THERMOVISION DIAGNOSTICS OF ELEKTRICAL WIRINGS AND EQUIPMENTS

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Abstract: *This paper analyses problems of thermovision diagnostics measurement. It examines basic principles and application of non-contact temperature measurement. Knowledge of problems of measurement in the infrared radiation allows us to use the thermovision diagnostic methods more effectively and to localise the disturbance which determines the quality of electrical wiring and equipments in the inside distribution of electric energy.*

Key words: thermovision, emissivity, radiation, temperature, diagnostics, calculation

1. Introduction

Fundamental for a non-destructive diagnostics of electrical equipments using thermovision, is the ability to record and to work infrared radiation (heating) to the form of real thermal images of objects, and on the basis of overheating of certain surround, for a detection of a failure (defect).

With non-contact measurement it is able to detect the temperature distribution on the surface of objects using sensitivity measuring of a few Kelvin (or ˚C) decimal. Fig.1. [1]

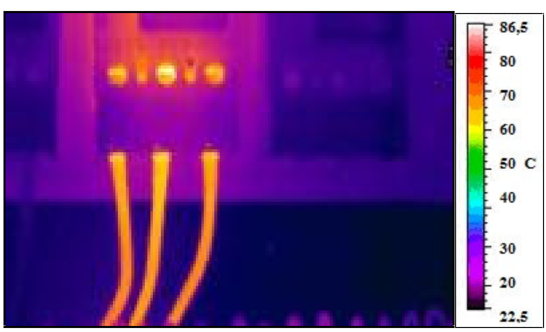

Fig. 1. Thermogram of electric wiring breaker

Infrared radiation is generated as a result of physical processes that take place in the object of radiation; moving atoms, molecules, vibration in crystal lattice, and transition of electrons from one energy level to another. The basic source of infrared radiation is elevated temperature of the source of radiation.

Radiation of hot sources acts like (in respect of surrounding conditions), like visible light. To display temperature fields we can use visualization techniques used in optics. The only differences are materials used for elements of visualization systems, size of values which are derived from the wavelength of radiation, and also sensitivity of sensors for recording the signal.

The surface of the measured object in a state of thermodynamic equilibrium emits electromagnetic radiation and the radiated power depends on the thermodynamic temperature and properties of the surface object.

2. The theory of infrared radiation

Radiation power (intensity) $H(\lambda,T)$ is the only parameter that is measured by infrared receiver and is a function emission coefficient $\varepsilon(\lambda,T)$ and temperature T of radiation source.

$$H(\lambda,T) = \varepsilon\sigma T^4 \qquad (1)$$

This uncertainty (the value of one parameter is subject of another parameter) is one of the problems of measuring the infrared radiation. Emission coefficient depends on the direction from which is the radiation recorded, on the temperature and also on the surface of material.

If the absorption coefficient of incident radiation on the body is equal to α then the temperature of body will grow as quickly as will coefficient α grow.

The body with temperature T which is slightly above the ambient temperature, will provide energy to the surroundings in the form of radiation whose spectral allocation according to Win's law, is moved to the side of long waves comparing to spectrum radiation of incident energy (Fig.2).

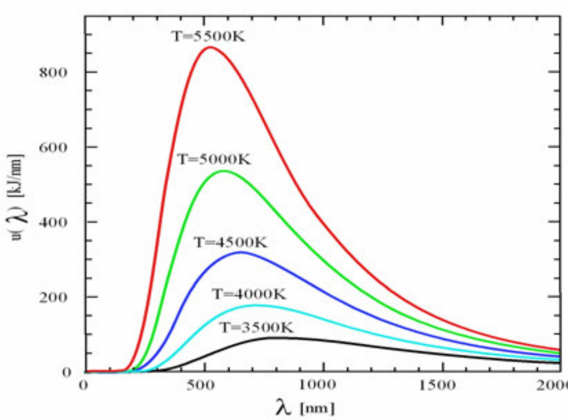

Fig. 2. Dependence of spectral density - intensity of radiation to wavelength

Heating is defined by the relationship α/ε, where α is the absorption coefficient of energy and ε is the emission coefficient (emissivity) of the measured body. [2]

Ratio of intensity radiation of actual body and ideal black body at the same temperature is defined by spectral coefficient of emissivity:

$$\varepsilon_{\lambda}(\lambda,T)=\frac{H_{\lambda}(\lambda,T)}{H_{0\lambda}(\lambda,T)} \qquad (2)$$

It is clear that the coefficient of spectral emissivity is equal to the spectral absorption coefficient.

