Basics Zero-Flux Technology

Roland Bürger

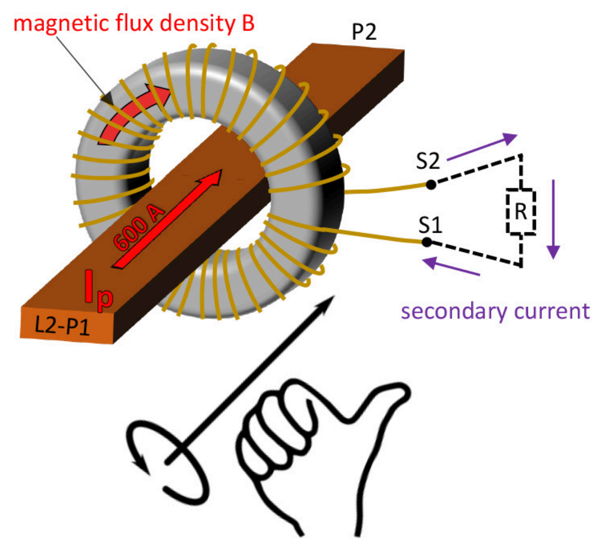
A Senseleq White Paper

Zero-Flux Technology

Introduction

Inductive current transformers are not capable of measuring currents at low frequencies, 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 In this case, the specified accuracy class is often no longer maintained.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 (**D**irect **C**urrent **C**urrent **T**ransducer), which operates according to the Zero-flux principle, can transmit those signal components to the secondary output terminal.

The Zero-flux principle was discovered in the 1930s and used for air gap magnetometers. The First Zero-flux 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.



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

nt

$$\boxed{\begin{aligned} B_{peak} &= magnetic\ flux\ density\ [Tesla] \\ I_p &= primary\ current\ [A] \\ f &= rated\ frequency\ [Hz] \\ A_{Fe} &= iron\ cross-section\ [cm^2] \\ R &= burden\ resistor\ [Ohm] \\ N_2 &= secondary\ turns \\ N_1 &= primary\ turns\ (=1) \\ f_u &= filling\ factor\ iron\ core \end{aligned}}$$

Figure 1: Principle of the inductive current transformer and the calculation of the magnetic flux density B

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.

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

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

Basics of the Zero-flux principle

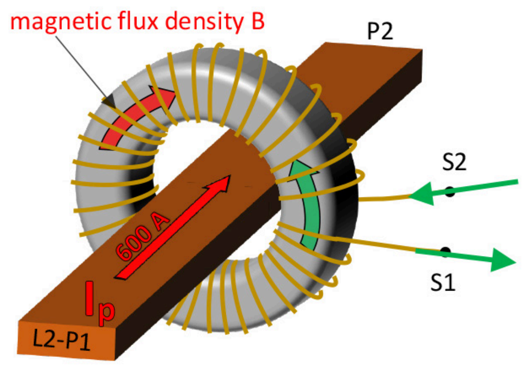
The Zero-flux principle is based on the fact that the magnetic flux density generated by the primary current is always regulated to zero Tesla. For this purpose, a current must flow in the secondary winding which induces an opposite magnetic flux density in the iron core to the primary current.

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

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

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.

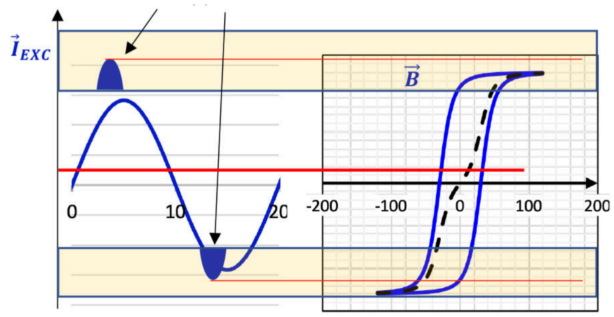
The slight saturation of the iron core results in symmetrical deformations in the secondary signal of the additionally applied control winding.



Secondary compensation current ($I_{secondary}$) to balance the magnetic flux density, B, generated by the primary current, I_p,.

Figure 2: The sum of the magnetic flux densities in the iron core is always zero due to the Zero-flux principle

Deformations occur in the peaks, since partial saturation of the iron core is already present there.



