FLUKE ®

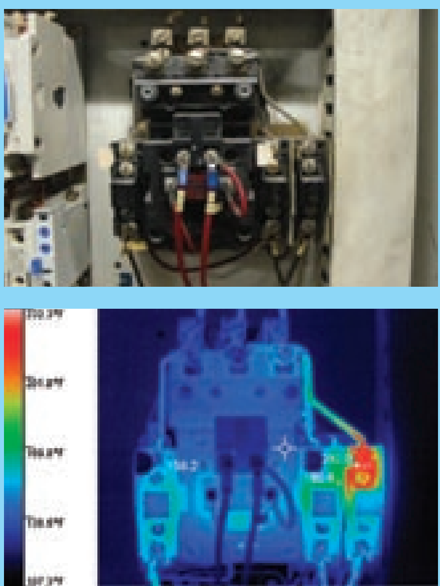
# Industrial Maintenance Thermal Imaging Application Guide

## Contents



# 1. Detecting loose or corroded electrical connections

**Thermal images of electrical systems can indicate the operating condition of the equipment in those systems. In fact, since the beginning of thermography more than four decades or more ago, the principal commercial application for thermal imaging has been electrical system inspection.**



The connections on this evaporator pump read over 50 degrees hotter on phase C.

The reason thermography is so applicable to the monitoring of electrical systems is that new electrical components begin to deteriorate as soon as they are installed. Whatever the loading on a circuit, vibration, fatigue and age cause the loosening of electrical connections, while environmental conditions can hasten their corroding. Briefly stated, all electrical connections will, over time, follow a path toward failure. If not found and repaired, these failing connections lead to faults.
Fortunately, a loose or corroded connection increases resistance at the connection and since increased electrical resistance results in an increase in heat, a thermal image will detect the developing fault before it fails.
Detecting and correcting failing connections before a fault occurs averts fires as well as impending shutdowns that can be critical to manufacturing, commercial and institutional operations. Such predictive actions are important because when a critical system does fail, it inevitably increases costs, requires the reallocation of workers and material, reduces productivity, threatens corporate profitability and impacts the safety of employees, customers and/or clients.
The following discussion focuses on using thermal imaging to troubleshoot loose, over-tight or corroded connections in electrical systems by comparing the temperatures of connections within panels.

### What to check?

Check panels with the covers off and power at ideally at least 40 % of the maximum load. Measure the load, so that you can properly evaluate your measurements against normal operating conditions. Caution: only authorized and qualified personnel using the appropriate personal protective equipment (PPE) should remove electrical panel covers.
Capture thermal images of all connections that have higher temperatures than other similar connections under similar loads.

### What to look for?

In general, look for connections that are hotter than others. They signal high resistance possibly due to looseness, tightness or corrosion. Connection-related hot spots usually (but not always) appear warmest at the spot of high-resistance, cooling with distance from that spot.
As noted, overheating connections can, with additional loosening or corrosion, lead to a failure and should be corrected.
The best solution is to create a regular inspection route that includes all key electrical panels and any other high-load

connections, such as drives, disconnects, controls, and so on. Save a thermal image of each one on the computer and track your measurements over time, using the software that comes with the thermal imager. That way, you'll have baseline images to compare to, that will help you determine whether a hot spot is unusual or not, and to verify repairs are successful.

