CALIBRATION OF NON QUADRATIC SENSIBILITY THERMAL CONVERTERS

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Abstract: A measurement system for the ac-dc transfer difference of thermal converters whose power response is not exactly quadratic is presented. The previous method, due to the simplifications of the equations, was not valid for those ac-dc transfer standards with a sensibility slightly different from 2. The error in using these equations for those standards has been evaluated and can be as high as 20 μV/V when dealing with single junction thermal converters whose sensibilities can be around 1.6. In the new measurement system, some terms, before considered negligible, have been retained. A modified bridge has been developed according to this equation to allow the calibration of all kind of thermal converters, including those with sensibilities not exactly quadratic. This new bridge has been validated with some measurements as detailed below in this paper.

Key words: ac-dc transfer, ac-dc standards, thermal converters.

1. INTRODUCTION

1.1. The ac-dc quantities and the standards

The base electrical unity in the SI is the Ampere, but in fact, the realization of the Ampere depends on the Ohm´s law knowing the Ohm (electrical resistance) and the Volt (electrical voltage) based on the quantum Hall effect and the Josephson effect, due to its high excellent reproducibility that allowed the realization of the Volt and the Ohm just depending on physical universal constants whose values have been assigned for the practical realization of these units.

Then, the first steps in the National Metrology Institutes are the realization of direct current and voltage quantities. Later, the ac quantities are obtained from the dc by the so called transfer methods.

The transfer method most used for NMIs was developed by Hermach [1] in the fifties and is based on the use of thermal converters. Basically they are made of a heater resistance and a thermocouple in thermal contact with the resistor but electrically isolated. The method is based on the equivalence in dc and ac power dissipated in the resistor. Knowing the input direct voltage or current applied to the resistor it is possible to transfer that value to the alternate applied voltage or current. That simple device, the resistor and the thermocouple, is what it's called a thermal converter and nowadays are the most used standard at the national metrology institutes to make the transfer from direct to alternate quantities, [2].

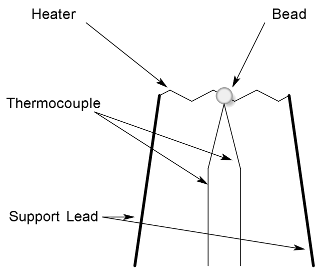

Fig. 1. Single junction thermal converter.

But not everything is so simple. In fact, that behaviour of the thermal converter (the same voltage output when the same ac or dc is applied) it's only ideal and the true output of this standard, when applied the same alternate or direct current, is just different. That's why we need to quantified this difference which has became the basic quantity of the ac-dc transfer laboratories. The name of this quantity that characterizes these standards is the *ac-dc transfer difference* that is defined as the difference between the ac input voltage (V_{ac}) and the dc input voltage (V_{dc}) when the output voltages (E_{ac} and E_{dc}) of the thermal converter are equal:

$$\delta \equiv \left. \frac{V_{ac} - V_{dc}}{V_{dc}} \right|_{E_{ac} = E_{dc}} \tag{1}$$

The voltage generated at the output of the thermocouple by the warm up of the heater is defined by the following equation:

$$E = k \cdot V^{n} \tag{2}$$

where E is the output voltage generated by the thermal converter, V is the input voltage applied to the thermal converter, k is a constant and n is the sensibility of the thermal converter, that ideally is 2.

1.2. The evolution of the standards

At the beginning, in the early fifties of last century, the first thermal converters where made by just one junction of the thermocouple with the resistor. Those single junction thermal converters were easier to be theoretically characterized but, on the other hand, present some dependence with the frequency because of the Peltier, Thomson and other effects, [3]. Those effects are more significant at low frequency and at high frequency.

When the thermal time constant is much longer than the period of the double-frequency heating (joule heating varies with double of the frequency applied), the variation of temperature becomes negligible due to the thermal inertia of the heater. But when the frequency decreases, the thermal inertia of the heater becomes insufficient to suppress the double-frequency thermal ripple. The thermal ripple causes the ac-dc difference of thermal converter due to the imperfections in the thermal converters elements [4, 6].

At high frequency, the ac-dc difference is due to skin-effect, dielectric loss and the stray capacitance and inductance [6].

Several improvements have been made in these thermal converters in the second half of the last century. First, adding more thermal junctions of the thermocouple to the resistor, the MultiJunction Thermal Converters. Then these standards were improved laying the thermocouples and the resistor on thin-film technology. This way, the behaviour of the standards was improved to a wider frequency range, [4, 5].

The sensibility of the thin-film thermal converters is very close to 2, but the single junction thermal converters do not always present so ideal output.

By the way, some commercial standards have not a perfect quadratic output, for example, the ones based on solid state, which have a linear behaviour, and those with single, or double, junction thermal converter, with sensibilities not exactly equal to 2.

