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New generation of AC-DC current transfer standards at Inmetro

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This paper describes the new primary standard for the ac-dc current transfer at Inmetro, based on PMJTCs and the new shunts manufactured by Fluke for rated currents from 10 mA up to 20 A. The build-up of the ac-dc current scale is described together with the uncertainty budgets which result in final uncertainties at 5 A of 6 µA/A to 12 µA/A in the frequency range from 10 Hz to 100 kHz. The recalibration of the standards after one year showed very small differences which are included in the uncertainty budget.

Keywords: ac-dc difference; PMJTC; comparison

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1. INTRODUCTION

Inmetro, the Brazilian National Metrology Institute, is responsible for developing new calibration set-ups and standards that will improve the capacity of providing a higher quality calibration service, specially to the Brazilian accredited laboratories, which are responsible for providing calibration services to all other laboratories and industries in Brazil.

The Inmetro started to invest in PMJTCs (Planar Multijunction Thermal Converters), to replace SJTCs (Single Junction Thermal Converters) as primary standard at 10 mA current level. For higher currents the new TCCs (Thermal Current Converters) are built from high quality coaxial shunts, model A40B, manufactured by Fluke in parallel to PMJTCs. This Fluke design of shunts with small current level effect on the ac-dc current transfer difference follows the design by several authors in different national institutes [1, 2, 3, 4, 5].

Thermal converters are capable of comparing the joule heating between ac and dc modes at 0.1 µV/V level, and are widely employed as the ac-dc current transfer standards in most of the national metrology institutes. The existing ac-dc current transfer standards of Inmetro are made of SJTCs which have one thermocouple at the midpoint of the heater and are enclosed in an evacuated glass bulb to improve its sensitivity [6].

The fundamental limitations of the performance of an SJTC are thermoelectric errors (Thomson and Peltier effects) in the heater due to the rather large temperature gradient along the heater (about 200 ºC), level dependence of the ac-dc difference, small output voltage and therefore small dynamic range. Moreover such an SJTC based ac-dc current transfer system needs to be recalibrated against higher level standards at least every 5 years to obtain small uncertainties.

To reduce these thermoelectric errors, the MJTC uses as many as two hundred thermocouples spaced along a much longer heater wire [6], which results in a larger output voltage and negligible temperature gradients along the heater. However, the MJTC fabrication process is complicated and expensive.

The design of PMJTCs is suitable to mass production without degradation of the performance of the MJTC. PMJTCs provide long-term stability together with high sensitivity and high dynamic range. They are well known for very small ac–dc current transfer differences at audio frequencies [7, 8].

Moreover the shunts used in the former ac-dc current transfer standards (model A40 shunts made by Fluke) were replaced by high quality coaxial shunts (model A40B manufactured by Fluke).

In order to validate the new system, an unofficial comparison was made between PTB (Physikalisch- Technische Bundesanstalt, Germany) [9] and Inmetro standards. The measurements were performed at 10 mA and 5 A, in the whole frequency range from 10 Hz to 100 kHz.

2. CALIBRATION SET-UP

The basic standard for ac-dc current transfer is the 10 mA PMJTC providing traceability to PTB. All standards for higher currents contain a shunt associated with a dedicated PMJTC which measures the voltage across the shunt. To build-up the current scale from 10 mA to 20 A, the different current ranges have to be calibrated against each other.

In this step-up method starting from 10 mA the next higher current standard for 20 mA is calibrated at the current of 10 mA. Under the assumption that it does not change its ac-dc current transfer differences, it is used then at 20 mA. This procedure continues step by step for all frequencies from 10 Hz to 100 kHz and currents up to 20 A.

The calibration set-up used is shown in detail in Figure 1. Two separate calibrators deliver ac and dc voltages. An ac-dc switch connects the ac and dc voltages to the transconductance amplifier which converts the voltage to the necessary current. Both ac-dc current transfer standards are connected in series and therefore get the same current for this comparison. The two nanovoltmeters Keithley 182 measure the output voltage of the PMJTCs. The nanovoltmeters are modified because their input amplifiers should be driven at the potential of the ac-dc transfer standards.

The basic design of the measurement set-up showing only PMJTCs for 10 mA is given in Figure 1. For higher currents, coaxial shunts, model A40B, manufactured by Fluke, are associated to them.

The different earth connections are chosen in a specific way to avoid any earth loops which may change the measured values in an unknown way. A coaxial choke (CC) has been introduced to suppress earth currents causing common mode voltages at the input of the transconductance amplifier.