### What represents a "red alert?"

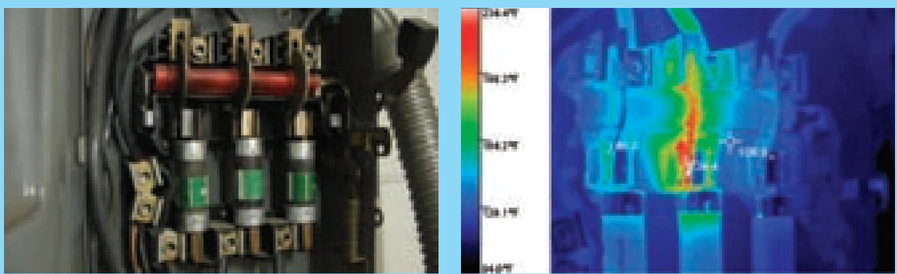
Equipment conditions that pose a safety risk should take the highest repair priority. Guidelines provided by the NETA (InterNational Electrical Testing Association) say that when the difference in temperature (DT) between similar components under similar loading exceeds 15 °C immediate repairs should be undertaken. The same organization recommends the same action when the DT for a component and ambient air exceeds 40 °C.

### What's the potential cost of failure?

Left uncorrected, the overheating of a loose or corroded electrical connection could blow a five-dollar fuse and bring down an entire production process. Then, it will probably take at least half an hour to shut off the power, get a spare fuse from the store-room, and replace the blown fuse. The cost in production losses will vary depending upon the industry and the process, but in many industries a half hour of lost production can be very expensive. For example, in the steel casting industry, lost production costs from downtime have been estimated at about €1,000 per minute.

### Follow-up actions

Overheating connections should be disassembled, cleaned, repaired and reassembled.
If, after following this procedure, the anomaly persists, the problem may not have been the connection, although a faulty repair remains a possibility.
Use a multimeter, clamp meter or a power quality analyzer to investigate other possible reasons for the overheating, such as overloading or unbalance.
Whenever you discover a problem using a thermal imager, use the associated software to document your findings in a report, including a thermal image and a digital image of the equipment. It's the best way to communicate the problems you found and the suggested repairs.



The temperature readouts show that connections on both phases A and B on this main lighting disconnect are hot, suggesting an unbalanced load.

## An imaging tip

Hardware used for electrical connections and contacts is often shiny and will reflect infrared energy from other nearby objects, which can interfere with temperature measurement and image capture. Extremely dirty equipment can also interfere with accuracy. To improve accuracy, wait until the equipment is de-energized and paint dark, less-reflective spots onto the target measurement areas. Be careful not to use combustible materials such as black paper or plastic tape.

# 2. Detecting electrical unbalance and overloads

**Thermal images are an easy way to identify apparent temperature differences in industrial three-phase electrical circuits, compared to their normal operating conditions.**

**By inspecting the thermal gradients of all three phases side-by-side, technicians can quickly spot performance anomalies on individual legs due to unbalance or overloading.**

Electrical unbalance can be caused by several different sources: a power delivery problem, low voltage on one leg, or an insulation resistance breakdown inside the motor windings.

Even a small voltage unbalance can cause connections to deteriorate, reducing the amount of voltage supplied, while motors and other loads will draw excessive current, deliver lower torque (with associated mechanical stress), and fail sooner.

A severe unbalance can blow a fuse, reducing operations down to a single phase. Meanwhile, the unbalanced current will return on the neutral, causing the utility to fine the facility for peak power usage.

In practice, it is virtually impossible to perfectly balance the voltages across three phases.

To help equipment operators determine acceptable levels of unbalance, the National Electrical Manufacturers Association (NEMA) has drafted specifications for multiple devices. These baselines are a useful point of comparison during maintenance and trouble-shooting.

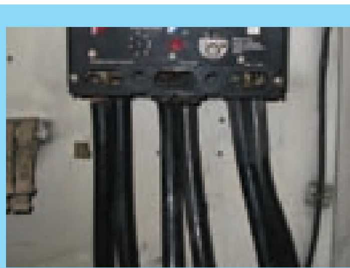
### What to check?

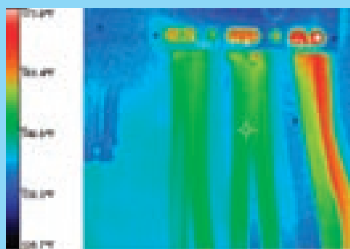
Capture thermal images of all electrical panels and other high-load connection points such drives, disconnects, controls and so on. Where you discover higher temperatures, follow that circuit and examine associated branches and loads.

