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How accurate is your accuracy statement?

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Accuracy Statements Are Not Created Equal.

Accuracy specifications for pressure instruments don't always describe performance in the same manner. From one manufacturer to the next, they can be as different as apples and oranges. Unlike gauges, in many regions of the world there are no governing bodies or societies to establish a consistent set of standards for pressure sensors and transducers. That leaves the door open for manufacturers to publish performance data and statistically derived accuracy specifications that appear more precise than they actually are.

LOOK FOR THE RED FLAGS.

Root of the sum squared (RSS) and best fit straight line (BFSL) specifications are red flags that specifying engineers and procurement professionals should look for in accuracy statements. *RSS and BFSL specifications cannot guarantee that every pressure point indicated by the instrument falls within the stated error band.* Since these methods do not require the zero or span point to be fixed during testing, the zero and span will often have to be reset after the instrument has been installed to achieve the desired accuracy. To set the span, a portable high accuracy secondary standard will be required. This could have a negative impact on:

- Initial production and set-up costs
- Field interchangeability
- The additive overall system performance specification

What about the effect of external factors such as ambient temperature deviation? Temperature errors are usually listed as separate additive inaccuracy statements. These statements typically describe the resulting consequences to accuracy when the instrument operates in temperatures that diverge from standard room temperature. These additional specification is an important part of understanding accuracy under extreme operating conditions and should be taken into consideration. However, since temperature is a unique variable and not part of the accuracy specification, we will omit it from this discussion and consider that all of the examples and calculations herein are based on an operating environment of room temperature (70-72° F / 21.1-22.2°C).

WE'LL HELP YOU DECIPHER THE NUMBERS.

This paper will address different methods of deriving accuracy specifications, with a concentration on pressure transducers and transmitters, where this phenomenon is most prevalent. However, the concepts may be universally applied to other pressure instruments. The goal is to inform engineers and end users how to decipher accuracy statements so they can ensure that the instrument they are choosing *honestly* satisfies their accuracy specification requirements.

Accuracy. How It's Defined. How It's Shown. What To Really Look For.

WHAT IS ACCURACY?

Accuracy is the departure of a measured value of a quantity from the accepted standard for that quantity (Gillum, p.395). The accuracy of a transducer is derived from its *inaccuracy*, which is defined as the maximum positive and negative difference between any measured value and the ideal value. This includes increasing and decreasing inputs over multiple test cycles. This value is expressed as a percentage of the ideal output span (IEC 61298-2, p.12). The accuracy of a transducer does not completely describe how the transducer measures pressure. For this reason, accuracy should be incorporated into an accuracy statement.

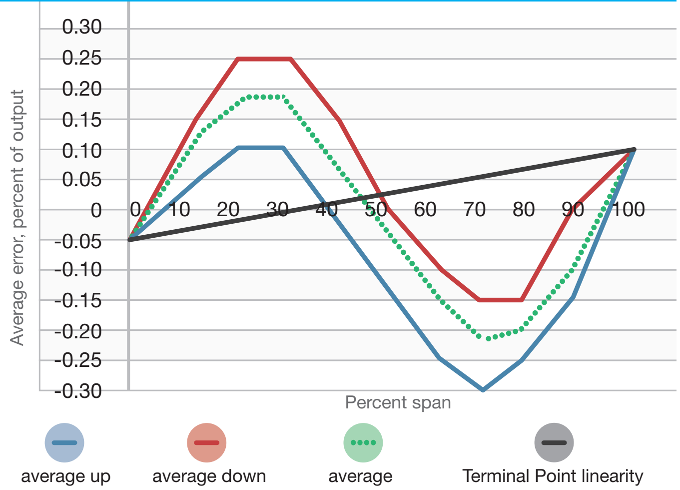
WHAT ARE THE COMPONENTS OF AN ACCURACY STATEMENT?

A transducer's accuracy statement should include all potential sources of error relevant to the specific application. The most common sources of error for a transmitter are non-linearity error, hysteresis error, non-repeatability error, zero offset error, and span setting error. Zero and span temperature coefficient errors are common when a sensor is operated outside of its reference temperature. To ensure accuracy, specifying engineers need to know how accuracy is tested.

