Understanding Errors and Accuracy

1.0. General

Specifications of a device can be written in different ways. Some of them can be not clear enough, some of them can even be misleading. This is true for many parameters, including errors and accuracy. Understanding errors and accuracy is important when selecting a device for your application. Or when trying to evaluate its performance.

In any measurement that we make there is some error. Even the most accurate meter we can find and use still has some error. The lower the error, the higher the accuracy. And the higher the error, the lower (the worse) the accuracy. Like any other parameter in the specifications the error and/or the accuracy have to be clearly specified. The conditions at which the error was specified have to be also clearly stated.

Statement like: "the error is 1 GPM" does not give the necessary information or mislead. One GPM, at what flow rate? And at what temperature of what liquid/gas ? At what pressure?

Or a **statement like**: "the error is 1%". One percent of what? At what conditions?

It would be **wrong** to say: "the typical accuracy is 1 degree, the maximum accuracy is 4 degrees". Four degrees is a lot **less** accurate than one degree. So 4 degrees is **not the maximum** accuracy, but **the minimum** or **the worst** accuracy.

It would be much better if the **statement is**: "the **typical error** is 1 degree, the **maximum error** is 4 degrees".

If the error is 1% (of something, at specified conditions) then the accuracy is 99% (of the same thing, at the same conditions). If the error is 2%, the accuracy is 98%.

It would be correct to say:

- We measured flow rate of water and it was 100 GPM +/- 1%, at 25 ^{o}C
- We measured a flow rate of 100 GPM with an error lower than 1 GPM
- The temperature we measured was 100 degrees, accurate to within 1 degree

2.0. Types of errors used in practice

2.1. Absolute error

The **absolute error** is the difference between the "**real value**" and the meter reading, in engineering units. The "**real value**" is 57 degrees, the meter reads 55. The **absolute error** is 2 degrees.
The **absolute error** itself out of the context may not give the full information or may mislead. Two degrees error when we measure 200 is 1%, but it is 10% when we measure 20 degrees.

2.2. Relative (of rate) error

The **relative error** (**of rate error**) represents how the **absolute error** relates to the "**real value**" that was measured (with that error).
We measure pressure which "**real value**" is 300 bar. Our device reads 295 bar. The **absolute error** is 5 bar. The **relative error** is 5 bar divided by 300 bar = 1.67% (**of rate**, of 300 bar). The accuracy is 98.33 % (**of rate**).

The relative error does not consider the range (the full scale) of the meter and where the "**real value**" is within that range or full scale.

No matter where it is, no matter what is the real value we have clearly specified the error.

EXAMPLE: We have a magmeter that is specified to have a maximum error of 1% **of rate**, from 1:1 to 10:1 turn-down. The meter is specified for maximum 1000 GPM.

This means that we should be able to measure from 1000 GPM down to 100 GPM with an error lower than 1% **of rate**. Which in turn means that no matter what flow rate we measure (between 1000 and 100 GPM) we have the same (relative) error of 1% (the same accuracy of 99%) of the flow rate measured.

So when we measure 100 GPM the meter will read between 99 and 101 GPM. When we measure 1000 GPM the meter will read between 990 and 1010 GPM. If we measure 700 GPM, the meter will read between 693 and 707 GPM. In all three cases the error is 1% **of rate**, the accuracy is 99% **of rate**.

NOTE: Some companies write "O.R." leaving you to assume they mean "**of rate**" error. But if you ask them for details it will prove they actually mean "**of range**", and their understanding for "**of range**" will prove to be "**of full scale**". This way the error of their device can look many (tens or even hundreds of) times lower.

2.3. Full scale (FS) error

Full scale (FS) error is the **absolute error** divided by the **range, the full scale** (the maximum value). We have a magmeter that is specified to measure maximum 1000 GPM. We measure 50 GPM flow rate and the meter reads 45. The **absolute error** is 5 GPM. The **full scale error** is 5/1000 = 0.5% full scale.

EXAMPLE: We have the same magmeter from the example in **paragraph 2.2.** above. It is specified to have a maximum error of 1% **full scale** (FS), from 1:1 to 10:1 turn-down. The meter is specified for maximum 1000 GPM, so the **full scale** is 1000 GPM, and 1% **of full scale** is 10 GPM.

This means that no matter what the flow rate is (between 1000 and 100 GPM) the (absolute) error will be 10 GPM.

So when we measure 100 GPM the meter will read between 90 and 110 GPM. When we measure 1000 GPM the meter will read between 990 and 1010 GPM. If we measure 700 GPM, the meter will read between 690 and 710 GPM.

In all three cases the error is 1% **of full scale.**

The meter from **paragraph 2.2.** above would be much more accurate and higher quality than the meter in this example.

