When a motor stops operating all maintenance resources are directed to the repair or replacement of the motor. The question that should come up is, could the failure have been predicted before shutdown? Or even better, could it have been prevented or could action have been taken to prolong the life of the motor? If the motor, mechanical drive and the electrical circuit providing power to it is considered a system, and that system is monitored and analyzed on a routine basis, the answer can be “Yes”.

The industrial facilities that have graduated from reactive or breakdown maintenance to using condition monitoring techniques within their predictive maintenance program have increased the overall facility reliability. After all, motors do make the world go around. It would be very difficult to find any process, facility or building that does not involve the use of electric motors somewhere. Motor driven systems account for almost 70% of industrial electricity use. Motors are most critical to the reliability of any facility or process.

In recent years heightened concern for safety and reliability, and the onslaught of global competition are impacting maintenance practices and testing methods. Throw in today’s recessionary climate, and it becomes even more important to move from reactive to condition-based maintenance.

Two primary reasons cited for implementing a condition monitoring motor program are: to prevent failure and to detect the onset of failure. The results are improved overall plant reliability, increased safety, improved productivity, reduced downtime, a more competitive product and higher profitability.

Condition Monitoring Techniques For Motors

Many motor failures can be averted or their life extended if predictive measures are initiated. Most failures will provide some warning that they are about to occur or are in the failure mode. There are many tests and condition monitoring techniques used on motors and the electrical system to detect a failure symptom. There are other techniques to correct the problems and proactive technologies to improve reliability.

Condition monitoring (CM) provides a means of determining whether maintenance is required and when it is required. Condition monitoring is the continuous or periodic measurement and interpretation of data to indicate the condition of an item to determine the need for predictive maintenance. CM techniques will measure natural parameters in a non-intrusive manner while the equipment is in operation.

To ensure a long dependable life of a motor, much more than the motor must be considered within a predictive maintenance program. Condition monitoring and testing of motors will include all that is attached to a motor including the mechanical drives, the electrical system feeding the motor and the associated electrical equipment and protection devices within the motor control center.
Condition monitoring techniques are:
• Infrared Thermography
• Visual Inspection
• Vibration Monitoring
• Lube Oil Analysis
• Ultrasonics
• Motor Current Evaluation

Cross Technologies
Even though this article will concentrate on the use of infrared thermography for condition monitoring of the motor system, it is important to utilize all tests at your disposal.

It is up to the predictive maintenance and/or inspection group to determine the correct test and/or combination of tests that will provide the greatest amount of information to assist in determining the condition of the equipment. In some situations, one technique will provide all the information necessary to determine the condition of a component. In other situations, the information gathered from several techniques is necessary to identify a problem and to assist in the determination of the degree of deterioration that has occurred. By crosschecking using several technologies, all departments can be satisfied that they will make the correct decision to repair or not.

Why Temperature?
In industry, temperature is one of the first observable parameters that will indicate the condition of operating processes and equipment. Heat, or thermal energy, is a by-product of all electrical or mechanical systems. The thermal behavior of electrical, mechanical or process equipment can be a powerful clue to diagnose problems and predict reliability of industrial equipment.

What Is Infrared Thermography?
Infrared thermography is an electronic technique that allows us to see thermal energy. With this new capability, plant maintenance personnel have recognized infrared thermography as one of the most versatile and effective condition monitoring tools. Thermal imaging enhances a company’s ability to predict equipment failure and plan corrective action before a costly shutdown, equipment damage, or personal injury can occur. The technique allows for the monitoring of temperatures and thermal patterns while the equipment is online and running under full load. Most mechanical equipment has allowable operating temperature limits that can be used as guidelines.

An infrared camera produces an infrared image or thermogram. It depicts the thermal radiation in a scene as emitted and reflected by the objects in the scene based on their temperatures. The standard image is a greytone image that shows hot objects as white descending in greytones until black is reached, which is the coolest temperature in the scene. When appropriate, we can colorize the image. Yellows and reds usually depict hotter objects and violet and blue shades show cooler items.

How Does Thermography Work?
All motor systems generate thermal energy during normal operation, which allows infrared thermography to evaluate the operating condition. One of the biggest problems in a motor system is excessive temperature. This excessive heat can be generated by friction, cooling degradation, material loss or blockages. An excessive amount of friction can be caused by wear, misalignment, over or under lubrication and misuse.