Non-linearity errors are defined as the deviation between a transducer's linear trend line and the ideal output of the transducer. To calculate the non-linearity error one must first calculate the linearity. This is accomplished by measuring the output of the transducer over its calibrated full span to create a calibration curve. The calibration curve is then plotted and fit with a trend line. The three most common transducer linearity trend lines are terminal point, best fit straight line (BFSL), and zero-based best fit straight line.

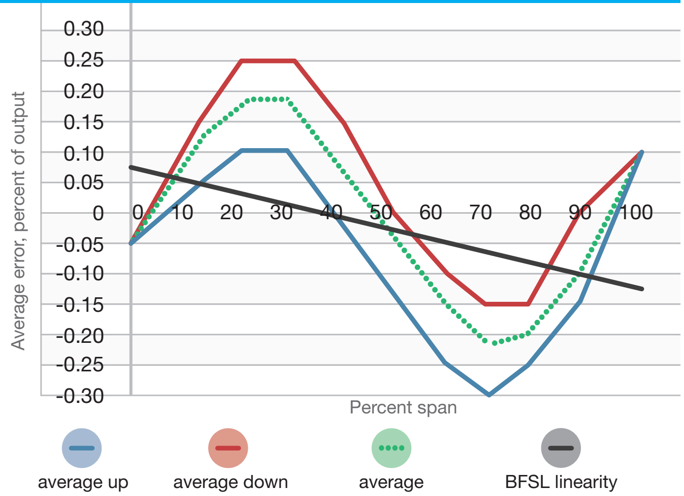
Terminal point linearity is determined by drawing a straight line that coincides with the calibration curve at the full span point and at the zero point (IEC 61298-2, p.13). One of the major benefits of terminal point linearity is that it includes zero offset error and span setting error. This is because terminal point linearity is fixed to the sensor's full span point and zero point. A benefit of sensors tested this way is that they can be easily interchanged with other units in the field because their accuracy comes set from the factory and includes errors associated with setting the zero and span points.

TERMINAL POINT LINEARITY



Best fit straight line (BFSL) linearity is determined by drawing a trend line that minimizes the maximum deviation between the trend line and any data point on the calibration curve (IEC 61298-2, p.13). A best fit straight line does not need to pass through the zero or span points. The only requirements are that it is a straight line and that it minimizes the maximum deviation of the calibration curve. This is problematic because sensors calibrated using the best fit straight line method will need to be re-calibrated once installed in the field to correct for zero offsets and span setting errors. Since these errors can have a noticeable effect on the sensor's accuracy, they should be included in the calculation.

BEST FIT STRAIGHT LINE LINEARITY



Zero offset and span setting errors are typically written as either a percentage of span or a percentage of output. Some sensor manufacturers list the zero offset and span setting errors under the sensor's electrical data or specifications. For a sensor with a voltage output, the zero and span offset error will likely be shown as a ± mV reading. For sensors with a current output the zero and span offset error will likely be shown as a ± mA reading. To convert this value into a percentage, the ± mV or ± mA error should be divided by the sensor's output span.

Output Span = (output at full span) - (output at zero span)

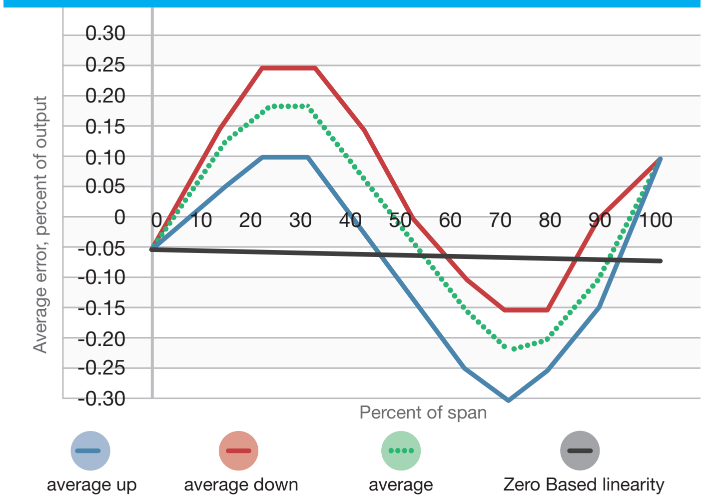
$$\textbf{Zero Offset Error} = \frac{(\pm \text{ zero output error})}{(\text{output span})}$$

$$\textbf{Span Setting Error} = \frac{(\pm \text{ span output error})}{(\text{output span})}$$

