Mistakes that can be Made During Thermographic Measurements and How to Avoid them

György Györök[1], Bertalan Beszédes[1]
[1] Óbuda University, Alba Regia Technical Faculty, Budai Str. 45, H-8000 Székesfehérvár
{gyorok.gyorgy, beszedes.bertalan}@amk.uni-obuda.hu

***Abstract* — Thermal imaging or thermography is an extremely versatile measurement procedure. The user-friendly handling of modern thermal cameras is comparable to the widespread digital camcorders. In order to make thermal images that are accurate from the point of view of measurement, adequate theoretical, professional knowledge, experience and, in addition, measurement preparation are required. This article details the most important metrological requirements and practical knowledge of thermographic testing of electrical equipment. The effects of some common thermal camera operator errors, the accuracy and credibility of the measurements are also presented.**

Keywords—thermal imager, heat camera, heat emission, thermal reflection, IR camera, frame rate, depth of field, temperature measurement

I. MEASUREMENT DIFFICULTIES AND SUGGESTIONS FOR SOLUTIONS

The biggest problem arises from the object of measurement itself, from its material [1]. One of the common defects of electrical equipment is the inadequate conductivity of the wires and rails, which are based on screw, spring or crimped contacts [2]. Increased contact resistance – for any reason – leads to heating of the contact in proportion to the load. But because of the low emissivity of metallic, mostly polished surfaces, there is only minimal heat emission [3]. Thus, with the help of thermographic instruments, it is possible to detect contact heat, but it is almost impossible to accurately measure it.

The low emissivity of the surface of the object has a high reflection factor, so our measurement activity must be organized so that the measurement error is minimized [4]. The ambient temperature measurement should be as homogeneous as possible [5]. During the measurement, do not operate a strong heat source such as a radiator, radiant heating, high temperature technology, or other point or line interfering radiation sources in the angular direction of the object's reflected radiation. What cannot be temporarily decommissioned should be avoided using a different angle of observation. If this is not possible, cover it with a screen or other shielding surface, but without touching the interfering heat source.

Both the person carrying out the measurement and his / her attendant as well as the spectators watching the measurement are all sources of interfering radiation, causing reflection. In order to eliminate the heat radiation caused by the heat of our body, it is advisable not to measure at 90° to the object surfaces. It is recommended to measure the object surface at an angle of 70-80°.

If moving the thermal camera changes the position of the projected reflection, it is an actual reflection. If the motion of the thermal camera does not change the position of the reflection, it is a real heat effect. Figure 1 and 2 shows that there is reflection, not a material heat effect. Misleading reflections cause problems with the perception of true object temperatures. There is usually some labeled, painted or insulated surface which, due to the heat of the fault location, will also heat up – due to the good thermal conductivity of the electric conductors.

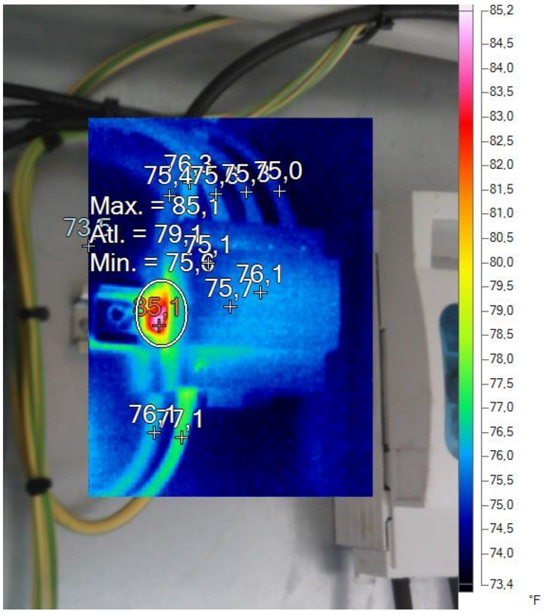

Fig. 1. Reflection of a thermal object

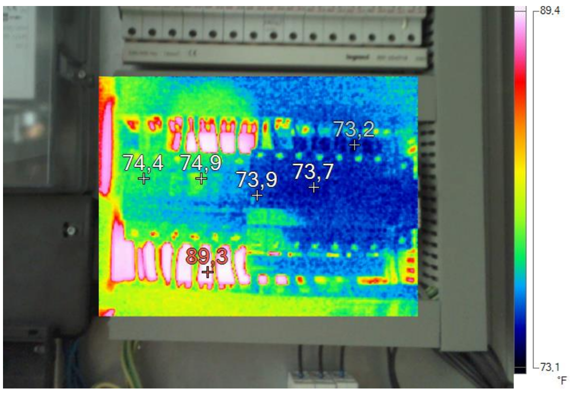

Fig. 2. Reflection of the person carrying out the measurement

II. THERMAL IMAGER ADJUSTMENT

A. Geometric resolution

Thermographic status survey is an effective way of working, but this is true only if we have met the geometric resolution requirement when reviewing. Failure to do so will cause the thermal effects of smaller wires and contacts to go unnoticed (see Fig. 3 and 4). A pre-validation calculation shall be performed with the IFOV (Individual Field Of View or Instantaneous Field Of View) parameter valid for the data thermal camera and the lens combination:

$$p_{x,y} = d\ IFOV \qquad (1)$$

where $p_{x,y}$ is the pixel size in [mm], d is the measuring distance in [m], and IFOV is in [mrad].