Since most equipment or processes are designed to eliminate thermal energy under normal operation, simply identifying a thermal pattern does not mean a problem has been located. The thermographer must be familiar with the components being evaluated. Once a normal thermal signature is obtained and understood, any deviation from this normal signature will then provide evidence of a problem developing.

Thermography is an excellent tool for locating problems within the entire motor system, but not necessarily determining the cause of the overheating. Other CM techniques and electrical test equipment such as vibration analysis, oil analysis, and ultrasound can be employed to further determine what the problem actually is.

Unlike many other test methods, infrared can be used on a wide variety of equipment including the electrical system, motors, pumps, bearings, pulleys, fans, drives, conveyors, etc.

The Motor System
Excessive temperatures always signal the presence of a problem. Loose, worn and/or corroded connections, equipment degradation, unbalanced loads, harmonics, blocked or restricted cooling apparatus, poor contacts, motor winding deterioration, bearing degradation etc.

Black and white and colour thermograms showing respective temperature relationships.
will cause excessive heating. The results are destroyed electrical components and motors, electrically caused fires, wasted energy, costly down time and safety concerns.

Thermography is a key inspection tool selected for analyzing electrical components, motors, and rotating equipment. As well, it will assist technicians in using the other inspection tools, such as vibration analysis, more effectively. When a thermal anomaly is found, then other tools may be employed to provide additional fault information and help isolate the cause of the problem.

Applications of infrared thermography involve inspections and analysis of the entire motor system, including the motor, mechanical drives and the electrical system. (See table)

**High Temperature Hurts Motors**

Motors are energy conversion devices that convert electro-magnetic forces into mechanical forces. The conversion from electrical to mechanical energy is not 100% efficient. A significant amount of this conversion process creates thermal energy, or heat. Excessive internal and/or external temperatures are a motor’s worst enemy, since it deteriorates winding insulation and shortens motor life.

Motors are designed with close tolerances that can only be maintained with proper use, maintenance and operating conditions. These conditions include operation within specific temperature limits. When these limits are exceeded, both mechanical and electrical stresses will shorten the life of the equipment or even cause catastrophic failure.

All motors have a normal thermal pattern as well as a maximum operating temperature. This temperature is usually stated on the nameplate of the motor and is normally given as a rise in degrees C above the ambient air temperature. Most motors are designed to operate in ambient temperatures that do not exceed 40° C.

Motors are rated by their maximum allowable operating temperature that is determined by the type of electrical insulating materials used in the motor. Motor insulation is particularly temperature sensitive. It is well understood that when a motor exceeds its thermal rating, the insulation degrades rapidly. In fact, for every 10° C rise in temperature above the rating, the service life expectancy of the motor is reduced by 50%. This irreversible effect can occur within hours of operating above maximum rated temperatures.

Ratings for motors are based on the hottest allowable spot within the insulation of the motor. This is the temperature inside the insulation when the motor is operating in a 40° C (104° F) ambient environment. The temperatures obtained with an infrared instrument are taken on the outside of the motor, not the inside. When measuring the outside surface of a motor casing it is safe to predict that the insulation temperatures on the inside will be at least 20° C above the measured casing temperature.

**Reasons For High Temperature**

Although electrical, mechanical and environmental factors affect the life of a motor insulation system, the primary limiting factor is heat. How long the insulating material will last depends on the temperature and duration of heat to

<table>
<thead>
<tr>
<th>APPLICATION</th>
<th>CONDITIONS DETECTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motors - terminal box connections, inlet and exit air temperature, windings, bearings, brushes</td>
<td>Overheating of windings and bearings, shorted coils, blockages in cooling passages, friction, damping, material deformations, brush contact problems, rotor problems</td>
</tr>
<tr>
<td>Drives, conveyors, pillow blocks, couplings, gears, power transmission belts, pulley, shafts</td>
<td>Overheated bearings or rollers, misalignment of shaft, pulley or coupling, lubrication failure, uneven pressure</td>
</tr>
<tr>
<td>Pumps, compressors, fans, blowers</td>
<td>Overheated bearings, high compressor discharges temperature, high oil temperature, and broken or defective valves</td>
</tr>
<tr>
<td>Miscellaneous electrical apparatus, switches, breakers, load centres, motor control centres, contactors, thermal overloads, transformers</td>
<td>Loose or corroded connections, poor contacts, unbalanced loads, overloading, overheating</td>
</tr>
</tbody>
</table>
which the motor is exposed.
Common causes of motor overheating include:
• Excessive overloading
• Bearing failure
• Misalignment
• Excessive friction or other drive problems
• High ambient environment
• Restricted ventilation
• Locked rotor
• Improper load match
• High altitude
• Power supply variations (high, low or unbalanced voltage)
• Single phasing on three phase motors
• Excessive stop/start cycles