Correcting zero offset and span setting errors will have an effect on the overall accuracy of the transducer. Changes made to the zero offset will cause a linear shift of the trend line, while changes to the span will affect the slope of the line. If zero and span setting errors are corrected, the accuracy of the transducer should be reevaluated.

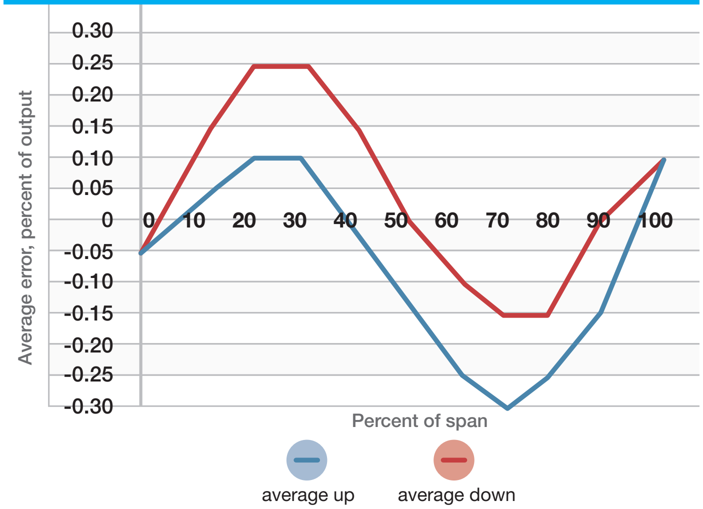
Zero based best fit straight line linearity is determined by drawing a trend line that is fixed to the zero value of the calibration curve but also minimizes the potential deviation between the trend line and all the other data points on the curve. Zero based best fit straight line linearity is less common than terminal point linearity or standard best fit straight line linearity. It provides a more accurate measurement of the sensor's non-linearity error than the best fit straight line method, but it is a less inclusive measurement of error than the terminal point method. Similar to the standard best fit straight line linearity, the zero based best fit straight line linearity does not account for span offset error. Thus, the span offset error must also be calculated and added to the total error statement when calculating a sensor's true accuracy.

ZERO BASED BEST FIT STRAIGHT LINE LINEARITY



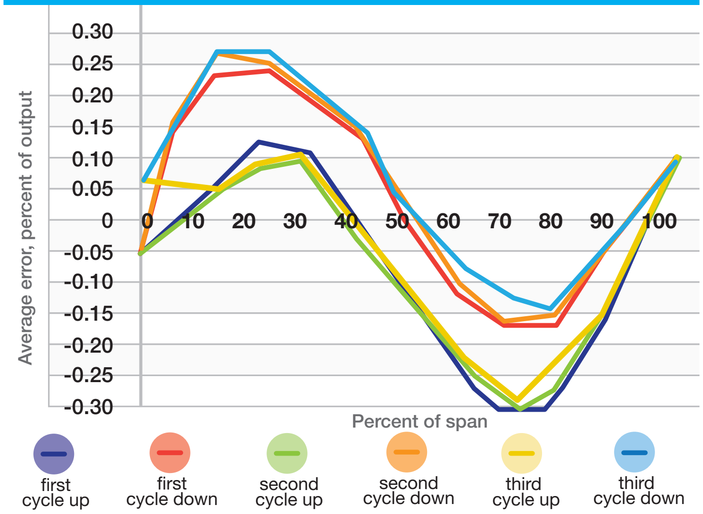
Hysteresis is defined as "property of a device or instrument whereby it gives different output values in relation to its input values depending on the directional sequence in which the input values have been applied" (IEC 61298-2, p. 8). More simply, hysteresis describes the difference between the pressure sensor's output when pressure is increasing compared to when it is decreasing. This error is commonly given as a percent of full span or output span. Hysteresis is considered a property of a sensor and should only account for a small portion of an accuracy statement. Hysteresis is considered to be a cumulative error when referring to an accuracy statement. It is independent of linearity, and non-repeatability.

