EMERGING TECHNOLOGIES

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Infrared Inspection

Infrared thermography is the use of infrared radiation to qualitatively and quantitatively express heat signatures and heat differences. Infrared inspection can help identify weak connections in an electrical box, uneven heating of pump windings, overheating of bearings, and many other possibly devastating problems well before any failure occurs. The use of thermography as a preventative tool can increase system reliability and efficiency.

Infrared radiation is emitted by any object that is warmer than absolute 0 (0 Kelvin or negative (-) 273° Celsius). Infrared radiation is just outside the visible wavelength region of the electromagnetic spectrum. The eye cannot see infrared radiation. In order to get an infrared image, a detector is used to detect the wavelength of the radiation. This wavelength is related to a specific temperature, and a color is then assigned to that temperature or wavelength. Generally, a gradient color scheme is used in color thermal images, so that the hotter the object the whiter the image, and the cooler the object the darker the image. Upper-end thermal camera systems have the ability to quantitatively describe the temperature of a surface to 8/100ths of a degree (Celsius). Spot radiometers can provide spot temperatures, without an image, with an accuracy of 1-2 degrees Celsius.

Equipment

There are two main categories of infrared inspection equipment available for customers.

Spot radiometers are the simplest type of infrared sensing devices. They are generally hand held point-and-shoot devices that detect a temperature at one point. The temperature of that specific point is displayed digitally to the user and can be recorded by hand or datalogger. It can be difficult to determine what point is actually being inspected. Some spot radiometers use laser pointers as a guide for inspection. Generally, spot radiometers are used to scan an entire surface for changes in temperature.

There is also a full line of thermal imaging equipment varying in quality and price. This equipment has the most potential for accuracy, if used correctly. FLIR Systems™ is the largest producer of infrared imaging equipment. The ThermaCAM™ PM 695 is one of the newest IR inspection tools on the industrial market. It is the size of a small video camera or a large digital video camera. It features both thermal and visual imaging capabilities, as well as an internal filing system that allows the user to either type in or voice-record information about the equipment being inspected. The filing system links multiple infrared and visual images to the text and voice recorder so that all information can be integrated when the report is generated at a later time.

FLIR provides report software (ThermaCAM QuickReport™) that automatically generates the entire survey report. The user simply drags all relevant inspection files into the report program, and the digital and thermal images, text and voice recording for each piece of equipment inspected are organized in the report automatically. Thermal images from the ThermaCAM™ PM 695 provide a temperature measurement for each image pixel with accuracy of 8/100th of a degree Celsius. Using either the camera or the software on a PC (laptop or desktop), the user can view temperatures of any pixel on the image. Graphs can be generated showing temperature changes in any direction along the image. Reports for a site inspected multiple times can be linked to examine thermal trends (for example, if a bearing was inspected every six months for 5 years, the average temperature of the bearing during each inspection may increase as it wears. The software can automatically link and display this trend, providing information that the bearing may need replacement).

What is Needed for Your Application?

Infrared technology can be used for a myriad of applications. Probably the largest potential in the water industry is the inspection of motors, bearings, and electrical connections and circuits. Faulty connections, misaligned shafts, motor insulation breakdown causing winding shorts, and other problems associated with electrical motor driven pumps can cause inefficient use of electricity, system outages, and even risk to human life. Each of these problems results in excessive heat generation, which may be pinpointed before a catastrophe occurs with the proper use of infrared technology.

The equipment used for infrared inspections has a wide range of costs. Low-end spot radiometers cost under $100 and infrared video cameras range in pricing from $25,000 – $80,000. The ThermaCAM™ PM 695 with software is $55,000 for private agencies and $45,000 for government agencies. This equipment, including software, can be rented for about 10% of the total equipment cost per month ($5,500 or $4,500) with a minimum rental time of generally 2 weeks ($2,750 or $2,250).

A one-week training course in thermography is recommended before any IR inspection, and costs approximately $1,500 (Level I certification).

Consultants can be hired to inspect facilities for between $600-$1200 per day. Many inspections will only take one day, including a report and presentation. Of course this depends on the number of sites the consultant must inspect. The consultant should be certified with at least an ASNT (American Society for Nondestructive Testing) Level II certification. References are also recommended when selecting a consultant.

