# Improvements in Noninvasive Precision Current Measurement

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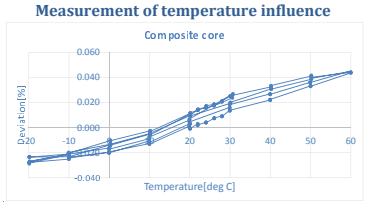
## AC current

A new design of the Rogowski Coil sensor with essential improvements has been developed and tested:

- Composite core reduces temperature influence, improves long term stability, influence of temperature cycling and improves manufacturing repeatability
- Windings arrangement with two in opposite wound layers suppresses the transversal field capture
- Small diameter (1.5mm) of the sensing fiber reduces the influence of variable bending
- Integrated end gap compensation
- Dual sensor with symmetrical output eliminates common mode strange signals
- Electrical shielded consisting of mutually in opposite wound groups of enameled wires interconnected only in one point at the end of the cable.

### Measurement of temperature influence

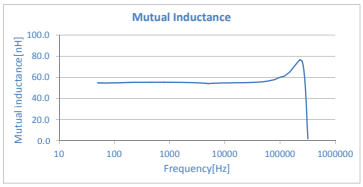



Temperature influence for -20 to +60deg continuous cycling



### Measurement of frequency dependence

The frequency behavior of the final coil was tested with the Agilent E4980A LCR meter in mutual inductance measurement mode and direct measurement of ratio of coil output voltage to the current into calibration toroid.



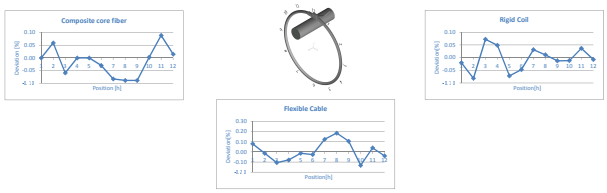

Frequency influence on the mutual inductance of the rogowski sensor

The resonant frequency of the coil is approximately 230 kHz. Therefore the frequencies expected as harmonic and non-harmonic content of the power line signals extending up to 50 kHz can be captured with the coil with sufficient reserve.

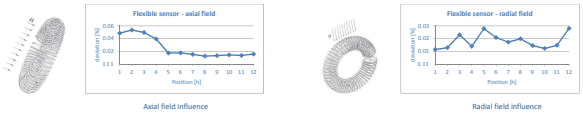


### Measurement of wire position influence

The position sensitivity of the sensor has been tested with local current 720 A at various positions of probe located directly on the test current carrying conductor (6-wire bundle) at positions from 1 hour to 12 hour. The probe located at 12 hour which corresponds to the position of the sensing fiber junction is shown below.




### Measurement of external field influence




Axial field influence

Radial field influence



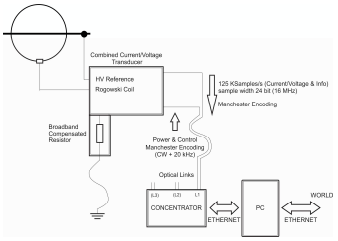
### Embodiments

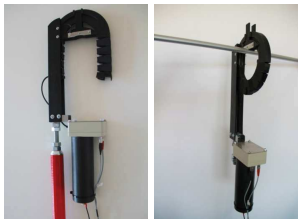
Flexible coil

Rigid coil

Current transformer X/5A (40Hz to 10kHz)

### Combined current / voltage high voltage sensor



Prototype of the 50 kV combined Current/Voltage transducer

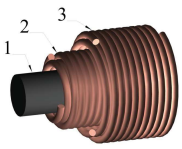
- Working voltage up to 50 kV (modification up to 150 kV)
- Current range 1 A to 6000A (40 Hz – 10 kHz)



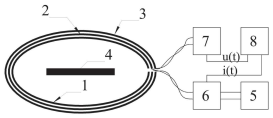
## DC current

### Magnetic Fiber Integrator

The magnetic sensor consists of a flexible fiber from soft magnetic material. The fiber is equipped with excitation coil and with sensing coil.




Fiber winding arrangement




Principal configuration of the fiber integrator

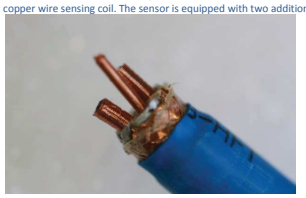
The measured current is calculated from the formula

$$I = \int_{T_1}^{T_2} i(t)u(t)\,dt \Big/ \int_{T_1}^{T_2} u(t)\,dt$$



### Sensor Embodiment

The presented method has been verified on the realized sensor based on 125µm diameter continuous mumetal fiber equipped with 6-layer 0.05mm copper wire exciting coil and 2-layer 0.05mm copper wire sensing coil. The sensor is equipped with two additional AC Rogowski fibers.



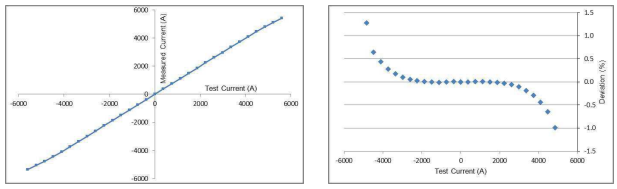
### Evaluation unit

The evaluation unit integrates all control, sampling and data processing components.



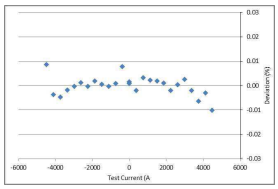

### Sensor Evaluation

DC calibration equipment

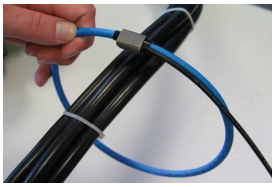



Linear model

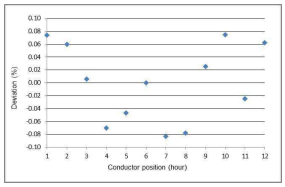





End effect including calibration model



Magnetic ring around the probe junction




Position dependence with magnetic screening

### Conclusion

The presented magnetic field integration method is experimentally approved and can significantly improve the state of the art in noninvasive DC current measurement.