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High current ac metrology using Rogowski coil

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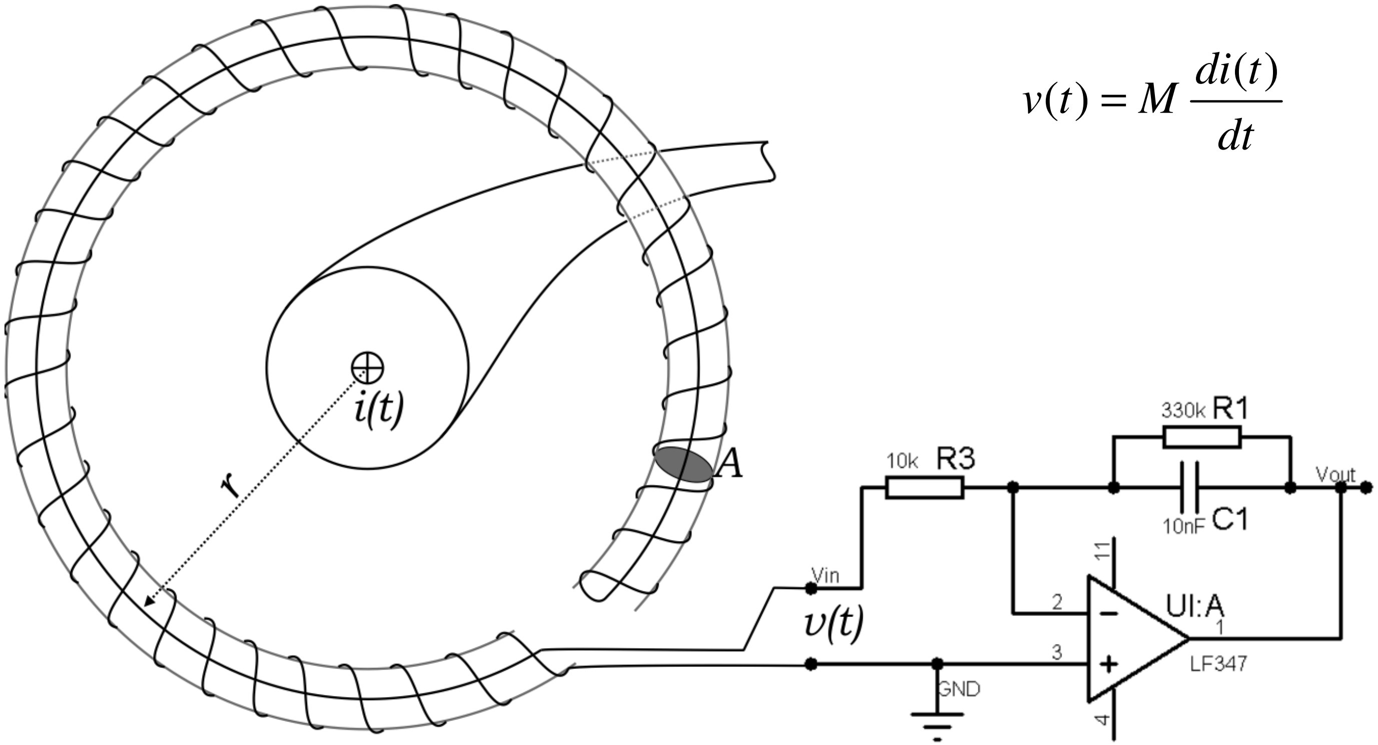
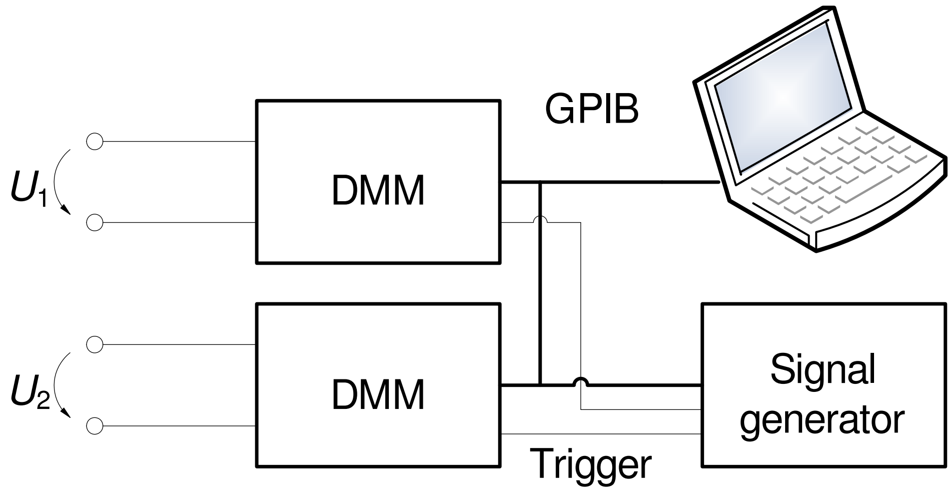
Rogowski coil