The introduction of potential driven guards (Figure 2) in the comparison circuit of the two ac-dc transfer standards avoids systematic changes of the ac-dc transfer difference of the standard, which is at the higher potential in the series connection of the two standards, especially at higher frequencies [10, 11]. This is necessary because the standard is calibrated at low potential and used at high potential. Photos in Figure 3 and Figure 4 show the calibration set-up.

With this calibration set-up, standards for all current ranges have been built-up with a standard deviation of the measurement smaller than 1 µA/A.

In Figure 5 the different steps in the step-up procedure are

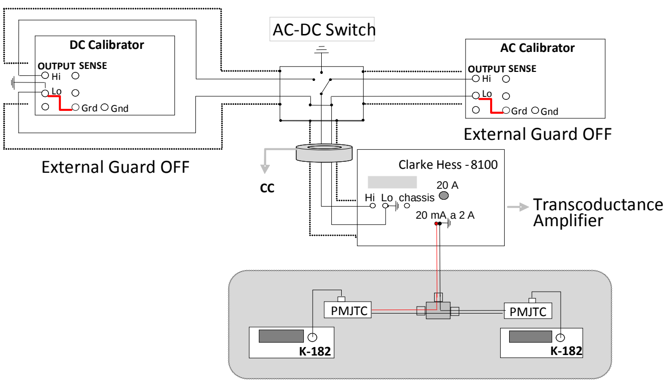

Figure 1. Measurement set-up for ac–dc current transfer difference measurements.

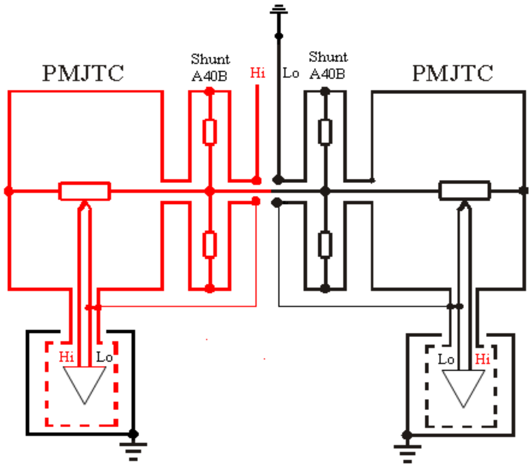

Figure 2. ac-dc current transfer with potential driven guards (PMJTCs with shunts for current ranges above 10 mA).

shown. All PMJTCs called 90 have heater resistances of 90 Ω, whereas the 400 has a heater resistance of 400 Ω and the 900 has a 900 Ω one. The second name is the shunt for the different currents.

In Figure 6 some thermal converters are shown. The first one from the left is a 10 mA PMJTC; the second one is a boxed

Figure 3. ac-dc current transfer set-up.

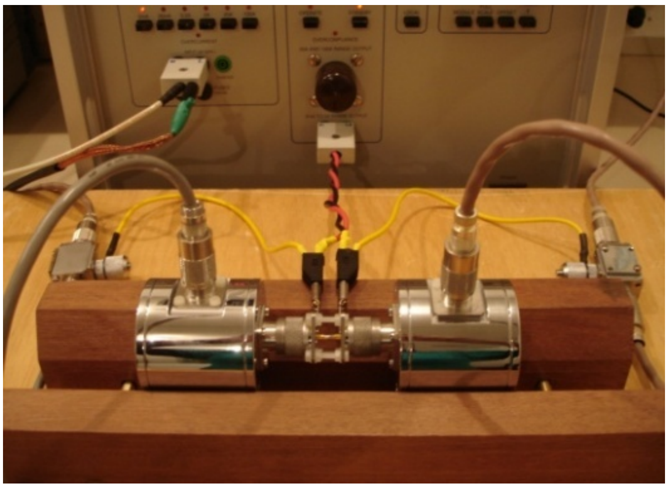

Figure 4. Connection of the ac-dc current transfer standards in series.