The induced magnetic flux density, B, is driven into the saturation regions by the excitation current. DC-$I_{primary}$ = 0.

Figure 3: Excitation Current

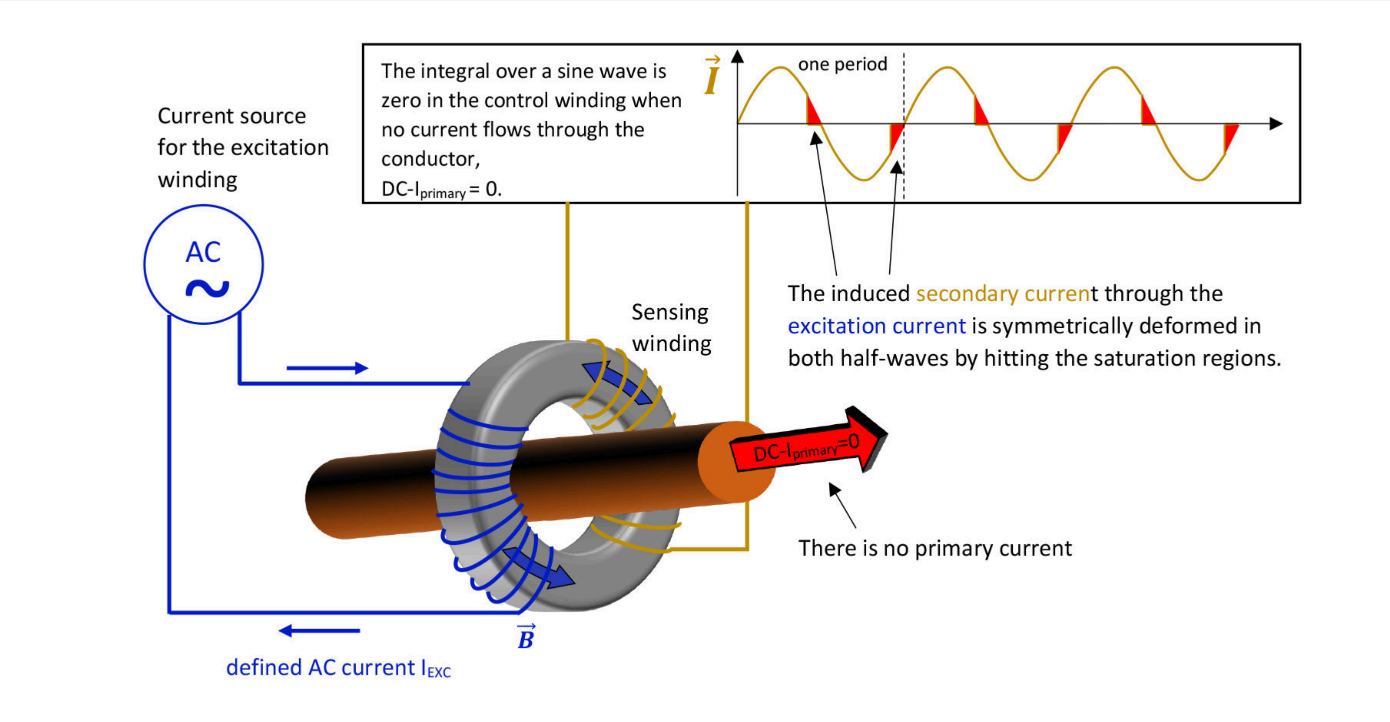


Figure 4: Excitation current and the secondary sensing winding.

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.

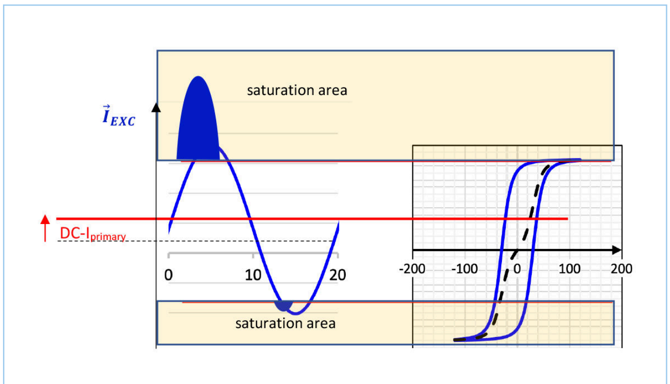


Figure 5: Shift of the magnetic operating point by a primary DC current

This scenario can also be detected in the secondary sensing winding. The asymmetric deformations in the secondary signal can be seen in Figure 6. They correlate with the magnitude of the primary current.

