Electric circuits in the eyes of a thermographic camera

PETR KÁCOVSKÝ
Department of Physics Education, MFF UK, Prague

Abstract

This contribution describes three experiments which require the use of thermographic camera for observing the thermal effects in electric circuits. First experiment shows the construction of the conductive labyrinth in which the Joule heating is used to searching the path between two exits. Second experiment focuses on different thermal capacity of resistors of various size which will show due to uneven heating. Third experiment is dedicated to the thermal differences in alternating current circuit with very low frequency.

Introduction

Thermographic cameras are becoming more frequently used as helpful tools not only in building and other industries but also in schools due to their continuously decreasing price. Various methods how to use thermographic camera in physics experiments were described (e.g. [1-4]), particularly in areas of molecular physics and thermal physics in connection with thermal conductivity, phase transitions or internal energy. This proceeding is a continuation of [5] and extends the usage of thermographic cameras in the field of electromagnetism specifically during studies of thermal effects in electric circuits.

All three experiments are based on detection of the rising temperature which is caused by loosening of the Joule heating generated by electrical current passing through the conductor. For conductor with resistance R through which current I is flowing during time interval t, the Joule heating Q_J is

$$Q_\mathrm{J} = RI^2t,$$

where RI^2 is electric power in the conductor.

1. Thermographic labyrinth

The idea of using heating by the electric current for solving the conducting labyrinth is published e.g, in [6] from where the form of the labyrinth introduced in this contribution is taken. Physics principle is trivial – if we connect two interconnected outputs of the labyrinth to a voltage source electric current will flow between them and raise the temperature of those "corridors" of the labyrinth through which it is flowing. Thermographic camera can easily reveal the whole conducting path. If more different solutions exist the thermographic camera will show all paths whereas longer paths are going to be less heated and therefore visible because of its bigger resistance (we assume homogenous material of the labyrinth).

Construction of the labyrinth is rather more difficult. The possibility to cut it out of the metal foil is for those manually able, and in the case of students not realistic due to safety reasons. Usage of conducting paint for drawing the labyrinth is also largely restricted if you want the paths of the labyrinth to be homogenous in means of electric resistivity. A more usable version seemed to be to build the labyrinth by gradually gluing of copper tape which is on the bottom part equipped with conductive glue and is usually available in ordinary electrician store. In the left part of figure 1 there is a sample of the labyrinth made out of 4 meters of tape of the width of 5 mm. Through measuring of this conductive path it showed that within the matter of seconds its resistivity fluctuates in range from tens of ohms to tens of megaohms even without external impact (movement or change of the position). The probable cause of such instability can be a big count of contact resistance in all perpendicular connections, loss of contact between the metal and the glue or poor connection between the labyrinth and the supply conductors. Whether it's a combination of all of them or one of them dominated, the whole construction is unusable for our experiment either way.

Working model of the labyrinth was managed thanks to conducting plastic which was introduced on PTIF 19 in proceeding [7] by cutting out the labyrinth from kapton foil. Physical form of the kapton labyrinth is shown in figure 1 in the middle and the thermographic picture showing conducting path between its two ends in the same figure on the right.

Figure 1: On the left non-functional labyrinth made from copper tape, in the middle labyrinth from the kapton foil and on the right its thermographic picture after connection of the voltage of 40 V DC. On the thermographic picture we can see the branching of the circuit (right bottom part) and also the spot where the circuit was unfortunately cut and then fixed by conducting paste (clear bright spot in the top left).

2. Heat capacity of the resistors

Two years ago in [5] the author of this article presented among other things a situation where electric current passes through the pair of resistors in parallel with the same resistivity. Thermographic measurements in this case precisely correspond with the physics theory by which the current between the two resistors (and therefore also the electric power in them) is identical – both resistors in that case heat up equally fast.

It needs to be said that this easy conclusion has one very fundamental presumption – in order to get suspected result the size, geometry and material of the resistors must be the same. This experiment shows what happens if this is not fulfilled. Two resistors with resistance of 10 Ω were connected in parallel but the upper resistor weighed more and its volume was also bigger (figure 2 on the left). After connecting a flat battery (voltage 4.5 V) the Joule heat on both resistors develops equally but the bigger resistor has far higher heat capacity and therefore it heats up more slowly (figure 2 on the right). On the contrary, if we disconnect the voltage source the bigger resistor will cool down more slowly as well.

