Cal-Tek Company, Inc.
Measure with Confidence

Understanding Specifications

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Introduction

In a perfect world, your calibrated instrument would read perfectly…

However, we all live in the real world. There are many factors that go into determining how a device will represent a given measured value. Before we consider error that may be the result of measurement technique or calibration uncertainty, we need to first interpret the design specifications of the instrument being used.

Buyer Beware

It is very important that the instrument user is aware that multiple sets of specifications may exist for a single instrument. In some cases, instrument manufacturers will have a 'banner specification' that is put in cut sheets and advertising. The banner specification may not tell the whole story.

A banner specification might present an accuracy specification of ± 0.05%. However, delving deeper into publications such as the User or Service Manuals might provide any number of additional factors you need to be aware of:

- Is the ± 0.05% a Percentage of Full Scale or of Reading?
- Is the ± 0.05% limited to a portion of the instruments range (e.g., 10% to 90% of range)?
- Is the ± 0.05% dependent on a specific calibration interval (e.g., Calibrate every 90 days)?
- is the ± 0.05% only obtainable at a certain ambient temperature range?

You need to also consider other factors such as how the instrument might be used as part of a system. A temperature meter might sport a banner specification of ± 0.05%, but what does that mean if it is used in conjunction with a thermocouple that provides a tolerance of only +/- 1 degree?

This white paper will attempt to explain some of these factors and simplify the tangled web of specification terminology.

Terminology

Percent Full Scale

This is often abbreviated as % FS.

Let's say for example that your instrument has a specification of ± 0.05% FS. If your instrument has a range (or Full Scale) of 1000.00, then the tolerance is 1000.00 X 0.05% or ±0.50.

It is important to note that for instruments whose tolerance is in percent of full scale, the closer they are used to the full-scale value, the less of a factor the tolerance becomes (see Table 1).

Table 1

If the instrument is used at 25% of its Full Scale: Measured value = 250.00 Tolerance (from Full Scale calculation) = ±0.50 0.50 is **0.2%** of 250.00	If the instrument is used at 75% or its Full Scale: Measured value = 750.00 Tolerance (from Full Scale calculation) = ±0.50 0.50 is only **0.06667%** of 750.00

Note that if you are dealing with an analog instrument that has a range of -1000 to +1000, your Full Scale is 2000. Sometimes used in the analog world is a term called End Scale (ES). For the same instrument, if it is zero-centered, the End Scale value is 1000.

Percent of Reading

For the Percent of Reading term, the tolerance is applied to whatever the measured value is, regardless of where you are in the operational range of the instrument.

If your instrument has a specification of ± 0.05% of Reading and you are taking a measurement a 500.00, your tolerance would be simply 500.00 ± the 0.05%. This equates to 500.00 ± 0.25.

LSD

In instrumentation, LSD refers not to the 1960's, but is an acronym for Least Significant Digit. The value of the least significant digit is dependent on the resolution of the instrument. It is most commonly expressed together with one of the other terms we've defined, e.g., "± 0.05% of Reading, ± 2 LSD".

Here, your tolerance would be 500.00 ± the 0.05% (± the 2 LSD). With a display resolution of hundredths, this equates to 500.00 ± 0.25 (± 0.02). So, your tolerance at 500.00 would be anywhere between 499.73 and 500.27.

Pressure Gauges

Certain industries have developed languages of their own. Pressure gauges are one example. Here you will find the instruments categorized by Grade (Grade A, B, 1A, etc.).

A Grade B gauge will have an accuracy of ± 3% of span on the lower and upper ends of the scale, with a ± 2% accuracy in the middle 50% of the of the scale.

Generally, pressure gauge tolerances are expressed in percent of Full Scale (or Span), but some may be Percent of Reading.

Pressure Transducers

We have seen pressure transducers recently with the accuracy published being only a value for BFSL (Best Fit Straight Line) or BSL (Best Straight Line). We call BS (Beguiling Specmanship) on that.

The BFSL specification defines nonlinearity. It does not consider measurement error at the transducer end points (zero and span). There are also other factors such as hysteresis or the effects of temperature that need to be considered and should be a part of the detailed specifications.

Furthermore, it is cause for concern whenever we see the words *best* or *typical* in as part of a performance specification. We would look for the *total* value of transducers' accuracy characteristics. If one were not published, one would need to examine all the elements that contribute to measurement uncertainty to determine the actual tolerance.

Scales and Balances

Scales and balance specifications are typically listed by manufacturers in a series of individual terms. These include Repeatability, Linearity, Readability (resolution), and Eccentricity (off-center loading effect). Often, when confronted with a plethora of different factors, common metrological practice would have us use a statistical analysis method called RSS (Root Sum of Squares) to determine a total combined uncertainty. However, given the challenge of this analysis, weighing devices are often calibrated to standards specific to the industry.

For example, *NIST Handbook 44 (2023)* covers mass measurement specifications and tolerances for everything from berry baskets to vehicle tanks. It is available at no charge, compliments of the United States' National Institute of Standards and Technology.

For the pharmaceutical industry there are USP (United States Pharmacopeia) guidelines. USP General Chapter 41 sets performance requirements, including accuracy and repeatability, for balances used in testing of chemicals and biologics.

Calibration Intervals

ISO/IEC 17025:2017 advises us against making specific calibration interval recommendations. Interval(s) should be based upon process tolerances, risk exposure, and quality system requirements. But calibration interval may be an important part of device specifications.

An example is a pressure gauge we encountered that was found out of tolerance on consecutive calibrations. The 'banner specifications' seemed quite optimistic for the type of instrument we were looking at, so we investigated further. Buried deep in the manual was the disclosure that the specifications provided were based on a 90-day calibration interval. We are sure the customer was not aware of that provision when the instrument was purchased.

Other Factors

Keep in mind, there are other factors to consider when making your measurements that may not be included in the numerical expression(s) of your instrument's tolerance. These may include warm up and stabilization times. We are aware of one device that who's manual states there is a "stabilization time of one hour to 95% of published tolerance." The manual does not go on to explain how much stabilization is required to reach 100 % of the actual published value.

A Case Study

A customer recently came to us with a question on an *Agilent* 34401A multimeter.

With the unit measuring a known AC signal (sine wave at 1 kHz) of approximately 180 mV and the meter set to the millivolts position, the unit reading was fine: 00.178,6 VAC (interpreted as **178.6 mV**). As soon as the range of the multimeter was changed to the higher (ACV) position, the display went to 000.040 VAC (interpreted as **40.0 mV**). The input signal had not changed. The customer thought there was an issue with the meter.

We directed the customer to the operator's manual which reads, "For ac voltage and ac current measurements, note that the smallest value that can be measured is different from the sensitivity. For the *Agilent* 34401A, these functions are specified to measure down to 1% of the selected range. For example, the multimeter can measure down to 1 mV on the 100 mV range."

Based on that example and for this device, the lowest value that should be read on the 750 VAC range would be 7.5 VAC.

It was determined that nothing was wrong with the meter.

Summary

Specifications are a language unto themselves. Look to reputable manufacturers and clearly written manuals to help clarify performance expectations.

We welcome your questions, comments, and observations!