CT's - Fluxgate vs. Inductive

Welcome dear friends of protection and control engineering. In our new technical article, Roland Bürger (SENSELEQ) explains the technical difference between classic inductive current transformers and new fluxgate converters.

Enjoy reading, we pass!

Non-linearity of inductive current transformers

The current transformer is often described in the literature as a non-linear measuring device. This is because the amplitude error is not constant in most cases. The magnetizing current of the core, which is mainly responsible for the undesired amplitude error and phase displacement, is the reason.

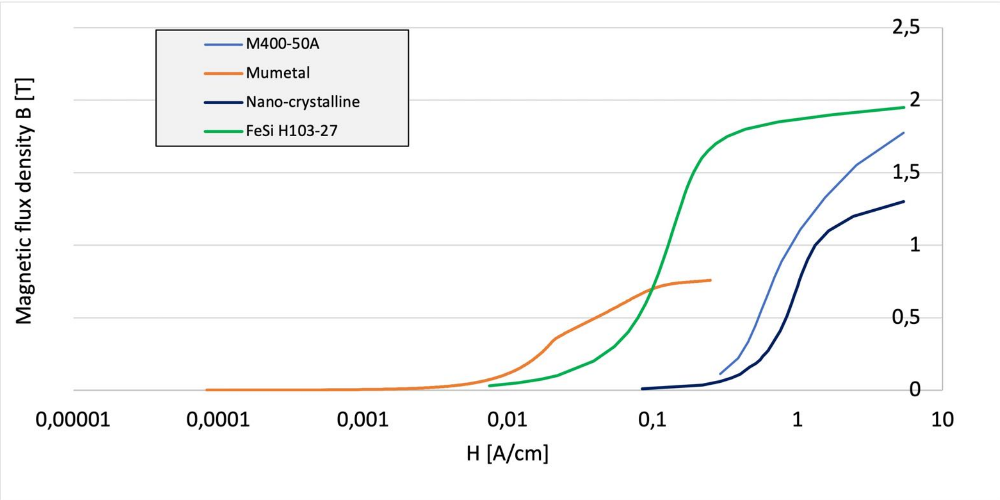


Figure 1: Magnetization characteristics of different iron core materials

The current transformer error can be illustrated by the following graph.

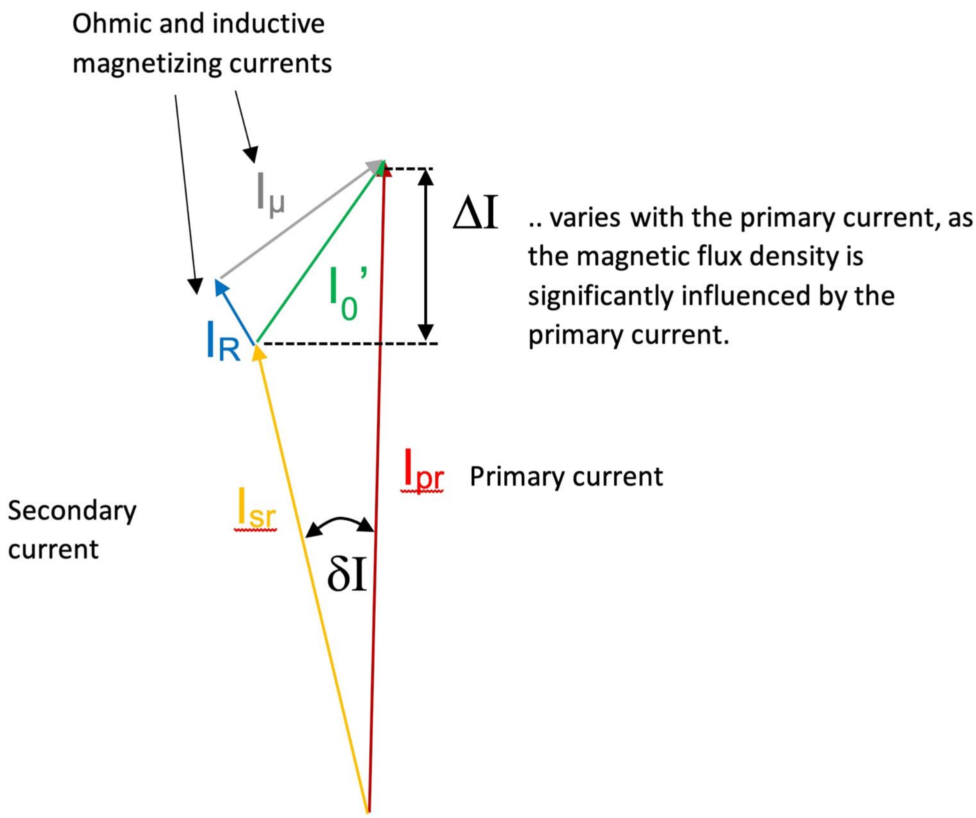
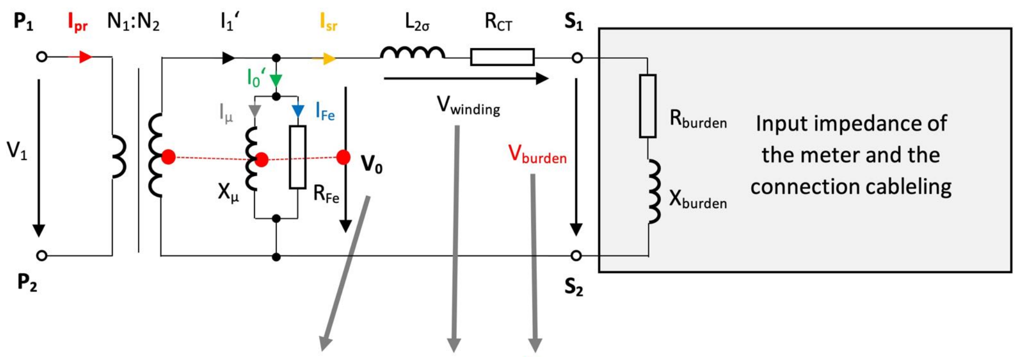


Figure 2: Drawing of the current transformer error

In contrast to the voltage transformer, where the voltage can only change by ± 10 % in normal operation, the current is not constant. The magnetic operating point of the current transformer therefore passes through a much larger range on the magnetization characteristic than the voltage transformer.



$$\boldsymbol{V_0}(voltage\ across\ iron\ core) = V_{winding} + V_{burden}$$

magnetic flux density in Tesla [T] →

$$B_{peak} = \frac{\sqrt{2} \times \boldsymbol{V_0} \times 10^4}{2\pi \times f \times A_{Fe} \times f_U \times (number\ of\ secondary\ windings)}$$

cross-section iron core (A_{Fe}); filling factor iron core (f_U)

Figure 3: Electrical equivalent circuit of an inductive current transformer

The voltage drop V_0 across the core is responsible for the actual magnetic operating point of the current transformer. The voltage is determined by the magnitude of the secondary current and the resulting voltage drops across the secondary winding (copper resistance) and the input impedance of the meter.