You can see and compare a **relative (of rate) error** to a **full scale error** on the diagrams below:

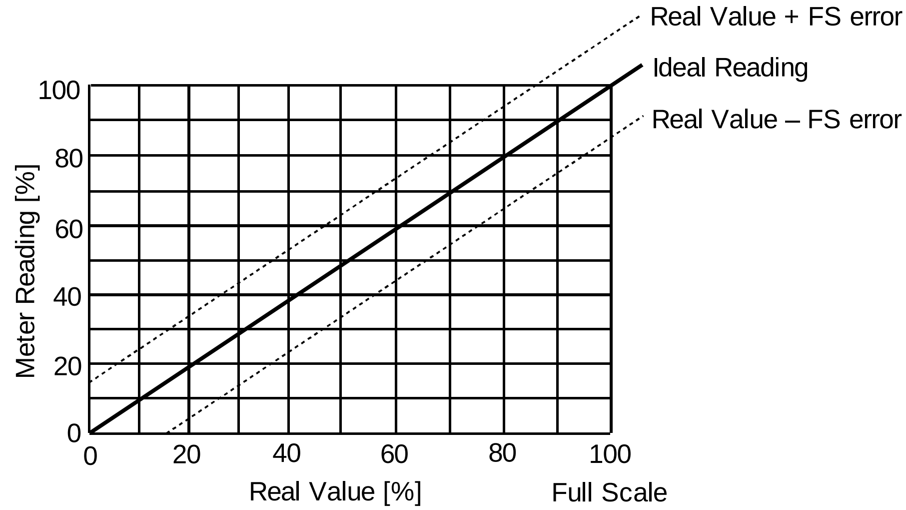

Fig. 1 Meter Reading when specified full scale error

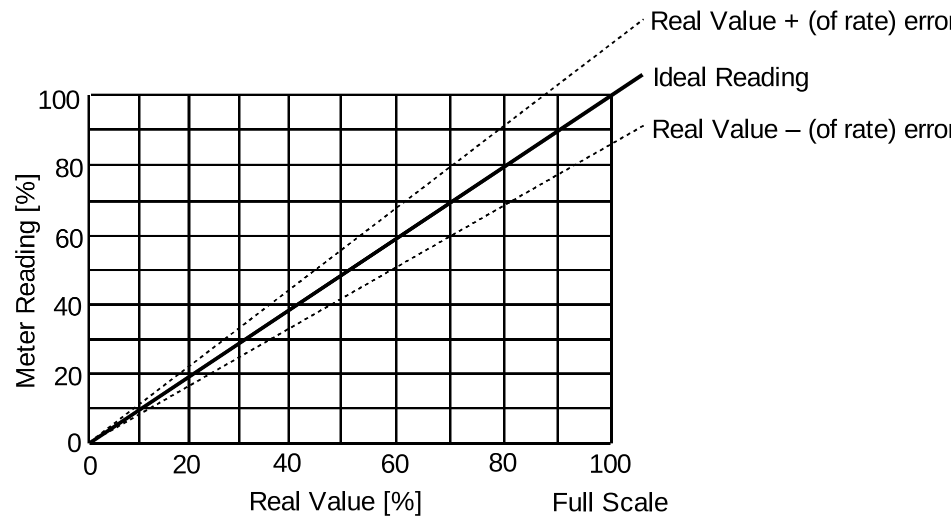

Fig. 2 Meter Reading when specified (of rate) error

Fig. 1 shows a meter reading when the error of the meter is specified as percents **of full scale**. The meter reading will be between the dotted lines.

Fig. 2 shows a meter reading when the error of the meter is specified as percents **of rate**. The meter reading will be between the dotted lines.

The meter on Fig. 2 will measure much more accurately when the flow rate is below full scale. It will be times more accurate with flow rate times lower than full scale.

2.4. The “Real Value”

The real value of the parameter is unknown. We can only know it with some certain error. It can be a reference value that we measured with some much higher accuracy meter, or a calculated value, or a value that somebody we trust specified with certain accuracy / error.

If we calibrate a flow meter we use a higher accuracy meter for a reference and then calculate the error of our meter under calibration. Or we use an accurate scale to calibrate by weight. But the reference meter or the scale are not perfect and they have their own errors.

So we do not really know what the "real value" of the flow rate is but use some (as accurate as possible) estimates instead.

3.0. Conclusion

Understanding and properly using the errors and accuracy specifications is very important. Some manufacturers do not specify clearly because of bad documentation. Some because they just do not understand and do not know what exactly and how to specify. Some intentionally do not specify clearly so their products can look much better. Understanding the numbers in the specs will help you make the right decision.

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