The sensor matrix has gaps due to manufacturing technology and the optical system also has imperfections, so in practice multiplying the above pixel size by three to determine the minimum size of the object to be measured.

$$p_{min} = 3\ d\ IFOV \qquad (2)$$

where p_{min} is the minimum size of the object to be measured in [mm]. [6]

It must be guaranteed that the measuring spot is completely cover the measured object. If this is not observed, the measurement spot also includes the temperature of the objects in the vicinity of the measured object. As the measurement spot is averaged, the measurement result may be lower or higher than the actual temperature of the object. The greater the difference in temperature, the greater the error of the measurement.

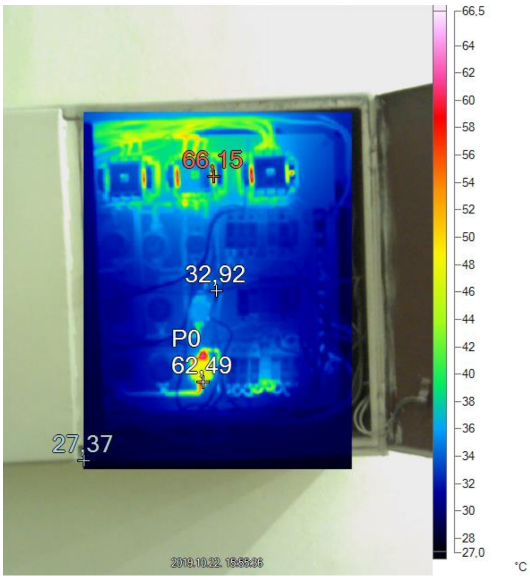

Fig. 3. Overview image with invalid resolution

B. *Overheating lose connection*

All plastic covers covering the elements to be measured must be removed before the thermal measurements. In most cases, the error of the encapsulated device or contact can be clearly linked to the temperature of the outgoing wire, which decreases with distance from the device in question (see Fig. 5).

C. *Frame rate*

The integration time for the lower refresh rate (around 9 Hz) is 110ms. The integration time for the average refresh rate

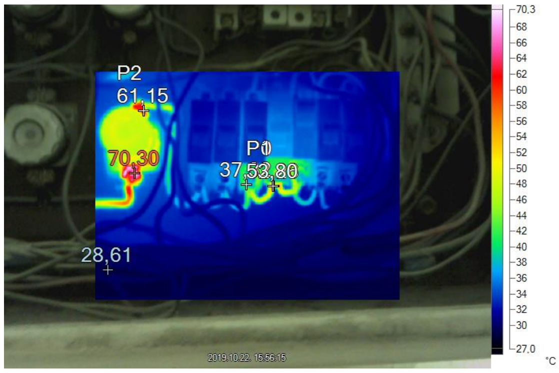

Fig. 4. Overheating lose connection

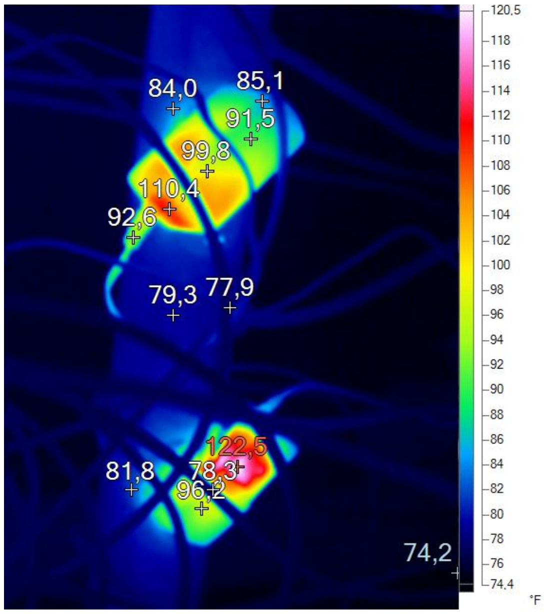

Fig. 5. Thermal conductivity of electric cables

(around 50 Hz) is 20ms. In photography, an amateur's insecure hand can occasionally produce blurry images at 1/125th shutter speed, it means 8ms integration time. A tripod is required to take thermal images that utilize the resolution of the thermal camera, or a thermal imaging camera with a refresh rate of 60 Hz or more.

