FLUKE®

Calibration

How to evaluate pressure measurement specifications

Application Note

There are thousands of different pressure measuring devices out there. How do you decide which instruments to invest in to calibrate them all? The secret to calibrating the most workload with the least investment lies in understanding the term "rangeability." To do that, you'll need to know how to evaluate instrument specifications. This application note covers:

- Types and examples of percentage specifications
- Comparing specifications
- Test accuracy ratios (TARs)
- Determining rangeability

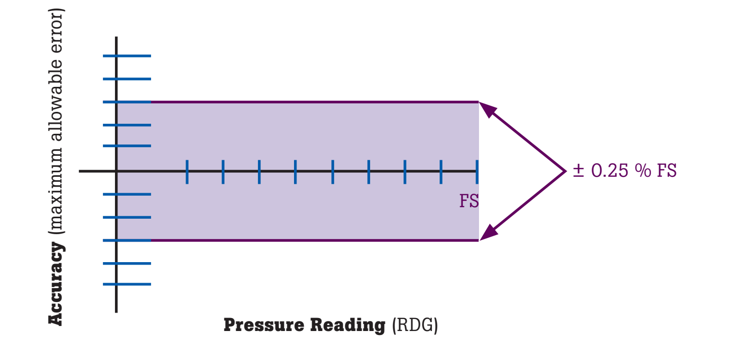
Types of percentage specifications

Pressure measurement devices, like gauges, transmitters, and transducers, have specifications that describe how well they measure pressure. When you calibrate or validate one of these devices, you want to confirm that it is performing within its specifications. During a calibration, you typically compare your device's measurements to the measurements of a reference standard that has the same types of functions but better accuracy. To ensure that your reference standard is accurate enough to do the calibration, it's common to compare the specifications of the device under test (DUT) to the reference standard's specifications using a test accuracy ratio.

A pressure device's measurement specification is often expressed as a percentage. But there are different ways of expressing a percentage, and each one means something different:

Percent of full scale

This type of specification is a constant value throughout the range of the device.

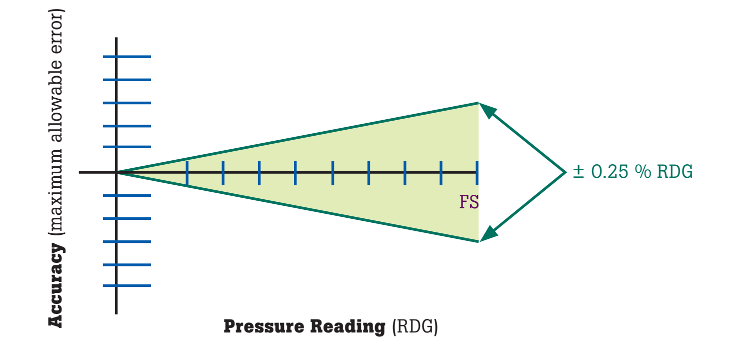


Example:
Upper range limit = 1,000 psi
Accuracy specification= ± 0.25 % FS
FS= Full scale = upper range limit = 1,000 psi
± 0.25 % of 1,000 psi = ± 2.5 psi
The accuracy of the gauge is ± 2.5 psi at all pressures throughout the range.

"Percent of full scale" specification.

Percent of reading

This type of specification is a function of the indicated pressure, so it changes as the pressure reading changes.



Example:
Upper range limit = 1,000 psi
Accuracy specification= ± 0.25 % reading
Reading is the indicated pressure: 0 psi, 500 psi, and 1,000 psi
Find the maximum allowable error at the indicated pressures.

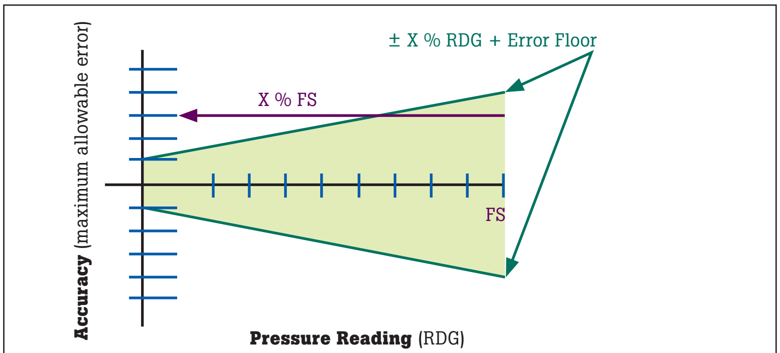
Indicated pressure	Accuracy specification
0 psi	± 0.25 % of 0 psi = ± 0 psi
500 psi	± 0.25 % of 500 psi = ± 1.25 psi
1,000 psi	± 0.25 % of 1,000 psi = ± 2.5 psi

Note: In this case, the upper range limit does not affect the accuracy specification.