The research on issues of radiation of solid bodies is based on knowledge of absolute black body; an object which is able to fully absorb the full spectrum of radiated energy.

By Kirchhoff's law the black body is an ideal emitter. Plank defines the spectrum of black body radiation.

$$\frac{dH(\lambda,T)}{d\lambda}=\frac{2\pi hc^{2}\lambda^{-5}}{e^{\frac{hc}{\lambda kT}}-1} \qquad (3)$$

when

$dH(\lambda,T)$ - spectral radiant flux density surface, i.e. radiated power, which is emitted by a unit surface of the black body in an interval of wave length,

h = 6.625.10-34 J.s - Planck constant,

k = 1,38054.10^{-23} - Boltzmann constant,

c - speed of light,

T - absolute temperature of black body in ºK.

Spectral radiant flux density of black body surface depends on the length of the wave and temperature. Flux density of blackbody radiation (Fig. 4) on the range of wavelengths λ_a, λ_b we receive by integrating Planck equation for λ.

$$H_T=\int_{\lambda_a}^{\lambda_b}\left[dH(\lambda,T)/d\lambda\right]d\lambda=\sigma T^{4} \qquad (6)$$

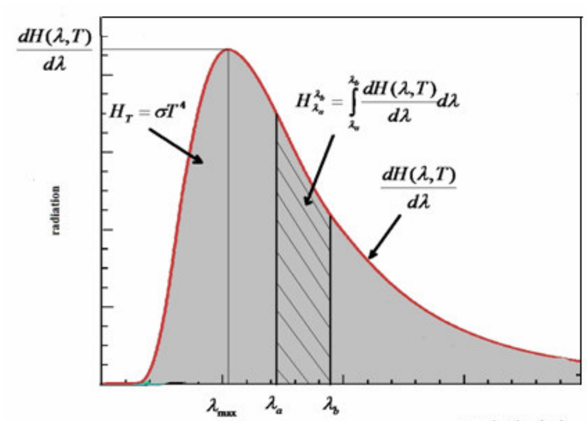

Fig. 3. Radiant flux density at temperature T

Derived Planck equation on temperature dT, we receive change of spectral flux density emitted from black body as a function of temperature:

$$\frac{\partial(dH/d\lambda}{\partial T}=\frac{(hc/k)e^{(hc/\lambda kT)}}{\lambda T^{2}\left[e^{(hc/\lambda kT)}-1\right]}\cdot\frac{dH}{d\lambda} \qquad (7)$$

Measured objects in thermography are mostly with the temperature about T = 300 ºK, where effective measuring is in the spectral range of λ = 10μm and when object temperature is about 750 ºK in a spectral range λ = 4μm, so in both cases $\lambda.T$ = 3000μm and $h.c/k$ = 14388, so if $e^{hc/\lambda kt}$ is much greater than 1 we could use Win's equation in this form:

$$\frac{\partial(dH/d\lambda)}{\partial T}=(hc/\lambda kT^{2}).\frac{dH}{d\lambda} \qquad (8)$$

If we see an object with temperature T_0, which we see on background with a temperature T_f, then thermal contrast in spectral interval $\Delta\lambda$ we can express with equation: [4]

$$C=\frac{\int_{\Delta\lambda}\left[dH(\lambda,T_0)/d\lambda\right]d\lambda-\int_{\Delta\lambda}\left[dH(\lambda,T_f)/d\lambda\right]d\lambda}{\int_{\Delta\lambda}\left[dH(\lambda,T_0)/d\lambda\right]d\lambda+\int_{\Delta\lambda}\left[dH(\lambda,T_f)/d\lambda\right]d\lambda} \qquad (9)$$

3. Experimental analysis

In measurement of electrical equipment and wires we deal with warming of contacts, switches, power cables, clamps, contacts of fuses. In electrical substation temperature of each object is measured, focusing on the expansion joints, junctions, bends and coats drivers.

Thermovision is used to measure warming of connections and clamps in electrical machines, as well as to the measurement of electrical equipments in the internal and external electrical distributing of systems. These measurements warn us about the progressive deterioration of transition resistances of connections, about overheating and deterioration of isolation systems condition, machinery and electrical equipment.

If we have a thermal camera with sensitivity of 3÷5μm and we have two filters with characteristics:

$\Delta\lambda_1$ = 0,2 μm	$\Delta\lambda_2$ = 0,2 μm
λ_{1a} = 3,5 μm	λ_{2a} = 3,9 μm
λ_{1b} = 3,7 μm	λ_{2b} = 4,1 μm

On the Fig.4 we can see the thermogram of measured object BR1 at a temperature T_0 and emisivity ε_0 which we want to know (radiant breaker BR1 on the left) and from the other side we can see parasitic object with temperature T_e, which is larger than T_0 (radiant breaker BR2 on the right).