In the lower range of the current transformer, a larger proportion of the secondary current is often required for the magnetization of the core. Thus, larger percentage errors occur in the lower current range of the current transformer. This relationship becomes clear in the defined accuracy classes in the current transformer standard IEC 61869-2. For example, if the primary current is less than twenty percent of the nominal value, the accuracy class 0.5S allows larger percentage deviations.

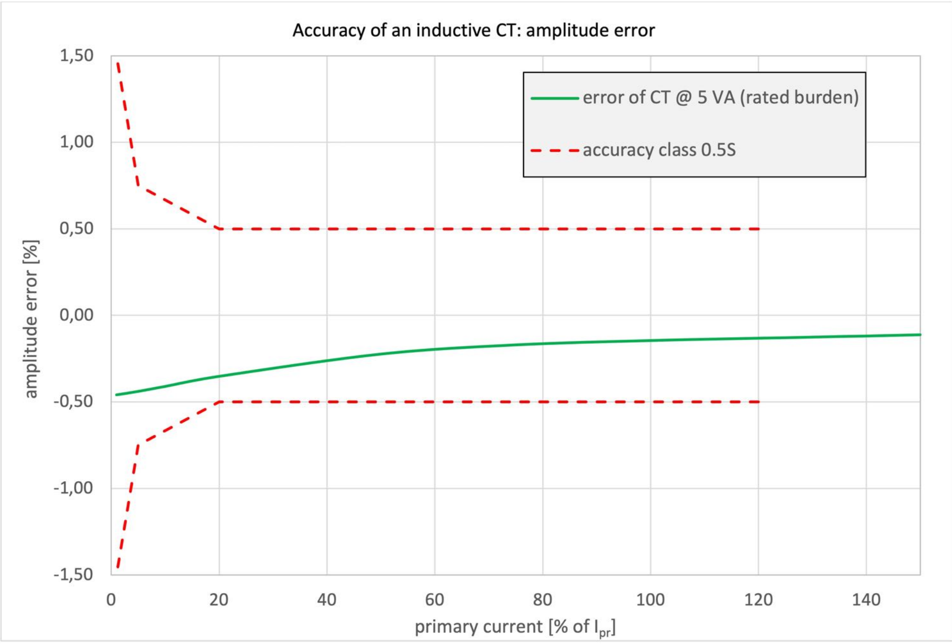


Figure 4: Amplitude error of an inductive current transformer

Primary switchable current transformers

To prevent inaccuracies at smaller current amplitudes, there are switchable current transformers. On the primary side, the rated primary current can be chosen by different configurations of the input terminals.

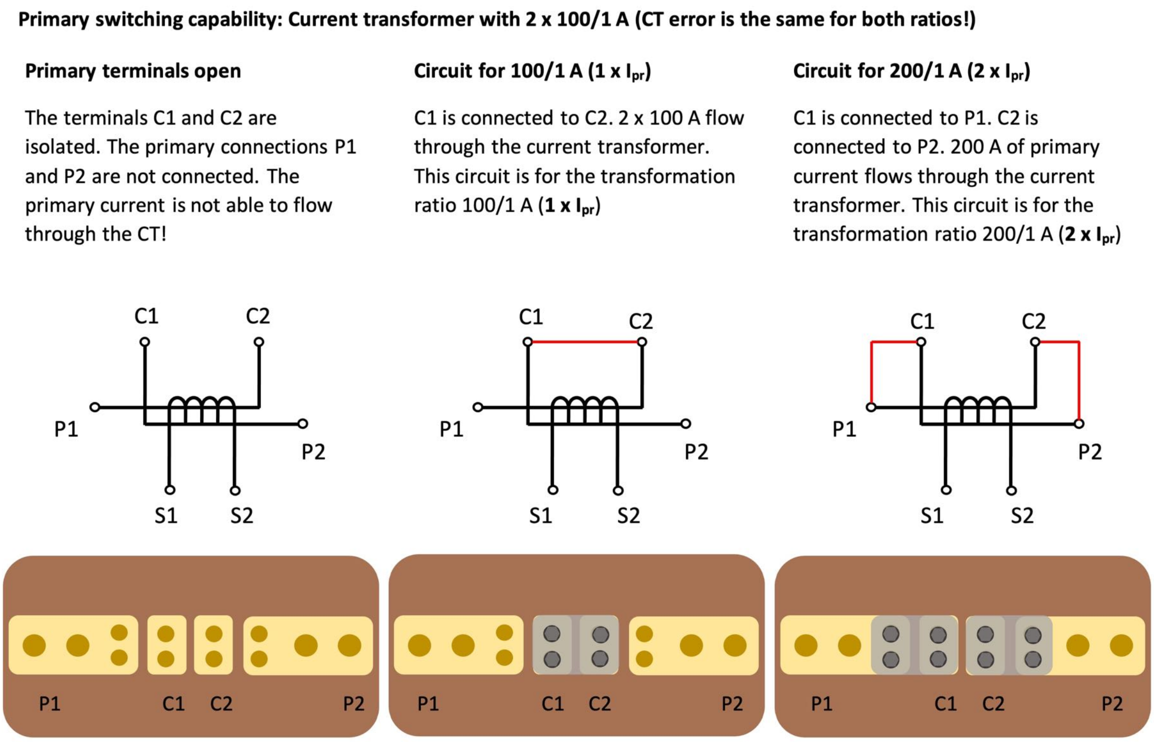


Figure 5: Current transformer (medium voltage block design) with switching capability

All the inner wounded cores have the ratio of 200/1 A. The aim of this instrument transformer concept is to keep the primary current close to the rated current of the current transformer. The percentage error is thus minimized. Inaccuracies with smaller primary currents are intended to be prevented in this way.

