INFLUENCE OF CURRENT LOAD, REFLECTED THERMAL RATIATION AND DISTANCE IN THERMOGRAMS' INTERPRETATION

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ABSTRACT: When we choose to diagnose the problems encountered in electric systems using a thermovision camera based on infrared technology, the output of the investigation will be a thermogram which represents a distribution of thermal radiation in a range of colors. In this paper the authors intend to underline the importance of the role played by current load and reflection of thermal radiation in the interpretation of such a thermogram, because both could strongly influence the interpretation if they are not taken into account correctly, and thus will influence the result of diagnosis, causing major problems to the investigated systems.

1. INTRODUCTION

Infrared thermographers involved in predictive maintenance programs often use temperature measurement as a means of quantifying the severity of a problem. Temperature is certainly an important factor in evaluating equipment. However, if you follow guidelines that are based solely on absolute temperature measurement - or on a temperature rise (Delta T) – you run the risk of incorrectly diagnosing your problems. The consequences of such actions can lead to a false sense of security, equipment failure, fire, and even the possibility of personal injury. Understanding the additional factors involved in diagnosis is essential for obtaining productive results. One of these factors is the load or current flowing through conductors. The load can have a drastic effect on the temperature of a component. Changing loads can cause additional concerns because temperature changes lag behind load changes [1].

Also, if near the investigated area there is a heat source, most probably it would reflect its heat over our area, leading to more unwanted heat appearing in the thermogram. When interpreting the thermogram, it would seem like there is a problem at the investigated system or equipment, because the heat reflected on its surface appears in the thermogram as if it were its own heat. There are some factors which lead to a correct interpretation if taken into account, and will be discussed further on.

2. THE RELATIONSHIP BETWEEN CURRENT LOAD AND TEMPERATURE

An experienced thermographer can inspect numerous components quickly with an infrared imager. In addition he or she can make an informed recommendation to prioritize repair schedules based on the condition of the equipment rather than according to a timetable. For the most part, these recommendations are based on temperature criteria. In a perfect world, electrical equipment supply manufacturers would provide these threshold criteria. Currently, very little information is available from the manufacturers. Thermographers are therefore aced with the problem of deciding how to classify equipment as properly functioning, requiring more frequent monitoring, or critical. The problem lies in the fact that there is a wide variety of equipment in the field that was produced by many manufacturers and installed as long as 30 years ago. Thermally characterizing this equipment would be resource intensive. To add to the problem, variability in the conditions under which the equipment is surveyed will have dramatic effects on the results. Several independent organizations have begun to address this need by publishing severity criteria recommendations including the International Testing Association and the Electric Power Research Institute.

The printed word carries a lot of weight, and many people are inclined to follow established guidelines, confident that they are "going by the book." Inevitably, an anomaly will be found and classified as normal; or at the most, requiring maintenance when it is convenient to do so. This anomaly then causes the equipment to fail even though all the guidelines were followed to the letter. So, what went wrong? There are many factors that can cause this situation. Some of these factors are: load, wind, solar heating, emissivity, variations in material properties (i.e. thermal conductivity), and the structure of the target. All too often in the tables, load is ignored, loosely defined, or grouped in with other parameters, such as equipment type, temperature ratings, etc. The following five aspects relating to the importance of current load are examined in this paper: temperature as a severity criteria, using delta-T's vs. absolute temperatures, compensation equations, transient vs. steady state evaluation, and minimum load requirements for accurate thermograms [1].

2.1. Temperature as a severity factor

How hot is too hot? New thermographers ask this question often. It is a legitimate inquiry. If a sincere effort is made toconduct a thermographic inspection in the most efficient manner, it is necessary to locate and repair problems that truly need corrective measures; and, to avoid misdiagnosis of problems, so that efforts are not expended in fixing components that are working properly. So, thermographers are constantly searching for a means of identifying real problems. It is inevitable that temperature is going to be one of the factors, if not the primary factor, involved in the identification of problems. Theclassical approach to the identification of faults has been the utilization of a criteria table with temperatures and characterizations, grade assignments, or suggested actions.

Temperature specifications vary depending on the exact type of equipment. Even in the same class of equipment (i.e. cables) there are various temperature ratings. Heating is generally related to the square of the current; therefore, the load current will have a major impact on temperature rise. In the absence of consensus standards for temperature rise, the values in this table will provide reasonable guidelines.

2.2. Temperature rise

A single temperature reading, of and by itself, is usually insufficient information with respect to diagnosing a potential problem. One must take into account the environmental temperature as well as any other heat loss or gain that can take place. In a transformer heat is generated by eddy currents, (in the core) and by resistance, (in the windings). A correct understanding of the equipment being inspected is essential if one is to make a proper thermographic diagnosis. And, as we shall see, understanding how current loads contribute to temperature is an integral factor in evaluating the severity of a fault.