Check panels and other connections with the covers off. Ideally, you should check electrical devices when they are fully warmed up and at steady state conditions with at least 40 % of the typical load. That way, measurements can be properly evaluated and compared to normal operating conditions.

### What to look for?

Equal load should equate to equal temperatures. In an unbalanced load situation, the more heavily loaded phase(s) will appear warmer than the others, due to the heat generated by resistance. However, an unbalanced load, an overload, a bad connection, and a harmonic imbalance can all create a similar pattern.





The connections on this evaporator pump read over 50 degrees hotter on phase C.

**Caution:**
Only authorized and qualified personnel using the appropriate personal protective equipment (PPE) should remove electrical panel covers.

Measuring the electrical load is required to diagnose the problem.

**Note:** A cooler-than-normal circuit or leg might signal a failed component.

It is sound procedure to create a regular inspection route that includes all key electrical connections. Using the software that comes with the thermal imager, save each image you capture on a computer and track your measurements over time. That way, you'll have baseline images to compare to later images. This procedure will help you determine whether a hot or cool spot is unusual. Following corrective action, new images will help you determine if repairs were successful.

### What represents a "red alert?"

Repairs should be prioritized by safety first—i.e., equipment conditions that pose a safety risk—followed by criticality of the equipment and the extent of the temperature rise.

NETA (InterNational Electrical Testing Association) guidelines dictate immediate action when the difference in temperature (ΔT) between similar electrical components under similar loading exceeds 15 °C or when the ΔT between an electrical component and the ambient air temperatures exceeds 40 °C.

NEMA standards (NEMA MG1-12.45) warn against operating any motor at a voltage unbalance exceeding one percent. In fact, NEMA recommends that motors be de-rated if operating at a higher unbalance. Safe unbalance percentages vary for other equipment.

### What's the potential cost of failure?

Motor failure is a common result of voltage unbalance. Total cost combines the cost of a motor, the labor required to change out a motor, the cost of product discarded due to uneven production, line operation and the revenue lost during the time a line is down.

Assume the cost to replace a 50 hp motor each year is €5,000 including labor. Assume 4 hours of downtime per year with income loss of €6,000 per hour.

***Total Cost: €5,000 + (4 x €6,000) = €29,000 annually***

### Follow-up actions

When a thermal image shows an entire conductor is warmer than other components throughout part of a circuit, the conductor could be undersized or overloaded. Check the conductor rating and the actual load to determine which is the case.

Use a multimeter with a clamp, a clamp meter or a power quality analyzer to check current balance and loading on each phase.

On the voltage side, check the protection and switchgear for voltage drops. In general, line voltage should be within 10 % of the nameplate rating. Neutral to ground voltage tells you how heavily your system is loaded and helps you track harmonic current. Neutral to ground voltage higher than 3 % should trigger further investigation.

Loads do change, and a phase can suddenly be 5 percent lower on one leg, if a significantly large single-phase load comes online.

Voltage drops across the fuses and switches can also show up as unbalance at the motor and excess heat at the root trouble spot. Before you assume the cause has been found, double check with both the thermal imager and multi-meter or clamp meter current measurements.

Neither feeder nor branch circuits should be loaded to the maximum allowable limit. Circuit load equations should also allow for harmonics. The most common solution to overloading is to redistribute loads among the circuits, or to manage when loads come on during the process.

Using the associated software, each suspected problem uncovered with a thermal imager can be documented in a report that includes a thermal image and a digital image of the equipment. That's the best way to communicate problems and to suggest repairs.

## An imaging tip

The primary use of thermography is locating electrical and mechanical anomalies. Despite a popular perception to the contrary, a device's temperature—even its relative temperature—may not always be the best indicator of how close it is to failure. Many other factors should be considered, including changes in ambient temperatures and mechanical or electrical loads, visual indications, the criticality of components, histories of similar components, indications from other tests, etc. What all of this indicates is that thermography serves best as part of a comprehensive condition monitoring and predictive maintenance program.