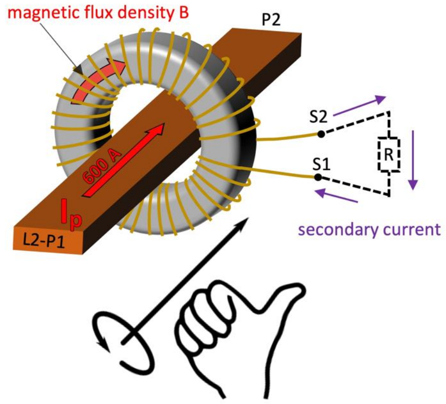
DCCT – Direct Current Current Transducer

In addition to the non-linearity of inductive current transformers, there are also inaccuracies in the current amplitudes to be measured with low frequency, which occur, for example, in frequency converter drives (e.g., 5 Hz). DC components are not transferred at all and can lead to saturation. In this case, the specified accuracy class is often no longer maintained. The waveform is also deformed on the secondary side. A DCCT sensor (Direct Current Current Transducer), which operates according to the fluxgate principle, can transmit those signal components to the secondary output terminal.

The fluxgate principle was discovered in the 1930s and used for air gap magnetometers. The First fluxgate DCCTs were built in the 1960s by the Danish company DANFYSIK, amongst others. Today, the technology facilitates highly accurate current measurements from DC up to the megahertz range. Likewise, a few mA up to 40 kA can be measured with highest precision, accuracy and stability. The basic measurement principles are explained next.

Basics of inductive current transformers

Basically, Ampère's law applies to a simple inductive current transformer. An electric current generates a magnetic field around the conductor. The strength of the magnetic field correlates with the current strength.



$$B_{peak} = \frac{\sqrt{2} \times \left(I_p \times \frac{N_1}{N_2}\right)^2 \times R \times 10.000}{2 \times \pi \times f \times I_p \times N_1 \times A_{Fe} \times f_u}$$

B_{peak} = magnetic flux density [Tesla]

I_p = primary current [A]

f = rated frequency [Hz]

A_{Fe} = iron cross − section [cm^2]

R = burden resistor [Ohm]

N_2 = secondary turns

N_1 = primary turns (=1)

f_u = filling factor iron core

Figure 6: Principle of the inductive current transformer and the calculation of the magnetic flux density B

The direction of the magnetic field can be determined using the right hand. The changing magnetic flux in the iron core induces a secondary current, which can be tapped at the terminals S1 and S2. The secondary current can be quickly calculated, given the number of turns.

$$I_{secondary} = I_{primary} \times \frac{primary\ turns}{secondary\ turns}$$

Basics of the fluxgate principle

The fluxgate principle is based on the fact that the magnetic flux density generated by the primary current is always regulated to zero Tesla. For this purpose, a current must flow in the secondary winding which induces an opposite magnetic flux density in the iron core to the primary current.

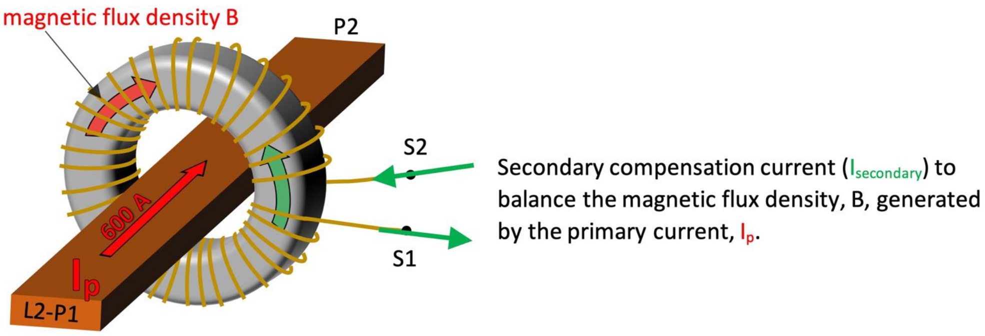


Figure 7: The sum of the magnetic flux densities in the iron core is always zero due to the fluxgate principle

The question now is how to detect the point at which this condition:

$$B_{primary\ current} + B_{secondary\ current} = 0$$

is fulfilled.

Detection is achieved using an excitation winding and its excitation current (IEXC). This is an alternating current that drives the core into the saturation range.

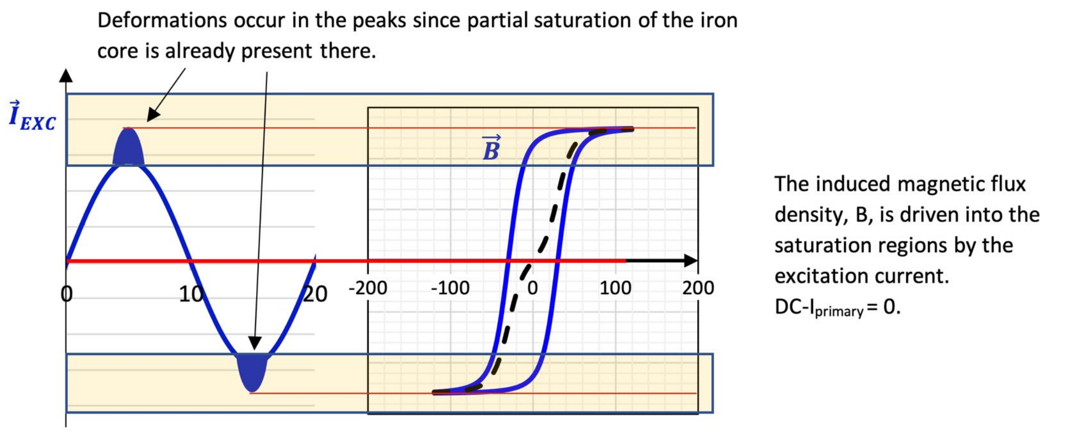


Figure 8: Excitation Current

The slight saturation of the iron core results in symmetrical deformations in the secondary signal of the additionally applied control winding.