1.3. The calibration of the standards. The methods.

There are two main methods to compare the ac-dc transfer difference of two thermal converters, [6], both implemented at CEM.

One is the so called dual-channel method. This method consists of measure the output of each thermal converter separately, when alternatively the same dc and ac is applied, as illustrated in figure 2. The first step in this method is the determination of the sensibility of the thermal converters. The main advantage of this method is the possibility of compare thermal converters with quite different sensibilities.

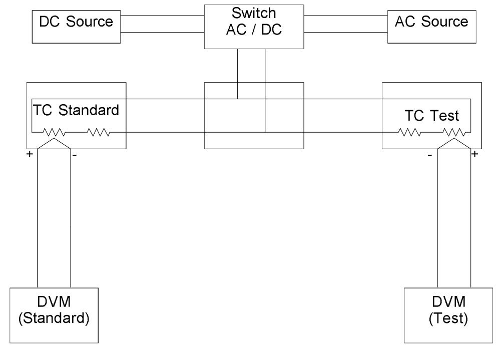

Fig. 2. Schematic configuration of the dual-channel method.

The other method is the so called differential method. This is the one applied by CEM to obtain its ac reference and it is detailed in this paper. The schematic diagram of measurement circuit of the differential method is shown in figure 3. It is understood, in this method, that the sensibility of the standards is quadratic. Even if dealing with linear output sensibility like standards based on solid state diodes (e.i. Fluke 792) it becomes necessary to make the output quadratic by connecting an extra thermal converter at the output of the linear standard.

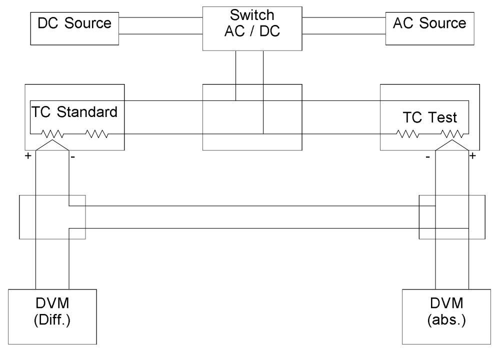

Fig. 3. Schematic configuration of the differential method.

The equations for this method were developed by M. Klonz in his PhD Thesis [7]. At the end he proposes the next equation for the comparison of the ac-dc transfer difference of two thermal converters:

$$\delta_1 - \delta_2 = \frac{1}{n_2 E_{dc2}}\left[\left(E_{ac2} - E_{dc2}\right) - \left(E_{ac1} - E_{dc1}\right)\right] - C \tag{3}$$

where C, called the correction term, is:

$$C = \frac{1}{n_2 E_{dc2}}\left(E_{ac1} - E_{dc1}\right)\left[\frac{n_2 - n_1}{n_1} + \frac{E_{dc2} - E_{dc1}}{E_{dc1}} + \frac{n_2 - n_1}{n_1}\frac{E_{dc2} - E_{dc1}}{E_{dc1}}\right] \tag{4}$$

where, δ_1 and δ_2 are the transfer differences of the two standards compared; n_1 and n_2 are the sensibilities of both standards; E_{dc1} and E_{dc2} are the voltage outputs of both standards when a dc voltage is applied to their inputs; and

E_{ac1} and E_{ac2} are the voltage outputs of both standards when an ac voltage is applied to their inputs.

Usually the equation (3) is simplified assuming that the term C is negligible [8]. That happens when the next three conditions are fulfilled:

i. $\left|\frac{E_{ac1}-E_{dc1}}{E_{dc1}}\right| < 2\times10^{-5}$, i.e., the relative difference between the output of the standard 1 when an ac input voltage and a dc input voltage is applied is less than 2×10^{-5}.

ii. $\left|\frac{n_1-n_2}{n_1}\right| < 5\times10^{-3}$, i.e., the relative difference between the sensibility of both standards must be less than 5×10^{-3}.

iii. $\left|\frac{E_{dc2}-E_{dc1}}{E_{dc1}}\right| < 5\times10^{-3}$, i.e., the relative difference between the output of both standards when a dc input voltage is applied is less than 5×10^{-3}.

2. THE PROBLEM

In the daily calibration work, CEM, [9], has to deal with standards that do not fit those conditions. Actually, the single junction thermal converters usually do not behaviour exactly quadratic. The CEM has measured the sensibility of some thermal converters finding values up to 20 % far from 2. That means the condition ii) is not satisfied when comparing a thin film thermal converter with a sensibility very close to 2 against a single junction thermal converter with sensibilities of 1.8, 1.7, or even, 1.6,.

In that case, the correction term C can be typically around 20 μV/V. So, the error that can be introduced in a calibration of a single junction thermal converter when compared with a thin film multijunction thermal converter, using the differential method bridge comparator with equation (3), without C term, could be greater than 20 μV/V.

