



INFLUENCE OF THERMOCOUPLE MEASUREMENTS ON TEMPERATURE IN POWER ELECTRONIC DEVICE

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Abstract: *The paper describes influence of thermocouple on measurements of temperature of power electronic device during measurements. Two important aspects of this influence is considered in the paper. The first one is disturbance of temperature distribution in device. The second one is measuring error caused by disturbance of temperature and by thermal resistance between measured point and thermocouple. The results of analysis, carried out here, based on Finite Elements Method analysis, allows for reduction of uncertainty of the measurement. The results could be applicable in advanced and precise measuring procedures.*

Key Words: *Electronic device heating, thermocouple measurement, FEM modeling*

1. INTRODUCTION

Thermocouples are very popular and useful sensors for dynamic measurements [1] as well as measurements in systems of high efficiency and broad range of operating temperatures (from 196 C to ~2000 C [4, 6, 7]). They exhibit multiple advantages. High accessibility, low cost, small dimensions and good dynamics (~0.1 ms of time constant) are examples. Unfortunately thermocouples have also some drawbacks. The most important are influence on temperature distribution, especially when measured device is small, sensitivity on AC magnetic field and sensitivity on electric field. Described here analysis concerns only the first feature

Described below system of thermocouple measuring temperature of device, e.g. transistor – cf. Fig. 1, will be modeled by FEM (ANSYS [5]) method and analyzed from the point of view of thermal field. Authors give the answer how to derive the temperature distribution of semiconductor or magnetic device operating without thermocouple when one has at the disposal the temperature distribution of the device, to which the thermocouple is coupled.

2. INFLUENCE OF TEMPERATURE ON DEVICE PROPERTIES

Temperature very influences on characteristics of power electronics devices. It is necessary to take into

account temperature influence during designing process. Two important type of devices are considered here under temperature dependence point of view. The first one is power transformer, the second one is magnetic core of inductive component. Both of them exhibit heating due to power losses causes increasing of temperature.

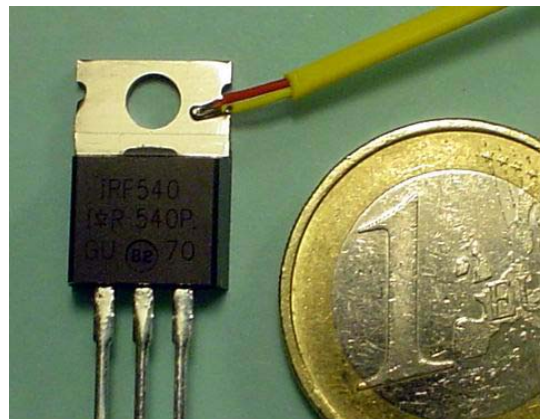


Fig. 1. Thermocouple coupled to IRF 540 transistor[2]

Power transistors are designed for operation near temperature limit, but the higher the temperature the lower maximum current (drain, collector) of the transistor is – Fig. 2.

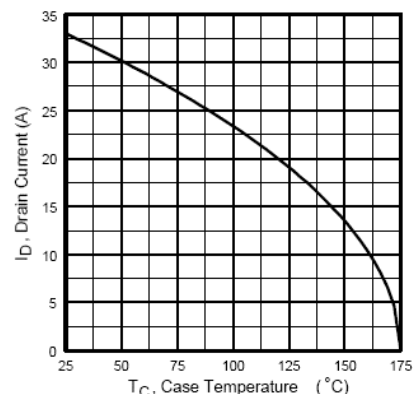


Fig. 2. Influence of temperature on drain current of IRF540 transistor [2]

If allowable temperature (due to needed drain current) is determined by thermocouple it is important to take into account influence of thermocouple on measured temperature.

Also dependence of temperature is observed in magnetic core properties. Dependence of temperature on magnetic permeability for 3C91 Such characteristic of Ferroxcube core is depicted in Fig. 3 [2]. For small inductive components equipped with magnetic core the influence of thermocouple could be considerable. Properties of magnetic core depend on its temperature where the inductance, flux density saturation and power losses of coils or transformers are examples. It is very important in resonant converters where precise value of inductance determines resonant frequency (most often equal switching frequency).