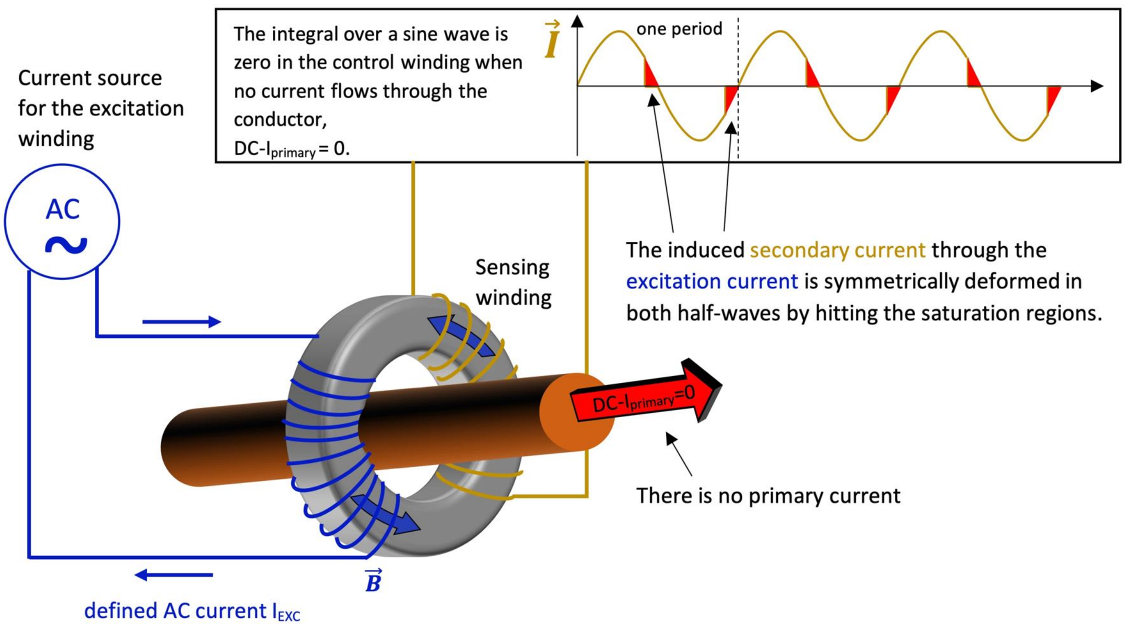


Figure 9: Excitation current and the secondary sensing winding

If a DC current now flows through the primary conductor, the sinusoidal oscillation of the excitation current is shifted in the Y axis. The excitation current and the DC current now form the total current which is responsible for the magnetic flux density. The magnetic flux density induced by the sum of the two currents is shifted into deep saturation with the positive half-wave of the excitation current.

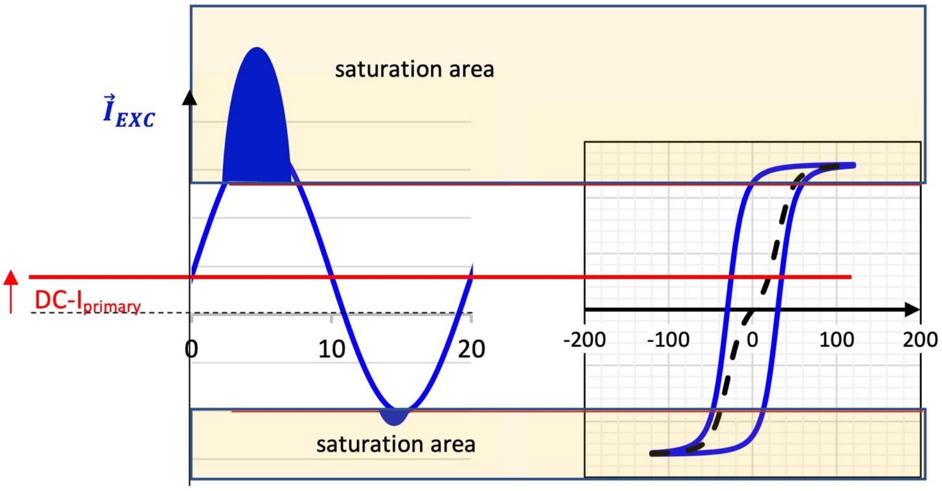


Figure 10: Shift of the magnetic operating point by a primary DC current

This scenario can also be detected in the secondary sensing winding. The asymmetric deformations in the secondary signal can be seen in Figure 11. They correlate with the magnitude of the primary current.

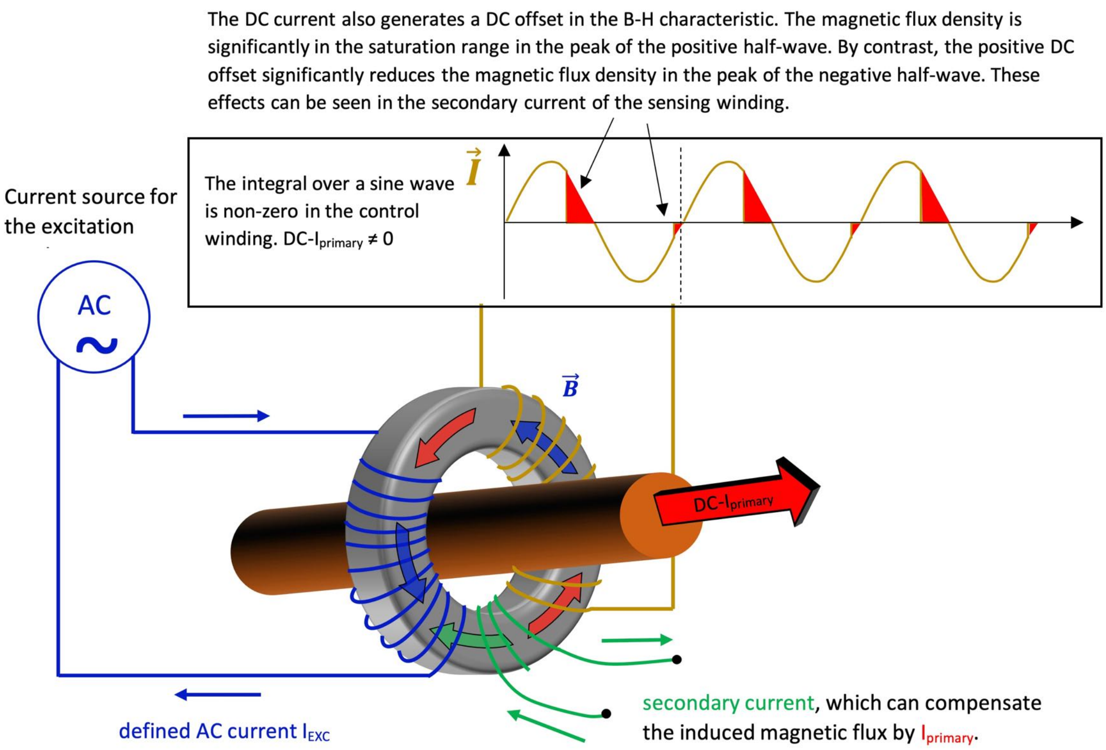


Figure 11: Asymmetrical deformation of the current signal in the secondary sensing winding by a primary DC current