2.3. How resistance generates heat

To understand why current load is important with respect to temperature measurements, it is necessary to understand how heat is generated in electrical equipment. There is a fairly straightforward relationship between current I, resistance R, and power P. The power generated in a circuit is the product of the current squared and the resistance. Or:

$$P = I^2R$$

All current carrying conductors used in electrical equipment have some resistance. Therefore, power will be generated in any conductor carrying a load. Properly operating electrical equipment will have a thermal signature that depends on the type of equipment, environmental temperatures, current load, and how long the equipment has been under load.

In general, conductors that have been carrying a reasonable current load continuously, over an extended period of time, will look hotter than their surroundings. It is normal for conductors to heat up. Most guidelines, as indicated, suggest that thermographic surveys should be conducted at maximum load, or at some reasonable percentage of maximum. Most electrical faults areessentially high resistance paths, caused by loose connections, corrosion, etc. If we assume that resistance remains fairly constant, consider what happens as the load increases.

- If the load doubles, the power increases by a factor of four.
- If the load triples, the power increases by a factor of nine.
- If the load quadruples, the power increases by a factor of sixteen.

These values clearly indicate the importance of current load with respect to power dissipated through a high resistance path. To quantify and examine this more closely, a special test fixture was constructed. The resistance was kept constant, current load was varied, and temperature measurements were taken.

2.4. Load-temperature correction factors

Correction factors have been offered as solutions for dealing with load problems. The data clearly shows that temperature rises will vary considerably with different loads. If the load doubles, from 0.11 amperes to 0.23 amperes, as indicated above, the temperature rise increases almost by a factor of four (3.7). If one considers this, as well as the fact that the power produced by a resistive element is proportional to the current squared, it is not difficult to ascertain how correction factors have been developed using current ratios squared in their computations.

Correction factors should be used with a skeptical eye. There are just too many factors involved in the generation and dissipation of heat in electrical equipment to quantify temperature and current in a reasonably definitive manner. Here are some variables to consider:

- Emissivity variations - This can result in differential radiative cooling.
- Thermal conductivity - A good thermal conductor will act as a heat sink and conduct heat away from the source.
- Insulation – A component that is well insulated electrically, such as an elbow connector, is also well insulated thermally. It is very difficult to ascertain the real internal temperature rise without extrapolating about load increases.
- Electrical resistance - Faulty connections will change resistance.
- Load variations - Changes in load do not result in immediate changes in temperature. Experience has shown that it takes forty-five minutes or more for a component to become thermally stable after a load change. This concept will be discussed in more detail.
- Wind – The movement of air over a component can drastically affect its temperature.

We do not want to discourage thermographers from using correction factors. If a circuit is observed operating at a reduced load, some kind of prediction or extrapolation, inevitably, will be utilized to make a judgment as to what will happen when the load increases. Through experience in the field, and experimentation in the laboratories and classrooms, thermographers are constantly refining their methods. Like anything else, there is an error budget to consider. Do not become over confident, simply because you have an equation. One should recognize that these correction factors have a limited value. If used with caution, they can assist in finding real problems. If accepted and used as definitive scientific laws, they can lead to errors.

These errors, as shown above, may be unacceptable with respect to severity criteria used for inspections.[1]

3. REFLECTION OF THERMAL RADIATION

In order to compensate for the radiation reflected in the object and the radiation emitted from the atmosphere between the camera and the object, a parameter is used, called *reflected teperature*. If the emissivity is low, the distance very long and the object temperature relatively close to that of the reflected it will be important to set and compensate for the reflected temperature correctly [2].

The following figures exemplify very well the powerful “amprent” left by the reflected temperature on thermographic images.

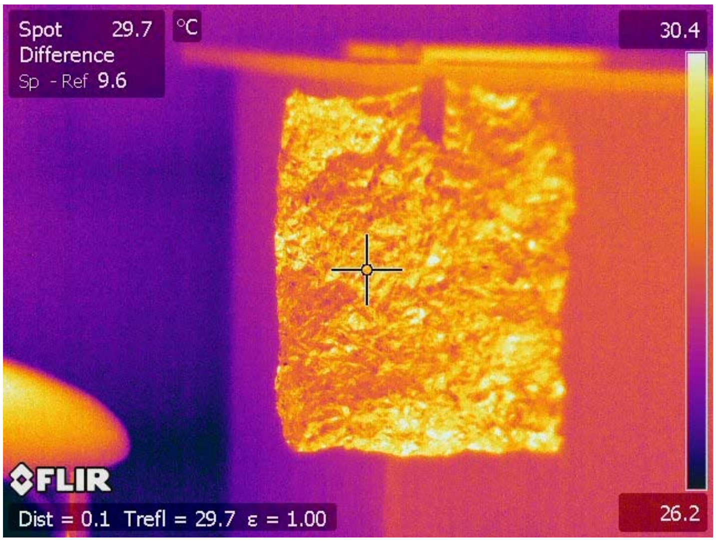

Figure1. Thermogram taken with Flir Systems ThermaCam B620 of an aluminum foil which reflects thermal radiation [3]

Figure 2. . Thermogram taken with Flir Systems ThermaCam B400 of an aluminum foil which reflects thermal radiation [3]

Figure 3. Thermogram of a high voltage switch heated at the superior side [3]