# 3. Inspecting bearings

**Thermal images of electrical systems can indicate the operating condition of the equipment in those systems. In fact, since the beginning of thermography more than four decades or more ago, the principal commercial application for thermal imaging has been electrical system inspection.**

Many predictive maintenance (PdM) programs use thermography to monitor the apparent temperatures of operational equipment, using the heat values to detect and avoid equipment loss. By using thermal imagers to capture two-dimensional infrared maps of bearing and housing temperatures, technicians can compare current operating temperatures to benchmarks and detect potential failures.

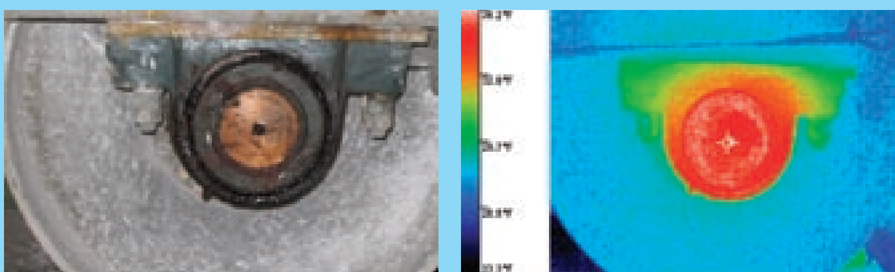
## What to check?

Generally speaking, vibration analysis is the PdM technology of choice for monitoring large, accessible, relatively high-speed bearings, but it can only be done safely when transducers can be placed on the bearings. For bearings that are relative small (e.g., in conveyor rollers), in low-speed operations, physically inaccessible or unsafe to get close to while the equipment is running, thermography is a good alternative to vibration analysis. In most cases, thermography can be performed at a safe distance while the equipment is operating. Capturing a thermal image with a handheld imager also takes less time than performing vibration analysis.

Mechanical equipment should be inspected when it has warmed up to steady state conditions and is running a normal load. That way, measurements can be interpreted at normal operating conditions. Capture a thermal image of the bearing to be checked, and if possible, capture images of bearings in the same area performing the same or a similar function, e.g., the bearing at the other end of a conveyor or paper machine roller or another pillow block on the same shaft.

## What to look for?

Problems with bearings are usually found by comparing the surface temperatures of similar bearings working under similar conditions. Overheating conditions appear as “hot spots” within an infrared image and are usually found by comparing similar equipment. In checking motor bearings, this procedure entails comparing end bell to end bell (for motors and bearings of the same type) or stator to end bell temperatures.



This overheating shaft and bearing may be an indicator of bearing failure, lack of proper lubrication, or misalignment.

In general, it is a good idea to create a regular inspection route that includes all critical rotating equipment. If a route for regular vibration analysis already exists, thermography can be added easily to these existing bearing-monitoring efforts. In any case, save a thermal image of each piece of key equipment on a computer and track your measurements over time, using the software that comes with the thermal imager. That way, you'll have baseline images for comparison. They will help you determine whether a hotspot is unusual or not and help you verify when repairs are successful.

### What represents a "red alert?"

Equipment conditions that pose a safety risk should take the highest repair priority. Beyond that, determining when action is required in your facility to keep a bearing from causing the loss of a crucial piece of equipment is an case-by-case undertaking that gets easier with experience. For example, on one difficult-to-monitor line, an auto manufacturer moved from vibration analysis to a combination of vibration and thermography to determine that normal operating temperatures for bearings on the line fell within a specific range. The company's PdM personnel, well trained in thermography, now treat a bearing running above the upper limit of the normal operating range as an "alarm" situation.