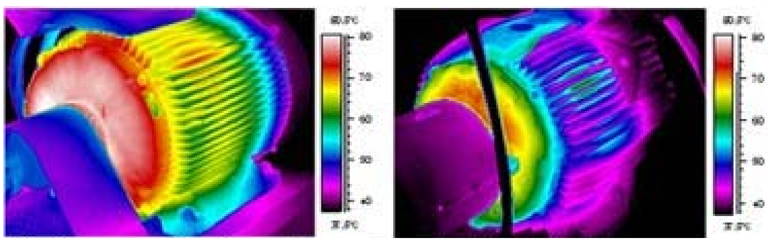
Thermographic Inspection Overview

AC Motors

Motor temperature ratings signify the maximum operating temperature, at which the motor insulation starts to break down. For every 10° Celsius over that rating the motor life is reduced 50%. The ratings are based on the hottest spot inside the motor. External temperatures, those indicated using infrared technology, are usually 20° Celsius lower.

A few thermal patterns associated with various motor problems are outlined below (from Jack Nicholas, 1997 Thermal Solutions Conference Proceeding, ASNT):

- A hot spot or uneven heating can indicate a resistive imbalance
- An overall temperature increase or uneven heating can be associated with an inductive imbalance in the stator due to a shorted coil.
- Shorted coils in an AC synchronous motor will have cooler poles on the rotor, while hotter poles are associated with damaged pole laminations.
- Rotor coil shorts may cause uneven heating between the slip rings and speed control.

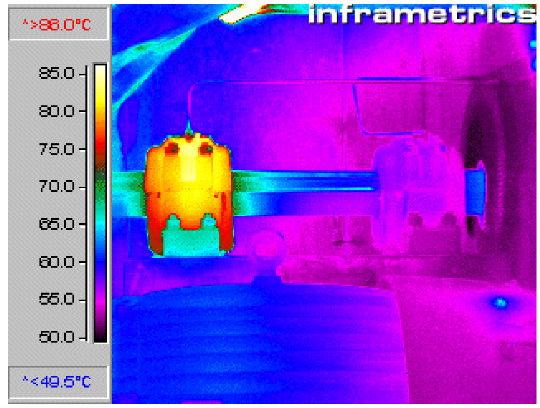


When comparing these two motors, the thermal patterns are similar, but the motor on the left has a markedly higher overall temperature. *Image courtesy of the Academy of Infrared Thermography*

Bearings

There are a number of causes for bearing failures, but the results are always the same. The bearing gets progressively hotter until the failure takes place. A bearing can easily be tested using infrared temperature sensors by: a) comparing the bearing with its own housing (the bearing and housing should be the same temperature); b) comparing the bearing to a similar bearing under the same load in the same conditions.

Determination of heat anomalies can be difficult if comparisons are not available. There is no specific temperature that indicates bearing failure. A trend showing increased heating over time is one method used to determine heat anomalies. This requires regular inspection of equipment.



Two bearings under the same load conditions. One bearing is significantly warmer (~30 degrees Celsius) than the other. *Image Courtesy of Snell and Inframetrics*

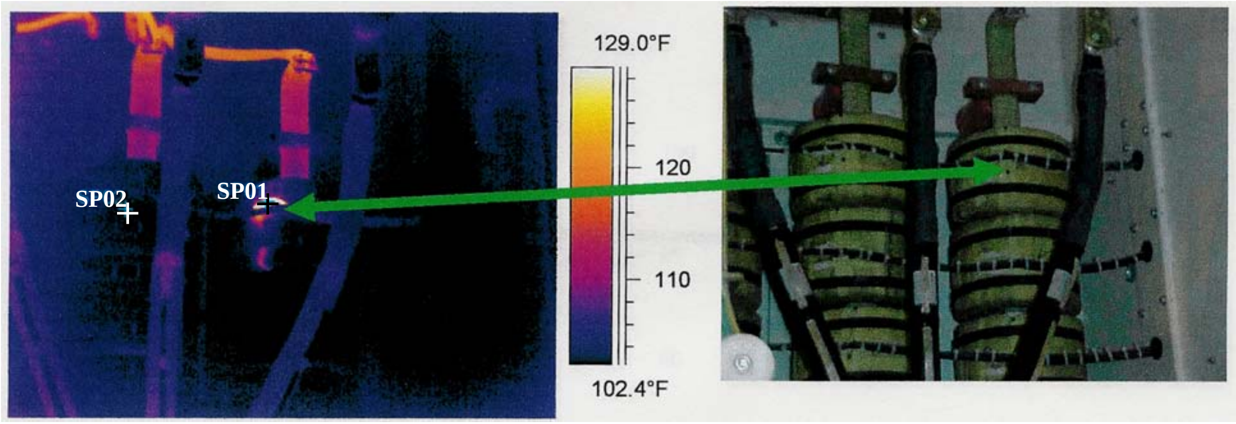
Excessive heat and bearing failure is caused by friction due to misalignment, improper lubrication, lack of lubrication, contamination of lubrication, or excessive loading.