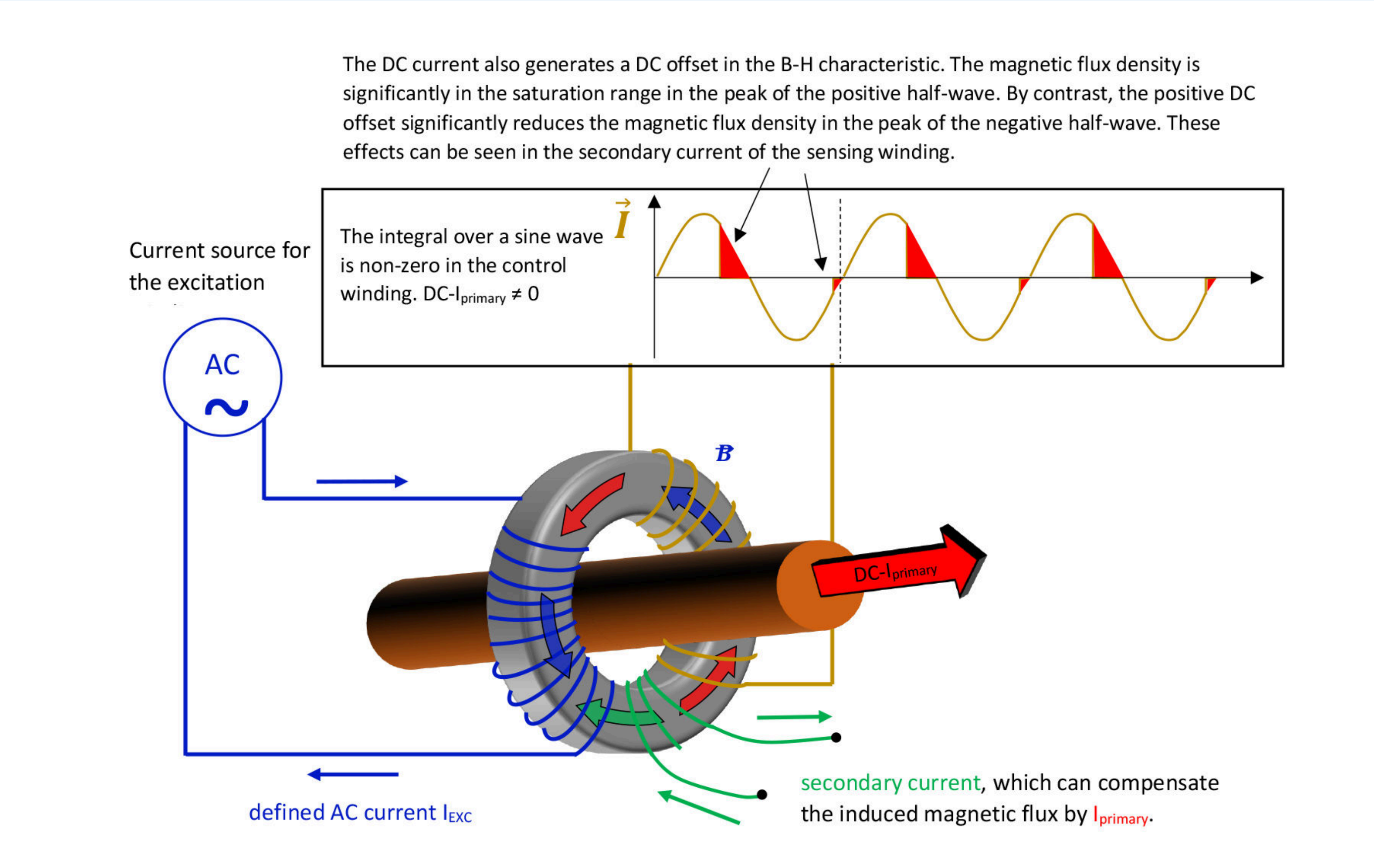


Figure 6: Asymmetrical deformation of the current signal in the secondary sensing winding by a primary DC current

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.

$$B_{EXC} + B_{primary} + B_{secondary} = 0$$

$$I_{primary} = N_2 \times I_{secondary}$$

The Zero-flux 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.