"Percent of reading" specification.

Combined percent of reading and percent of full scale

A maximum allowable error of ± 0 units as in the example above is probably unrealistic for any instrument. To avoid this problem, the manufacturer either limits the instrument's range or includes an error floor with the percent of reading specification. The error floor may be given as a constant, a percentage of full scale, or sometimes with a reference to the instrument's resolution.



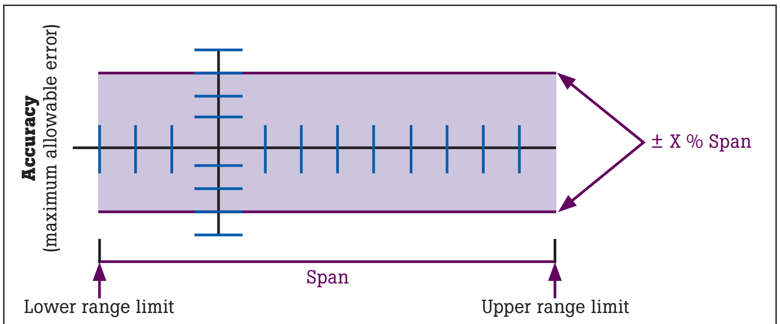
Example:
Full scale = 1,000 psi
Accuracy specification= ± 0.25 % reading plus 0.125 % full scale

Indicated pressure	Accuracy specification
0 psi	± (0.25 % of 0 psi + 0.125 % of 1,000 psi) = ± 1.25 psi
500 psi	± (0.25 % of 500 psi + 0.125 % of 1,000 psi) = ± 2.50 psi
1,000 psi	± (0.25 % of 1,000 psi + 0.125 % of 1,000 psi) = ± 3.75 psi

"Combined percent of reading and percent of full scale" specification.

Percent of span

The specification is a constant value throughout the range of the device, but is based on the difference between the upper range limit and the lower range limit.



Example:
Accuracy = ± 0.25 % of span
Upper range limit = 100 psi
Lower range limit = -10 psi
Span = Upper range limit – lower range limit = 110 psi
± 0.25 % of span = ± 0.25 % of 110 psi = ± 0.275 psi
The accuracy is ± 0.275 psi at all pressures throughout the range.

"Percent of span" specification.

Comparing specifications for three reference pressure gauges

To ensure that you are properly comparing the DUT and the standard (master gauge), you need to convert their specifications into like quantities. Ideally, this means you'll convert all specifications into actual pressure values at each test pressure. Table 1 shows specifications for three digital pressure gauges, which can be used as reference standards in a calibration. Two of the specifications are expressed as percent of full scale, and the third is expressed as percent of full scale plus percent of reading. In this comparison, each gauge is the same full scale (1,000 psi) and we are showing the specification in 10 % increments.

	Pressure gauge #1	Pressure gauge #2	Pressure gauge #3
Pressure	0.05 % FS	0.02 % FS	0.04 % reading + 0.01 % FS
0	0.5	0.2	0.1
100	0.5	0.2	0.14
200	0.5	0.2	0.18
300	0.5	0.2	0.22
400	0.5	0.2	0.26
500	0.5	0.2	0.3
600	0.5	0.2	0.34
700	0.5	0.2	0.38
800	0.5	0.2	0.42
900	0.5	0.2	0.46
1000	0.5	0.2	0.5

Table 1. Comparing specifications for three digital pressure gauges.

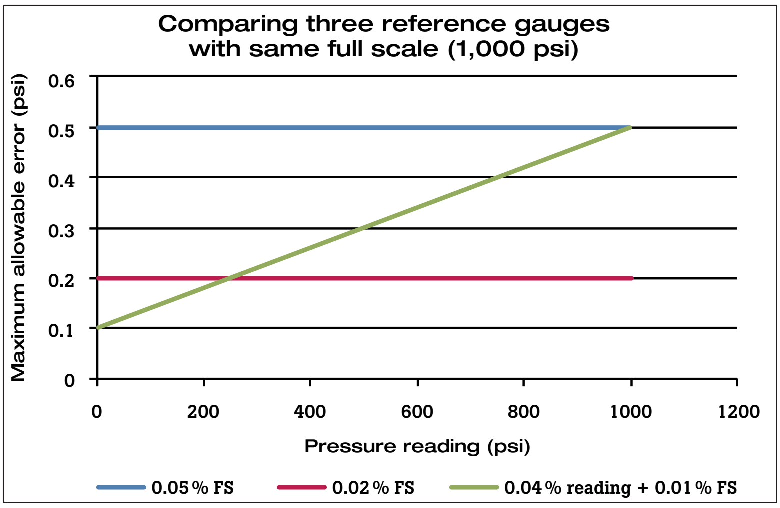


Figure 1. Comparing specifications for three Fluke Calibration digital pressure gauges.