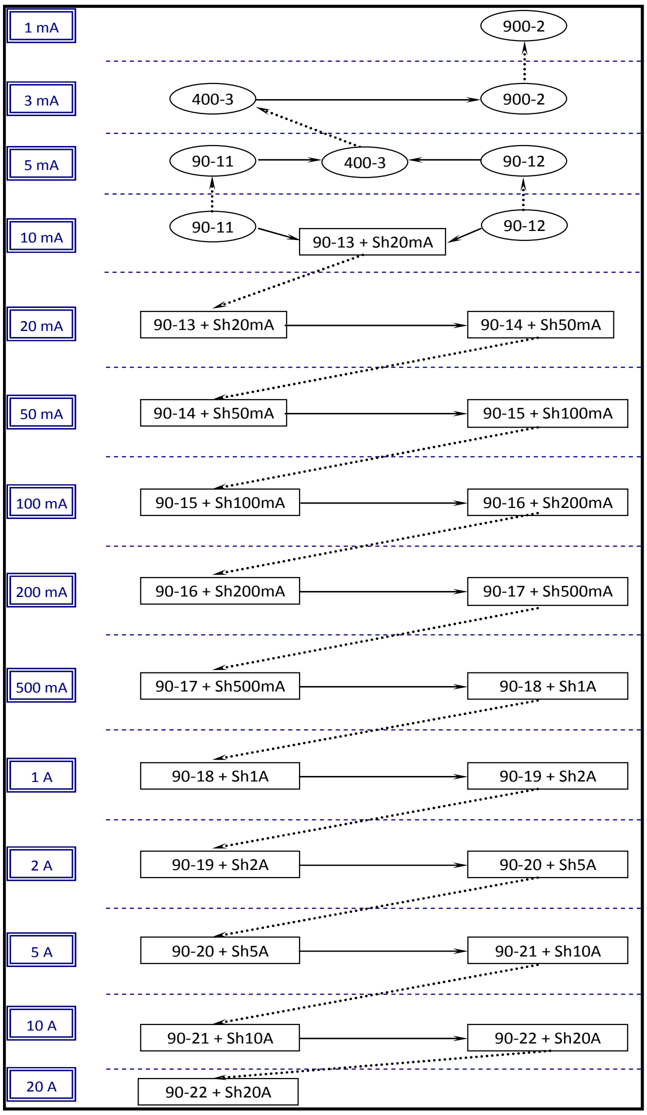

Figure 5. Schematics of the step-up procedure.

50 mA shunt connected to a 90 Ω PMJTC and the others are PMJTCs connected to coaxial shunts for currents up to 100 mA and for higher currents up to 20 A.

Figure 6. ac-dc current transfer standards.

3. UNCERTAINTY ANALYSIS

The model equation is

$$\delta_{\text{step } i} = \delta_{\text{step } i\text{-}1} + \delta_{\text{CA}} + \delta_{\text{C}} + \delta_{\text{com. mode}} + \\ + \delta_{\text{Lev}} + \delta_{\text{LF}} + \delta_{\text{diff. step-ups}} \tag{1}$$

with

$\delta_{\text{step } i-1}$: Transfer difference of standard at the step $i - 1$.

δ_{CA}: Contribution of the mean of repeated twelve measurements.

δ_{C}: Contribution of the measurement set-up.

$\delta_{\text{com. mode}}$: Transfer difference from the common mode effect in the transconductance amplifier determined from the difference of measurements with and without the choke CC in Figure 1.

δ_{Lev}: Transfer difference due to level dependence of shunts estimated from the design of the shunts.

δ_{LF}: Transfer difference due to low frequency behavior of PMJTC.

$\delta_{\text{diff.step-ups}}$: Correction with the difference of different step-up measurements performed in the same measurement set-up.

The sum of the variances of the different contributions results in the variance of the result:

$$\mathrm{u}^2\left(\delta_{\text{step } i}\right) = \mathrm{u}^2\left(\delta_{\text{step } i\text{-}1}\right) + \mathrm{u}^2\left(\delta_{\text{CA}}\right) + \mathrm{u}^2\left(\delta_{\text{C}}\right) + \\ + \mathrm{u}^2\left(\delta_{\text{com. mode}}\right) + \mathrm{u}^2\left(\delta_{\text{Lev}}\right) + \mathrm{u}^2\left(\delta_{\text{LF}}\right) + \mathrm{u}^2\left(\delta_{\text{diff. step-ups}}\right) \tag{2}$$

where $\mathrm{u}^2(x)$ represents the variance of x.

The uncertainty budgets of the different current steps are given in Tables 1 to 4.

4. COMPARISON RESULTS

An unofficial interlaboratory comparison of ac-dc current transfer standards between PTB and Inmetro was performed with a travelling standard for 10 mA and one for 5 A. The current points chosen were 10 mA and 5 A, in the frequency range from 10 Hz and 100 kHz. In Inmetro each current point was measured against Inmetro standards in twelve cycles at all frequencies, and the mean was calculated using the results of the sequence which gives the ac-dc current transfer difference, represented by $\delta_{Inmetro}$. Tables 5 and 6 show the results obtained.

PTB uses a similar calibration set-up and similar standards. The shunts are manufactured by the Norwegian Metrology Institute Justervesenet with a different design [12]. The results obtained in PTB are represented by δ_{PTB}. The associated expanded uncertainties are given by U.