$$v(t) = M\frac{di(t)}{dt}$$



Split-core coil, ID 150 mm

Our tool: 2 DMMs (3458A) sampling synchronously

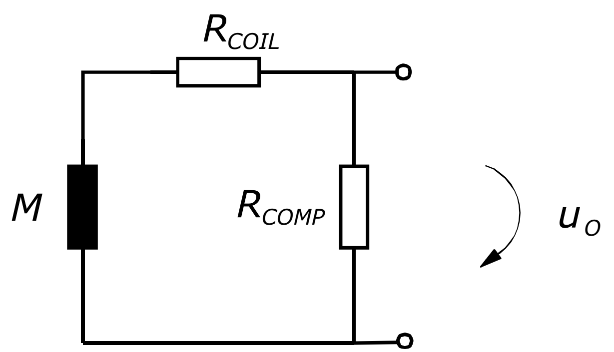


Characteristics studied

1. Temperature dependence
2. Linearity with applied current
3. Frequency dependence
4. Dependence on conductor location

1. Compensation of temperature dependence

- Two temperature dependent phenomena can be recognized:
  1) Mechanical expansion of the core material, which causes mutual inductance *M* to change.
  2) Increase in the resistance of coil wire (R_{COIL}, copper)
- A resistor R_{COMP} in parallel with the output forms a resistive voltage divider with the resistance of the coil wire.
- The value of R_{COMP} can be selected so that the change of the divider ratio compensates the mechanical expansion effect.
- TC of the split Rogowski coil was reduced from c. 50 ppm/K to < 5 ppm/K by adding a compensation resistor.