When using thermography on bearings not normally monitored using vibration analysis or even when spot-checking bearings, try to follow the lead of the automotive company and establish some "alarm" criteria, as you would for other condition-monitoring technologies. Some thermography experts, for example, have established rules-of-thumb for allowable temperature differentials ((Ts) for bearings on specific types of equipment using specific lubrication techniques (grease, oil bath, etc.).)

### What's the potential cost of failure?

For a failed bearing in a specific motor, pump, drive or some other critical component, you can do analysis of the cost of the repair, lost production opportunity and lost labor costs. At one automotive facility, the estimated cost of the failure of a specific pump is more than €15,000 for repairs plus lost production of €30,000 per minute and labor costs of more than €600 per minute. Keeping that pump running is worth the effort.

### Follow-up actions

All rotating equipment generates heat at the friction-bearing points in the system - the bearings. Lubrication reduces friction and thereby reduces and to varying degrees (depending upon the type of lubrication) dissipates the heat. Thermal imaging lets you literally "picture" this process while revealing the condition of bearings. When thermal images indicate an overheating bearing, you should generate a maintenance order to either replace the bearing or lubricate it. Vibration analysis or another PdM technology may help you determine the best course of action.

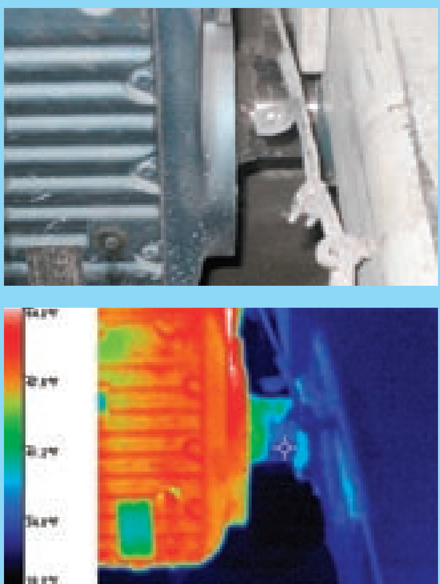
Whenever you discover a problem using a thermal imager, use the associated software to document your findings in a report, including a thermal image and a digital image of the equipment. That's the best way to communicate problems you find and to suggest repairs.

## An imaging tip

Modify equipment guards and covers on conveyor systems and drive components so that bearings and couplings can be inspected using thermography. Consider installing a small, hinged door or using metal mesh instead of solid metal. In making any of these kinds of changes, be sure not to compromise personnel's safety.

# 4. Inspecting electric motors

**Electric motors are the backbone of industry. The U.S. Department of Energy estimates that in the U.S. alone there are 40 million motors operating in industry, and the fact that those motors use 70 % of the electricity consumed by industry indicates their importance.**



Properly functioning bearings should show cool temperatures.

A program to avert costly failures in your facility will benefit from including thermal imaging as a condition-monitoring technique for electric motors. Using a handheld thermal imager, you can capture infrared temperature measurements of a motor's temperature profile as a two-dimensional image.

Thermal images of electric motors reveal their operating conditions as reflected by their surfact temperature. Such condition monitoring is important as a way to avert many unexpected motor malfunctions in systems that are critical to manufacturing, commercial and institutional processes. Such preventive actions are important because when a critical system fails, it inevitably increases costs, requires the reallocation of workers and material, reduces productivity and, if not corrected, can threaten corporate profit-ability and, possibly, the well being of employees, customers and/or clients.

### What to check?

Ideally, you should check motors when they are running under normal operating conditions. Unlike an infrared thermometer that only captures temperature at a single point, a thermal imager can capture temperatures at thousands of points at once, for all of the critical components: the motor, shaft coupling, motor and shaft bearings, and the gearbox.

**Remember:** each motor is designed to operate at a specific internal temperature. The other components should not be as hot as the motor housing.