The measured differences Inmetro-PTB between both institutes were small compared to the given uncertainties which is also represented by the small En-values. This is a very satisfying result of the comparison.

5. CONCLUSIONS

In the first step a new step-up procedure was developed to build-up the ac-dc current transfer standards for 10 mA up to 20 A and to perform an uncertainty analysis for the whole build-up.

The second step towards the introduction of the new ac-dc current transfer system of Inmetro was performing a comparison between Inmetro and PTB, which proved that Inmetro's new calibration set-up and standards work as expected.

Table 1. Uncertainty analysis for the step-up at 10 mA.

Influencing quantity	Measurement uncertainty in µA/A at the frequency in kHz													
	0.01	0.02	0.03	0.04	0.055	0.12	0.5	1	5	10	20	50	70	100
$u(\delta_{10\,\mathrm{mA}})$	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
$u(\delta_{\mathrm{CA}})$	0.5	0.4	0.3	0.5	0.6	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.6
$u(\delta_{\mathrm{C}})$	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
$u(\delta_{\mathrm{com.\ mode}})$	1	1	1	1	1	1	0	0	0	0	0	0	0	0
$u(\delta_{\mathrm{Lev}})$	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$u(\delta_{\mathrm{diff.\ step\text{-}ups}})$	0.2	0.2	0.0	0.3	0.1	0.0	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.2
$u(\delta_{\mathrm{LF}})$	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
$u(\delta_{10\,\mathrm{mA}})$	1.9	1.9	1.8	1.9	1.9	1.8	1.5	1.5	1.5	1.5	1.5	1.5	1.6	1.6
$U(\delta_{10\,\mathrm{mA}})$ $k = 2$	3.8	3.8	3.6	3.8	3.8	3.6	3.0	3.0	3.0	3.0	3.0	3.0	3.2	3.2

Table 2. Uncertainty analysis for the step-up at 100 mA.

Influencing quantity	Measurement uncertainty in µA/A at the frequency in kHz													
	0.01	0.02	0.03	0.04	0.055	0.12	0.5	1	5	10	20	50	70	100
$u(\delta_{50\,\mathrm{mA}})$	3.0	2.6	2.5	2.5	2.5	2.4	1.7	1.7	1.7	1.7	1.7	1.7	1.8	1.9
$u(\delta_{\mathrm{CA}})$	0.5	0.3	0.5	0.4	0.3	0.5	0.4	0.4	0.4	0.2	0.4	0.4	0.4	0.5
$u(\delta_{\mathrm{C}})$	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
$u(\delta_{\mathrm{com.\ mode}})$	1.0	1.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
$u(\delta_{\mathrm{Lev}})$	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.4
$u(\delta_{\mathrm{diff.\ step\text{-}ups}})$	0.1	0.1	0.1	0.1	0.3	0.2	0.1	0.1	0.2	0.4	0.2	0.1	0.1	0.1
$u(\delta_{\mathrm{LF}})$	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
$u(\delta_{100\,\mathrm{mA}})$	3.2	2.9	2.8	2.7	2.8	2.7	1.8	1.8	1.8	1.8	1.8	1.8	1.9	2.0
$U(\delta_{100\,\mathrm{mA}})$ $k = 2$	6.4	5.8	5.6	5.4	5.6	5.4	3.6	3.6	3.6	3.6	3.6	3.6	3.8	4.0

Table 3. Uncertainty analysis for the step-up at 1 A.

Influencing quantity	Measurement uncertainty in µA/A at the frequency in kHz													
	0.01	0.02	0.03	0.04	0.055	0.12	0.5	1	5	10	20	50	70	100
$u(\delta_{500\,\mathrm{mA}})$	3.8	3.5	3.4	3.3	3.4	3.4	2.1	2.0	2.1	2.1	2.1	2.1	2.1	2.5
$u(\delta_{\mathrm{CA}})$	0.4	0.3	0.3	0.3	0.3	0.4	0.3	0.3	0.2	0.2	0.2	0.2	0.3	0.3
$u(\delta_{\mathrm{C}})$	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
$u(\delta_{\mathrm{com.\ mode}})$	1.0	1.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
$u(\delta_{\mathrm{Lev}})$	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.5
$u(\delta_{\mathrm{diff.\ step\text{-}ups}})$	0.1	0.1	0.1	0.2	0.2	0.1	0.4	0.1	0.2	0.3	0.1	0.3	0.1	0.4
$u(\delta_{\mathrm{LF}})$	0.4	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
$u(\delta_{1\,\mathrm{A}})$	4.1	3.8	3.7	3.6	3.7	3.7	2.4	2.3	2.3	2.3	2.3	2.3	2.4	2.9
$U(\delta_{1\,\mathrm{A}})$ $k = 2$	8.2	7.6	7.4	7.2	7.4	7.4	4.8	4.6	4.6	4.6	4.6	4.6	4.8	5.8

Table 4. Uncertainty analysis for the step-up at 5 A.

