INFRARED EMISSION CHARACTERISTICS OF OVERHEAD LINES AND THEIR INTERSTICES OF THE SURFACE WIRES

Philipp Pretis[1], Stefan Jaufer[2], Jürgen Fabian[1]*, Michael Muhr[1]
[1]Graz University of Technology, Austria
[2]Weidmann Electrical Technology AG, Switzerland
*Email: juergen.fabian@tugraz.at

Abstract: Temperature is one of the commonly measured physical units in high voltage engineering, as temperature allows operators to detect and prevent failures at an early stage. More specifically, temperature monitoring is a very useful tool for an efficient and a safe operation of any electrical equipment because it helps to avoid their outage. With the use of thermographic systems, the specific temperature for every body or area can be assigned, because it measures the emitted infrared radiation, and visualizes the distribution of temperature at the same time. Some of the benefits are: galvanic separation from the high voltage, no influence on the device being tested and achievement of fast measurement results.

The following paper deals with the difficulties encountered when measuring the temperature of bodies with a reflecting surface. An example of a body with a reflecting surface are overhead lines, which are mostly made of aluminium and steel. It is difficult to measure the temperature of bodies with a reflecting surface because not only the temperature of the body will be detected, but the reflection of the surrounding will also be detected. By factoring in the emission coefficient and the temperature of the surrounding, the temperature of the test object can be evaluated. In most cases, overhead lines consist of circular wires. The consequence is that the surface of overhead lines is not a single surface that reflects and emits thermal radiation. Instead it is a structured surface resulting from a complex arrangement of different partial surfaces elements with different radiation angles and geometric arrangements. These elements also form interstices where reflections appear, so they are similar to cavity bodies. Hence, it is possible to achieve useful results even for high reflecting bodies.

Therefore, a simulation model in MATLAB© was programmed to calculate the number of reflections under a specific angle to get information on the radiation power and accordingly the temperature distribution. The plots of the simulation as well as the measured results of the real overhead line model are shown in the full paper. The overhead line temperature is one parameter of the capability of a transmission line. The knowledge of the emission behaviour of the conductor is the key factor to obtain reliable results for measurements using thermography.

1 INTRODUCTION

The first man who ever discovered Infrared Radiation was William Herschel in the 18th century. However, it was his son, John Herschel, who first made it visible to the human eye. He made this possible using thin oil films. As the oil film absorbed Infrared Radiation, it became heated. As a result, the thickness of the oil film changed and, by using interference phenomena, so did the colour of the oil film. Based on this principle, the first infrared camera was developed. It was called “Evaporograf”, which became the foundation of modern thermography systems. Examples for this are the well-known night vision aid, which is based on the visualization of photoelectrons, the infrared vidicons, radiation thermometers, and the line scanner [1]. This paper will only focus on the measurements with detector arrays of micro bolometers.

2 BASICS OF INFRARED MEASUREMENT

In physics, radiation is generally understood as the diffusion of elementary particles and waves. If a physical system transforms from a higher energy level to a lower one, electromagnetic radiation emerges. Anything, with a temperature that is higher than the absolute zero (-273.15° Celsius) can be viewed by such Infrared Radiation Measurement System [1]. The emitted radiation can be divided into different types which are depending on the wavelength (see Table 1).

Table 1: Different wavelengths according to [1]

Name	Region of wavelength
Optical radiation	100 nm …. 1 µm
Ultraviolet radiation	100 nm …. 380 nm
Visible light	380 nm …. 780 nm
Near-infrared	780 nm …. 3 µm
Mid-wavelength infrared	3 µm …. 50 µm
Far infrared	50 µm …. 1 mm

2.1 Detector arrays

Due to the rapid development in the field of microelectronics, infrared systems advanced from electromechanical mechanism to those with arrays. Nowadays, most of the infrared cameras are working with micro bolometer (based on temperature rise of the sensor) or micro QDIP (Quantum Dot Infrared Photodetector) detectors (based on evaluation of wave effects on a PN-semiconductor layer), arranged in an array, which are called detector arrays. This line-up is also the core of such camera, and it can be divided into two main groups. In one group are the cooled arrays, in most cases with QDIP detector, and, in the other group (bolometer), are the uncooled or tempered ones. The two groups are both advantageous and disadvantageous for each technique. Cooled arrays are likely to have very small inhomogeneity, but they need external cooling and time to cool down. When the cooling system malfunctions, the measurement becomes inaccurate. The opposite applies for uncooled arrays, which occurs in a compact form, but restricts the resolution.

The function of micro bolometers is quite similar to bolometers. The basis for this technique is the temperature coefficient α, which is depending on the temperature itself [1, 2]:

$$\alpha = \frac{1}{R(T)} \cdot \frac{dR(T)}{dT} \qquad (1)$$

where: R = Resistance in Ohm (Ω)
T = Temperature in Kelvin (K).