### What to look for?

All motors should list the normal operating temperature on the nameplate. While the infrared camera can not see the inside of the motor, the exterior surface temperature is an indicator of the internal temperature. As the motor gets hotter inside, it also gets hotter outside. Thus, an experienced thermographer who is also knowledgeable about motors can use thermal imaging to identify conditions such as inadequate airflow, impending bearing failure, shaft coupling problems, and insulation degradation in the rotor or stator in a motor.

In general, it is a good idea to create a regular inspection route that includes all critical motor/drive combinations. Then, save a thermal image of each one on a computer and track measure-ments over time. That way, you'll have baseline images to compare to, that will help you determine whether a hotspot is unusual or not, and, following repairs, to help you verify if the repairs were successful.

## What represents a "red alert?"

Equipment conditions that pose a safety risk should take the highest repair priority. After that, consider that each motor has a maximum operating temperature that usually appears on its nameplate and represents the maximum allowable rise in temperature of the motor above ambient. (Most motors are designed to operate in ambient temperatures that do not exceed 40 °C.) Generally speaking, each 10 °C rise above its rated temperature cuts a motor's life in half. Regularly scheduled infrared inspections of electric motors identify motors which are starting to overheat. Even an initial thermal image will reveal whether a motor is running hotter than a similar motor doing a similar job.

## What's the potential cost of failure?

For a specific motor, you could do an analysis based on the cost of the motor, the average amount of time a line is down from a motor failure, the labor required to change out a motor, etc. Of course, productivity losses from downtime vary from industry to industry. For example, lost production from a papermaking machine can be as much as €3,000 per hour while in the steel casting industry losses can be as high as €1,000 per minute.

## Follow-up actions

If you suspect overheating is the result of one of the following, consider the action described:

a. **Inadequate airflow.** If a brief shutdown is possible without affecting the plant process, shut off the motor long enough to perform minor cleaning on the air intake grills. Schedule a thorough motor cleaning during the next planned plant shutdown.

b. **Unbalanced voltage or an overload.** The usual cause, a high-resistance connection in the switchgear, disconnect, or motor connection box, can usually be pinpointed by a thermographic inspection and confirmed using a multimeter, clamp meter or a power quality analyzer.

c. **Impending bearing failure.** When the thermal images indicate an overheating bearing, generate a maintenance order to either replace the bearing or lubricate the bearing. While somewhat expensive and requiring an expert, vibration analysis can often help you determine the best course of action.

d. **Insulation failure.** With an insulation tester the windings of a motor can be tested. When the insulation shows failures, generate a work order to replace the motor as soon as possible.

e. **Shaft misalignment.** In most cases, vibration analysis will confirm a misaligned coupling. If a shutdown is possible, dial indicators of laser-alignment devices can be used and the misalignment can be corrected then and there.

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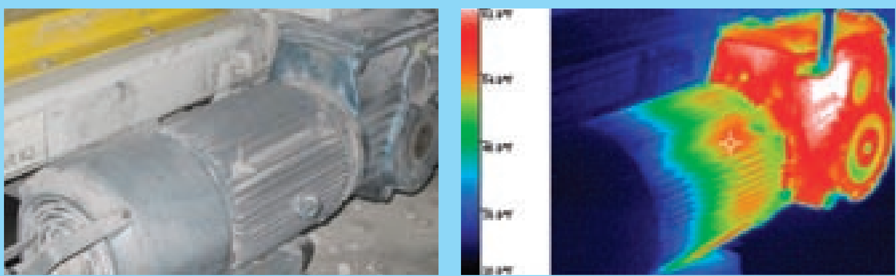


This thermal image shows a cool motor on the left and a hot gearbox on the right, with an especially white-hot anomaly.