In all instances the result is higher than normal winding temperatures, which, if continued, will result in reduced motor life. An infrared thermography inspection provides early warning of failure in all of the above problems and is therefore critical to any motor CM program.

Infrared Motor Inspection
The three common types of motors are induction, synchronous and DC. On most motors, temperatures should be acquired from at least three positions on the motor surface, as well as one over each of the bearing areas. Any localized “hot spots” should also be measured to ensure that the maximum allowable temperatures are not exceeded.

While regularly scheduled inspections following specific routes yield the best results, “one time” inspections of motors in conjunction with an electrical infrared inspection can also alert maintenance personnel to impending problems by identifying equipment that is operating out of acceptable specification limits.

When temperatures from each measurement point are plotted over time, any significant increase in temperature will usually predict a future failure. The ability to predict these problems gives the equipment operator the opportunity to schedule the repair, order in the necessary parts or replacement piece and thus limit production down time.

The frequency of your inspections can vary from weekly to quarterly. Factors such as criticality to operation, replacement availability and the value of the motor are a few of the issues that will help determine inspection frequency.

Mechanical Applications
A major reason for motor failures is mechanical in nature with bearings leading the pack. Infrared thermography, vibration analysis and oil analysis are the best tools to identify impending mechanical failures caused by factors such as misalignment, imbalance, under or over lubrication, and contamination, to name a few.

Overheating of motors and motor failure are due many times to a problem with the mechanical side. To gain a more accurate understanding of the failure mechanism it is important to inspect and analyze both the motor and what the motor is driving.

An effective application for thermography is the evaluation of gears, gearboxes, pumps, compressors, and all mechanical drives. Once the normal thermal pattern and temperatures of these components are understood, thermography provides an early warning of impending failure.

Mechanical components that are not working at optimal performance or are
in a failure mode will cause additional load on the motor. The motor will operate at higher temperatures and begin to fail. When doing a motor inspection it is important to inspect the motor, drive and mechanical components.

Bearings
Elevated operating temperatures not only affect the insulation material in a motor but also have an adverse effect on lubricants used in bearings. As the temperature increases, the viscosity of the lubricant is reduced, which leads to premature bearing failure. As the friction increases due to improper lubrication, the temperature of the bearing area of the motor will also increase. An experienced, well-trained thermographer can identify the various thermal patterns and correctly calculate the actual temperatures, which will help identify the cause of the elevated temperatures.

Bearing problems are generally found by a comparison of surface temperatures; comparing one bearing to another working under similar conditions.

Overheating conditions are documented as hot spots within the infrared camera and are usually found in comparing equipment to equipment, end bell to end bell (for the same type of bearings) and stator to end bell temperatures (determined by motor design and configuration).

Belts And Pulleys
Belts and pulleys are good candidates for thermographic inspection. The interaction of the pulley wheel and the belt generates friction as the belt contacts and then leaves the pulley surface. Additionally, the continuous tension and compression of the belt causes internal friction. Both of these processes result in heat being generated that can be seen with the infrared camera. Comparing the thermal patterns of several pulley belt systems can provide clues to improper operation.

Case Study
The temperature distribution across a pulley sheave should be uniform if everything is working as intended. In one documented case of a pulley arrangement with several belts, some belts were found to be running hotter than others. The belts were replaced with no improvement in the thermal distribution. Something was obviously wrong. The pulley did not appear to be worn; yet, it was replaced to see if the uneven heating would disappear. To everyone’s surprise the uneven thermal distribution...
remained. At this point some people were questioning the thermography data!