As the temperature changes, so does the resistance and the voltage. With Analog to Digital (A/D) converters it is possible to create a visible frame which depends on the assessed radiation.

Further information about detector arrays can be found in [6].

2.2 Advantages and Disadvantages of Infrared Systems

In order to decide whether or not to use touchless systems, it is important to consider what is needed to be measured.

The advantages of an Infrared System are [1, 3]:

- Rapid measurement is possible (ms)
- Measurements of moving parts
- Measurements of dangerous parts
- Measurements of temperatures of more than 1500° Celsius
- No influence of the measuring system during the measurement
- Measurements of objects with low heat capacity are also possible (i.e. thermal insulators wood, plastic, etc.)
- No damage to the measured object
- Measurement is available from both short and long distances (with distance corrections)

The disadvantages are:

- There are inaccurate results without complex calibrations
- Ambient temperature and humidity affects the accuracy of the results
- Object must be visible, smoke or dust would affect the results
- The accuracy depends on the material and the surface of the object (different emission factors)

2.3 The emission factor ε

The emission factor ε plays a very important role in touchless measurements. It is one of the factors that have a major influence on the precision of the measurements. As a result, knowledge of ε is of great advantage. The mathematical definition for ε is the following [4]:

$$\varepsilon(\lambda, T) = \frac{M_K}{M_S} \qquad (2)$$

where: M_K = specific radiation of a body in W/m²
M_S = radiation of the black body in W/m²
λ = wavelength in meter (m)
T = Temperature in Kelvin (K).

The more the value of M_K approaches the value of M_S, the more radiation is emitted from this body. Hence, the closer ε gets to the value of 1, the more accurate is the result of measurement.

However, ε also depends on the wavelength λ, and the temperature T, but beside these two factors also the

- Composition of the material,
- The surface of the object, and
- The constitution of the crystal lattice

influences ε [1]. There are various tables of emission factors for the numerous types of materials given in literature. Some of these materials are shown in Table 2. For instance, aluminium and steel are the two main materials needed for producing overhead lines. They have low emission factors, which can lead to inaccurate results.

Table 2: Emission factor ε for different materials according to [3]

Material	ε
Aluminium	0.09
Stainless steel	0.45
Silver	0.03
Rubber	0.95
PVC	0.93

2.4 Black Bodies

Kirchhoff's law of radiation (1861), states that the rate of emission of energy by a body is equal to the rate at which the body absorbs energy [5].
Black bodies (also named by Gustav Kirchhoff [1]) are defined as the ideal bodies, which are able to absorb all emitting radiation. Therefore, the formula for the emission factor ε of a black body is always:

$$\varepsilon = 1 \tag{3}$$

including independence from material, wave length and geometric properties.

Till day, no real black body exists, only good approximations of it, for instance, the cavity bodies (see Figure 1). In order to achieve useful results, the inner surface of these cavity bodies used where multiple reflexions occur. There are different ways to get a useful cavity body, and, it is important that the length of the porthole d is many times smaller than the length L [1, 3].

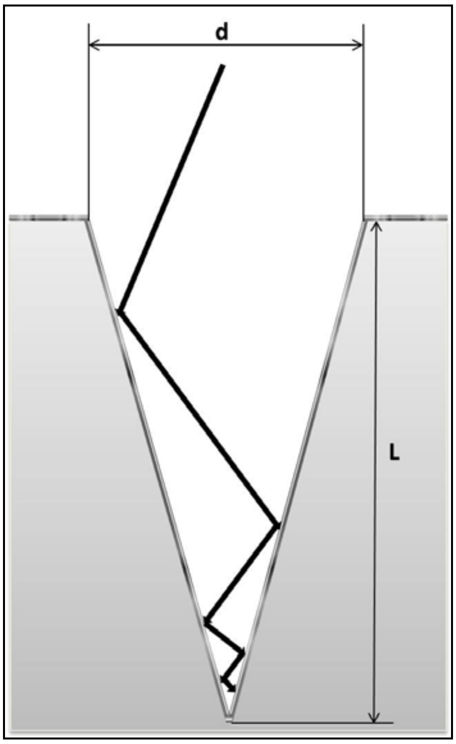

Figure 1: Example for a cavity body according to [1]

3 INVESTIGATIONS

The goal of the investigations was to get useful results of the temperature of an overhead line with a high level of accuracy, although the surfaces of overhead lines are nearly 100% reflective. To achieve this goal, the idea was to make use of the geometric properties of overhead lines. These lines consist of circular wires, resulting in a structured surface. The surfaces also form interstices where reflections appear, so they are similar to cavity bodies (see Figure 2). Thus, the more reflection of the temperature of the body occurred inside this interstice, the better the measurement results. In order to show the dependence of the measured temperature on the reflections, the authors programmed a simulation in MATLAB©. It calculates the number of reflections under a specific angle φ (see Figure 3), plots them, and provides information about the radiation power (see Figures 4 and 5).