Emissivity ε_e of parasitic object is high and the distance from measured object d is small. The temperature value T_e and emissivity ε_e is unknown. The thermal camera distinguishes this different temperature of objects, i.e. temperature, which would have absolutely black body in this spectral range.

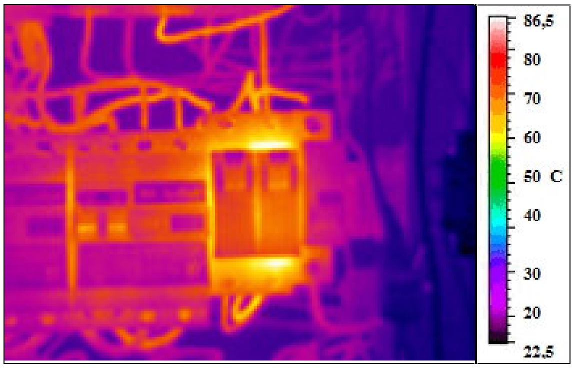

Fig. 4. Thermogram of breakers in electric switchgear

Following values were measured:

$\Delta\lambda_1 : T_1 = 346{,}3°K \quad T_1' = 357{,}4°K$
$\Delta\lambda_2 : T_2 = 344{,}6°K \quad T_2' = 355{,}6°K$

From these effective temperatures values we can calculate the radiant flux density, i.e. radiant flux, which would have a black body at the temperature T_1, T_1', T_2, T_2'.

For T_1'=357,4°K is spectral distribution maximum of radiant flux density by Win:

$$\lambda_{\max} = \frac{2898}{357{,}4} = 8{,}10\mu m \qquad (10)$$

Physically the radiation flux density H in emission spectrum $\Delta\lambda$ at temperature T is represented by the area under the Planck's curve between the wavelengths $\lambda_{1a} = 3{,}5\mu m$ and $\lambda_{1b} = 3{,}7\mu m$.

This area is equal to the derivation of spectral radiation flux density for the maximum top of wavelength 3,6 microns in the range of interval $\Delta\lambda_1 = 0{,}2\mu m$

$$H_T = \int_{\lambda_{1a}}^{\lambda_{1b}} \left[dH(\lambda, T_1')/d\lambda \right] d\lambda = \left[dH(\lambda_1 = 3{,}6\mu m, T_1' = 357{,}4°K)/d\lambda \right] \Delta\lambda_1$$

then

$$H_1' = \frac{2\pi hc^2 \lambda_1^{-5}}{e^{(hc/\lambda k T_1')} - 1} \Delta\lambda_1 \qquad (11)$$

$h = 6{,}63.10^{-34}$ Ws^{-2}, $k = 1{,}38.10^{-23}$ J/K, $c = 3.10^{8}$ m/s, $\lambda = 3{,}6.10^{-6}$ m, $T = 357{,}4°K$, $\Delta\lambda = 0{,}2.10^{-6}$m

$$H_1' = \frac{1{,}240.10^{5}}{e^{(4{,}004.10^{3}/T_1')} - 1} = 0{,}096 W/cm^2 \qquad (12)$$

For others temperatures:

$\Delta\lambda_1 \rightarrow H_1 = 0{,}023.10^{-2}$, $H_1' = 0{,}096.10^{-2}$ W/cm^2
$\Delta\lambda_2 \rightarrow H_2 = 0{,}025.10^{-2}$, $H_2' = 0{,}083.10^{-2}$ W/cm^2

4. Calculation T_e and ε_e of parasite object

From measured values of T_1 and T_2 we can calculate the density of radiant flux H_1' a H_2':

$$H_2' = \int_{\Delta\lambda_2} \varepsilon_e(\lambda) \left[dH(\lambda, T_e)/d\lambda \right] d\lambda \qquad (13)$$

If the parameter ε in this spectral range is constant, then it can be removed by dividing equations

$$\frac{H_1'}{H_2'} = \frac{\int_{\Delta\lambda_1} \left[dH(\lambda, T_e)/d\lambda \right] d\lambda}{\int_{\Delta\lambda_2} \left[dH(\lambda, T_e)/d\lambda \right] d\lambda} = \frac{0{,}096}{0{,}083} = 1{,}156 \qquad (14)$$

then

$$1{,}156 = \int_{\Delta\lambda_2} \left[dH(\lambda, T_e)/d\lambda \right] d\lambda - \int_{\Delta\lambda_1} \left[dH(\lambda, T_e)/d\lambda \right] d\lambda = 0$$