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.

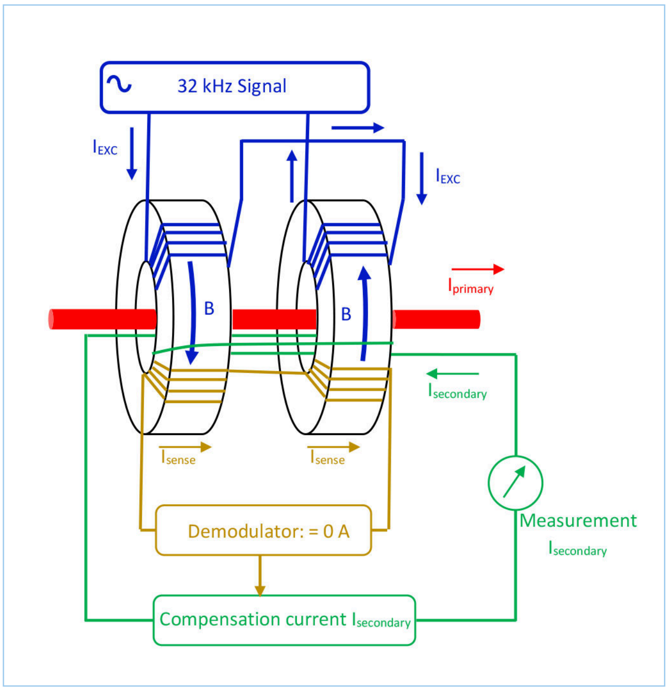


Figure 7: Zero-flux principle two core design

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 double-peak detector (demodulator) is used as before to determine the DC current flow. The AC component is transferred to the control loop via the third core.

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.

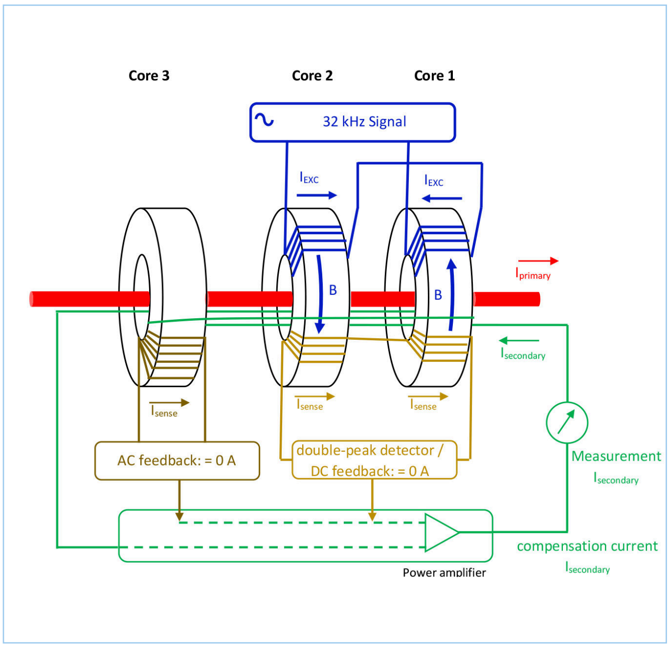


Figure 8: Zero-flux principle with three cores

The unique design of the Zero-flux 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.

