

Unraveling Measurement Accuracy Specifications for Battery Testers

Understanding system accuracy specifications is important when specifying and assessing test system choices to know exactly what you're buying and what you can achieve with that equipment.

When specifying and purchasing cell and battery test equipment for your R&D lab or production line, it's critical to understand its performance specifications.

While it may be easy to clearly state price, how many channels you need, and current per channel, the accuracy of the equipment is perhaps the most important specification. However, it can be a challenge to understand and ensure you're specifying your needs correctly.

Getting Started: What is Accuracy and Error?

When test equipment makers, like my company Keysight Technologies, refer to accuracy, we specify accuracy as the amount of error you will see with respect to the parameter. For instance, if we're talking about current measurement accuracy, we specify the amount of error you will encounter when making a current measurement, such as 100 μ A of error or uncertainty on a current measurement of 5 A.

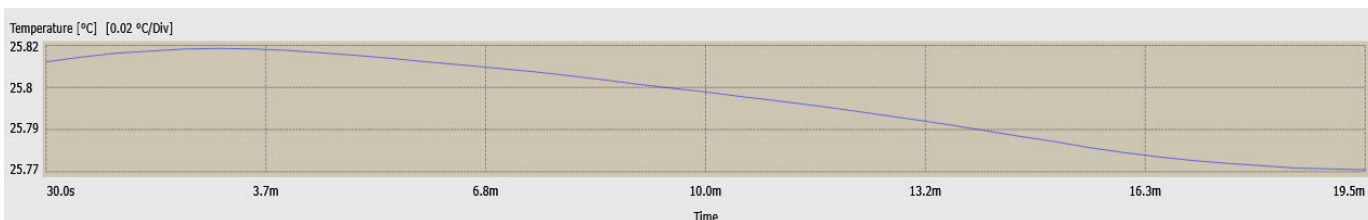
If we're talking about current programming or source error, it concerns the error in setting the desired current value.

So, if you want to set a constant current charge rate of 10 A, the system may have a programming error of 25 mA. Thus, you will not actually achieve 10 A, but an output value within 25 mA of 10 A.

While the examples given were for current sourcing and measurement, this concept applies to any parameter that can be measured, such as voltage in volts, current in amps, resistance in ohms, temperature in degrees, pressure in various units, etc. Similarly, you will have a sourcing or programming error for any parameter that can be sourced by the system, which is normally limited to voltage and current.

This topic might seem to apply just to channels in a cell or battery tester or formation system. However, these accuracy specification concepts work with any measurement device (e.g., a voltmeter or internal resistance measurement instrument), or to any source device (e.g., a power supply, source-measure unit, or analog output signal generator).

Often, measurement resolution is mixed up in any discussion of measurement accuracy. I'll cover resolution at the end of this article.



Shown is measurement of temperature drift vs. time using a high-resolution temperature measurement system taking measurements at 30-second intervals. In this case, while the absolute accuracy of the temperature measurement is $\pm 2^\circ\text{C}$, the resolution is better than 0.01°C . This makes it possible to see very small changes in temperature relative to each other. However, the absolute accuracy of any measurement point is still $\pm 2^\circ\text{C}$.

Ways to Specify Accuracy

In general, there are four ways to specify accuracy. The actual number established by the accuracy specification is the amount of error you will encounter. Based on this amount of error and the true value of the desired parameter, you can then determine the accuracy. For the remainder of this discussion, I will refer to measurement accuracy, but the concept applies identically to programming or source accuracy.

1. Fixed error

In this case, the error is a fixed value, such as 10 mA. It means that no matter how large or how small the parameter you're trying to measure, there will be the same amount of error. For example, if the error is 2 mA, you will have 2 mA of error whether you are measuring 100 mA or 100A.

2. Fixed percent of range

Here, the error scales with the range of the measurement device and will be specified as “% of FS” (means percent of full scale) or “% of range.” For example, if the error is 0.2% of FS and the full-scale range is 10 A, then you will have 0.2% of 10 A, which is 0.02 A or 20 mA of error. On many measurement devices, you will see ranges. One benefit of the ranges is to match the range to the size of the parameter being measured to ensure the lowest error in measurement.

Let's look an example. You're trying to accurately measure a 500-mA signal. Your measurement device has three ranges: 1, 10, and 100. If the error is 0.2% of FS, the error will be 2 mA of error on the 1-A range, 20 mA of error on the 10-A

range, and 200 mA of error on the 100-A range. While the 500-mA signal can be measured on any of those three ranges, you will get the lowest error when using the lowest range.