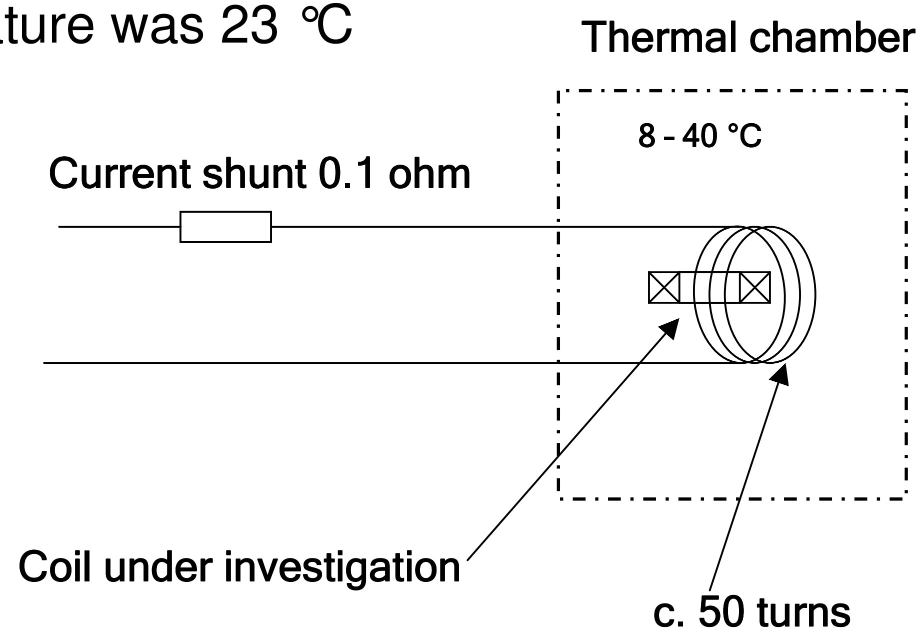


$$u_o = M \frac{di}{dt}$$

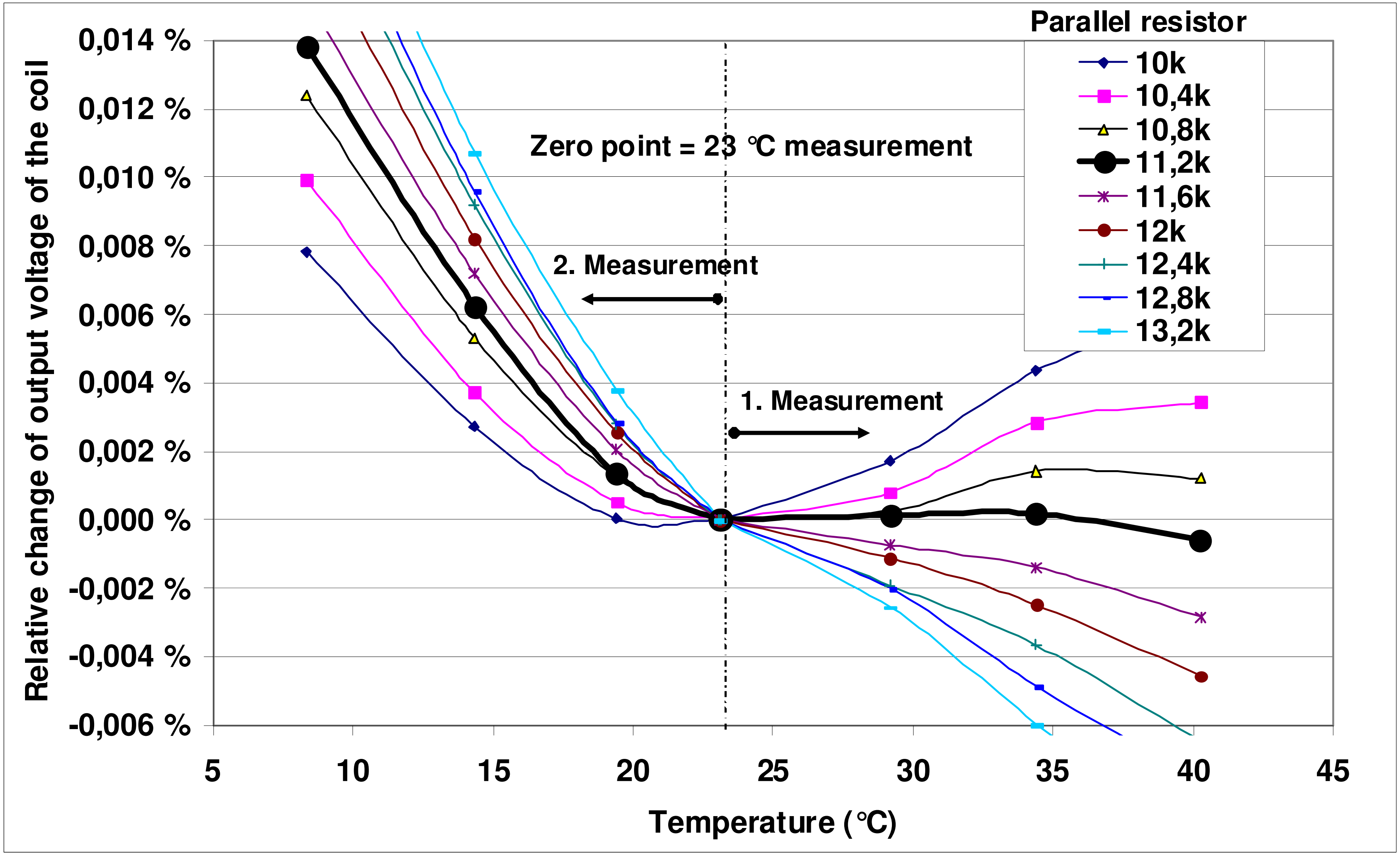
D.A. Ward: “Precision measurement of AC currents in the range of 1 A to greater than 100 kA using Rogowski coils”, British Electromagnetics Measurement Conference, NPL, October 1985.