A DC current can now be injected through a third green winding, which regulates the integral via the current in the control winding back towards zero. This additional secondary current can again be measured accurately and it is possible to reconstruct the amplitude of the DC current in the primary conductor. The magnetic flux in the core is again zero.

$$B_{EXC} + B_{primary} + B_{secondary} = 0 \qquad I_{primary} = N_2 \times I_{secondary}$$

The fluxgate principle is thus implemented since the magnetic flux in the core can be regulated to zero at any time by the secondary current.

Optimization DCCT

A negative effect of the excitation current is that the primary current is minimally influenced by the alternating field generated through the excitation winding. For this reason, a second iron core is added to which the excitation winding is applied in the opposite direction to the first iron core. This neutralizes the magnetic fields generated by the excitation current. The primary current remains almost unaffected.

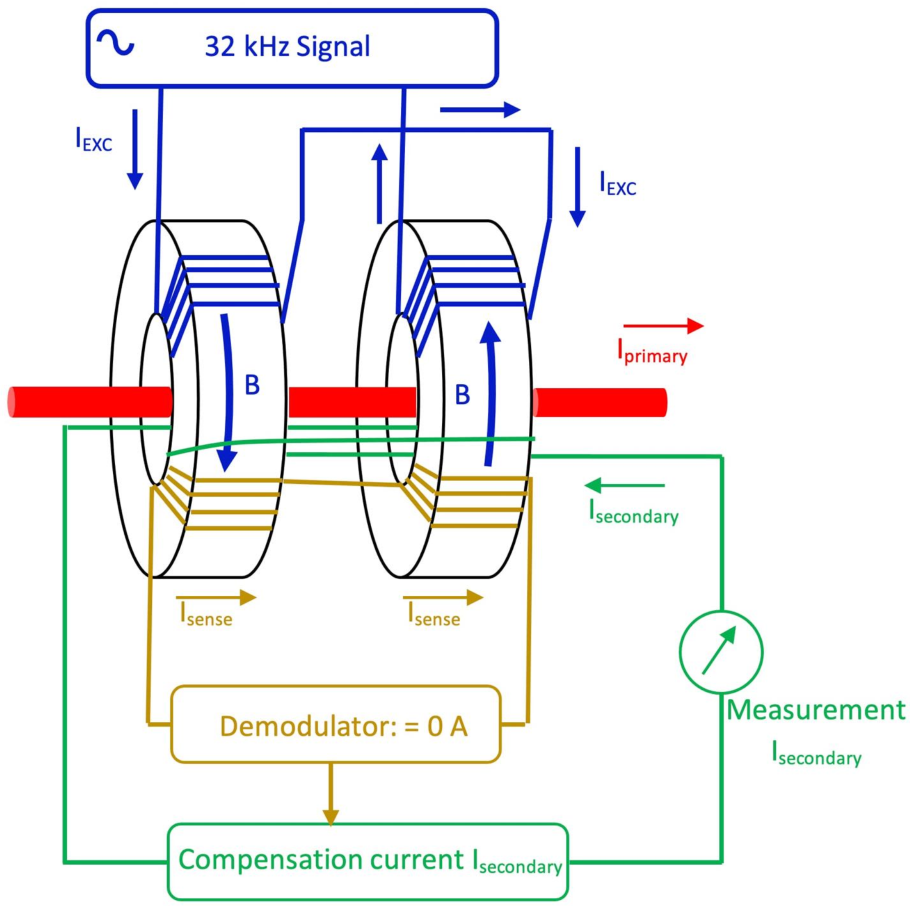


Figure 12: Fluxgate principle two core design

Up to this point, the construction necessary to measure direct currents has been shown. To be able to measure alternating currents as well, a third iron core is required.

Measurement of the AC component by a third core

If the primary current, $I_{primary}$, consists of AC components in addition to a DC value, a third iron core is required. The AC component is added to the control loop via the third core. To further improve the accuracy in the lower frequency range, the excitation signal is implemented as a square wave signal. The electronic evaluation is performed via the analysis of the second harmonic of the excitation signal.