D. *Focusing*

Inadequate Focusing not only results in blurred thermal images but also causes serious measurement errors. In case of incorrect focusing, only a part of the actual amount of radiation falls on the sensor surface, the rest are projected around it. This results in the measured temperature being lower than real local maximum and higher than real local minimum. The worse the focus setting, the greater the deviation from the true value.

E. *Depth of field*

The degree of error also depends on the depth of field related to the measurement distance. The shorter the distance (and hence the smaller the depth of field), the more critical the focus is. And as the local minimum and maximum geometric sizes of the object increase, the amount of value falsification decreases.

The depth of field range depends on the following parameters:

- the smaller the focal length of the lens, the greater the depth of field,
- the smaller the aperture window, the greater the depth of field range,
- the greater the subject distance, the greater the depth of field.

Therefore, the problem is most common with low-sensitivity microbolometer thermal cameras, especially at short range distances (for example, working with macro lenses or microscope lenses).

The hyperfocal distance (the distance to which the depth of field focuses to infinity when focused) can be calculated as follows:

$$H = f^2 k / r_p \quad (3)$$

where f is the focal length in [mm], k is the aperture, and r_p is the detector pixel size in [μm].

The sharpness of the thermal image extends from the half of the hyperfocal distance to infinity.

III. Practical Temperature Limits

Electrical equipment thermographic surveys shall be carried out only when at least 50% of the rated load is present (see Fig. 6 and 7). With a minimum load of 75%, and in case of a 20-40 degrees in Celsius (or Kelvin) warming relative to the ambient temperature, a revision is required; in case of a 40-60 degrees difference, an urgent revision is required; and in case of a higher than 60 degrees difference, the situation is critical. [7] [8] [9]

With a minimum load of 75%, in temperature limit difference between phases: in case of a 5-20 degrees difference, a revision is required; in case of a 20-40 degrees difference, an urgent revision is required (see Fig. 8); and in case of a higher than 40 degrees difference, the situation is critical. [10] [11] [12]

With a minimum load of 75%, the limits vary depending on the insulation material: in case of rubber insulated cables, it is 60 degrees in Celsius; in case of PVC insulated cables, it is 70 degrees in Celsius; and in case of silicon insulated cables, it is 180 degrees in Celsius. [13]

With a minimum load of 75%, other limit values: in case of plastic casings (depending on the material) max. 50-75 °C; in case of contactors, max. 85 °C; in case of transformers, max. 85 °C; inside electrical cabinets, max. 35°C; power rails, max. 65 °C. For lower load measurements, lower limits apply. [14] [15] [16] [17] [18] [19] [20] [21] [22]

Conclusion

The article attempts to introduce some typical mistakes that can be made during thermographic measurements and how to eliminate them. This paper proposes some further useful measuring recommendations for reducing measurement errors in the area of thermal imaging diagnostics. The proposes techniques are makes more reliable measurements. The author believes the high industrial usability of the shown adjustments.

Fig. 6. Loaded circuit breaker board

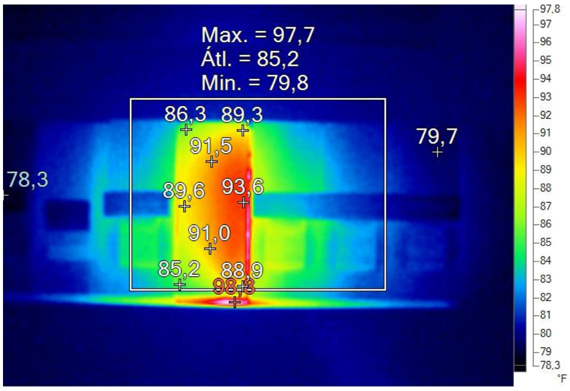

Fig. 7. Loaded circuit breaker

Fig. 8. Overloaded wires

Acknowledgment

We acknowledge the financial support of this work by the Hungarian State, the ITM, the NKFIH, and the Óbuda University under the UNKP 2019 project.

References

[1] Benedict, R. P. Fundamentals of Temperature, Pressure, and Flow Measurements, 3rd ed. JohnWiley & Sons, New York, 1984.

[2] Györök György, Beszédes Bertalan, "Using thermal imaging cameras to test electrical systems," in IEEE International Conference and Workshop in Óbuda on Electrical and Power Engineering : IEEE CANDO-EPE 2018, 2018, pp. 147–152.

[3] John G. Webster. The measurement, Instrumentation, and Sensors Handbook. ISBN: 0-8493-2145-X. ISSN: 1523-3014. 1999

[4] J.M. Lloyd, Thermal Imaging Systems, New York, Plenum Press, 1975, 20-21. pp.

