Accurate DC Current Ratio Measurements for Primary Currents up to 600 A

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Abstract **A setup has been developed for the accurate calibration of DC current ratios for DC currents up to 600 A. The setup is based on a DC current comparator and suitable for the calibration of DC current ratio measurement devices up to 100 A primary current. For higher primary currents, multiple turns of the primary conductor are made through the device under test, which for well-designed devices adds less than 0.5 ppm to the measurement uncertainty. The final expanded (k = 2) total uncertainty of current ratio measurements is 1 ppm for primary currents up to 600 A, limited by the behaviour of the device under test.**

Introduction

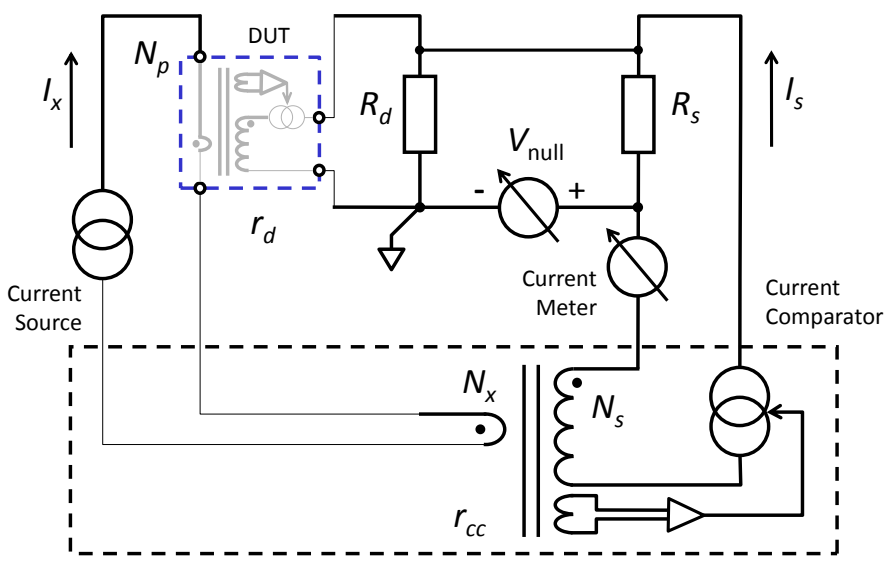
DC current measurements are relevant for among others:

- Heavy industry – aluminum production, electrochemical process
- HVDC grids – electricity transport over large distances
- Large magnets, such as LHC in CERN

Best commercial DC current measurement devices are ratio devices based on zero-flux principle.

Measurement method

VSL measurement setup for calibration of DC current ratio devices is based on low-ohmic resistance measurement bridge.



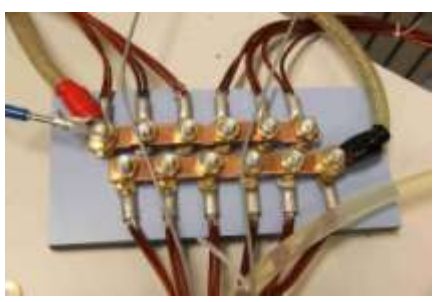
Unknown DC ratio r_d can be determined via:

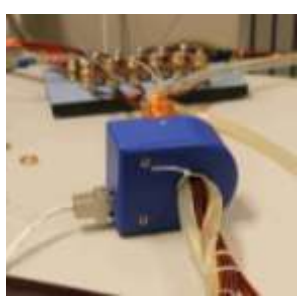
$$r_d = r_{cc} \times (R_s / R_d) \times (1 / N_p) + V_{null} / (R_d \times I_x)$$

R_d is adjusted to match nominal DC ratios $r_{cc} / (r_d \cdot N_p)$ (R_s = 1 Ω)

Implementation

- Calibration at pos^{ve}, neg^{ve}, reversed current (0,+I,0 0,-I,0 +I,-I,+I)
- 100 A current source - option for multiple primary turns to realize larger A·t signal up to 600 A·t
- R_d made up from L&N 4020B resistors in oil bath (0.25 Ω - 1.5 Ω)
- Water cooling