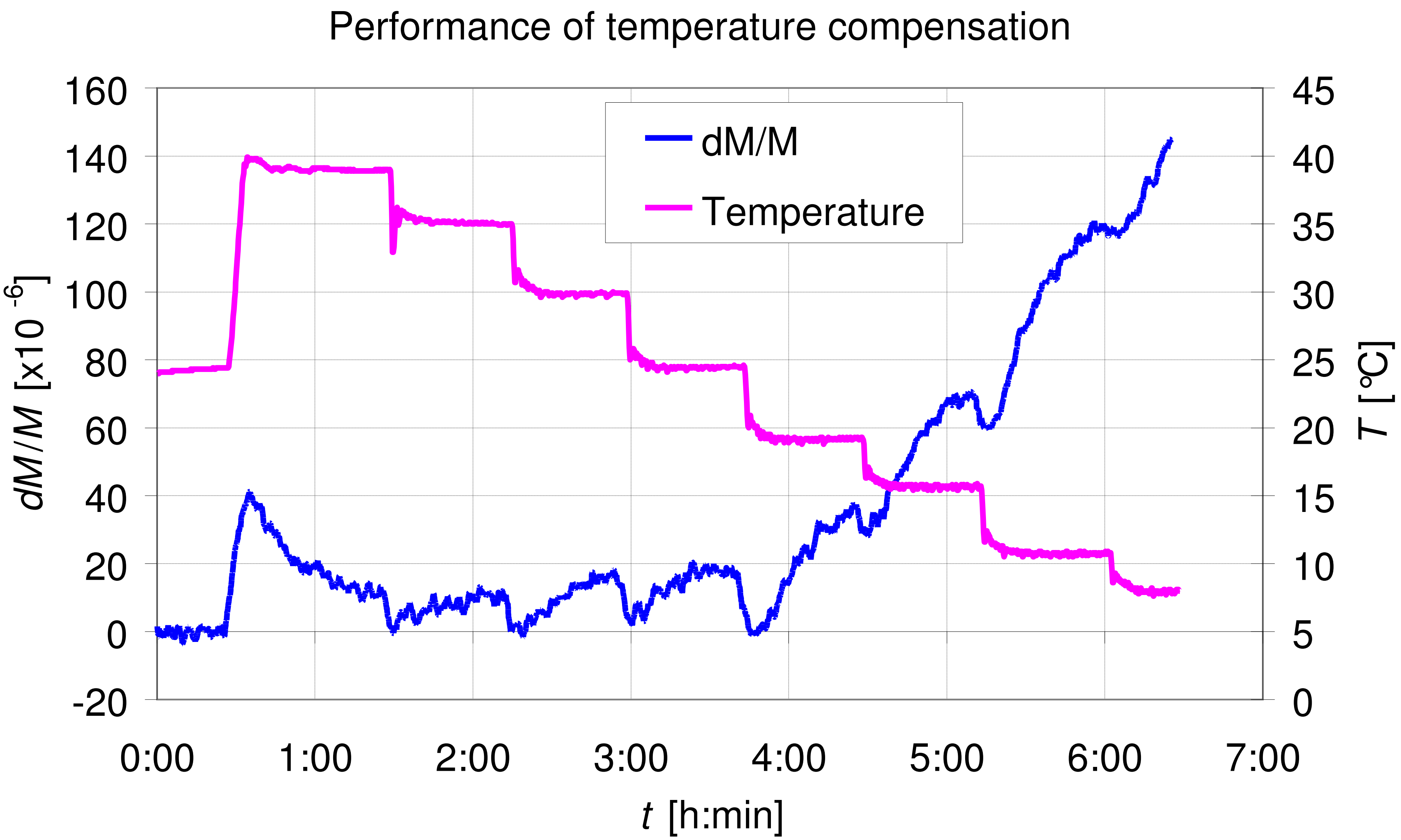
Compensation of temperature dependence

- Rogowski coil was kept in thermal chamber;
  temperature was varied from 8 to 40 ℃
- Test frequency was 60 Hz
- Test current of c. 0.7 A was fed through the Rogowski coil 39 times, producing an effective current of about 30 A
- Reading was compared with a reading from stable current shunt
- Reference temperature was 23 ℃