Usually a typical uncertainty assigned to the calibration of a single thermal converter, at 1 V and 1 kHz, could be less than 4 μV/V (k=2). That means the error is more than five times bigger than the uncertainty.

So, it's obvious that the simplified equations can not be used for comparing non quadratic standards.

3. THE SOLUTION

If the sensibility of the thermal converters has become critical, as show before, it is now mandatory to measure carefully the sensibility of the standard before calibrate it. It is also important to use the equations without the simplification that assumes the difference in the sensibility of the thermal converters as low as 5×10^{-3}, condition ii) before. This way, the equation to use is:

$$\delta_1-\delta_2=\frac{1}{n_2 DC_{abs}}\left[AC_{dif}-DC_{dif}-\left(AC_{abs}-DC_{abs}\right)\cdot\left(\frac{n_2-n_1}{n_1}\right)\right] \tag{6}$$

where AC_{dif} and DC_{dif} are the lectures taken by the nanovoltmeter that measures the difference output of both standards when an ac and dc input voltage is applied, respectively; and AC_{abs} and DC_{abs} are the lectures taken by the nanovoltmeter that measures the absolute output of standard 1 when an ac and dc input voltage is applied, respectively.

The use of this new more detailed equation has involved an improvement in the comparator bridge.

New software, with new algorithms that implements equation (6), has been developed. But even more important, the equation (6) has new inputs, before absent in (3). These ones are the lectures of the absolute nanovoltmeter, i.e., AC_{abs} and DC_{abs}, that have to be measured three times in each measurement cycle to get the δ_1 - δ_2 for every cycle according to (6).

4. THE RESULTS

With all these improvements in the comparator bridge CEM has made measurements to compare the ac-dc transfer differences of two thermal converters whose sensibility satisfy the condition ii), [10]. The results of the comparison of both ac-dc transfer differences of the thermal converters are resumed in table 1:

Table 1. Comparison of the results measured with the new bridge against the ones obtained from the PTB calibration certificates of the two thermal converters.

Frequency (kHz)	$\delta_1-\delta_2$ (measure with the new bridge) (μV/V)	$\delta_1-\delta_2$ (from the PTB certificate) (μV/V)
1	0.0	0.0
10	- 0.6	- 0.6
800	- 53	- 52
1000	- 68	-67

Figure 4 shows the comparison of the results measured for the ac-dc transfer difference of one of the thermal converter.

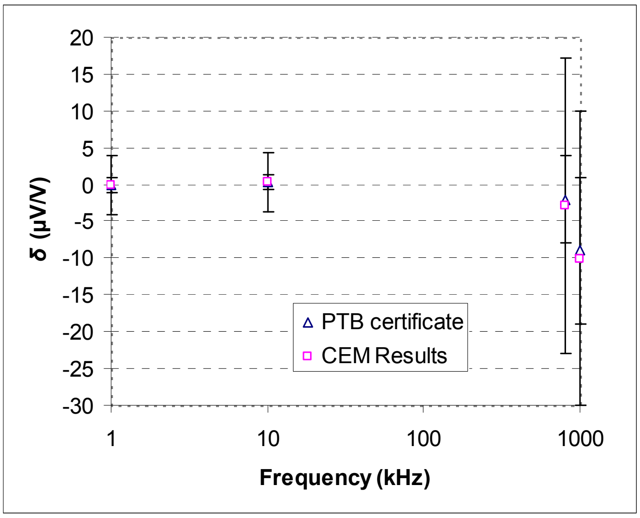

Fig. 4. Comparison of the results obtained with the new bridge developed by CEM against the values certified by the PTB.

These results validate the modifications in the comparator bridge for the thermal converters with quadratic sensibility.

For those thermal converters which do not satisfy condition ii), that is, whose sensibility is not exactly quadratic and the relative difference between both sensibilities is bigger than 5 x 10^{-3}, new measurements are in progress. The strategy is to compare the results made with the new comparator bridge with those measured with the dual-channel method bridge. The results will be presented at the symposium.

5. CONCLUSIONS

CEM has developed a bridge to compare ac-dc standards based on the Klonz equations without assuming simplifications and restrictions.

The error in using the differential method, with the simplified equation, when dealing with thermal converters whose relative difference between both sensibilities is bigger than 5 x 10^{-3} were evaluated. It was show that the error in the ac-dc transfer difference can be as high as 20 μV/V when a thin film multijunction thermal converter, with a sensibility really near to 2, is compared with a single junction thermal converter, with a 1.60 sensibility.

A more complete equation was proposed and the new necessary modifications were made in the old bridge comparator.

The new comparator bridge has been validated after comparing the results measured with this new bridge with those obtained with the old one and will be confirmed with the dual-channel method bridge, both for thermal converters that fit condition ii) before and those that do not.

This new bridge allows CEM to calibrate ac-dc standards like the single junctions thermal converters who usually are far away from an ideal quadratic behaviour.

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