As a preliminary step before testing it on real overhead lines, a model was built up to simulate the geometric properties of overhead lines.

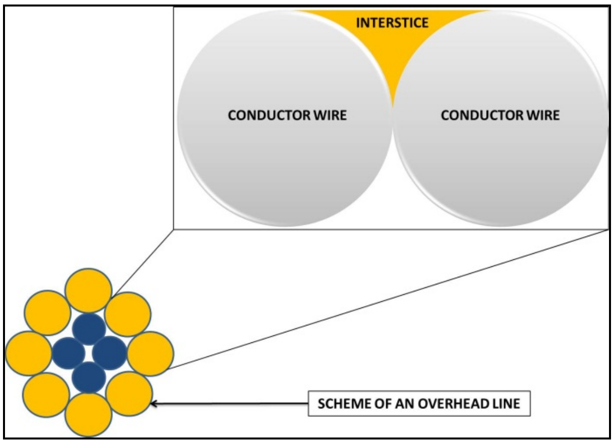

Figure 2: Formation of an interstice by two conductor wires

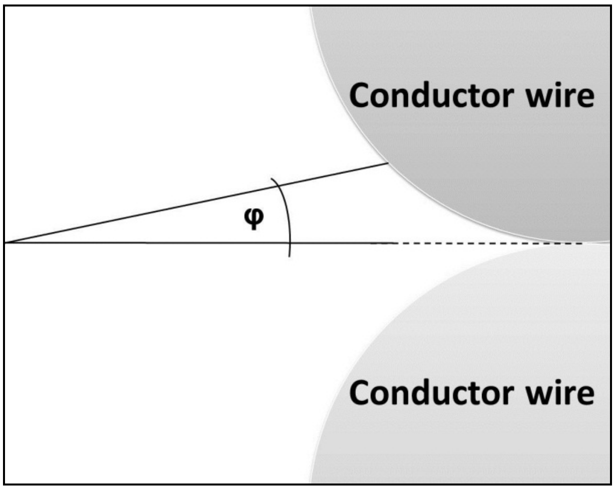

Figure 3: Example of an angle φ which was used for the calculations in MATLAB©

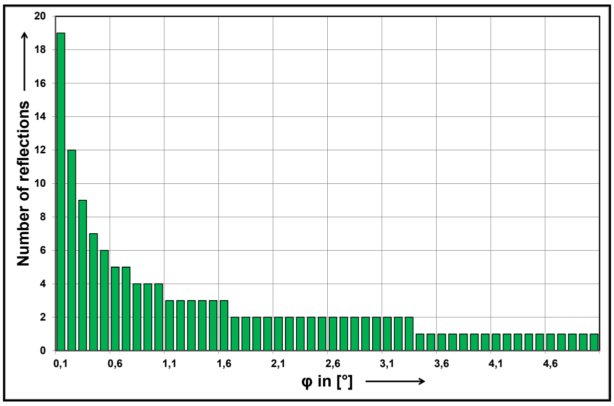

Figure 4: Number of reflections as a function of φ

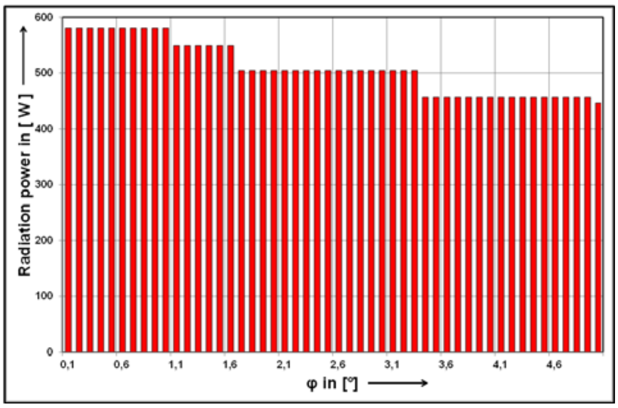

Figure 5: Radiation power as a function of φ

3.1 Tests with the model

The model consisted of two aluminium bottles, which were arranged as shown in Figure 6, and filled with hot water. As to simulate the touchless measurement, thermometers were placed inside the bottles to measure the temperature. The third thermometer measured the ambient temperature. To achieve a mostly homogenous ambient temperature without influence from outside, the whole model was positioned in a box (ε ≈ 1). Three different measurements were made with three different cameras, which were focused on the interstice. The results can be seen in Table 3.