Electrical Connections and Circuits

There are a number of electrical problems that can exist and be identified using infrared technology. Poor connections, overloaded wires, corrosion, and a number of other possibilities can cause hot spots.

Overheated fuse. Could be caused by a poor connection or the fuse failure. *Image courtesy of the Academy of Infrared Thermography.*

As with bearing analysis, it can be difficult to determine whether a hot area is an anomaly or a normal condition. Comparison with a



Anomaly on a hot "A" phase CT connection. The arrow indicates the same spot on both images for reference. These images were obtained from an MWD infrared inspection report. The temperature scale between the images is set by the report writer and does not represent the full range of temperatures in the infrared image.

similarly loaded connection can be the easiest way of spotting an anomaly, but this is not always possible. Another possibility is to look at the differential between the ambient temperature and the temperature of the anomaly.

Early detection of faulty electrical connections cannot only save in the form of unexpected downtime, but can also prevent fire and human injury.

The causes of problematic connections are usually simple. Basic causes are loose and/or corroded connections, or inappropriately used connections (overloaded connections).

Metropolitan Water District of Southern California

Metropolitan Water District of Southern California(MWD) uses thermographic inspection as one type of preventative maintenance throughout the district. Of course, some facilities in MWD are much larger than typical agricultural water agencies. Nevertheless, similar problems can occur in any size facility that has electrical connections and high speed moving parts. Duane Putnam, Chief Hydroelectric Specialist for MWD oversees most preventative maintenance inspections throughout the district. During a tour of the Diamond Valley Lake, East Side Dam facility he pointed out four anomalies that were found during the latest inspection. One important fact to note is that the facility is only 2-3 years old, yet problems already exist.

