MEASUREMENT OF RESISTOR LOAD COEFICIENTS

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Abstract: The main task of national laboratory for electrical measurements in Croatia (ETF-PEL) is to ensure a system of international traceability for the basic electromagnetic standards. Traceability of primary resistance standards in Croatia is achieved through comparisons with PTB primary resistance standards using our 1 W and 10 kW standards. We established traceability chain for the rest of our standards in our laboratory. The methods for comparing standards [1,2], and a method of calibrating DMMs [3] have been already published. Determination of DMM error has to be done for any combination of voltages applied to resistors, since there is different correction for different voltages. If we keep the same voltages on different resistance standards, in order to reduce DMM calibration runs, we have different power dissipation in each case. For high precision measurements of standard resistors load coefficients (RLC) have to be measured. In this paper we present a method of obtaining RLCs suitable when standard resistors are compared with digital multimeter (DMM).

Keywords: Resistance metrology, standards, load coefficients

1 INTRODUCTION

Primary resistance standard of PEL consists of five standard resistors of 1 Ω, two standard resistors of 10 kΩ and set of standard resistors from 0.1 mΩ to 10 MΩ. Traceability of primary resistance standards in Croatia is achieved through comparisons with PTB primary resistance standards using our 1 Ω and 10 kΩ standards. The resistors from 1 mΩ to 10 kΩ are held in thermostat oil bath with temperature of 23 $^{\circ}$C. Determination of DMM error takes only two measurements, but it has to be done for any combination of voltages applied to resistors. On the other hand, If the same voltages are kept on different resistance standards, there is different load in each case. For high precision measurements of standard resistors load coefficient (RLC) has to be taken into account in order to preserve the traceability chain. In this paper we present a method of obtaining RLCs suitable when standard resistors are compared with digital multimeter (DMM).

2 TRACEABILITY CHAIN

For comparing our standard resistors from 10 kΩ to 1 Ω a voltage ratio of 1 V:0,1 V is used in order to minimise the DMM calibration runs. A critical point in our traceability chain from 10 kΩ to 1 Ω is the comparison of 100 Ω standard with 10 Ω standard with voltages of 1 V and 0,1 V respectively, (table 1). Power dissipation is 10 mW on 100 Ω standard, and 1 mW on 10 Ω standard. After that comparison, a 10 Ω standard is compared with 1 Ω. If the same set of voltages are used, that is 1 V: 0,1 V, power dissipation is 100 mW on 10 Ω, which is 99 mW more when 10 Ω was compared with 100 Ω. Therefore, RLC of 10 Ω has to be found in order to preserve consequently our traceability chain. The 100 Ω standard also has dissipation change of 9,99 mW, but it has very low temperature coefficient and the RLC correction in its case does not bring significant change of value. All our standards are equipped with NTC sensors placed inside them, and they measure temperature inside standard resistor during comparison of standard resistors. Therefore, a correction due to temperature variation of oil inside standard resistors can be made. The sensors placed inside standards give actually only the temperature of oil inside the standard, since it is not possible to make the contact between NTC and the wire due to construction of resistors (Figure 1). The resistive wire that makes resistance standard is always heated more than NTC is suggesting. With our experiment, it was possible to determine how much wire is more heated than the oil around it, and since most of our standards are VEB Mellenbach type, that data is also correct for other standards of that type.
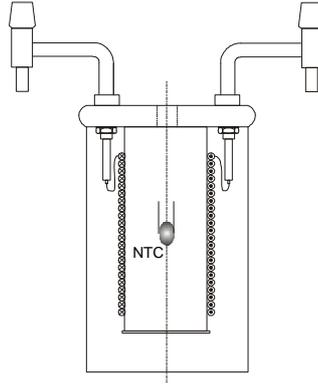
Figure 1. Standard resistor VEB Mellenbach Type with NTC sensor inside