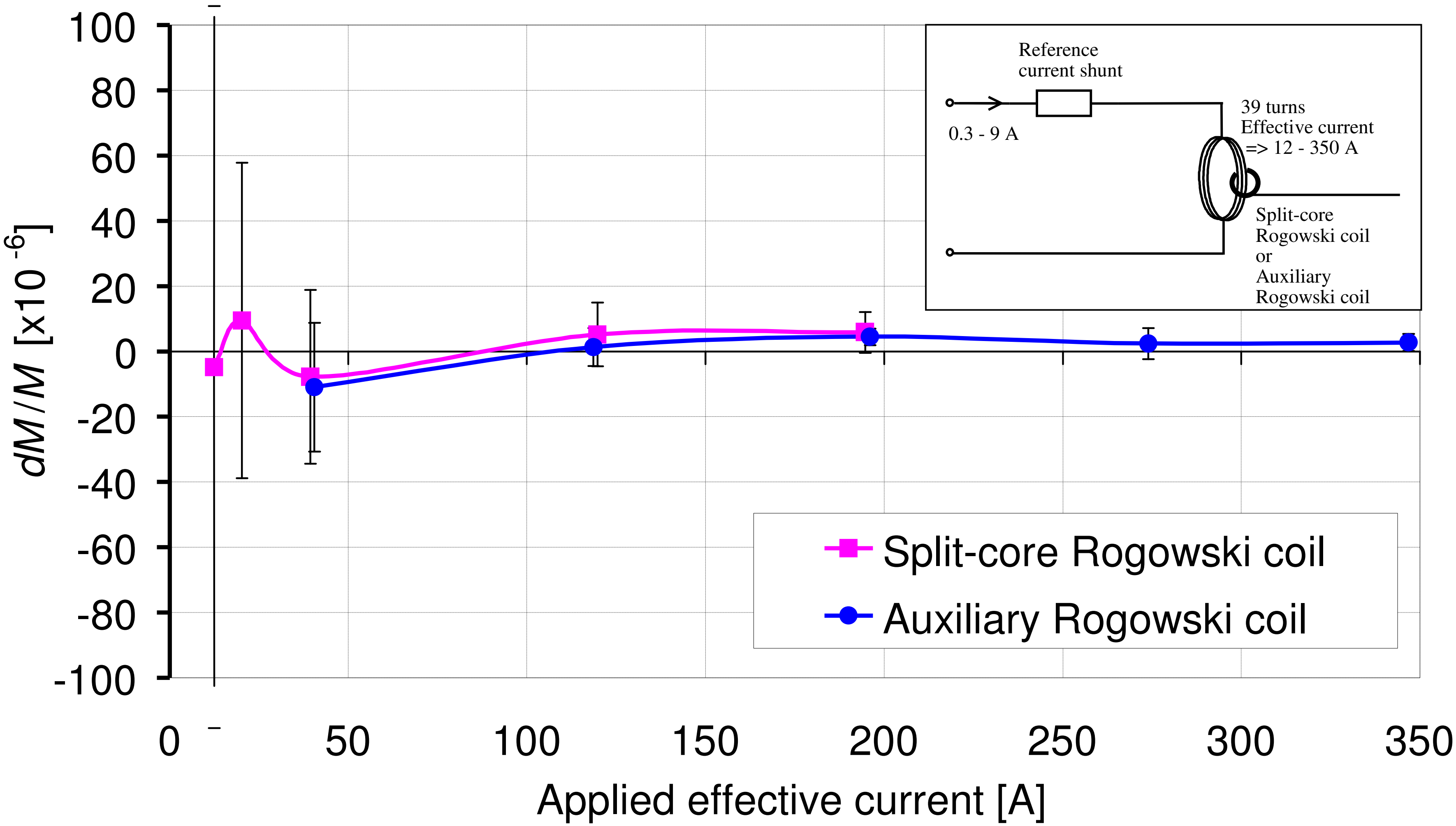


Compensation of temperature dependence

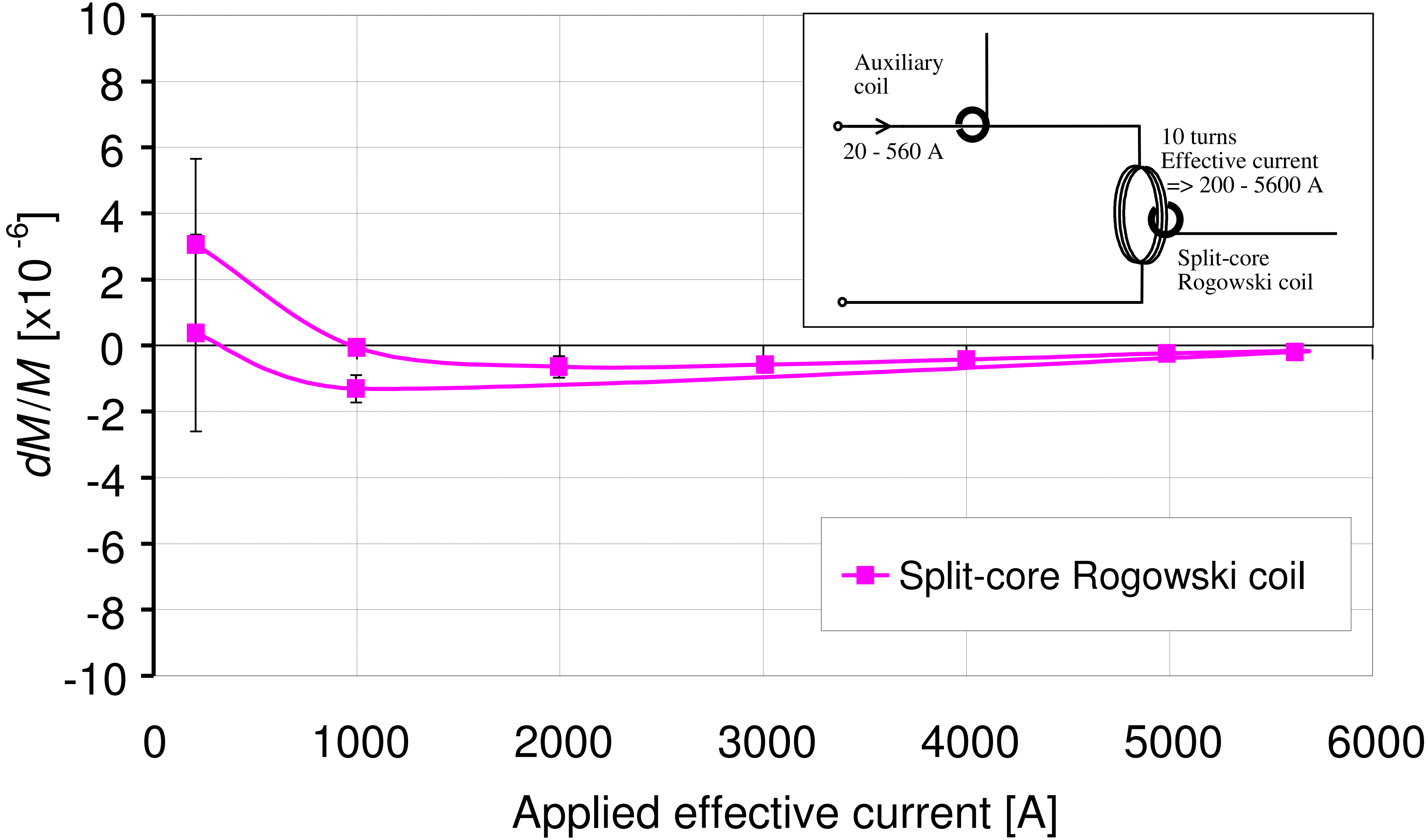



Performance of temperature compensation
dM/M
Temperature
160
140
120
100
80
60
40
20
0
-20
45
40
35
30
25
20
15
10
5
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
dM/M [x10^-6]
T [°C]
t [h:min]