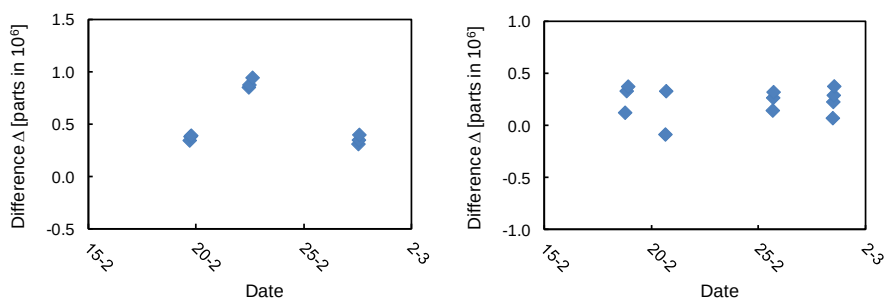




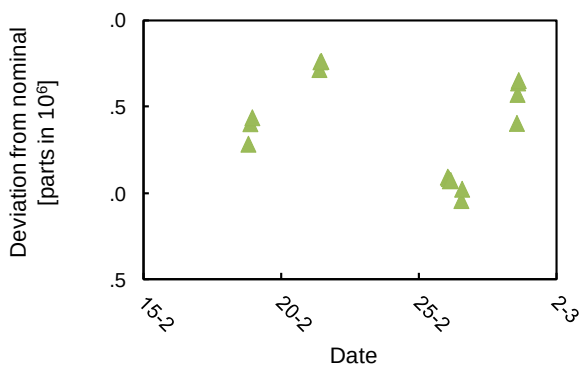
Measurement results

Multiple primary turn effect very small for a good DUT, e.g.:

- 1 turn vs 3 turns at 90 A·t: (0.54 ± 0.54) ppm
- 3 turns vs 6 turns at 150 A·t: (0.23 ± 0.28) ppm



Example calibration results of a zero-flux DUT (LEM IT-600 S, ratio 1/1500, 0 – 600 A): small error, no significant different results for positive or negative currents, small effect of conductor position



Conductor position	
bottom	6.2
top	7.8
left	6.3
right	7.5
Average	7.0
Centre	7.2

Uncertainty budget

Example mathematical model for uncertainty calculations:

$$r_{DUT} = r_{cc} \cdot (R_s / R_d) \cdot (1 + \delta_{ratio} + \delta_{scaling} + \delta_{pos})$$

where R_s and R_d include calibration, stability, temperature effects

Quantity	Value	Standard Uncertainty	Distribution	Uncertainty Contribution
r_{cc}	$1.00000000 \cdot 10^{-3}$	$0.12 \cdot 10^{-9}$	normal	$80 \cdot 10^{-12}$
R_s	1.0000038 Ω	$0.12 \cdot 10^{-6}$ Ω	normal	$83 \cdot 10^{-12}$
R_d	0.2499654 Ω	$0.07 \cdot 10^{-6}$ Ω	normal	$-180 \cdot 10^{-12}$
δ_{ratio}	$-14x.xx \cdot 10^{-6}$	$0.25 \cdot 10^{-6}$	normal	$170 \cdot 10^{-12}$
$\delta_{scaling}$	$-770 \cdot 10^{-9}$	$0.3 \cdot 10^{-6}$	normal	$200 \cdot 10^{-12}$
δ_{pos}	0.0	$0.17 \cdot 10^{-6}$	rectangular	$120 \cdot 10^{-12}$
r_{DUT}	$666.6xx \cdot 10^{-6}$	$360 \cdot 10^{-12}$ (1.1 ppm)		

Conclusion

A precision setup has been established for the accurate calibration of DC current ratio and DC current devices. Using multiple primary turns, calibrations can be performed up to 600 A·t with an uncertainty between 0.7 ppm and 1.1 ppm, depending on the DUT.

Calibration result of a LEM IT-600 S at 600 A: (-0.63 ± 1.1) ppm

- small effect of the multiple primary turns (< 1 ppm)
- small effect of primary current conductor positioning (< 0.5 ppm)

Ministerie van Economische Zaken

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