representative of the model class as a whole.

The calibrator that is purchased will most likely give excellent performance even though there is always a small chance that its performance will be marginal, or even out of specification, at some parameter or function.

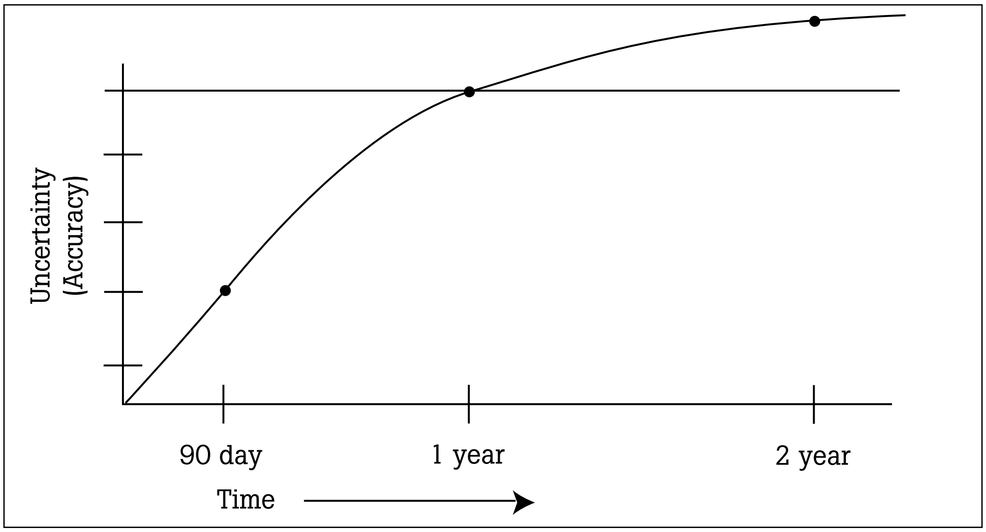

Figure 1. Uncertainty as a function of time.

Key components of a specification

The analysis of specifications can be complicated. To have a clear picture of the true specifications, you should be aware of the key components of a specification, and how to extract them from all the footnotes, from the fine print, and from the specification itself. Each specification must be carefully considered when comparing calibrators from different vendors. The four most important components of a documenting process calibrator specification are:

- time
- temperature
- allowance for traceability to standards
- confidence level

Accuracy vs. uncertainty

Typically, the number on the cover of a data sheet or brochure will read "accuracy to 0.02 percent." This is commonly accepted usage equivalent to saying "measurement uncertainty of 0.02 percent". This means that measurements made with this device can be expected to be within 0.02 percent of the true value. In examining a specification, you need to be aware that a specification such as this (1) is often over the shortest time interval, (2) is often over the smallest temperature span, (3) is sometimes a relative specification, and (4) may be derived using a non-conservative confidence level. The impact of each of these factors is discussed below.

1. Time

Specifications usually include a specific time period during which the calibrator can be expected to perform as specified. Setting this time period or calibration interval is necessary to account for the drift rate inherent in a calibrator's analog circuitry. This is the calibration interval, or the measure of a calibrator's ability to remain within its stated specification for a certain length of time. Time periods of 30, 90, 180, and 360 days are common and practical. For Fluke 700 Series calibrators, this time period may be either one or two years. While the specifications for Fluke calibrators include variations in performance due to the passage of time, other manufacturers' calibrators may not be specified in the same manner. Figure 1 shows how a calibrator's uncertainty increases over time. When evaluating specifications, make sure you're comparing the same time intervals.

Any calibrator can be specified to super-high performance levels at the time of calibration. Unfortunately, such levels are good for only the first few minutes following calibration. If the specifications for a calibrator do not state the time interval over which they are valid, the manufacturer should be contacted for a clarification.

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2. Temperature

Performance over the specified temperature range is also critical. Make sure the temperature intervals specified will meet your workload requirements.

The specified temperature range is necessary to account for the thermal coefficients in the calibrator's analog circuitry. The most common ranges are centered about room temperature, 23 + 5 °C. This range reflects realistic operating conditions. It should be remembered that temperature bounds must apply for the entire calibration interval. Thus, a temperature range specification of 23 + 1 °C presumes very strict long-term control of the operating environment. Such a temperature range would not be representative of normal operation for a process calibrator.

