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RENEWABLE ENERGIES

CURRENT TRANSDUCER ACCURACY

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Introduction

Sensors and transducers are by definition measuring devices. They are engineered to transform one defined event into useable information. The events can be acceleration, temperature and, in the case considered in this paper, an electrical event; specifically the movement of electrical charges. The transformation will be into another 'output' that is more useful to work with. Typically, this is an electrical current or voltage that can then be further transformed into digital information and processed.

The before mentioned process of transformation in current transducers is typically instantaneous. This input parameter becomes an output parameter by some predefined transform function. Simply stated, the output parameter is related to the input parameter by a defined and unchanging equation. Some propagation delay or response time delay may occur, but what is 'seen' on the input is what appears after transformation on the output.

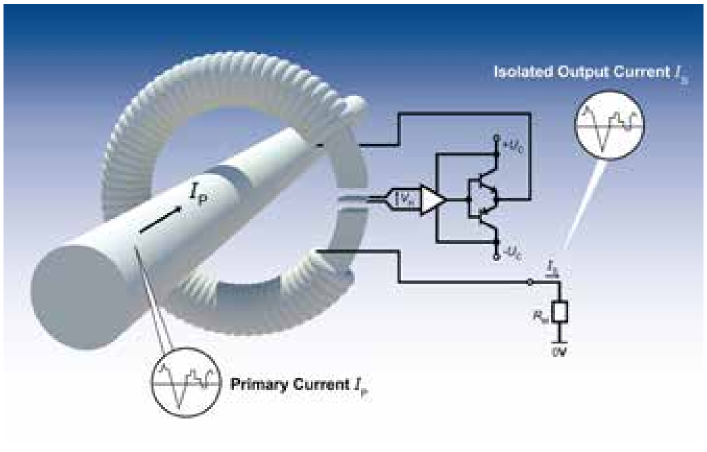
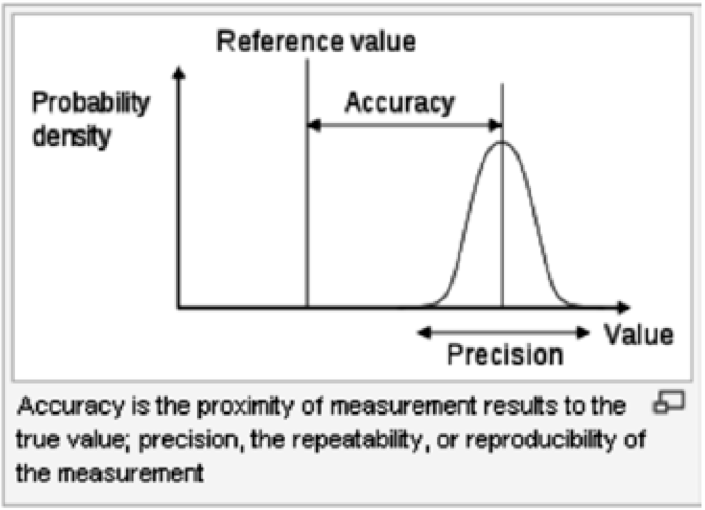


Fig 1. Input versus Output, Instantaneous

Like all processes this one involves probability. If the same measurement is taken multiple times and graphed a distribution will form. Additionally, the mean of the distribution will be some value different than what would be expected in a perfect test. The distribution is the 'precision' of the measurement, sometimes called the repeatability. The distance to the mean of the distribution is the accuracy.



Accuracy is the proximity of measurement results to the true value; precision, the repeatability, or reproducibility of the measurement

Fig 2. Accuracy and Percision

This graph is different from how measurement accuracy is usually interpreted. When the accuracy is stated, it is assumed that the measurements will be within limits defined, not a probabilistic curve centered on that limit.

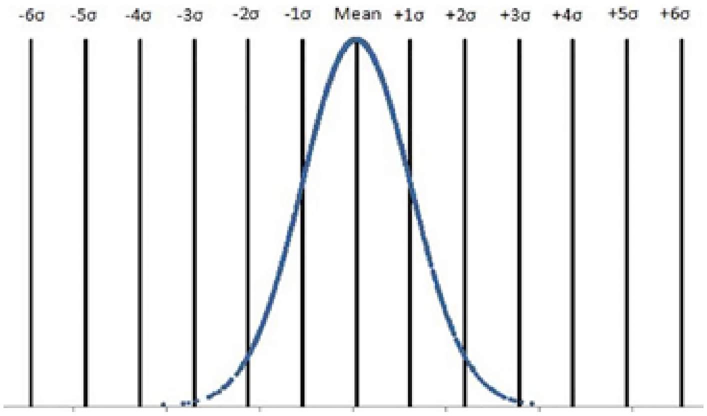


Fig 3. Probability Curve

Instead, it is assumed that the probability curve is within the limits defined by the accuracy. The right six sigma tale of the curve defines the accuracy at one limit and the left six sigma tale defines the accuracy at the other limit. The magnitude being measured is the mean, and the output of the transducer can be anywhere on the probability curve within the six sigma limits. An example would be a 100A transducer that is 1% accurate at 100A of reading current. This simple accuracy would give a mean of 100A with the six sigma limits defined as 99A and 101A.