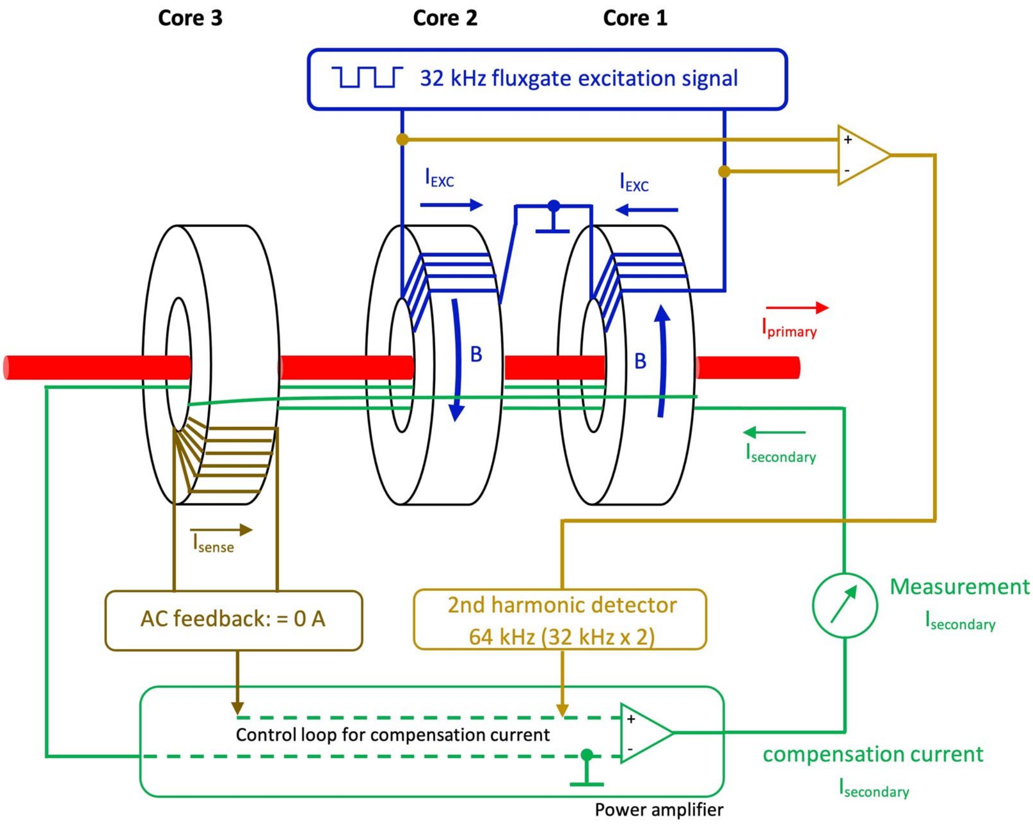


Figure 13: Fluxgate principle with three cores

The power amplifier then generates an accurate image of the primary current, which has simply been divided by the number of secondary windings. This secondary compensation current is fed to the outside via a terminal in the case of a desired current output signal. The current signal can then be routed through a measurement shunt outside the device. The measuring instrument can then process the voltage signal. If a voltage output is desired on the instrument, the secondary compensation current is routed internally through a shunt. The voltage across the shunt is then amplified to make the signal available in a standardized form for further use.

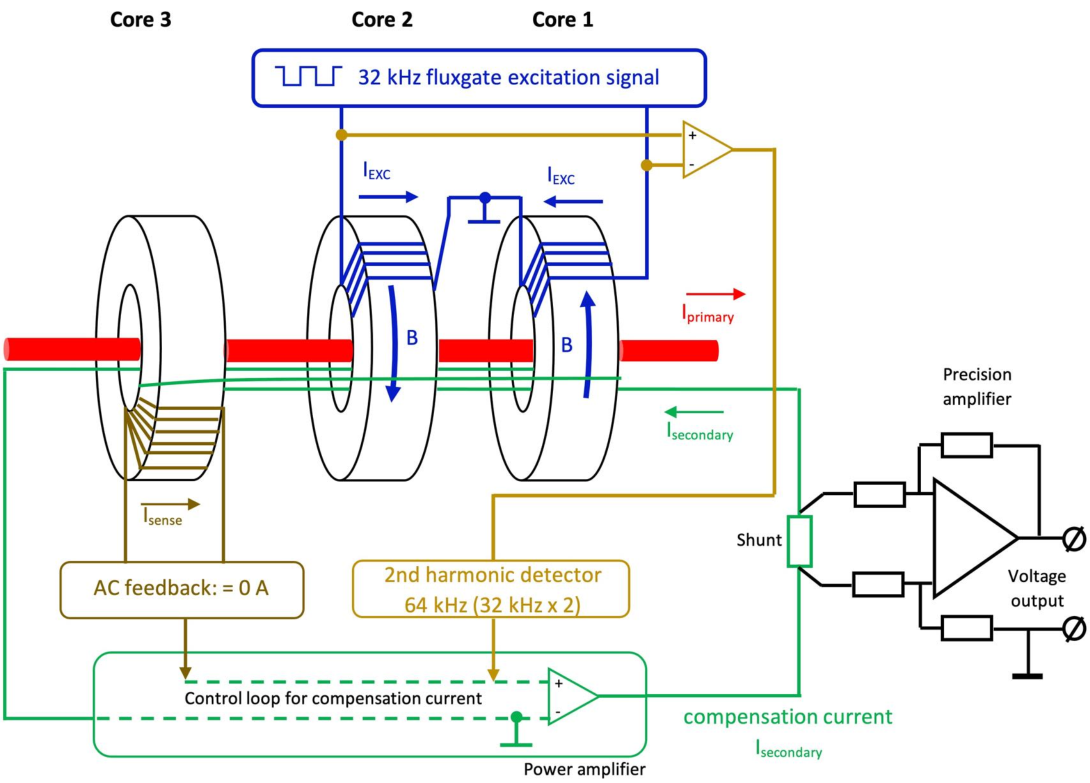


Figure 14: Fluxgate principle with three cores and voltage output

The unique design of the fluxgate system provides high accuracy and stability without the need for temperature control devices.

Above a several kHz, the power amplifier for the secondary compensation current no longer has active control over its output current, but simply forms a short-circuit. The third core now operates as a normal inductive current transformer. The bandwidth is only affected by the interaction of stray reactances and the capacitances of the winding. For current output signals, the connecting cable should also be considered.

Different measuring principles in one sensor

This sensor concept thus results in different measurement technologies with regarding to the frequency, as the following figure illustrates.

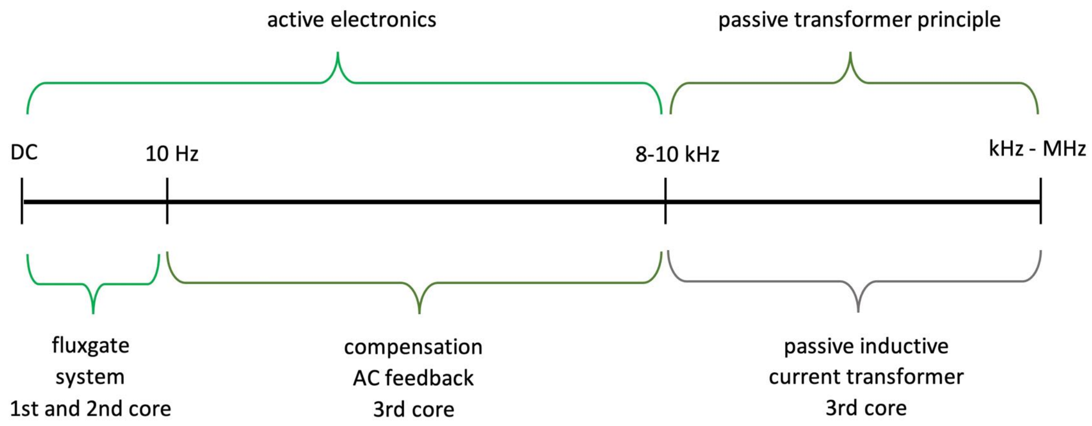


Figure 15: Different measurement technologies in the fluxgate sensor depending on the frequency

The frequency specifications may vary slightly from device to device.