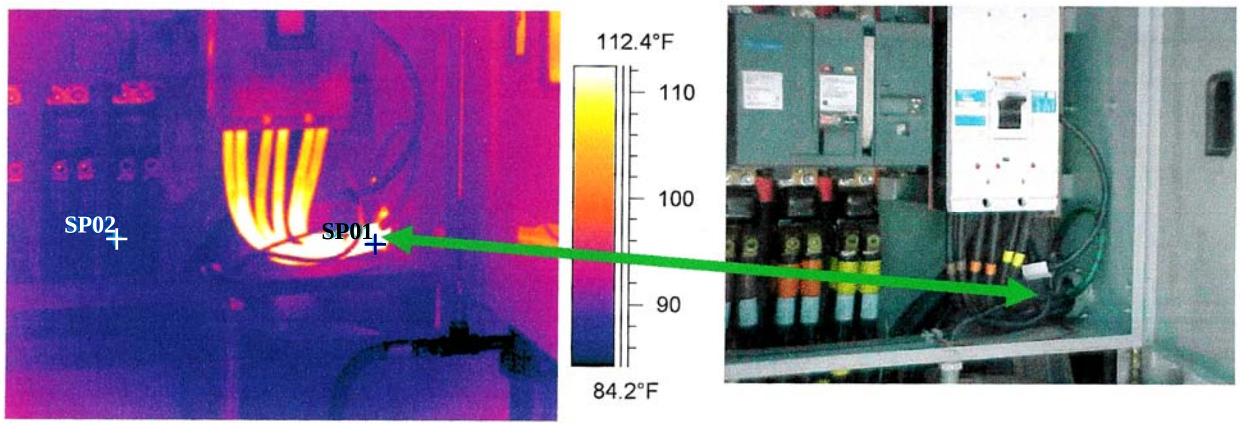
Anomaly 1. Hot "A" phase CT connection

The first anomaly was found in the main connection panel for one of the pump motors. An infrared camera was used to inspect the panel. The anomaly, labeled as SP01, can be seen in the figure above. It was identified by comparing the two pieces of similar equipment at the same approximate location (SP01 and SP02 in the figure). The temperature at SP01 is 161.9°F and the temperature at SP02 is 102.3°F (differential of 59.6°F). The temperature differential was significant enough to warrant a recommendation of "Should be repaired as soon as possible." In a priority scale of A-D where priority A warrants immediate repairs, this is a priority B.

According to Mr. Putnam, if this CT connection were to fail the motor would continue to be operational. However, it would have to be operated manually without the variable frequency drive. Since the problem was identified before any damage occurred, the CT connection can be cleaned and retested when the motor is out of scheduled operation (during the off-season) and probably will not need to be replaced.

Anomaly 2. Possibly undersized cables to load bank.

The second anomaly was found during an inspection of the main breaker panel for a stand-by generator. The anomaly can be seen in the figure below. The cables entering the main



Possibly undersized cables in a main breaker panel. The arrow indicates the same spot on both images for reference. These images were obtained from an MWD infrared inspection report. The temperature scale between the images is set by the report writer and does not represent the full range of temperatures in the infrared image.

breaker panel are significantly hotter than the rest of the panel. In this case the investigator did not have similar equipment with which to compare the anomaly. Instead, the anomaly was compared to a spot in the panel. In this case, as in many others, it is difficult to determine if the heat generated in the cables is normal under the load. The temperature of SP01 was 141.3°F and SP02 was 87.2°F (differential of 54.1°F).

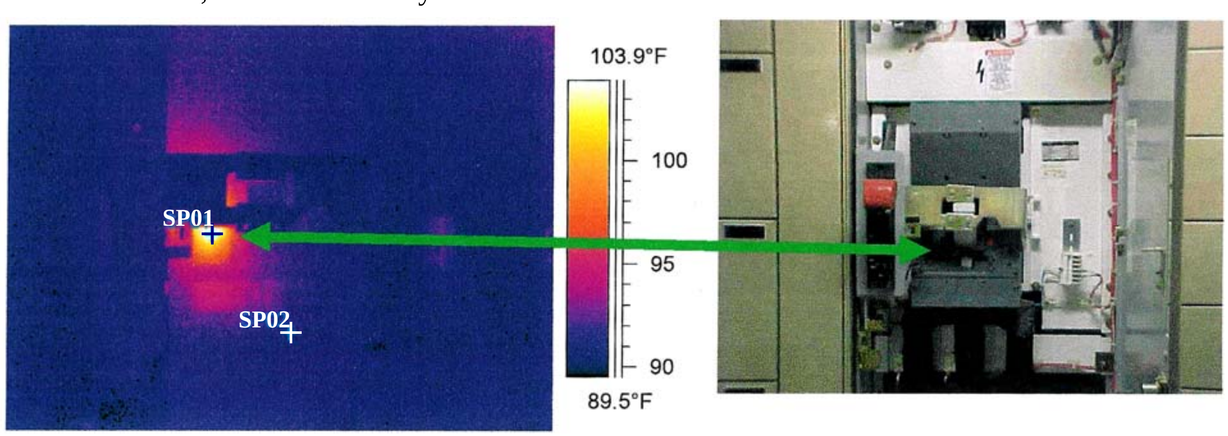
Nevertheless, the experienced investigator set a repair priority of B (Should be repaired as soon as possible), with a recommendation that the cable sizes be verified for the load requirement and replaced if necessary.

Because these cables are on an emergency stand-by generator, the problem may never escalate because the generator may never be used. However, if it is necessary to use the generator and the cables fail, the result would be catastrophic. All equipment using this generator would also fail. Further damage, besides the cables melting, would be likely to occur. Fire or excessive heat could damage much of the equipment in the main breaker panel, as well as creating a risk of human injury.

Because of preventative maintenance, the cables will be further inspected and replaced if necessary with no downtime to the facility and without replacing any other equipment in the main panel.