Another important issue in temperature measuring where thermocouple is using is the way it is coupled to the device the temperature which is to be measured. It is necessary to have the coupling of the thermocouple with measured piece reliable and made in repeatable way.

Also the constructional details of thermocouple is important because they are used for development of its computational model – two types of thermocouples are given in Fig. 4. In case of very small diameter of thermocouple wire application of precise resistance spot welding gun is needed.

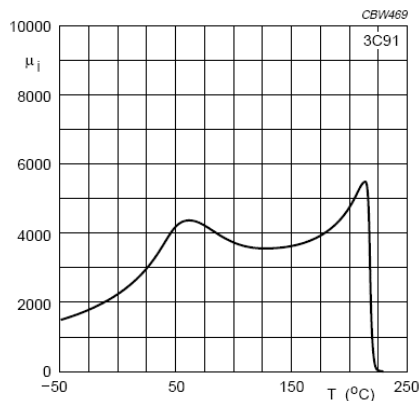


Fig. 3. Influence of temperature on incremental magnetic permeability of 3C91 Ferroxcube core [3]

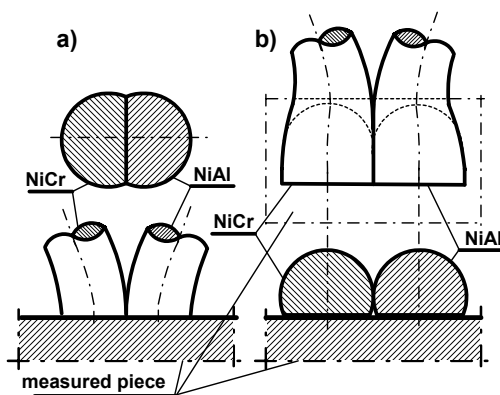


Fig. 4 Two types of thermocouple junctions; a) perpendicular, b) parallel to measured piece

3. SYSTEM THERMOCOUPLE – DEVICE

In order to get the answer to the questions what is the influence of thermocouple on device and what is the temperature of the measured device without attached thermocouple it is necessary to construct the FEM model and carry out the relevant analysis. In order to present some details of such analysis some examples are given that are close to small magnetic core in cylindrical shape and thermocouple type K (NiCr-NiAl) made of $\phi 100\mu\text{m}$ or $\phi 200\mu\text{m}$ wires and shaped as ball at the front end. Dimensions of the magnetic core are: outer diameter 6 mm, inner diameter 5 mm and height 6 mm. The thermocouple is coupled to device using flat spring exerting certain force (thermal conductivity coefficient between thermocouple and device is constant).

4. COMPUTATIONAL MODEL

The computational model was done using FEM method and ANSYS software. 3D model was created. Part of geometry of the thermocouple model with mesh is depicted in Fig 5. The diameter of the thermocouple ball end is approximately 4 times of wire diameter (0.8 mm of ball diameter at $200\mu\text{m}$ wire diameter). Length of the thermocouple wires is 100 mm and they are connected at the ends to cold spots (20°C). Temperature in the model is generated by resistive losses in the core (hysteresis losses are modeled also by ohmic losses). Heat generation is uniform in whole core.

Heat transfer in FEM analysis is modeled by convection and radiation coefficients. Nonlinear characteristic of specific heat was included in the model. Results of analysis are presented under steady-state operation.

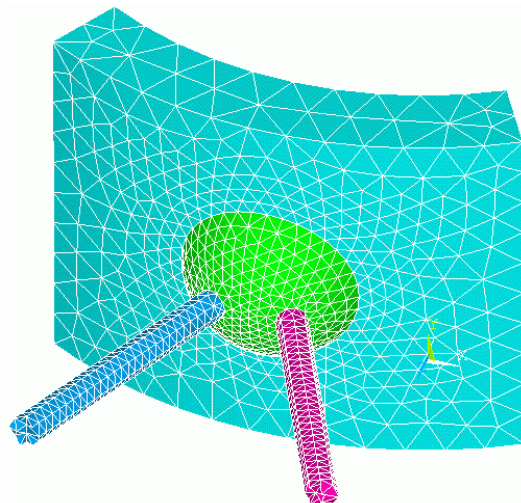


Fig. 5. Geometry and mesh of FEM model

4. RESULTS OF EXAMPLE ANALYSIS

Analysis of detailed dependence of temperature is difficult because it varies on thermal circuit of given measuring system. Because of nonlinearity and many factors influenced on results quantitative generalization is neglected in this paper. Qualitative generalization will be carried out basing on selected example analyses.