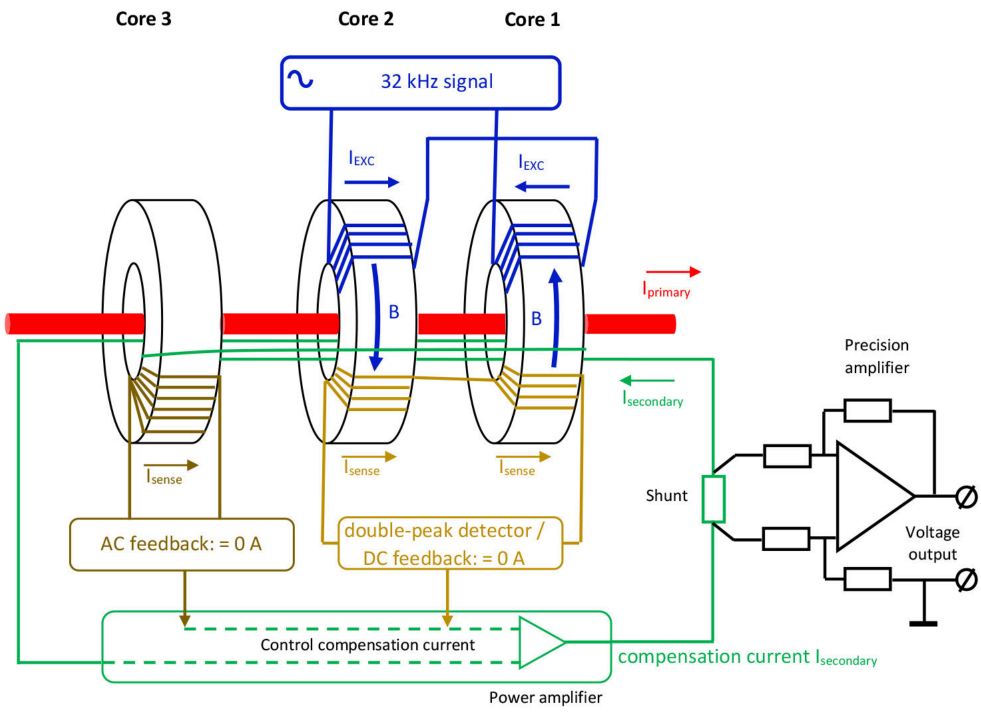


Figure 9: Zero-flux principle with three cores and voltage output

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.

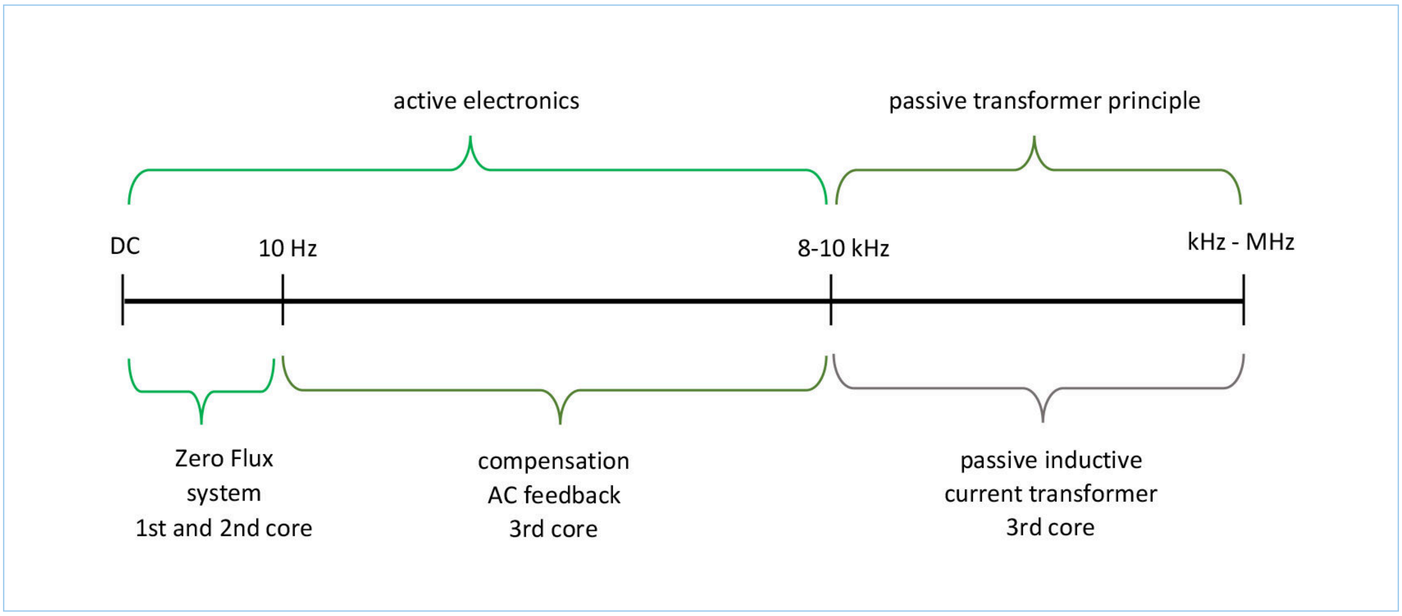


Figure 10: Different measurement technologies in the Zero-flux sensor depending on the frequency

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 1and 2) is inserted inside the third. core.