Outside the specified range, a temperature coefficient (TC) is used to describe the degradation of the accuracy specification. The TC represents an error component that must be added to a calibrator's specification if it is being used outside of its nominal temperature range.

For example, in Figure 2 we are looking at the uncertainty as a function of temperature at full scale on the 11 volt dc range of a Fluke 702 calibrator. The dashed line shows the specified accuracy for a 23 ± 5 °C temperature range common on most Fluke calibrators. Within the span of the dashed line, the accuracy is within the specifications of 0.030 percent of full scale. This is in line with a specification of "0.025 percent of reading + 0.005 percent of full scale when used at 23 ± 5 °C." This applies for a range of 18 °C to 28 °C. Beyond this range, the instrument's performance degrades as shown by the solid line. TC will usually be given in a specification footnote, and will take the form:

TC = x % / °C

where x is the amount that the performance degrades per change in degree beyond the base range specification. To calculate the accuracy due to temperatures outside of the given specification, the temperature modifier, t_{mod}, is needed. The formula is:

t_{mod} = |TC x Δt|

Where:

Δt = operating temperature minus the temperature range limit

t = the proposed operating temperature

range limit = the range limit that *t* is beyond

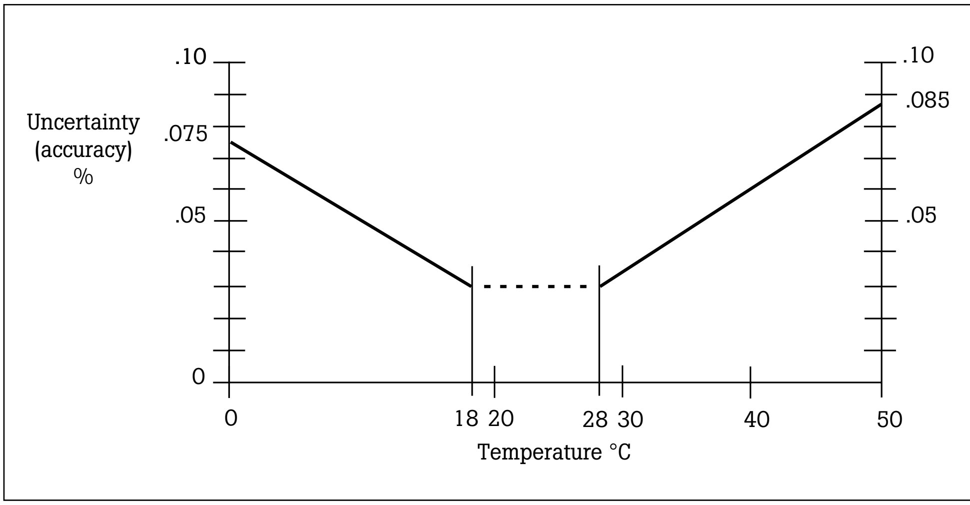

Figure 2. Uncertainty vs temperature, at full scale on the 11 volt dc range.

If one wishes to use a calibrator in an ambient temperature outside of its specified range, the effects of TC must be added to the baseline accuracy specification when calculating the total accuracy. The t_{mod} term is used to calculate the total specification using the general formula:

total spec = (basic accuracy at a specific temp. range)+t_{mod}

For example, suppose we have a calibrator whose rated accuracy is 0.030 % @ 23 ± 5 °C. Its TC is 0.0025 % / °C. To calculate the accuracy of the calibrator for operation at 32 °C or 90 °F:

t = 32

range limit = 23 + 5 = 28

t_{mod} = 0.0025 % |32-28|
= 0.0025 %|4| = 0.01 %

total spec = 0.030 % + 0.010 %
= 0.040 %

As can be seen, the specification may change dramatically when the effects of performance due to temperature are considered.

Knowing how to calculate t_{mod} will be necessary when comparing two instruments that are specified for different temperature ranges. For example, Fluke specifies most of its calibrators with a range of 23 ± 5 °C. However, another manufacturer may specify a calibrator at 23 ± 1 °C. To truly compare the two calibrators, one needs to put them in the same terms (23 ± 5 °C) using the preceding calculation.

The most modern calibrators and instruments are specified to operate in wider temperature ranges because calibration instruments are no longer used outside of the closely-controlled laboratory. Calibration at the process plant demands greater temperature flexibility. The preceding equation was used to characterize the degradation in performance that occurs when the calibrator is operated outside the 23 ± 5 °C temperature range restriction on the data sheet.