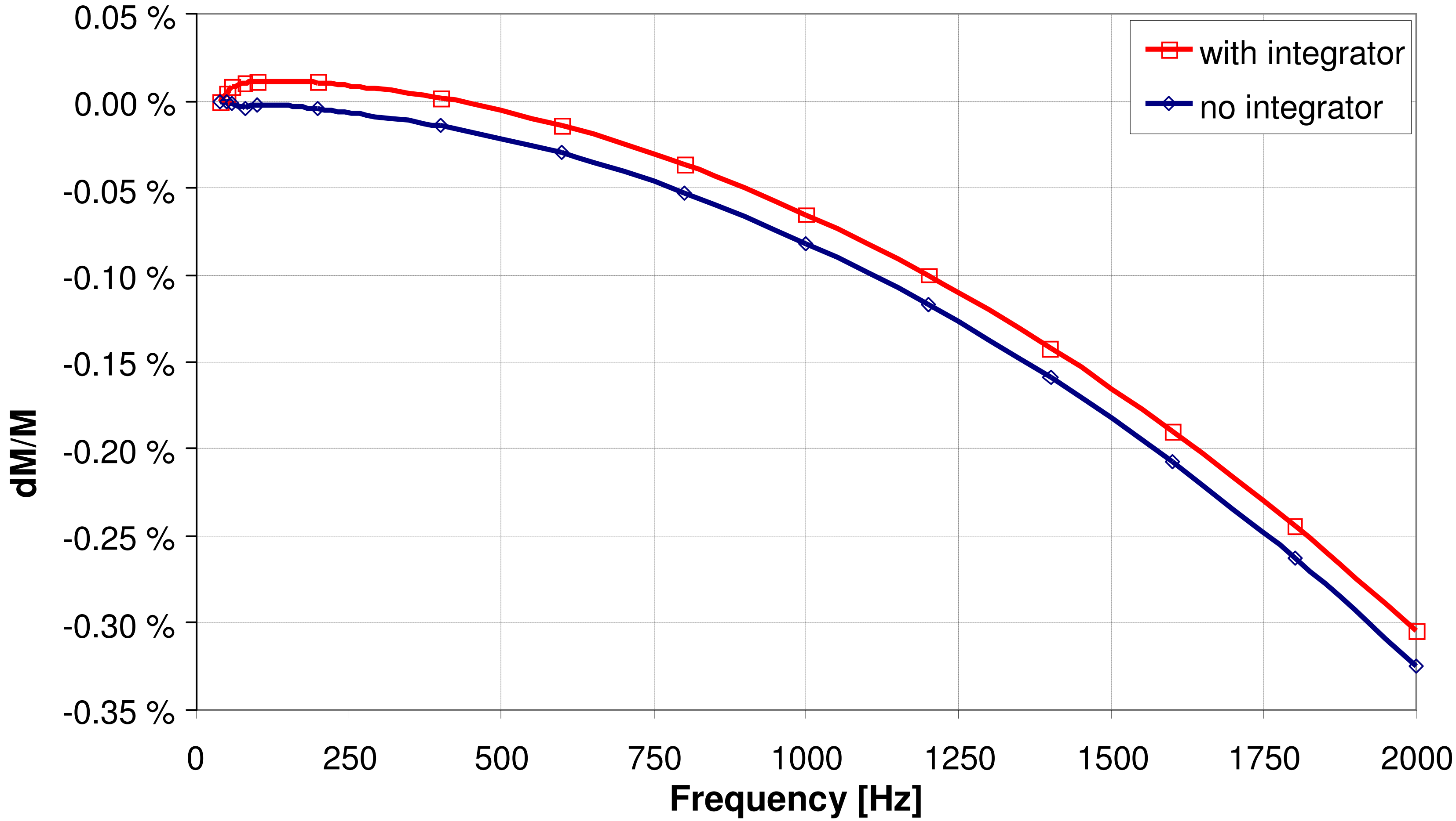
2. Linearity with applied current



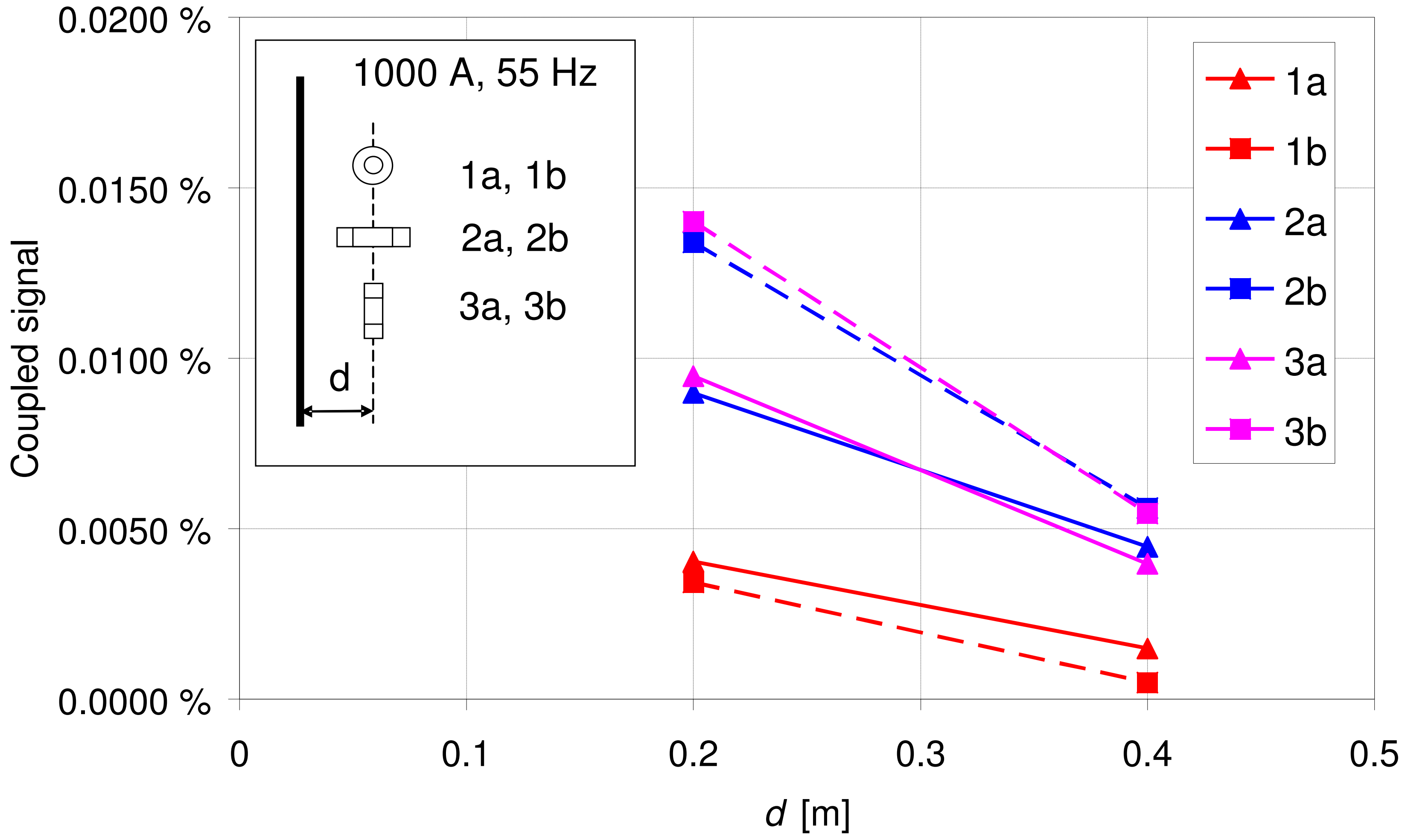
Linearity from 200 A to 5600 A



3. Frequency response



4. Pick-up from external conductors



Uncertainty budget

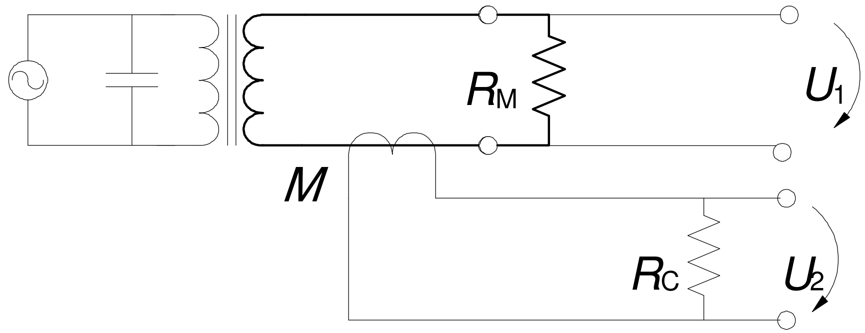
Mutual inductance, *M*	Uncertainty, $x10^{-6}$ (k=2)
Calibration uncertainty	50
Short term stability	60
Temperature dependence	70
Effect of ext. magnetic field	60
Effect of conductor position	230
Linearity	20
Overall uncertainty	260

Lower uncertainties can be reached if the coil is calibrated in the setup, relying on the linearity and low temperature dependence of the coil.

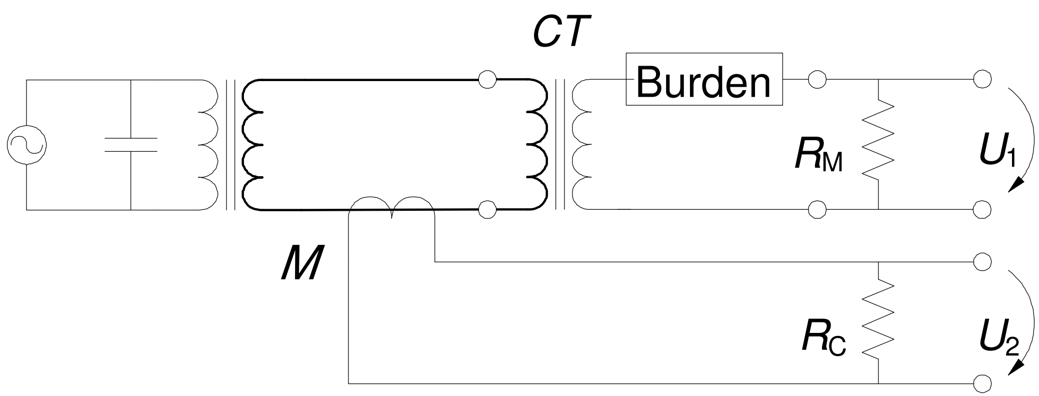
On-site calibration of CTs using Rogowski coil

Self-checking setup

1. System ratio (M / R_M) is calibrated on-site, using low (c. 10 A) current:



2. The CT is inserted into the circuit for calibration:



3. Absolute values of R_M and M are not important, only their ratio matters.

On-site calibration on a 400 kV substation

- December 2007
- Temperature: (3 ± 3) ℃
- External current feed up to 750 A, 52 Hz or 60 Hz, from 4,5 kVA ac power source
- Uncertainty: 300 ppm for the ratio error, and 1’ for phase displacement.

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Suomalainen, Hällström, On-Site Calibration of a Current Transformer using a Rogowski Coil. IEEE Trans. Instr. Meas., April 2009.

On-site with split-core Rogowski coil...

Case 1, November 2010

- Calibration of reference CT in customers testing laboratory
- Power frequency, 50 Hz
- Current from 80 A to 1000 A
- Discrepancies from earlier calibrations in the order of 50 to 150 ppm and 0.1´ to 0.9´.

Case 2, March 2011

- Calibration of CTs in a very compact MV test field
- Power frequency, 50 Hz
- Current from 50 A to 200 A
- Systematic difference from reference 550 pmm and 0.3´.

Experience

- Power frequency pick-up during calibration of the setup is a problem; output from the coil is c. 10 mV.
- It is difficult to find a busbar with large enough clearances for optimum calibration setup

Conclusions

- Temperature coefficient compensated to < 5 ppm/K.
- No saturation effects, linearity with applied current verified to < 5 ppm/K.
- Frequency response is not flat, this is a side effect of the applied TC compensation scheme.

- Conductor position and pick-up related effects can be controlled to < 100 ppm in fixed setup.
- On-site conditions are usually more challenging.

- Rogowski coil is linear by nature: it is an excellent tool for extension of the ac current scale.

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Thanks for your attention!