HYSTERESIS



Repeatability is defined as closeness of agreement between the results of successive measurements of the same measurement, carried out under the same conditions, using the same procedure, by the same observer, with the same instrument, used under the same condition, in the same laboratory, over a relatively short interval of time (IEC 60050, 311-06-05). The error is commonly calculated by testing a sensor over its pressure range three times in a row, under identical conditions, and finding the maximum difference between measurements, which is often defined as a percent of full span. This is commonly referred to as the non-repeatability error. Similar to hysteresis, repeatability is considered to be a cumulative error. When analyzing an accuracy statement it should be considered independent of linearity, and hysteresis.

REPEATABILITY



THE COMPONENTS OF ACCURACY ARE WELL DEFINED. METHODS FOR COMBINING THE INDIVIDUAL ERRORS OF A SENSOR'S ACCURACY STATEMENT ARE NOT.

The summed error of a sensor's accuracy statement is commonly calculated using the additive method (a.k.a. worst case method) or the root of the sum squared (RSS) method. For the summed error to be useful, it should include non-linearity errors, non-repeatability errors, and hysteresis errors. If the non-linearity error is calculated using a best fit straight line (BFSL) method, the zero setting error and span setting errors should also be included in the accuracy statement. The summed error of a sensor's accuracy statement is different from the sensor's real accuracy. In other words, a sensor's accuracy will always be defined by the maximum positive and negative deviations from any measured value to the ideal value, for increasing and decreasing inputs for any test cycle.

The worst case method is a summation of the individual components of accuracy that make up the accuracy statement. The worst case accuracy method is based on the fact that a sensor's accuracy could be equal to the sum of all of the possible errors that make up the accuracy statement. This is very different compared to the assumption the root of the sum squared (RSS) method makes.

$$\textbf{Worst Case Error} = \text{(non-linearity error)} + \text{(non-repeatability error)} + \text{(hysteresis error)}$$

The root of the sum squared (RSS) method is a statistical calculation commonly used to determine the sum of errors in an assembly. Taking the square root of the sum of the squares provides a few statistical benefits. First, squaring individual error values guarantees that all of the error values being added will be positive, meaning that negative errors will not offset positive errors. Second, squaring also weights the error values; errors greater than 1% are more heavily weighted, errors less than 1% are minimized and errors equal to 1% will remain the same. Most errors associated with the components of accuracy are typically less than 1%. Thus, the individual errors will be minimized before they are summed and then the square root will be taken after the minimized errors are summed. The final result is that the total error calculated with the root of the sum squared (RSS) method will be less than the worst case method that focuses on summing each of the individual errors.

$$\textbf{RSS Error} = \sqrt{\text{(Non-Linearity)}^2 + \text{(Non-Repeatability)}^2 + \text{(Hysteresis)}^2}$$

THE BOTTOM LINE: CRITICAL APPLICATIONS REQUIRE ACCURATE SENSORS.

It's important to understand the accuracy statement for the sensors used in an application. These statements vary from manufacturer to manufacturer. The sensor's error should not only be determined by a percent of span but also by what that error includes or excludes.

The most conservative accuracy statements will be a summation of terminal point linearity errors, which includes zero and span errors, non-repeatability errors, and hysteresis errors. These errors all contribute to defining how a transducer will perform but a transducer's accuracy will always be defined by its maximum positive and negative deviation from an ideal standard.

The least conservative accuracy statements will utilize an RSS accuracy statement and best fit straight line (BFSL) linearity errors. Repeatability errors and hysteresis errors may not be listed, and zero and span setting errors will likely be intentionally omitted or disguised as an electrical output. If accuracy and error data are not clearly defined on the manufacturer's datasheet, contact them and inquire about their accuracy statement and compare it to statements from other manufacturers.

Remember, *not all accuracy statements are created equal.*

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