Minimizing the influence of external fields

The three cores are positioned to be robust against electromagnetic fields. The Fluxgate sensor technology (core 1 and 2) is inserted inside the third core.

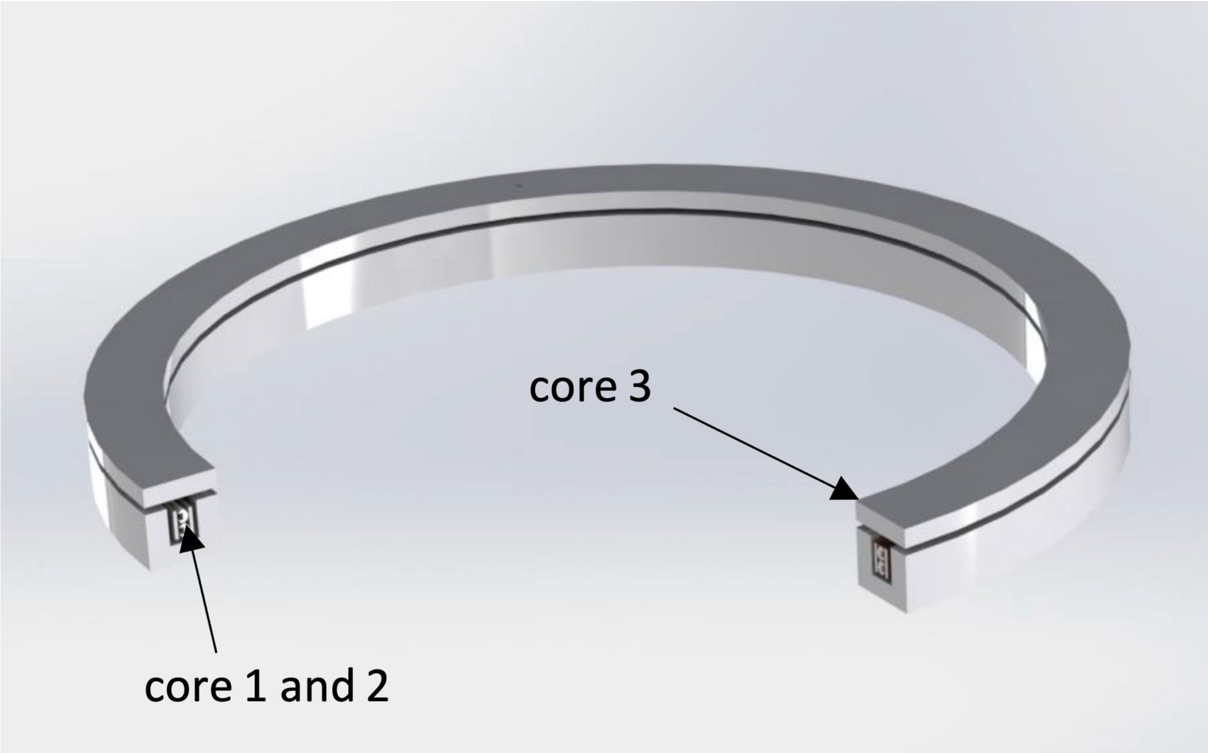


Figure 16: Basic core structure of a DCCT from SENSELEQ

If measuring devices can compensate the DC offset of the sensor, DC components in the mA range will be detected very accurately.

Cast resin sensor head for outdoor applications

After the copper windings have been applied to the corresponding cores, the sensor head with the electronic circuits can be installed in a plastic or metal housing. For applications in the transport or distribution network, sensor heads can also be encapsulated in cast resin. In this case, the electronics are installed in an electronics box a few meters away from the sensor head in a suitable control cabinet. The service life of the sensor head without electronics is then comparable with conventional current transformers.

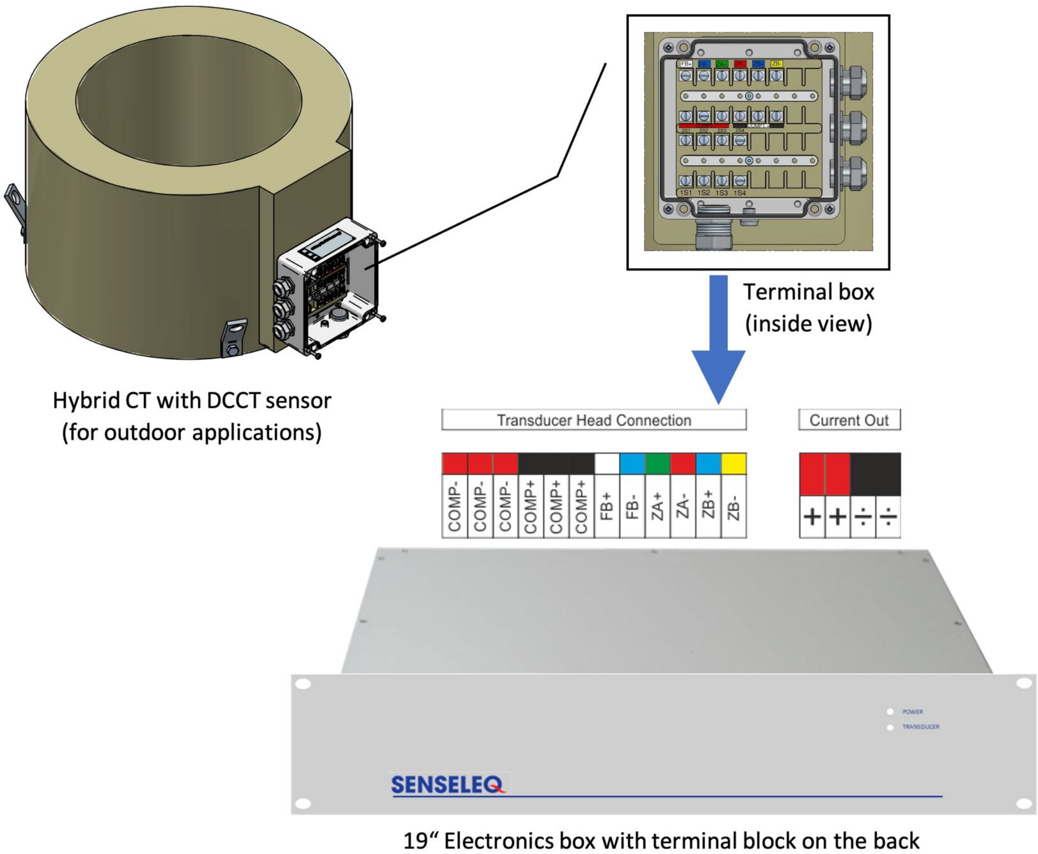


Figure 17: Fluxgate solution for outdoor applications with current output 1 A

Fluxgate current transformers from Senseleq can also provide a 1 A output like conventional current transformers. A 50 Hz accuracy measurement provides superior accuracy.