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3. Allowance for traceability to standards

Uncertainty specifications must also be evaluated as relative or total. Relative uncertainty does not include the additional uncertainty of the reference standards used to calibrate the instrument. For example, when a calibrator's uncertainty is specified as relative to calibration standards, this covers only the uncertainty in the calibrator. This is an incomplete statement regarding the instrument's total uncertainty. Total uncertainty includes all uncertainties in the traceability chain: the relative uncertainty of the unit, plus the uncertainty of the equipment used to calibrate it.

4. Confidence level

The most critical factor in a calibrator's performance is what percentage of the calibrators will be out of calibration at the end of its calibration interval. Specifications must be conservative to ensure the calibrator is in tolerance—with a high degree of confidence—at the end of its calibration interval.

For example, say that vendors X and Y offer calibrators. Vendor X's specifications state that its calibrator can supply 10 V with an accuracy of 0.019 percent, and vendor Y's specification is 0.025 percent accuracy for the 10 V output. Neither of the data sheets for the calibrators supply a confidence level for the specifications, nor do they state how the accuracy is distributed.

When questioned, the vendors will state that their specifications are based on a normal distribution of accuracy and have the following confidence levels. Their responses are tabulated in Table 1.

Vendor	Stated spec @10 V	Confidence level (coverage factor)
X	0.019 %	95 %
Y	0.025 %	99 %

Table 1. Specification comparison

In this example, as shown in Figure 3, the actual performance of the calibrators is identical! Vendor X, choosing a confidence level of 95 percent, is willing to risk 5 percent of their calibrators being found out of spec at the end of the stated time interval, and states a spec of 0.019 percent. The shaded and solid areas under the normal distribution curve represent the fraction of the calibrator population at risk. Vendor Y, choosing a confidence level of 99 percent, is willing to risk only 1 percent of their calibrators being found out of spec, and states a spec of 0.025 percent. The solid areas under the curve represent the fraction of the calibrator population at risk. So you see, identical calibrator performance can yield different specifications, depending on how aggressive the calibrator manufacturer chooses to be with the specifications of your calibrator.

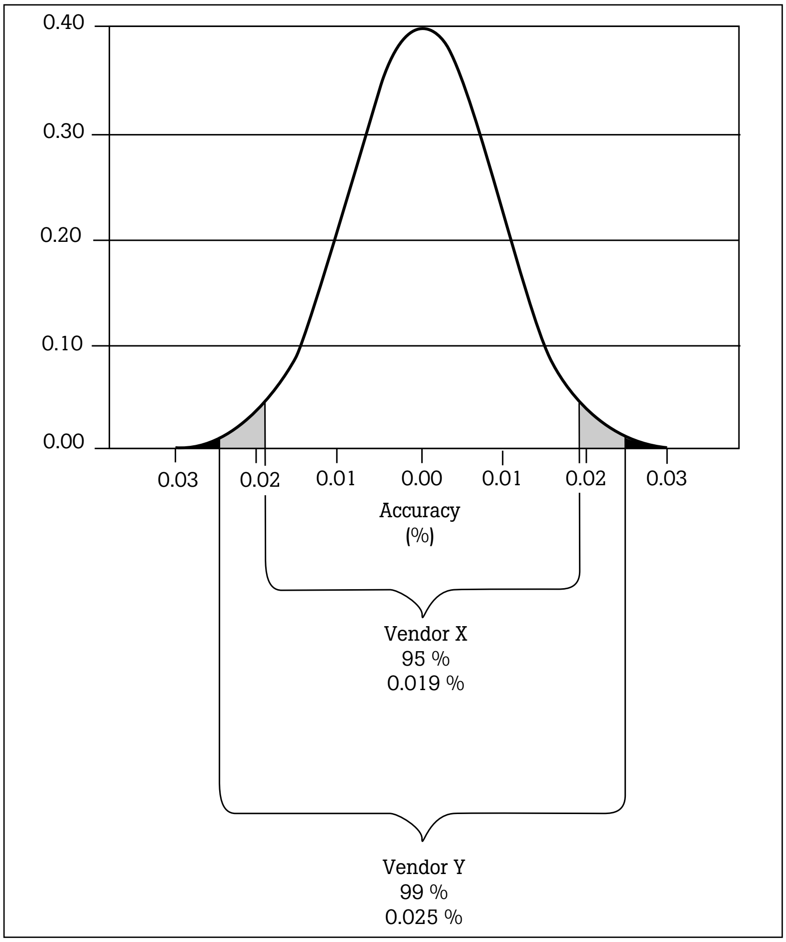

Figure 3. Same performance, different specifications.