<u>Anomaly 3. Warm "A" phase breaker contact.</u>

The figure below shows a breaker contact that was warmer than the surrounding equipment. SP01 had a temperature of 104.3°F



Warm breaker connection. The arrow indicates the same spot on both images for reference. These images were obtained from an MWD infrared inspection report. The temperature scale between the images is set by the report writer and does not represent the full range of temperatures in the infrared image.

and SP02 had a temperature of 91.7°F (differential of 12.6°F). In this case the breaker contact was faulty and warranted replacement of the breaker. Because of the relatively small temperature differential, the investigator gave a repair priority of C (Should be attended to at first priority).

If this problem were not repaired, over time the connection would continue to increase in temperature, possibly damaging additional equipment and hampering the effectiveness of the breaker itself. Instead, the breaker can be replaced at the facility's scheduled downtime without difficulty.

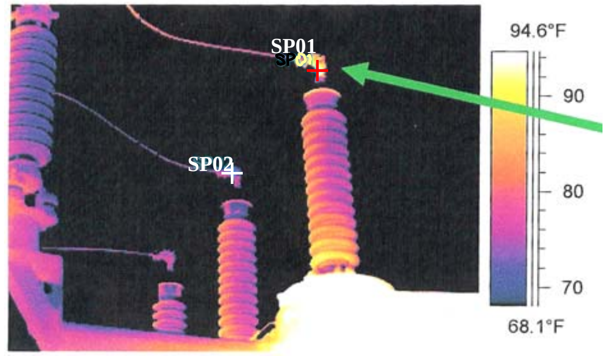
Anomaly 4. Warm "A" phase cable-to-bushing connection.

The final anomaly at the facility was on one of the facility's transformers. This is not a typical piece of equipment for a water agency to maintain, but it is interesting how a problem that could potentially be very expensive if allowed to develop could be prevented with early detection and minor cleaning. Most heat anomalies that occur at electrical connections can be solved with very minor, inexpensive maintenance. However, if they are allowed to run their course, the damage could be enormous.

In this case, the connection in the figure at SP01 had a temperature of 93.2°F and the temperature at an identical connection at SP02 was 72.2°F (differential of 21°F). Mr. Putnam estimated that catastrophic damage probably would not have occurred for another 10-15 years because of this problem. The investigator gave a repair priority of C (Should be attended to at first priority), with the recommendation to clean the connection and retest.

If the problem was not repaired, it is possible that the entire transformer could have been damaged, causing tens of thousands of dollars in damage just because of a faulty connection that needed cleaning.

MWD has used thermography for preventative maintenance for many years. Initially the district hired a consultant to complete inspections throughout the district. They became so impressed with the results that the district began their own thermography program. Best Infrared Services (consultants)



Warm "A" phase cable-to-bushing connection on main transformer. This image was obtained from an MWD infrared inspection report. The temperature scale is set by the report writer and does not represent the full range of temperatures in the infrared image.

assisted the district with training of personnel and the program design.

Duane Putnam recommended these steps for water agencies interested in thermography:

1. Complete a pilot study to determine how preventative maintenance will help the agency:
    a. Increase system reliability.
    b. Increase electrical efficiency.
2. Work with a consultant. Consultants have experience in the field. They can provide the service at a reasonable cost and they have the ability to find problem areas quickly.
3. If economically feasible, move towards an in-house program. Training and experience is very important. Most consultants will assist in training and program design.

Conclusion

Thermography can be very effective as a preventative maintenance tool. Of course, it is not error free. Thermography can only detect heat on the viewable surface. Problems that exist within equipment and do not generate enough heat to conduct out to the viewable surface will not be detected by the infrared equipment. Using thermography is not a replacement for regular maintenance and physical equipment inspection. However, a good preventative maintenance program can extend the period between physical inspections.

The equipment available is simple to operate. With less than an hour of training on a typical infrared camera, a novice can be inspecting equipment. However, the analysis of the images is very difficult. Determining what is an anomaly and what is a temperature caused by normal operation or the emissivity of the material can only be accomplished by an experienced thermographer.

In most instances, equipment will only need to be inspected once or twice a year. Most water agencies will only need 1-10 days per year of investigation. In these cases, using a consultant may be the most feasible.

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