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

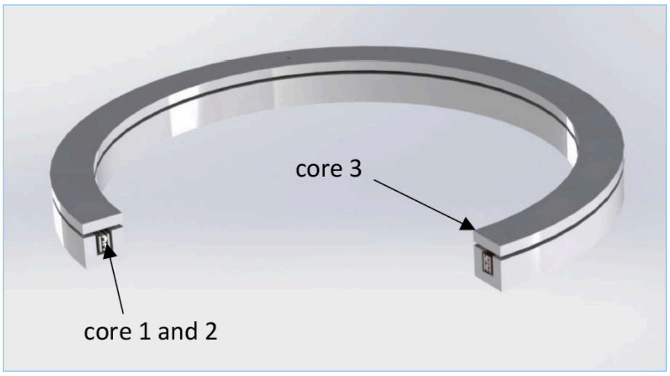


Figure 11: Basic core structure of a DCCT from SENSELEQ

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.

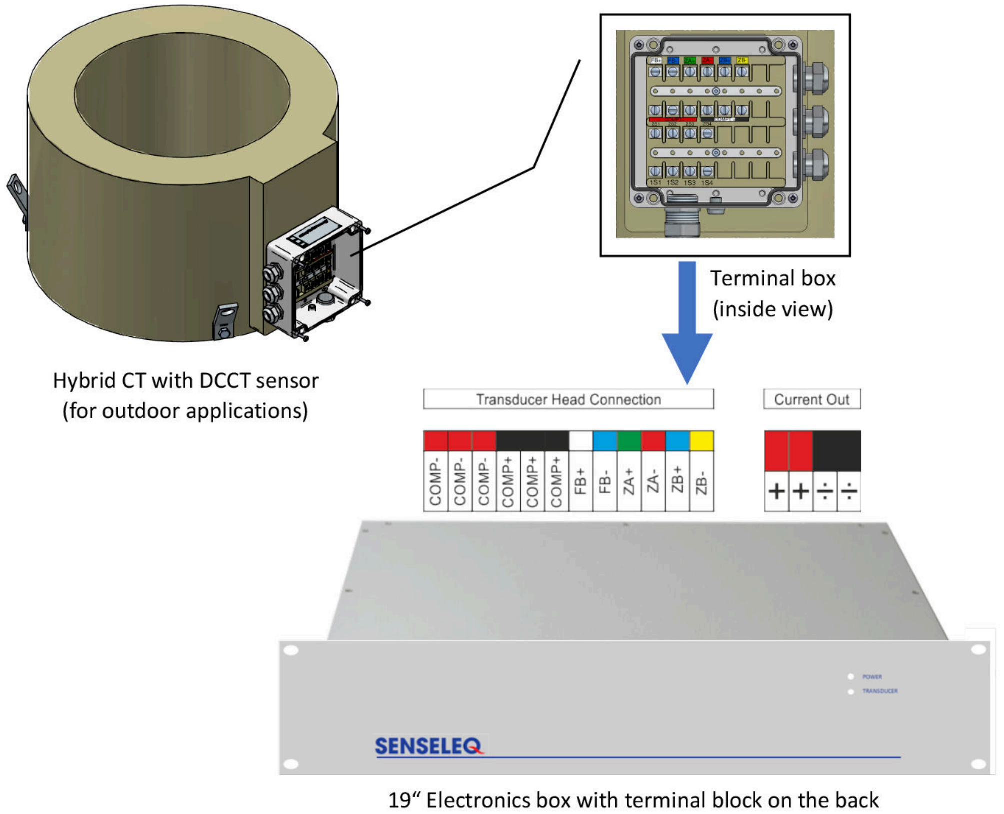


Figure 12: Zero-flux total solution for outdoor applications with current output

Summary and outlook

Zero-flux sensors 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 0-flux technology.

Power calculations and current analysis are much more reliable at all voltage levels due to the use of Zeroflux current sensors. 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.

Contact

Roland Buerger

Business Development

info@senseleq.com
Mobile: +49 179 7540018
Phone : +49 4187 9008877

Senseleq NV
Tukseweg 130,
8331 LH Steenwjik
Netherland