Influencing quantity	Measurement uncertainty in µA/A at the frequency in kHz													
	0.01	0.02	0.03	0.04	0.055	0.12	0.5	1	5	10	20	50	70	100
$u(\delta_{2\,\mathrm{A}})$	4.4	4.1	4.0	3.9	4.0	4.0	2.7	2.6	2.5	2.8	3.1	3.8	3.9	4.6
$u(\delta_{\mathrm{CA}})$	0.3	0.4	0.3	0.2	0.4	0.4	0.3	0.5	0.4	0.2	0.2	0.4	0.6	0.4
$u(\delta_{\mathrm{C}})$	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
$u(\delta_{\mathrm{com.\ mode}})$	1.0	1.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
$u(\delta_{\mathrm{Lev}})$	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.5	2.0	3.0	3.0	3.5
$u(\delta_{\mathrm{diff.\ step\text{-}ups}})$	0.1	0.2	0.3	0.0	0.1	0.2	0.3	0.1	0.3	0.3	0.2	0.6	0.5	0.7
$u(\delta_{\mathrm{LF}})$	0.4	0.3	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
$u(\delta_{5\,\mathrm{A}})$	4.6	4.4	4.3	4.2	4.3	4.3	2.9	2.8	2.8	3.2	3.7	4.9	5.0	5.9
$U(\delta_{5\,\mathrm{A}})$ $k = 2$	9.2	8.8	8.6	8.4	8.6	8.6	5.8	5.6	5.6	6.4	7.4	9.8	10.0	11.8

Table 5. Result of the comparison between Inmetro and PTB at 10 mA.

Institutes	AC-DC current transfer differences together with their uncertainties in µA/A at the frequencies in kHz													
	0.01	0.02	0.03	0.04	0.055	0.12	0.5	1	5	10	20	50	70	100
δ_{Inmetro}	5.5	1.3	1.0	0.7	0.3	-0.1	-0.5	0.1	0.4	0.6	2.2	17.6	34.8	70.9
U_{Inmetro}	4	4	4	4	4	4	3	3	3	3	3	3	3	4
δ_{PTB}	5.3	1.8	0.7	0.7	-0.3	-0.4	-0.1	-0.2	0.5	1.5	3.2	18.9	36.4	72.2
U_{PTB}	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Difference Inmetro - PTB	0.2	-0.5	0.3	0.0	0.5	0.3	-0.4	0.3	-0.1	-0.9	-1.0	-1.3	-1.6	-1.3
E_n	0.0	-0.1	0.1	0.0	0.1	0.1	-0.1	0.1	0.0	-0.2	-0.2	-0.3	-0.4	-0.3

Table 6. Result of the comparison between Inmetro and PTB at 5 A.

Institutes	AC-DC current transfer differences together with their uncertainties in µA/A at the frequencies in kHz													
	0.01	0.02	0.03	0.04	0.055	0.12	0.5	1	5	10	20	50	70	100
δ_{Inmetro}	0.0	0.4	0.2	0.1	0.0	-0.3	0.0	0.1	2.7	11.6	13.2	-88.1	-187.0	-353.9
U_{Inmetro}	9	9	9	9	9	9	6	6	6	7	8	10	10	12
δ_{PTB}	-0.9	-0.2	0.4	0.2	-0.4	0.5	0.5	0.4	3.0	10.6	10.5	-89.9	-187.2	-349.4
U_{PTB}	5	4	4	4	4	4	4	4	4	5	7	9	10	11
Difference Inmetro - PTB	0.9	0.6	-0.2	0.0	0.4	-0.8	-0.5	-0.3	-0.3	1.0	2.7	1.9	0.2	-4.5
E_n	0.1	0.1	0.0	0.0	0.0	-0.1	-0.1	0.0	0.0	0.1	0.2	0.1	0.0	-0.3

The results of both institutes' standards agreed within 2 µA/A for 10 mA and 5 µA/A for 5 A between 10 Hz and 100 kHz. That means that this new system works reliably and is ready for use in the next international comparison of ac-dc current transfer standards (SIM.EM-K12) [13].

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