Figure 6: Picture of the model during the measurements with the A320

Table 3: Results of the model

Camera (FLIR)	Solution	Measured temperature in °Celsius	Real Temperature in °Celsius
A-20M	160x120	43.9	49.0
A320	320x240	41.9	43.7
P620	640x480	36.6	41.0

The most accurate measurements were made with the A320, although the P620 has a higher solution, it works with a wide angel lens. Nevertheless, results were very satisfactory although the surface of the bottles were nearly reflecting to a 100% (ε ≈ 0.03).

3.2 Tests with the overhead lines

Two different types of cables were used for these measurements. First, an unused 680/85 ACSR (Aluminium Conductor Steel Reinforced) line, (680mm² Aluminium, and 85mm² Steel) free from impurities. The second was an aged 240/40 line. Moreover, one half of the surfaces were sprayed with black lacquer (see Figure 7, and 8). Using this technique, a good approximation of a black body was created, which was used as a reference for the measurement.

Figure 7: Macro of the used line (left coated, right bare)

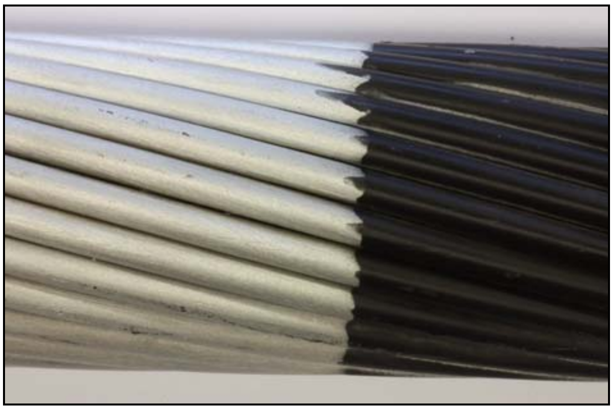

Figure 8: Macro of the unused line (left bare, right coated)

After this procedure both lines were homogeneously heated with an oven, and the temperature was measured with the P620. The results of this measurement can be viewed in Table 4, and the pictures from the camera are shown in Figure 9, and Figure 10. To calculate the ε of the overhead lines, the following values were used: the exact ambient temperature, a default value for the ε of the black body, and the results shown in Table 3. The values for ε were surprisingly high.

Table 4: Results for the overhead lines

Line	ε calculated	Measured temperature in °Celsius	Temperature of the black body in °Celsius
240/40	0.73	44.8	53.0
680/85	0.39	36.0	39.1

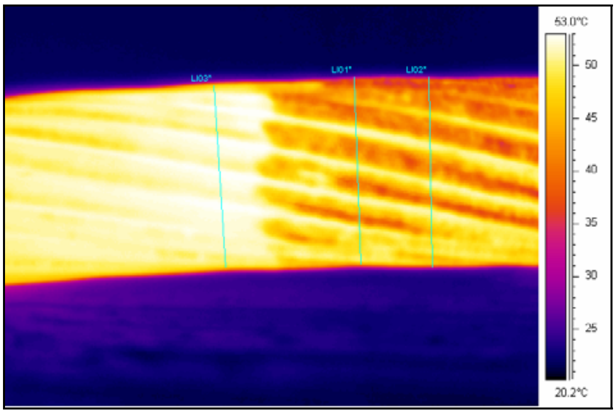

Figure 9: Measurement of the used line (left coated, right bare)

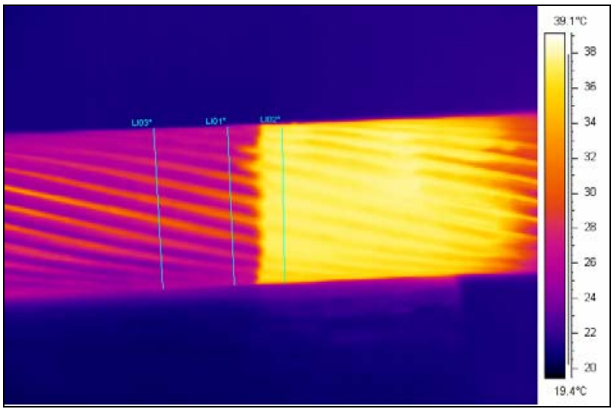

Figure 10: Measurement of the unused line (left bare, right coated)

4 CONCLUSION

As shown in this paper, it is possible to achieve useful results with thermography measurement systems even for predominantly reflecting surfaces (reflexion factor > emission factor). During this study it was revealed that the value of ε for overhead lines is different from what is found in literature. The literature estimated the value for overhead lines to be 0.1. But, as it was mentioned before, the calculated ε of the overhead lines were higher than 0.1. As a conclusion, overhead lines are able to radiate more heat. It is a small step in the consideration of increasing the capability of such energy systems. The temperature is always linked to the transmitted power, and perhaps this goal can be achieved, for instance, with a specific coating for the overhead lines. This coating should be able to reflect the incoming sunlight, but, emit the infrared radiation generated by the current losses.

5 REFERENCES

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