## An imaging tip

Sometimes it is difficult to get a direct view of the component you want to inspect, such as a motor or gearbox mounted high up on the top of a machine. Try using a thermal mirror to see the reflection of the component. An aluminum sheet (3 mm. thick) works very well. Either carefully slip it temporarily into place or mount it permanently in a location that facilitates your inspection. The aluminum does not have to be highly polished to be effective. However, if you are trying to secure true (as opposed to comparative) temperature readings, you must learn how to "characterize" the mirror and adjust your emissivity readings accordingly. For this technique to work, the surface of the mirror needs to be clean, since oil and other coatings will alter the reflective properties of the mirror.

# 5. Process: Inspecting steam systems

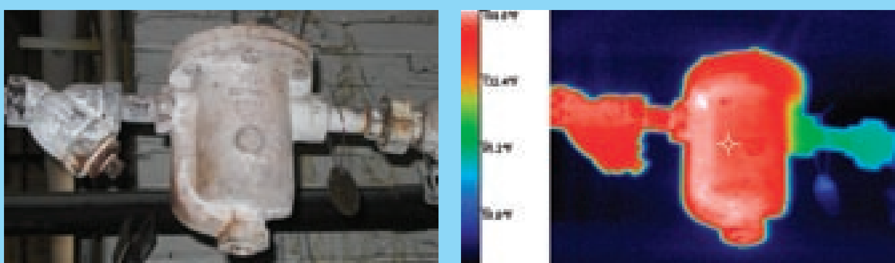
**According to the U. S. Department of Energy (DOE), more than 45 percent of all the fuel burned by U.S. manufacturers is consumed to raise steam. "Steam is used to heat raw materials and treat semi-finished products. It is also a power source for equipment, as well as for building heat and electricity generation. But steam is not free. It costs billions of Euro's annually to feed the boilers generating the steam."**

Generally speaking, steam is a very efficient way to transport heat energy because the amount of latent heat required to produce steam from water is quite large, and steam is easily moved in pressurized piping systems that can deliver that energy at manageable costs. When steam gets to its point of use and gives up its latent heat to the environment or to a process, it condenses into water, which must be returned to the boiler for re-conversion to steam.

Several condition-monitoring technologies are useful for monitoring steam systems to determine how well they are functioning. Among those technologies is infrared (IR) thermography, in which technicians use thermal imagers to capture two-dimensional images of the surface temperatures of equipment and structures. Thermal images of steam systems reveal the comparative temperatures of system components and thereby indicate how effectively and efficiently steam system components are operating.

### What to check?

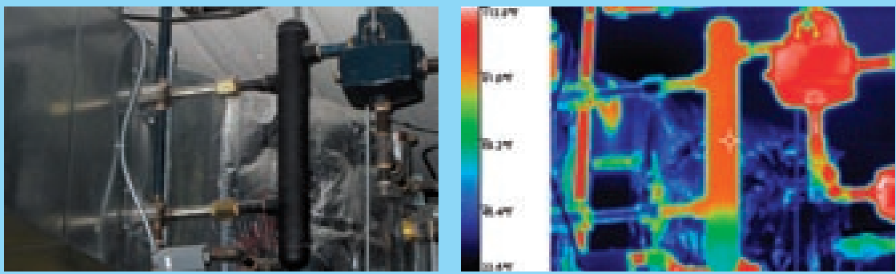
Using a combination of ultrasound and thermal inspections significantly increases the detection rate of problems in steam systems. Check all steam traps and steam transmission lines, including any underground lines. In addition, scan heat exchangers, boilers and steam-using equipment. In other words, examine every part of your steam system with a thermal imager.



When operating correctly, as in this example, steam trap thermal images should show an abrupt change in temeperature.