4.1. Measured temperature of device

At the beginning temperature measuring error is derived by changing measuring point. The temperature is measured by means of the voltage that appears between ends of thermocouple wires. The temperature of wire at the ball surface (measuring point) is lower than temperature of device. This situation is illustrated by FEM calculations in Fig. 6. It is the case the thermocouple is made of 200 μm diameter wires where thermocouple is coupled to magnetic core cylinder.

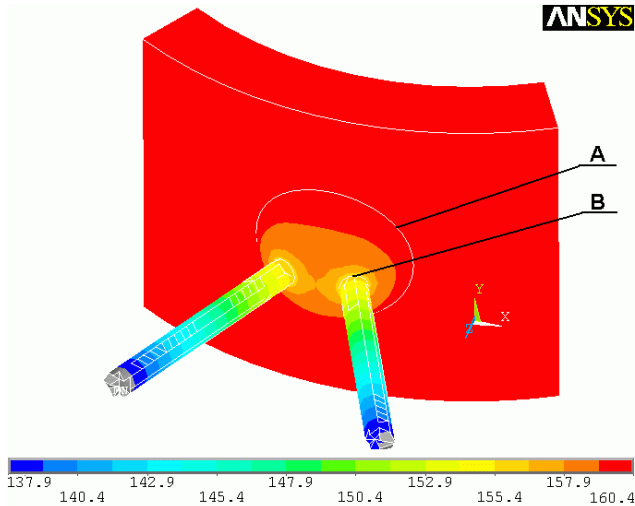


Fig. 6. Example temperature distribution, A – actual, B – measured temperature

Temperature difference in presented result is relatively small (approx. 5⁰C) but it depends on maximum temperature of the measured cylinder and thermal conductivity coefficient (small coefficient value results in higher temperature difference).

4.2. Influence on temperature of device

Another influence of thermocouple during temperature measuring in power electronic device is influence of thermocouple on temperature distribution in measured device. Example temperature distribution in device with connected thermocouple is depicted in Fig. 7.

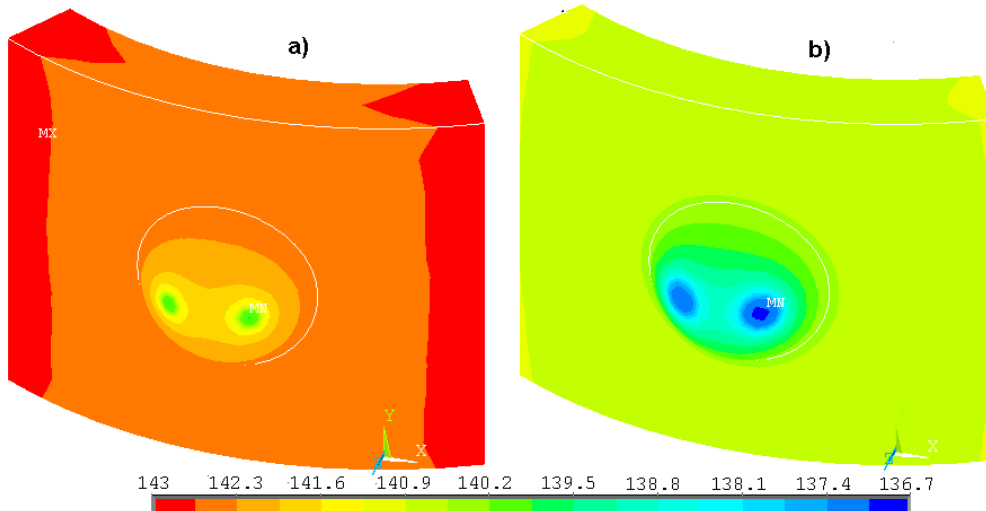


Fig. 8. Temperature distribution with thermocouple wires: a) 100 μm , b) 200 μm ; wires are hidden

Thermocouple causes non-homogenous temperature distribution in device. This disturbance is the reason for change device properties. For example, temperature measured in coil of symmetrical resonant converter cause change frequency in one of channel and detuning whole resonant circuit.