Test accuracy ratios

A test accuracy ratio (TAR) is the ratio between the stated accuracy (calibration tolerance) of the DUT and the accuracy of the calibrator. For example, if the stated TAR is 4:1 (read: four to one) that means that the master gauge or calibrator is four times more accurate than the device under test. We use test accuracy ratios because calibration quality needs to be ensured, but conventional uncertainty analysis is complex, time consuming and may not be warranted for instrument performance verification.

Over time, different industries have developed different standards for what a good TAR looks like. The most common is 4:1. By keeping the TAR to a ratio such 4:1, you are less likely to falsely accept or reject a pressure gauge based on the outcome of your calibration, especially when the error is near the established tolerance.

Test accuracy ratios may depend on:

- DUT accuracy specification
- DUT full scale
- Master gauge accuracy specification
- Master gauge full scale

Comparing reference pressure gauges and a DUT, where the DUT has specification of 0.1 % full scale

Understanding specifications help you compare the capabilities of pressure standards. Consider the scenario shown in Figure 2 where the same DUT has a full scale of 1,000 psi, and an accuracy specification of ± 0.1 % full scale.

In this scenario, the pressure standard with a percent of reading specification provides a sufficient test accuracy ratio at lower pressures, but at full scale it is only 2:1. That is problematic because, generally, the upper 80 % of the reference gauge's scale is the most used and the most important.

Determining rangeability

An instrument's rangeability is the ratio of the maximum to the minimum specified measured value at which the instrument has an acceptable performance. As we have seen, acceptable performance depends on a test accuracy ratio with the DUT, and the accuracy of the DUT usually depends on its own pressure range. Rangeability depends on the DUT specification, the specification of the standard, and full scale of both devices.

On the other hand, a ± 0.02 % FS master gauge can meet a 4:1 ratio when calibrating ± 0.1 % FS devices with full scales from 800 psi to 1,000 psi, ± 0.25 % FS devices with full scales between 320 and 1,000 psi, and ± 0.5 % FS devices with full scales between 160 psi and 1,000 psi.

The bottom line is that you can calibrate twice as many DUTs with one master gauge if it has twice the rangeability.

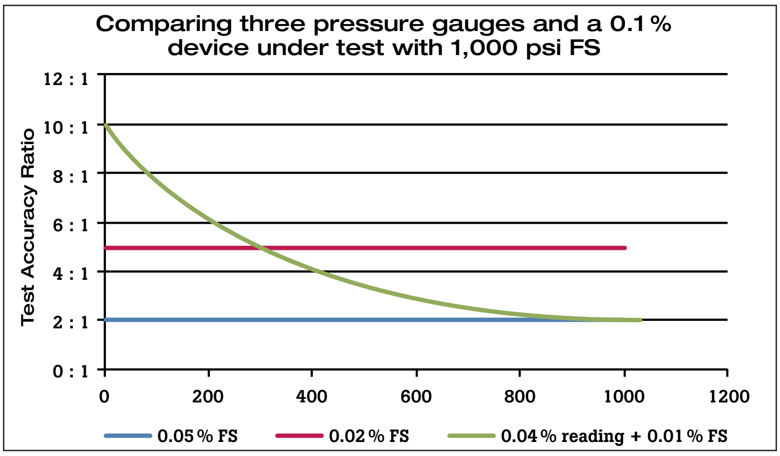
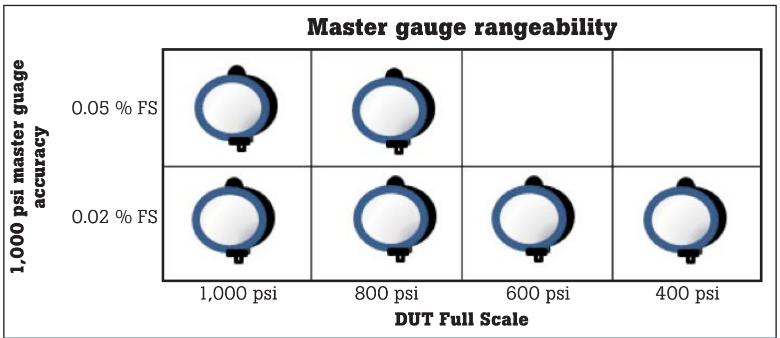


Figure 2. Comparing three pressure gauges and a device under test with 1,000 psi but a specification of 0.1 % full scale.



Example:
When a 1,000 psi master gauge is required to be four times more accurate than the device under test, a ± 0.05 % FS master gauge cannot calibrate a ± 0.1 % FS device. However, it can calibrate ± 0.25 % FS devices with full scales between 800 psi and 1,000 psi and ± 0.5 % FS devices with full scales between 400 and 1,000 psi.