Before making a purchase, it is critical to gain an understanding of a vendor's philosophy with respect to confidence level and ask the vendor to clarify the confidence level when there is doubt as to what it is. Fluke uses a very conservative 99 percent confidence level for its specifications for calibrators and standards.

Other considerations

Accuracy specifications are an important part of determining whether or not a particular calibrator will satisfy a need. There are, however, many other factors that determine which calibrator is best suited for an application, some of which are described below.

The workload

Remember that the calibrator's specification must match your workload requirements. There is a tendency for manufacturers to engage in a numbers race, with each new calibrator having more and more impressive specifications, although often this has little bearing on true workload coverage.

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Support standards

The support standard will typically be three to ten times more accurate than the calibrators supported. This is known as the test uncertainty ratio (TUR). Specialized calibrators or those that require exotic support equipment on an infrequent basis may best be served by an outside service bureau.

Manufacturer support

Manufacturer support is also important. Can the manufacturer provide support as calibration needs grow and vary? Are in-house experts available to assist with technical issues? Are training programs available? Are service facilities conveniently located? Is there an adequate line of support products and accessories?

Reliability

Reliability is another important consideration in how useful a calibrator will be. Precision electronic calibrators can have a seemingly high failure rate. Any condition that causes the calibrator to fall outside of its extremely tight tolerance constitutes a failure. One should ask for a Mean-Time-To-Fail (MTTF) rate to determine when the first failure might occur. Failures upon delivery usually make this interval shorter than the Mean-Time-Between-Failure (MTBF) rate. Whichever is quoted, consider whether the number is based on actual field experience or just calculated projections.

Service philosophy

When a calibrator does fail, the manufacturer's approach to service is critical. A responsive service organization is essential to getting equipment back in action fast. Issues to consider include one's proximity to service center locations, stocking levels for spare parts and subassemblies, availability of service manuals and service training for one's own technicians, all of which go into determining how soon equipment can be returned to service.

Reputation

Finally, the manufacturer's reputation should be assessed. Overall, how credible are its claims with respect to performance, reliability, and service? Will the company still be in business five years from now? All of these issues define the true cost of owning and using a calibrator.

Terminology

Accuracy—how close the measurement of a parameter is to the true value of that parameter. Often expressed as a percentage of the reading or as a percent of full scale.

Confidence level—the percentage of the area of the normal curve that lies within the confidence interval. A confidence level of 95 percent is obtained when the range of confidence is from minus two standard deviations to plus two standard deviations. Fluke usually uses a confidence level of 99 percent or greater when specifying test instruments.

Hysteresis—the maximum difference between output readings for the same measurand point, one point obtained while increasing from zero and the other while decreasing from full scale. The points are taken on the same continuous cycle. The deviation is expressed as a percent of full scale.

NIST—(National Institute of Standards and Technology): the U.S. national standards laboratory, which is legally responsible for maintaining the standards on which all U.S. measurements are based.

Noise—a disturbance, caused by random changes in voltage and current, which interferes with the measurement of a signal.

Nonlinearity—the deviation from standard line output plotted against linear input.

Repeatability—the ability of a calibrator to output the same readings given the same conditions of temperature, humidity, time, atmospheric pressure, etc.

Resolution—the smallest discernible amount that can be either measured or generated within a specific function's range. In a calibrator, it often refers to either the smallest incremental change that can be made in a signal sourcing function, or the smallest measurable change in a signal measurement function.

Test uncertainty ratio (TUR)—The test uncertainty ratio for a calibration point is the specified uncertainty of the instrument under test divided by the specified uncertainty of the calibrator or standard used to test it. The specifications for the instruments must reflect the same confidence level.

Traceability—a characteristic of a calibration, analogous to a pedigree. A traceable calibration is achieved when each test instrument, calibrator, and standard, in a hierarchy stretching back to the national standard, is itself properly calibrated, and the results properly documented. The documentation provides the information needed to show that all the calibrations in the chain of calibrations were properly performed.

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For more information about this useful, comprehensive textbook, call **1-800-FLUKE** in the U.S. or contact your local Fluke representative.

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