3a. Gain and fixed offset

In this case, there are two components to the error: A gain term that gives an error component that scales with the size of the parameter being measured, and a fixed term that's always present. You will see this error stated as something like “% of reading + value.” Accuracy specified as a gain and fixed offset can apply to a measurement device with a single range or multiple ranges, because the specification doesn't include “range” in the specification.

For example, once again, you're trying to accurately measure a 500-mA signal. Your measurement device has an accuracy specification of 0.1% + 750 μ A. The gain term is 0.1%, so the gain-term component of error will be 0.1% of 500 mA or 500 μ A. The fixed-term component is 750 μ A. Therefore, the total error when measuring 500 mA will be (500 μ A + 750 μ A) or 1.25 mA.

If the measured signal were to go up to 1 A, then the error would go up as well. At 1 A, the gain-term component of error will be 0.1% of 1 A or 1 mA. The fixed-term component would remain at 750 μ A. The total error when measuring 1 A will be (1 mA + 750 μ A) or 1.75 mA.

This is the best way to specify accuracy. While it's more complex to calculate, it means the measurement device is well characterized by the test equipment provider. On top of

	Based on measurement of current at 10% of full scale range	Based on measurement of current at 50% of full scale range	Based on measurement of current at 90% of full scale range
Measurement device range	1 Amp range	1 Amp range	1 Amp range
Measuring a current of	100 mA	500 mA	900 mA
CASE 1			
Accuracy Specification: Fixed error	± 2 mA	± 2 mA	± 2 mA
Error on measurement as % of measurement	2% error at 100 mA	0.4% error at 500 mA	0.22% error at 900 mA
Resultant measurement minimum	98 mA = 100 mA - 2 mA	498 mA = 500 mA - 2 mA	898 mA = 900 mA - 2 mA
Resultant measurement maximum	102 mA = 100 mA + 2 mA	502 mA = 500 mA + 2 mA	902 mA = 900 mA + 2 mA
CASE 2			
Accuracy Specification: Fixed Percent of Range	0.2% of Full Scale Range	0.2% of Full Scale Range	0.2% of Full Scale Range
Error term	± 2 mA	± 2 mA	± 2 mA
Error on measurement as a % of measurement	2% error at 100 mA	0.4% error at 500 mA	0.22% error at 900 mA
Resultant measurement minimum	98 mA = 100 mA - 2 mA	498 mA = 500 mA - 2 mA	898 mA = 900 mA - 2 mA
Resultant measurement maximum	102 mA = 100 mA + 2 mA	502 mA = 500 mA + 2 mA	902 mA = 900 mA + 2 mA
CASE 3			
Accuracy Specification: % reading + fixed offset	0.1% of reading + 750 μ A	0.1% of reading + 750 μ A	0.1% of reading + 750 μ A
Gain error term at 0.1% of reading	100 μ A = 0.1% of 100 mA	500 μ A = 0.1% of 500 mA	900 μ A = 0.1% of 900 mA
Fixed error term	750 μ A	750 μ A	750 μ A
Total error term of gain + offset	± 850 μ A	± 1250 μ A	± 1650 μ A
Error on measurement as a % of measurement	0.85% error at 100 mA	0.25% error at 500 mA	0.18% error at 900 mA
Resultant measurement minimum	99.15 mA = 100 mA - 0.85 mA	498.75 mA = 500 mA - 1.25 mA	898.35 mA = 900 mA - 1.65 mA
Resultant measurement maximum	100.85 mA = 100 mA + 0.85 mA	501.75 mA = 500 mA + 1.25 mA	901.65 mA = 900 mA + 1.65 mA

that, it will give the lowest error for each value measurement made because the error scales with the size of measurement.

3b. Gain and offset as % of range

Fundamentally, this case is the same as case 3a, but the fixed term is calculated based on the range of the measurement. If there's only one measurement range, then case 3a and 3b are identical.

To look at an example, you're again trying to accurately measure a 500-mA signal on a system with a 5-A range. Your measurement device has an accuracy specification of 0.1% of reading + 0.1% of range. The gain term is 0.1%, so the gain-term component of error will be 0.1% of 500 mA or 500 μ A. The fixed-term component is 0.1% of 5 A, or 0.005 A. Therefore, the total error will be (500 μ A + 5 mA) or 5.5 mA.

Actual Error vs. Specified Error

While the cases above explain how to interpret and apply accuracy specifications, what's critical to know is "what is my error on my measurement"? After you've calculated the error term, you will want to compare this error term to the measurement you're making. Let's revisit cases 2 and 3.