Figure 3. Rangeability of two 1,000 psi master gauges.

Rangeability

The ratio of the maximum to the minimum specified measured value at which the instrument has an acceptable performance. Rangeability depends on the DUT specification, the specification of the standard, and full scale of both devices.

Comparing reference pressure gauges and a DUT, where the standards and DUT have the same full scale

Figure 4 uses the same three gauges as Figure 1 and shows the test accuracy ratio (TAR) with an example device under test (DUT). Our DUT has a specification of 0.25 % full scale and a full scale of 1,000 psi. All gauges in this scenario meet a 4:1 TAR requirement.

Comparing reference pressure gauges and a DUT, where the standards and DUT have different full scale

In the previous example, the standards and the DUT had the same full scale (1,000 psi). Now let's consider a scenario where the DUT has a full scale that is only 500 psi, half that of our standards. See Figure 5.

Although the 500 psi gauge had the same percentage accuracy specification as the 1,000 psi gauge, the error limits were much tighter for the 500 psi gauge, because they were calculated as ± 0.25 % of 500 psi rather than ± 0.25 % of 1,000 psi. This caused the test accuracy ratios with the 500 psi pressure gauge to be smaller. In fact, they were so small that the test accuracy ratio for the ± 0.05 % FS gauge dropped below 4:1. This means the ± 0.05 % FS 1,000 psi pressure gauge probably would not be adequate to calibrate a ± 0.25 % FS device with a 500 psi upper range limit.

This example further demonstrates the concept of rangeability, because a more accurate test standard can calibrate a wider range of pressure gauges. All things being equal, a master gauge with twice the accuracy as another will be able to calibrate twice the range of instruments.

Conclusion

When you are choosing a pressure standard to calibrate a device under test, it's not sufficient to look just at the standard's percent specification. You also need to account for the different types of percent specifications (full scale, reading, span and combined), and also any difference in full scales of the DUT and the pressure standard.

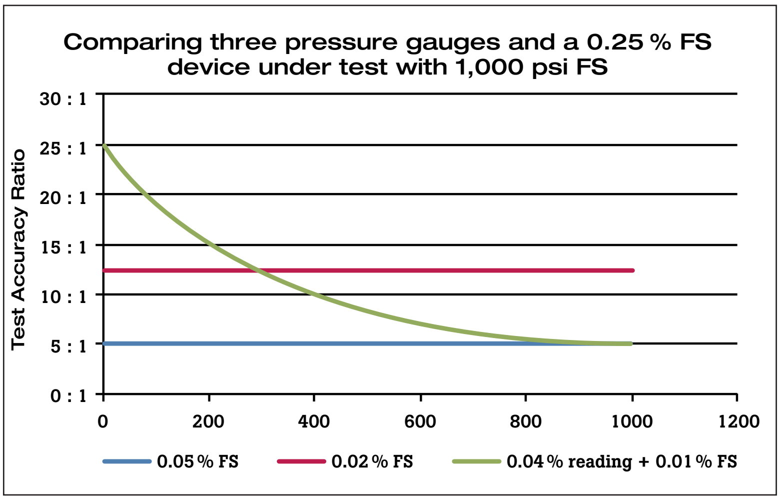


Figure 4. Comparing three pressure gauges and a device under test.

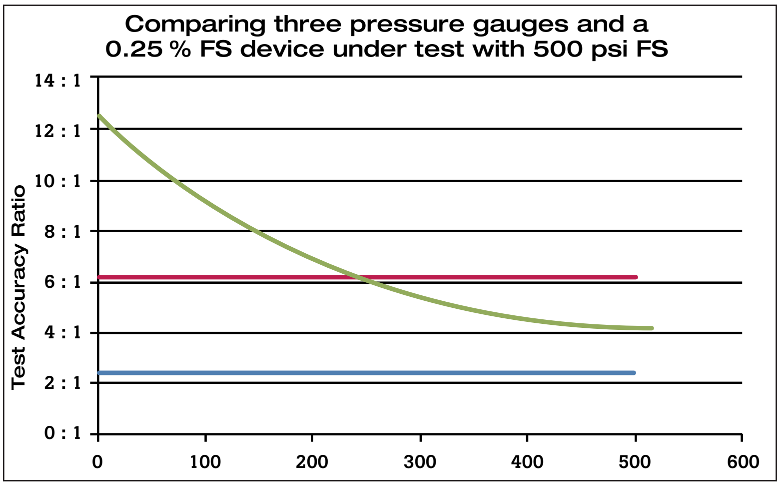


Figure 5. Comparing three pressure gauges and a device under test with 500 psi full scale.

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