When engineering a current measurement, it is assumed that all points within the accuracy limits have equal weight. That is not correct. Unless the production runs are in the millions, the majority of transducers will perform much better than the stated accuracy. The three sigma accuracy is much better than the six sigma accuracy, and only 1 in 1000 transducers will perform outside the three sigma limits.

A situation that occurs in engineering is the use of one device for prototyping and design, and then qualification. Depending on where that device is on the probability curve, the application may not interface well with production devices. For example, if the qualification testing is performed with one device that is the 1 in 1000 that does not fit within the three sigma limits, then the application goes into production and there are issues. This is due to the production measuring devices being mostly three sigma in their accuracy range, but the application was developed by a device that was not within that range. This is often referred to as ‘wrapping the application too tightly around the sensor’.

Components of Accuracy

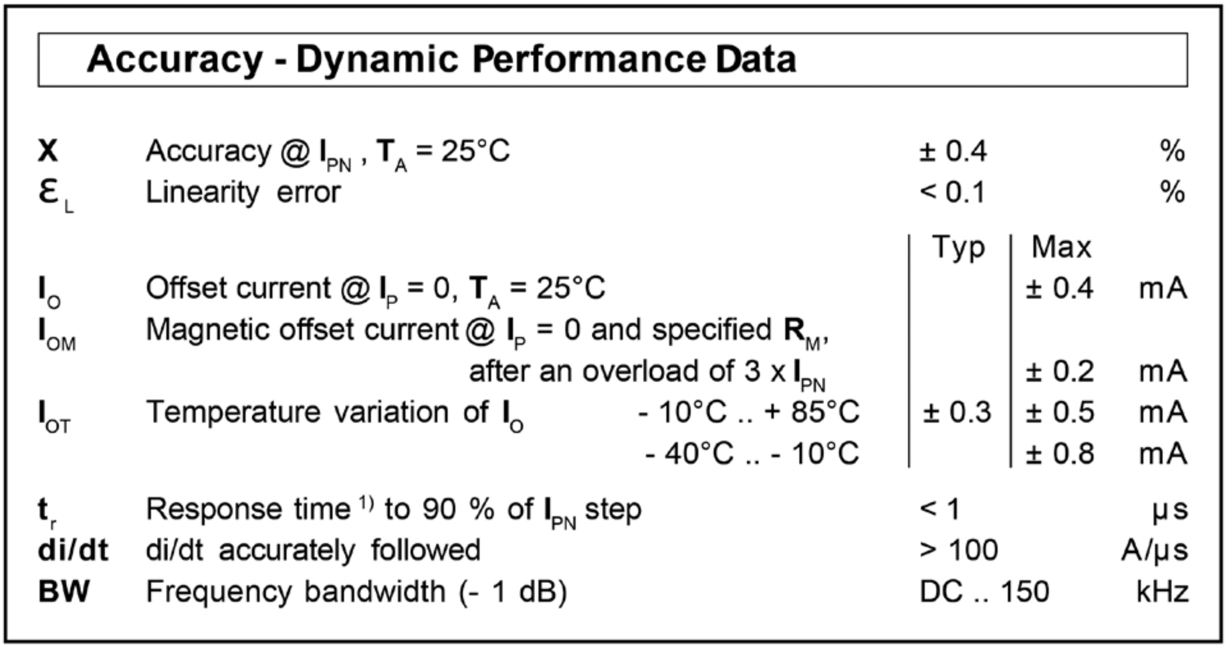
With the concept of accuracy defined, what are the components of accuracy in a current transducer? On a typical LEM data sheet, there are three fundamental accuracy concepts: Gain, Linearity and Offset.

Gain is the linear ratio between the input magnitude and the output magnitude. Current transducers are linear devices and the gain accuracy is multiplied by the actual current measured by the transducer. Gain is a factor of reading, not full scale rating.

Reading is the actual current being measured at the time the measurement took place. Rating or full scale rating is the number given on the data sheet for the transducer’s capabilities. Rating can be misleading due to a lack of standardization in data sheets for current transducers. Rating can be Nominal or it can be Measuring Range depending on the transducer and/or manufacturer. LEM automotive components are Measuring Range/Maximum ratings. LEM industrial products are taken from the Nominal rating.