The experiment is captured on video in the Collection of Physics Experiments [8].

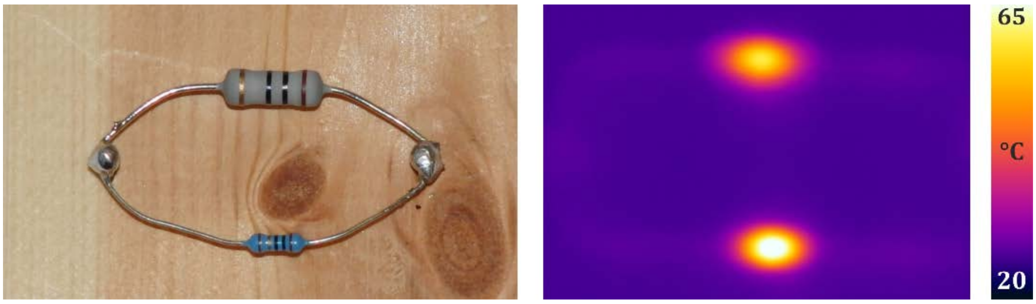

Figure 2: Pair of the diffrent size resistors on the left and IR picture 10 seconds after connection of the flat battery on the right.

3. Temperature changes in the alternating current circuit

In alternating current circuits where the current is periodically changing the electric power on the resistivity elements is also changing. Specifically for periodical course the ideal resistor with resistivity R has electric power $p(t) = RI_{\mathrm{m}} \sin^2(\omega t)$, where I_{m} is a current amplitude and ω is an angular frequency. The course of a function $\sin^2(\omega t)$ indicates that the electric power reaches a double of its maximum and two times its zero value over the time of one period.

Thermographic camera however does not measure the electric power but the temperature of the conductor. Therefore it is necessary to use a conductor which is able to quickly change electric power into the changes of temperature. The best is a conductor with very low heat capacity. It turned out that the best experimental tools for this purpose are the graphite pencil leads whose electric resistance given normal length 6 cm and diameter 0.5 mm is in units of ohms and enables flowing of quite a high current.

In the described experiment the pencil lead was connected to alternating function generator (figure 3 on the left) with effective value of voltage 1 V and frequency 0.1 Hz. It would be even more ideal to use even lower frequency in order for the pencil lead to cool properly in areas of power minima but the common school generators usually do not count with lower frequencies. Either way even the frequency of 0.1 Hz showed to be suitable for this experiment and enables to observe the maxima and minima in five second intervals. Author of this contribution was surprised that the delay between the power and temperature maxima was in his measurements very small.

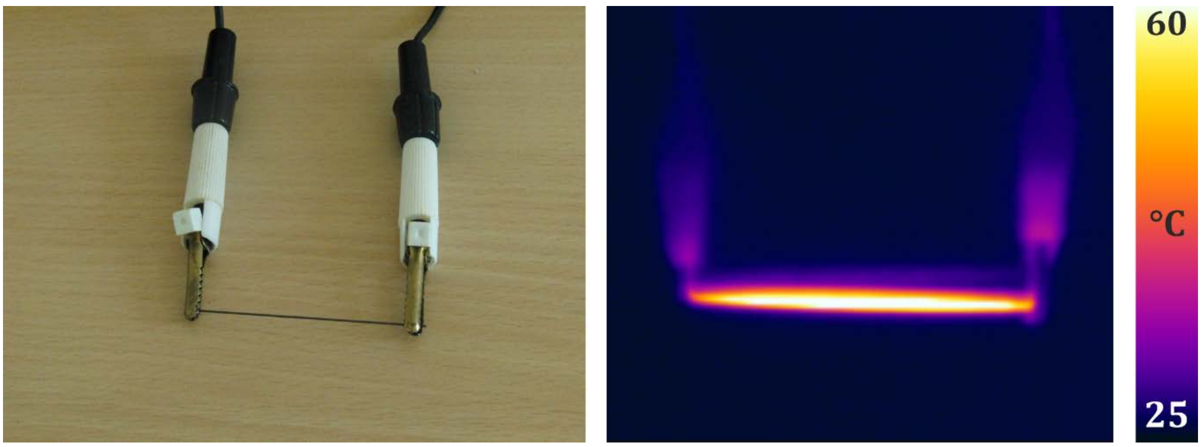

Figure 3: Connection of the pencil lead to the voltage source 1 V AC – in visual and IR range

Acknowledgements

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