In case 2, you're trying to accurately measure a 500-mA signal. The measurement device has three ranges: 1, 10, and 100 A. If the error is 0.2% of FS, the error will be 2 mA of error on the 1 A range, and you select the 1 A range to ensure the most accurate measurement.

If you compare this error term to the measurement you're making, you have 2 mA of error on a 500-mA measurement. This is 2 mA/500 mA = 0.4% error in your measurement, even though the accuracy specification was 0.2% of FS. Clearly, you can't just say my *measurement* will be 0.2% accurate because the *specification* was 0.2% FS.

In case 3, you're once again trying to accurately measure a 500-mA signal. The measurement device has an accuracy specification of 0.1% of reading + 750 μ A. The gain-term error component is 0.1% of reading, so this component of error will be 0.1% of 500 mA or 500 μ A. The fixed-term error component is 750 μ A. Therefore, the total error will be (500 μ A + 750 μ A) or 1.25 mA.

Comparing this error term to the measurement you're making, there's 1.25 mA of error on a 500-mA measurement. This is 1.25 mA/500 mA = 0.25% error in your measurement, even though the accuracy specification was 0.1% + 750 μ A.

Also, important to note, is that error terms are applied as a \pm to the measured value. If the error term is 2 mA on a 500-mA measurement and you want to know the range of results, you must both add and subtract the error term from the measurement as follows:

- Error term = ± 2 mA
- Value to be measured = 500 mA

- Resultant measurement minimum = 500 mA - 2 mA = 498 mA

- Resultant measurement maximum = 500 mA + 2 mA = 502 mA

So, this is saying if the error is 2 mA on a 500-mA reading, the measurement device will return a measurement between 498 and 502 mA.

The *table* shows a comparison of how to calculate and apply these three cases.

Note that the resultant error as a percent of the measurement reduces significantly as the measured values increase toward the maximum of the measurement range. With the fixed errors (cases 1 and 2), the resultant error as a percent of measurement suffers because the error is fixed, while with case 3, the resultant error scales with the reading, improving error as a percent of measurement at small measurement values.

Beware

There's another method to specify accuracy—and beware if you encounter it. If you see accuracy specified as a percent only, like 0.2% accuracy, the specification is misleading. While it may be very easy to understand and calculate, it's unrealistic.

Let's look at an example. You're trying to measure 500 mA with a measurement device specified at 0.2% accuracy. The error term of 0.2% of 500 mA is 1 mA of error. If instead you were trying to measure 1 A, the error would be 2 mA, as it simply scales. But what about the other direction?

If instead of measuring 500 mA, what if you wanted to measure 50 mA? Would the error be 100 μ A? And what about measuring 5 mA? Would the error be 10 μ A? If you were trying to measure an open circuit with current of 0 mA, does this mean the system will report 0 mA with 0 μ A of error, indicating a perfect measurement?

It's unrealistic that any measurement instrument could provide a constant error of 0.2% regardless of the size of the signal. When the accuracy is specified as a percent of reading, something is missing that describes the limitation of the measurement device at its low end. Therefore, you really can't trust the performance of this measurement device, especially at the low end of its measurement range.

And Finally, What About Resolution?

Frequently, resolution is thought to be more important than accuracy, but this isn't the case. While resolution can be a figure of merit that gives some indication of the quality and performance of a measurement device, as in 18 bits is better than 16 bits, the accuracy is the real governing specification on how good a measurement you can make.

For example, if your measurement device has a high resolution of 10 μ A, and an accuracy of 50 μ A, the 10 μ A has no

real bearing on the measurement as measurement error will be $\pm 50 \mu\text{A}$. The $10\text{-}\mu\text{A}$ resolution doesn't impact or improve the accuracy of the measurement device nor will it give you any higher confidence in the measurement, which will never be better than $\pm 50 \mu\text{A}$.

Having high resolution can be helpful to see the relative relationship between consecutive measurements, such as watching temperature drift, where you might see a 0.1°C change over time on a 25°C measurement that has $\pm 2^\circ\text{C}$ of accuracy. However, on an absolute basis, you can't say, for instance, that the temperature is 25.7°C vs. 25.8°C with full certainty because the measurement accuracy of any individual reading is $\pm 2^\circ\text{C}$ (*see figure*).

Summary

Understanding the performance specifications of your cell or battery test system is critical. By discerning how to interpret and apply the accuracy specifications, you can be certain you will request the right capabilities without over-specifying or under-specifying your needs when requesting a quotation. Likewise, you will be sure to know what you're buying and how well it fits your needs when reading a data-sheet or a statement of work for a customized system.