Table 1. Power dissipation ratio

Resistor ratio	Voltage ratio	Power dissipation ratio	Power dissipation change
10 kΩ:10 kΩ	1V:1V	0,1 mW:0,1 mW	0
10 kΩ:1 kΩ	1V:0,1V	0,1 mW:0,01 mW	
1 kΩ:100 Ω	1V:0,1V	1 mW:0,1 mW	0,99 mW on 1 kΩ
			9,99 mW on 100 Ω
100 Ω:10 Ω	1V:0,1V	10 mW:1 mW	
10 Ω:1 Ω	1V:0,1V	100 mW:10 mW	99 mW on 10 Ω
1 Ω:1 Ω	0,1V:0,1V	10 mW:10 mW	0

3   MEASUREMENT METHOD AND RESULTS

The usual method of obtaining RLC is to compare resistors with one power dissipation, then increasing voltage to desired power dissipation, making another comparison and then calculating RLC from the change of resistance ratio. In our case it is not convenient to use this method since we would have to find DMM error at all applied voltages, and also both resistors change value in second comparison. We use another method. For example, to find RLC for 10 Ω standard we make regular comparison of 100 Ω and 10 Ω with voltage ratio of 1 V and 0,1 V (figure 2.). In order to find correct value of RLC the measurement is done for several hours taking many readings. That gives power dissipation of 1 mW on 10 Ω standard. Then we apply AC current with 10 kHz frequency from AC calibrator (Fluke 5200A) via transformer parallel to 10 Ω, which adds another 99 mW of power dissipation to 10 Ω. Then approximately one hour is allowed for 10 Ω standard to heat up, and then another comparison is done.
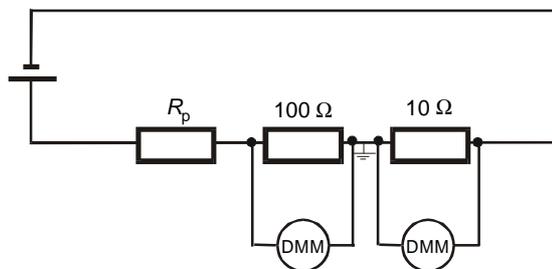

Figure 2. Resistance ratio measurement by DMMs

The AC voltage calibrator is connected through 4:1 ratio transformer (Figure 3.) in order to minimise the current needed from voltage calibrator for desired power dissipation on standard resistors. The capacitor is connected on the other side of transformer to avoid shunting the resistor with the transformer. DMMs on 10 Ω and 100 Ω standards are connected through 10 kHz filter used to cancel AC component, and thus keeping the same voltage ratio on DMMs, that is 1 V : 0,1 V. After waiting for approximately one hour for 10 Ω to heats up, we make second comparison. We still have the same voltage ratio on DMM, that is 1 V : 0,1 V DC since AC current is filtered out, and the ratio will change only because of 10 Ω resistor change due to 100 mW power dissipation in this case. DMM error will be the same in both comparisons since voltage ratio is the same in both cases, and will cancel out. Since the temperature coefficients of our standards are known, and the oil temperature inside standards are measured, it is possible with these two measurements to calculate how much is the wire more heated than the oil around it, and to calculate RLCs for our resistors. Our experiment have shown that 100 Ω : 10 Ω comparison ratio is 76,581 ppm (parts per million) from nominal ratio when 10 Ω has power dissipation of 1 mW, and 76,064 ppm from nominal ration when 10 Ω standard has power dissipation of 100 mW. The difference of $5,17 \times 10^{-7}$ could be accredited to 10 Ω standard resistor different power dissipation in second comparison. For next comparison in chain, that is 10 Ω : 1 Ω, which is done also at 1 V : 0,1 V, and power dissipation of 100 mW : 10 mW, a RLC has to be calculated in order to preserve the traceability chain.
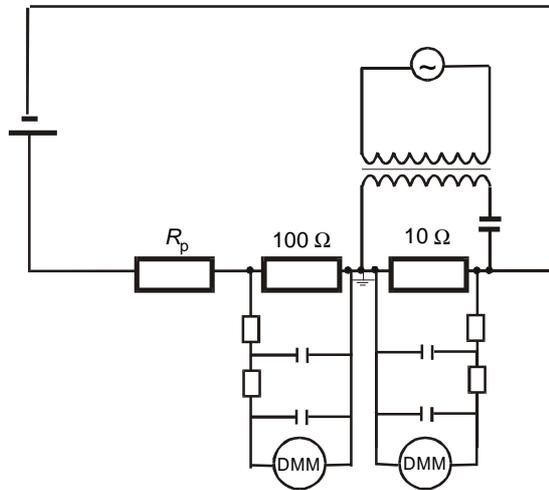