Linearity is the representation that the linear function of the gain is impacted by the non-linear magnetic properties of the magnetic core material used in most current transducers. The linearity of the transducer represents the variance in the magnetic properties of the core. Linearity is taken as a percentage of Rating or full scale (Nominal or Measuring range, depending). The actual current being measured does not impact the linearity accuracy. In some ways the linearity accuracy is a constant that could just be defined as a certain +/- current.

Offset may be a property of the magnetics and/or the electronic amplifiers producing the output of the transducer. Regardless of the source, the initial offset on power up is typically zeroed out in the software of the



Accuracy - Dynamic Performance Data

X	Accuracy @ I_{PN} , T_A = 25°C		± 0.4		%
ε_L	Linearity error		< 0.1		%
			Typ	Max	
I_O	Offset current @ I_P = 0, T_A = 25°C			± 0.4	mA
I_{OM}	Magnetic offset current @ I_P = 0 and specified R_M, after an overload of 3 x I_{PN}			± 0.2	mA
I_{OT}	Temperature variation of I_O	- 10°C .. + 85°C	± 0.3	± 0.5	mA
		- 40°C .. - 10°C		± 0.8	mA
t_r	Response time 1) to 90 % of I_{PN} step		< 1		μs
di/dt	di/dt accurately followed		> 100		A/μs
BW	Frequency bandwidth (- 1 dB)		DC .. 150		kHz

Fig 4. LEM LF 1005-S accuracy data from data sheet

application. Only offset change over temperature would normally be considered. Depending on the operating temperature, the transducer manufacturer and transducer technology, the offset change over temperature may not be insignificant. The need for accuracy at higher temperatures when matched with a transducer technology that has significant accuracy variance over temperature can result in undesirable operation. This may sometimes be referred to as 'Ghosts in the Machine'.

Global Accuracy

There are three components of accuracy: Gain, Linearity and Offset. How do they interact to give a global, final percentage of accuracy that can be used for decision-making? The Global Accuracy is not the sum of the individual sources of accuracy. The Global Accuracy is typically taken as the square-root-of-the-sum-of-the-squares. But what to multiply? Some data sheets show percentages of accuracy, others have ppm. Global Accuracy is given as a percentage of rating. However, one of the components of Global Accuracy is Gain, which is given as a percentage of rating. Therefore, Global Accuracy will be a dynamic value that changes with measured current magnitude.

Due to the nature of the square-root-of-the-sum-of-the-squares method, the global accuracy will be dominated by the largest value component (Gain, Linearity, Offset).

$$\sqrt{(\text{Gain error})^2 + (\text{Offset from Temperature error})^2 + (\text{Linearity error})^2}$$

$$\sqrt{(\varepsilon_G)^2 + (\varepsilon_L)^2 + (I_{OT})^2}$$

$$\varepsilon_G + \varepsilon_L = X$$

Fig 5. Accuracy Equation

A straightforward method renders each accuracy component into a current or percentage that relates to the nominal rating of the device. Convert the components to Amps at a certain test point, sum the currents and determine the percentage accuracy.

Precision, Repeatability and Reality

Some applications require absolute measurement (such as metering). Metering the application might call out 0.1% relative to the device rating across the temperature range. This is a challenging requirement, but one that can be satisfied. It is necessary to know that the measuring device relates a certain output and that output (within six sigma limits) is within 0.1% of the absolute value. Protection schemes for semi-conductors do not typically require such strict absolute value requirements. Within 10% of the absolute value is adequate. If the current is within 10% of 3x nominal rating, 2x or 3x, it is a problem regardless.

Many control functions, however, are not absolute. The control function is triggering on another input and then interrelating the current measurement with the other measurement (speed, position, tension for example). This interrelation may be through a control loop of some sort. For instance, a welder may have a knob that the operator adjusts. The operator knows that a certain position of the knob results in a quality weld. Every time the knob is set to a certain position only an exact amount of current flows during the weld. If the feedback from the sensor was not precise, the weld current would vary during operation. If the material changes, the operator might adjust the knob to another position, which then produces a predictable, precise, current. The operator is not adjusting absolute values, only relative precise values.

Assuming the input device is linear, 'the knob', or the output current is linear and predictable. Increase the knob 10%, and the current increases 10%. Many control applications are similar.

Interference

There are outside sources of interference that can defeat the accuracy of the transducer. Noise, both internal and external, can cause issues. External fields, especially time varying fields, act like unpredictable offsets that can impact control functions.

Conclusion

Defining and understanding an accuracy requirement will assist in making an application successful in implementation. Defining the concepts of Gain, Linearity and Offset, and a method of calculating global accuracy from the individual components should assist in better understanding an application's accuracy performance. Additional concepts such as absolute accuracy and relative, precise accuracy may also assist in a better understanding of the dynamics involved.

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