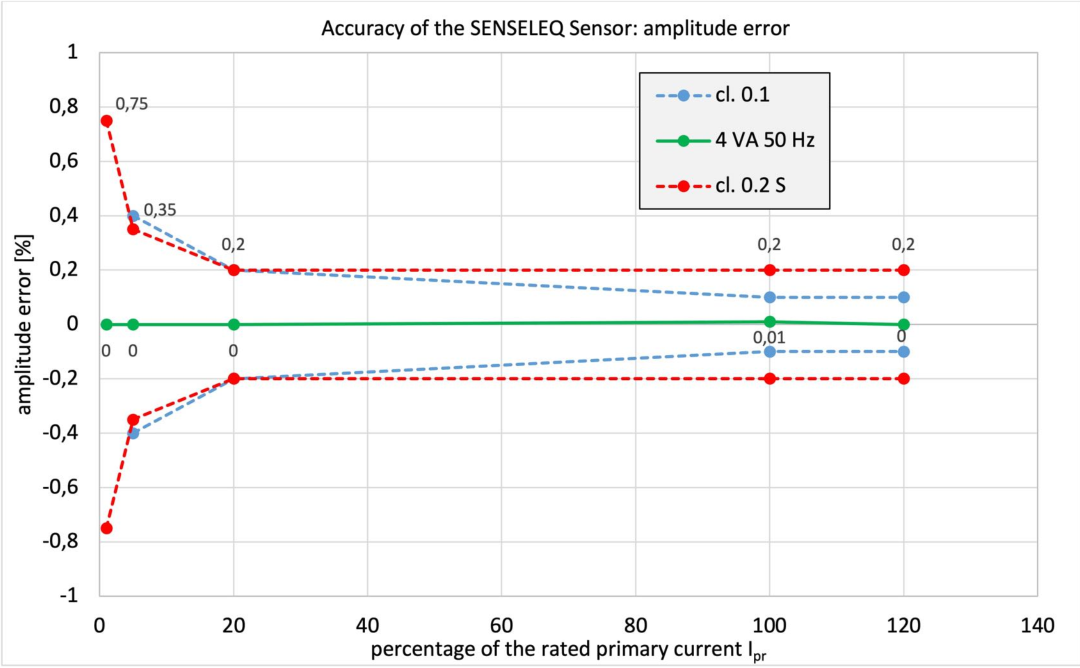


Figure 18: Amplitude error of fluxgate transducer with the ratio 2500:1

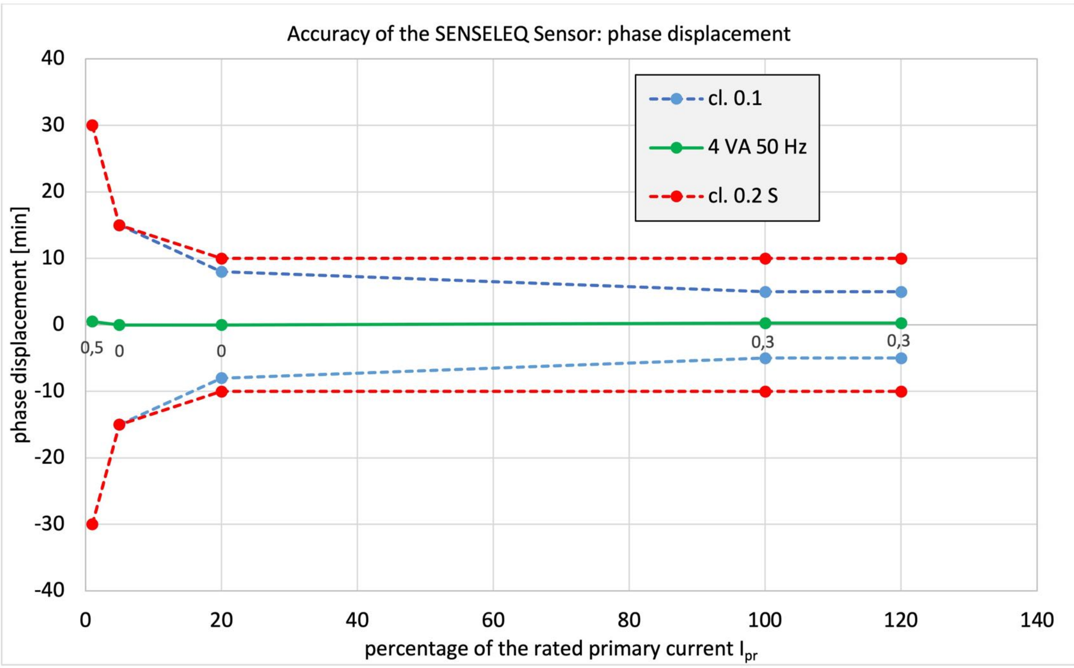


Figure 19: Phase displacement of a fluxgate transducer with ratio 2500:1

In addition to the high accuracy, the error path is always the same for all loads in the range from 0 to 4 VA, in contrast to the inductive current transformer.

Summary and outlook

Fluxgate Transducers have been used in measurement labs for decades to facilitate highly accurate power calculations. The only reason this technology has not being rolled out on a large scale is the high price compared to traditional current transformers. The negative aspects of traditional current transformers such as saturation effects due to parasitic DC currents, false burdens and the non-linear B-H characteristics of the iron cores are non-existent in fluxgate technology. Power calculations and current analysis are much more reliable at all voltage levels due to the use of fluxgate current transducers. Phenomena such as harmonics or sub-harmonics can also be detected with high accuracy.

In addition, the DC components in AC systems, which are already limited by standards, are already being detected and evaluated in some areas. In general, it can be stated that the measurement devices required in the laboratory are also now necessary in the supply and transport network. This is due to the new types of consumers and generators based on semiconductors, in order to be able to control the network disturbances and influences, which are not always benign.