Figure 3. Resistance ratio measurement with RC filters and AC current

4 RC FILTER AND AC CURRENT

For the purpose of filtering AC component, two special filters were built, each for one DMM (Figure 4). The DMM (Hewlett Packard model 3458 A) is cancelling AC component on DC measurement without any filters, but only full periods of sine wave, so for high precision measurements filters have to be used.
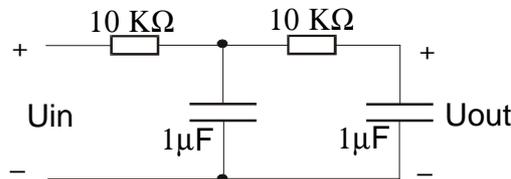

Figure 4. RC Filter

Filters are doubled to effectively cancel AC current. In our case, dissipation of 99 mW on 10 Ω needs 1 Vrms of AC voltage calibrator. Because of superposition of this AC current to 0,1 V DC, DMM has integration error when measuring on DC voltage range. The maximum error during integration time T will be when integration time lasts for n+1/2 periods of AC current with frequency f (Figure 5).

$$p_{max} = \frac{1V_{rms}}{1,11} \cdot \frac{1}{2 \cdot f \cdot T} \cdot \frac{1}{0,1V} \tag{1}$$

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With the frequency of AC current of f = 10 kHz, and the integration time of T = 1 s, the maximum error is p_{max} = 450 ppm. With double RC filter connected to the input of DMM, the influence of AC current is lowered according to expression:

$$\frac{U_{out}}{U_{in}} = \frac{1}{(2 \cdot \eth \cdot f \cdot R \cdot C)^2}$$

(2)

With the selection of R = 10 kΩ and C = 1 µF, the ratio U_{out}/U_{in} = 2,53*10^{-6}. Accordingly, the maximum integration error is then p_{max} = 0,00114 ppm. Experimentally, the RC filter influence on DMMs was checked by comparing 100 Ω with 10 Ω once without filters, and once with filters attached to DMMs, both times without any AC component. The results were in accordance to less than 0,02 ppm, which is inside measurement noise, for that comparison. The filters actually increase only the DMM internal resistance, and the internal resistance does not have any practical influence on the measurement [1]. The filters, however, have to cancel the AC current effectively, and the experiment was performed to check how the
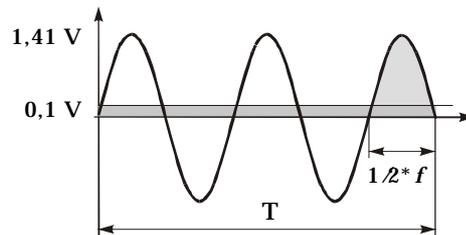

Figure 5. DMM integration error

filters cancel AC component. First, the DMM was connected to DC voltage from stable source, and the results were obtained, then AC current was superimposed, and another measurement was made without the filter on DMM, and then finally the third measurement was made with filter on DMM. The first and the last measurement produced the same result, while the second measurement produced high standard deviation due to AC current causing DMM integration error because of no filters attached to DMM.

5   CONCLUSION

With our method we are able to determine load coefficients of our standard resistors in order to preserve traceability chain. We have developed measurement method suitable for our needs, and found out RLC for our standard resistors. We have also analysed AC current used for acquiring desired power dissipation on standard resistors and RC filters used to cancel AC current from DMM.

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