### What to look for?

Steam traps are valves designed to remove condensate as well as air from the system. During inspections, use both thermal and ultrasonic testing to identify failed steam traps and whether they have failed open or closed. In general, if a thermal image shows a high inlet temperature and a low outlet temperature ($< 100$ °C), that indicates that the trap is functioning correctly. If the inlet temperature is significantly less than the system temperature, steam is not getting to the trap. Look for an upstream problem—a closed valve, pipe blockage, etc. If both the inlet and outlet temperatures are the same, the trap probably has failed open and is "blowing steam" into the condensate line. This keeps the system operating but with significant energy loss. Low inlet and outlet temperatures indicate that the trap has failed closed and condensate is filling the trap and the inlet line. Also use your thermal imager while your steam system is operating to scan: **Steam transmission lines** for blockages, including closed valves, and



When operating correctly, as in this example, steam trap thermal images should show an abrupt change in temperature.

underground steam lines for leaks, **heat exchangers** for blockages, **boilers**, especially their refractories and insulation, **steam-using equipment** for any anomalies and **recent repairs** to confirm their success.

Consider creating a regular inspection route that includes all key steam-system components in your facility, so that all traps are inspected at least annually. Larger or more critical traps should be inspected more frequently, as the potential for loss is greater. Over time, this process will help you determine whether a hot or relatively cool spot is unusual or not and help you to verify when repairs are successful.

## What represents a "red alert?"

Steam is very hot and often transmitted at high pressure, so any condition that poses a safety risk should take the highest repair priority. In many situations, the next most important kinds of problems to deal with are those that can affect production capabilities.

## What's the potential cost of failure?

The cost to an operation that completely loses its steam system varies from industry to industry. Among the industries that use the most steam are chemicals, food and beverage processing and pharmaceuticals. Hourly downtime costs for these industries are estimated between €700,000 and €1,100,000 an hour.

Viewed another way, in a 7 bar steam system, if a medium-sized trap fails open it will waste about €3,000 per year. If your facility has performed no maintenance of steam traps for three to five years, expect 15 to 30 percent of your traps to have failed. So, if you have 60 medium-sized traps on your system, losses from "blow by" are likely to be between €27,000 and €54,000 a year.

## Follow-up actions

To check steam trap performance, "sight, sound and temperature" are the dominant techniques. Implementing a basic annual inspection of the steam traps and associated equipment with infrared inspections will likely reduce steam losses by 50 % to 75 %. A sensible approach to a steam system management program is to establish repair priorities based on safety, steam/ energy loss, and possible impact on production and quality loss.

Whenever you discover a problem using a thermal imager, use the associated software to document your findings in a report, including a thermal image and a digital image of the equipment. It's the best way to communicate the problems you found and to suggest repairs.

## Reporting tip:

Make room on your report form to schedule a follow-up inspection. This can be something as simple as leaving a blank space labeled "follow-up thermogram" or entering an actual date. Plan your workload so that you can provide a follow-up inspection quickly after repairs have been made. Some thermographers leave the last Friday of the month as a day to do this. It not only gives you a chance to validate the repair, but also to build good will with the crew that did the repair work. More importantly, it gives you a chance to find out what was actually wrong and perhaps even see the damaged components. This is vital to your long-term growth as a thermographer.

FLUKE®

# Fluke Ti Series Thermal Imagers

**Representing a breakthrough in thermal imaging, the Fluke Ti Series lowers the entry threshold for this powerful technology. Designed for industrial applications, these products put the capabilities of thermal imaging within the hands of service and maintenance personnel who know the facility and equipment best.**

### Thermal imaging within your reach

Easy to use, thanks to one-handed 'point-and-shoot' operation and intuitive on-screen guidance, the Ti Series thermal imagers do not require specialist training to obtain accurate measurements. Just point at the target, focus the instrument, and it automatically adjusts the temperature range to show a crisp image. When the user pulls the trigger, the image and associated measurement data is stored. The affordable Fluke Ti Series puts the power of thermal imaging into the hands of the people most familiar with the machines and installations.

### Rugged and reliable

Fluke has one of the most extensive ranges of electrical and diagnostic test-tools, and the Ti Series Thermal Imagers complement the range. Like all other Fluke tools, they are reliable, rugged and built to withstand tough industrial environments.

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