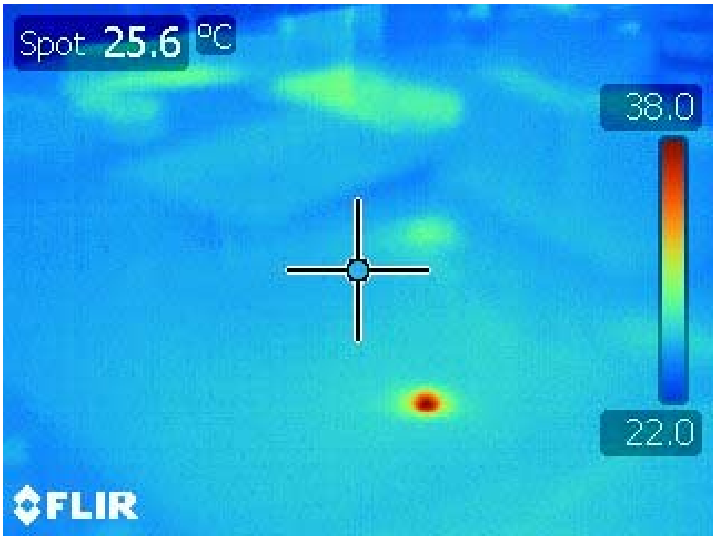

Figure 4. Thermogram of a shining porcelain table which reflects radiation of other objects and shows a “hotter” spot where a pencil hit the surface and released thermal energy[3]

In figure 1 and 2 are thermograms taken with Flir Systems cameras which represent an aluminum foil which reflects thermal radiation. Measuring the value of reflected temperature on the object to be observed is a technique used before any thermographic measurement in order to set the correct reflected temperature on the camera. The measurement will be then made from the same position. If the amount of reflected temperature on the inspected equipments is high, a medium area value will be used, but the errors might appear in measuring. If the aluminum foil is not used and the value of the reflected temperature is very high in some parts of the thermogram, as in figure 3, the interpretation of the image can be wrong.

In figure 4 is a thermogram of a shining porcelain table which reflects radiation of the lights above and shows a “hotter” spot where a pencil hit the surface and released thermal energy. When we see the green color, for example, we may incline to say well, there is a higher temperature than the areas colored in blue. It is false. Only the spot which contains a color gradient is indeed, hotter, because it had recently hit by a pencil, and the kinetic energy of the pencil transformed into thermal energy.

Some tips to recognize reflected temperature in a thermogram are:

- the hot spot or area moves on the observed object as we move the camera.
- real heating presents color gradients, reflected heat doesn’t.
- use a cardboard to shield the inspected object.
- don't stand in front of the inspected object in order to avoid your own reflection.

It is also wrong to say that if we measure the temperature difference between two components of the same type we don’t need to worry in case the focalization isn’t correct, or if we didn’t set correctly the emissivity and reflected temperature, because the errors will be identical in both cases and will cancel themselves mutually.[4]

CONCLUSIONS

Current load is an important factor to consider when conducting thermographic inspections of electrical equipment. For a resistive fault, the power generated is proportional to the current squared and the resistance (P=I2R). It would seem that there is a fairly straightforward relationship between the load and the temperature rise. However, there are just too many variables to consider to accurately predict the temperature rise expected at increased loads; even if there are no emissivity errors, and the component has reached steady state operation. Experimentation has shown that correction factors used to calculate temperature rises might not be accurate enough to comply with severity guidelines. The correction factors can provide a reasonable error budget, which can assist thermographers in analyzing potential problems. The element of time must be considered when trying to correlate current load and temperature rises. The thermal time constant of components is a means of quantifying the time delay between load change and thermal stabilization. For a typical fused cutout switch, it takes about forty-five minutes to reach steady state (adequate for a reasonably accurate temperature measurement) after a load change. Thermographers need to understand how current load, time, and temperature relate to one another. This knowledge will improve efficiency when conducting electrical inspections [1].

So, a thermographer’s job isn’t easy. The responsibility for a diagnosis is entirely his, thus he must be extremely careful and take into account all the outside factors which may influence his measurement, because if he interprets the thermogram wrongly, the whole process is suffering. All these factors depend on the inspected process, meaning that they can be different from a process to another or same factor can be found in every measurement (such as environmental temperature). As the case we analyzed in this paper, when a thermographer inspects an electric system, equipment or circuit (or other processes), besides the emissivity of the material from which the observed object is made of and ambient temperature, the thermographer must always take into account the reflected temperature and the current load.

4. Bibliography

[1] Bernard R. Lyon Jr., Gary L. Orlove, and Donna L. Peters - *The relationship between current load and temperature for quasi-steady state and transient conditions,* Infrared Training Center, 16 Esquire Road, North Billerica, MA 01862-2598, © 2002 Infrared Training Center;

[2] Flir Systems - User’s Manual for ThermaCam^{TM} Quick View, version 1.1+

[3] Pictures taken with Flir Infrared cameras B and T series, property of ITCC Romania, during the Laboratory of the Infrared Training Course, level I thermographer.

[4] ITCC Training Course for Thermographer level I, Bucure□ti, Romania.