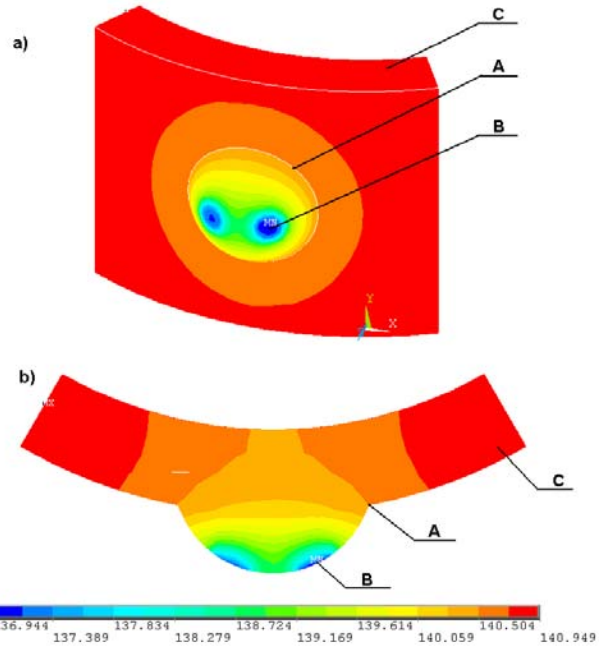


Fig. 7. Temperature distribution (without wires): a) in general view, b) in cross-section of device and thermocouple (wires are hidden), A, B – as in Fig. 6, C – temp. far from thermocouple

4.3. Influence of diameter of thermocouple wires

Because thermocouple wires are connected to cold spots heat generated in device is delivered through thermocouple to the outside environment. Heat transfer is proportional to cross-section of thermocouple wires (influence of length of wires and influence of thermal conductivity coefficients are comparable). It means that the influence of thermocouple is higher if the wires are thicker. It was calculated using FEM. Results are depicted in Fig. 8.

It shows that measured temperature of device is approx. 2°C higher using 100 µm wires than temperature when 200 µm thermocouple wires are used. Additionally, temperature of device without thermocouple connected is 147°C (maximum temperature difference 7°C). Because of advanced technology of measuring devices, nowadays thermocouples made of very thin wires (less than 50 µm) are available, they are of decreased influence of thermocouple on temperature of measured device.

5. CONCLUSIONS

1. Thermocouple influences on temperature of measured device. It also causes non-homogeneity of temperature distribution.
2. Heat removal from the heated device is more intensive when the thermocouple is coupled.
3. Decreasing of diameter of thermocouple wires is a method for decreasing thermocouple influence.
4. FEM model allows to derive the temperature distribution of power electronic device operating without thermocouple basing on temperature distribution of the device with thermocouple coupled.

6. REFERENCES

- [1] Grzesik B., Stepień M., Nowak A., Smółka J.: *Influence of cooling system on the performance of coaxial transformer*, 13th International Symposium on Power Electronics - Ee 2005, Novi Sad, (YU), November 2nd-4th, 2005
- [2] International Rectifier – Datasheets Web Page
- [3] Ferroxcube – Data Handbook 2005
- [4] Athena – The Temperature Control Company - Thermocouple Engineering Data
- [5] ANSYS Verification Manual – ver. 10.0
- [6] Measuring very low temperatures
<http://www.newton.dep.anl.gov/askasci/gen01/gen01316.htm>
- [7] Vernier Tech Info Library TIL #664
<http://www.vernier.com/til/664.html>