The result of calculated equation is the temperature of parasite object T_e = 361, 5°K. Value of calculated temperature T_{ce} =361, 5°K is near to measured temperature T_e = 357.45 °K:

$$\varepsilon_e = \frac{H_1'}{\int_{\Delta\lambda_1} dH(\lambda_1 = 3{,}6\mu m, T_e = 1070K)/d\lambda} = 0{,}82 \qquad (15)$$

5. Calculation ε_0 and T_0 of measured object

The size of radiation flux density of parasite object BR2 (ε_e = 0.96 and temperature T = 357.45 °K) is:

$$H_e = \varepsilon_e \int_{\Delta\lambda_1} \left[dH(\lambda, T_e)/d\lambda \right] d\lambda \qquad (16)$$

then the radiant flux density of the measured object is:

$$H = \varepsilon_0 \int_{\Delta\lambda} \left[dH(\lambda, T_0)/d\lambda \right] d\lambda + (1 - \varepsilon_e)\varepsilon_e S \int_{\Delta\lambda} \left[dH(\lambda, T_e)/d\lambda \right] d\lambda \qquad (17)$$

If S = 1 then for a measured value T_1 and T_2 we can use equations (5) and as a result we have the equation:

$$\int_{\Delta\lambda_1} \left[dH(\lambda, T_0)/d\lambda \right] d\lambda - 0{,}083 - 1{,}156 \int_{\Delta\lambda_2} \left[dH(\lambda, T_e)/d\lambda \right] d\lambda + 0{,}096 = 0 \qquad (18)$$

Where calculated temperature of measured object BR1 is T_0 = 303, 15°K.

And for emisivity:

$$\varepsilon_0 = \frac{H_1 - H_1'}{\int_{\Delta\lambda_1} dH(\lambda_1 = 3{,}6\mu m, T_0 = 357{,}4°K)/d\lambda} = 0{,}75$$

Following data were calculated:

BR1: T_0 = 303,15°K =43°C, ε_0= 0,75
BR2: T_e = 361,5°K = 84°C, ε_e= 0,82

6. Conclusion

Comparing the results of calculated and measured values; we see that real measured temperature values are influenced by parasite object.

The differences between the calculated and measured values are illustrated on the graph (Fig.5)

On the graph we see measured and calculated temperature differences of breaker BR1 at the current load.

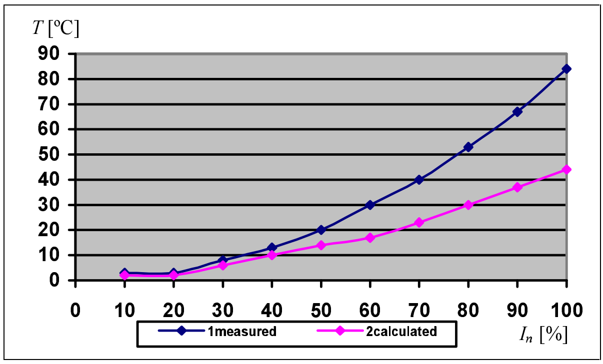

Fig. 5. Dependence of measured and recalculated warming T0 to breaker BR1

Measured temperature of BR1 is higher than calculated because close parasite object influences its temperature. As we can see on the graph (Fig.5) temperature differences depend on the value of current load (I_n).

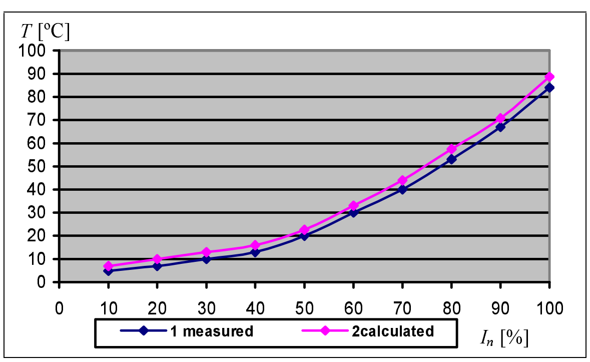

Fig. 6. Dependence of measured and calculated values of warming T_e on breaker BR2

The results of experimental measurements and mathematical calculations of temperature differences for parasitic object we can see on the graph (Fig.6).

In carrying out repeated surveys of professional and technical examinations of selected technical equipments thermovision is an important diagnostic method for determination in energy audits and revisions of power wiring and equipments. Heated objects with higher temperature near measured objects influences values of measured temperature of these examined electrical equipment.

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