[5] Gerald C. Holst. Common Sense Approach to Thermal Imaging. 2000. 370. p.

[6] Rahne Eric. Thermográfia – elmélet és gyakorlati méréstechnika. Invest-Marketing Bt. 650. p. 2018. ISBN: 9789638740168

[7] G. Györök and L. Simon, "Programozható analóg áramkör megszakításos alkalmazása mikrovezérlő környezetben," in Alkalmazott informatika és határterületei, Székesfehérvár, Magyarország: Óbudai Egyetem, 2009, p. 1–4.

[8] G. Györök and L. József, "The effect of cyclic thermal stresses in the life of PET shrink's heating body," in 8th IEEE International Symposium on Applied Machine Intelligence and Informatics (SAMI 2010), A. Szakál, Ed. Herlany, Szlovákia, 2010, p. 1–4.

[9] G. Györök and L. József, "A Special Case of Electronic Power Control of Induction Heating Equipment," in Acta Polytechnica Hungarica, vol. 11, no. 5, 2014, pp. 235–246.

[10] Ladislav Fozo, Rudolf Andoga and Radovan Kovacs, "Thermo-dynamic cycle computation of a micro turbojet engine," in: CINTI 2016. - Danvers : IEEE, 2016 P. 000075-000079. - ISBN 978-1-5090-3909-8

[11] Rudolf Andoga, Ladislav Madarász, Ladislav Főző, Tobiáš Lazar and Vladimír Gašpa, "Innovative approaches in modeling, control and diagnostics of small turbojet engines," in: Acta Polytechnica Hungarica. Vol. 10, no. 5 (2013), p. 81-99. - ISSN 1785-8860

[12] Maroš Komjáty, Ladislav Főző and Rudolf Andoga, "Experimental identification of a small turbojet engine with variable exhaust nozzle," in: CINTI 2015. - Danvers : IEEE, 2015 P. 65-69. - ISBN 978-1-4673-8519-0

[13] György Györök, Számítógép perifériák, Óbudai Egyetem, OE AREK 8003 ISBN 978 615 5018 57 2, Budapest, 2013.

[14] Széll Károly, Manhertz Gábor, Development of a web-based training module in robotics, 2016 International Symposium on Small-scale Intelligent Manufacturing Systems (SIMS), Narvik, Norvégia, 2016.06.21-2016.06.24., IEEE, 2016. pp. 1-6.

[15] R. Hemza, G. Péter, K. T. József, és S. Károly, „The Effects of Simultaneous Noise and Missing Information in Fixed Point Iteration-based Adaptive Control", in Proceedings of the 2019 IEEE International Conference on Systems, Man and Cybernetics (SMC), Bari, Italy, 2019, o. 1430–1435.

[16] I. K. Artúr, E. Renáta, H. Tamás, S. Károly, és G. Péter, „Optical flow-based segmentation of moving objects for mobile robot navigation using pre-trained deep learning models", in Proceedings of the 2019 IEEE International Conference on Systems, Man and Cybernetics (SMC), Bari, Italy, 2019, o. 3060–3066.

[17] Monika Pogatsnik. Dual education: The win-win model of collaboration between universities and industry. INTERNATIONAL JOURNAL OF ENGINEERING PEDAGOGY 8 : 3 pp, (2018):145–152, 2018.

[18] Monika Pogatsnik. The impact of dual higher education on the development of non-cognitive skills. Gergely Kovats, Zoltan R´onay (szerk.) In search of excellence in higher education Budapest, Magyarorszag, (2019):179–190, 2019.

[19] GYÖRÖK, György, et al. Multiprocessor application in embedded control system. In: 2012 IEEE 10th Jubilee International Symposium on Intelligent Systems and Informatics. IEEE, 2012. p. 305-309.

[20] Gergely, G., Menyhard, M., Sulyok, A., Orosz, G. T., Lesiak, B., Jablonski, A., ... & Varga, D. (2004). Surface excitation of selected conducting polymers studied by elastic peak electron spectroscopy (EPES) and reflection electron energy loss spectroscopy (REELS). Surface and Interface Analysis: An International Journal devoted to the development and application of techniques for the analysis of surfaces, interfaces and thin films, 36(8), 1056-1059.

[21] Gergely, G., Menyhard, M., Orosz, G. T., Lesiak, B., Kosinski, A., Jablonski, A., ... & Varga, D. (2006). Surface excitation correction of the inelastic mean free path in selected conducting polymers. Applied surface science, 252(14), 4982-4989.

[22] Orosz, G. T., Sulyok, A., Gergely, G., Gurbán, S., & Menyhard, M. (2003). Calculation of the surface excitation parameter for Si and Ge from measured electron backscattered spectra by means of a Monte-Carlo simulation. Microscopy and Microanalysis, 9(4), 343-348.