Vibration testing confirmed there was something amiss. Test data showed that the fan speed was decreasing in relation to the motor speed over a period of time. This meant that the belts were slipping. At this point, all the materials that had been removed were carefully inspected. It was then hypothesized that the belts may not have come from a matched set. After checking with the stockroom clerk, it was determined that these belts had not been stored and retained as a matched set. A matched set of belts was procured and fitted to the pulley system, and the thermogram showed even thermal distribution. This is an example where thermography used with other instrumentation and the perseverance of the investigators drove the inspection process to a correct and satisfactory resolution of the problem.

Misalignment is another cause of early motor and bearing failure. Many think shaft couplings take care of misaligned shafts and mechanical components. This may be the case in minor misalignments but is not the situation in most cases. All motors and mechanical systems should be aligned upon installation.

**Motor Control Centres (MCCs)**

MCCs normally contain copper and/or aluminum bus, circuit breakers (exposed and molded case), current transformers, potential transformers, starters, fuses and control circuits including relays, meters, switches and controllers. Many of these components are not overly expensive and the cost of testing and maintenance may be more than the component is worth. Yet, it is these components that provide power for the motor to operate, making them very critical components.

Infrared thermography is the most effective and cost effective tool available for testing in-plant electrical systems. It only takes minutes to look at hundreds of components and evaluate the condition. Overheated components, poor connections, overloading, unbalanced loads, high neutral currents, harmonics, eddy current and overheating breakers contacts are all quickly evaluated.

**Connections**

Poor connections are the most frequently found problem on an electrical system. It has been found that routine preventive maintenance on connections does not necessarily cure connection problems, and in many cases will create new connection faults.

Low contact pressure may occur when assembling a connection or through wear of the material, e.g., decreasing spring tension, worn threads or over-tightened bolts. Another source could be deteriorated conductors of motor windings. As the component continues to deteriorate, the temperature will continue to increase until the melting point of the material is reached and complete failure occurs.

**Thermographic Inspection - Routine**

Inspection with a thermal imager lets you know exactly where the problem is, allows you to schedule maintenance on the known problems and, after inspection, to verify that the problem is fixed.

**Conductors**

Infrared thermography is used to indicate general overheating due to overloading or undersized cables, high resistance, poor connections and bad splices. Excessive heating along a conductor

![Drive bearing is in failure mode.](image)

![The pulley tension was too great, causing overheating in the bearing and front of the motor.](image)
may indicate an overloaded conductor. Although varying materials will be able to withstand different temperatures, what is an excessive temperature for one will not be for another. A load reading should be taken if the temperature is in excess of 30°C above ambient. Overloading may be because of improper sizing of the conductor for load and heat dissipation requirements.

Hot spots along a conductor in an area where there are no connections, supports or enclosures around the conductor, indicate broken strands or a subsurface defect in the conductor.

Unbalanced load on a three-phase system with one conductor warmer along its length than the others will account for some differences between conductors. Use ammeters to check differences. The type of load will help indicate whether this is a problem or not. Three phase motor loads should be balanced, but lighting loads may be unbalanced.

A hot spot on an insulated cable at a support, but not near a connection, may be caused by high ground leakage current. This is a very unusual problem and the customer should be notified immediately (Hi-pot the cable for verification).

Localized hot spots can also be the result of a connection or bad splice.

Harmonics are another type of problem that will affect conductors and the motor the cable is supplying. Harmonics are currents or voltages that are at a frequency other than 60hz. The most damaging are the odd harmonics known as triplens. Triplen harmonics can create drastic overheating and even melting of neutral conductors, connections, contact surfaces, and receptacle strips. Other equipment affected by harmonics are
motors, transformers, stand-by generators, telecommunication equipment, electrical panels, etc.

The triplen harmonics are additive to the basic frequency and can cause severe over voltage and overheating. Thermography can identify the overheated neutral but other tests are required to verify the presence of harmonics. This could be done with voltage testing, however the best test would be the use of a harmonics meter.

**Protection Devices: Circuit Breakers, Overloads And Fuses**

Downtime is associated with two general failure types: those that occur due to motor failure such as bearing seizure or winding burnout, and those nuisance shutdowns which are temporary shutdowns due to operation of a protection system. Both types of shutdown occur on a fairly regular basis. Of the two failure types, the motor burnout, gets the immediate attention of the maintenance staff. Documentation is usually more complete regarding the nature of the fault, its correction, and subsequent production loss.

Not as much attention is paid when it comes to shutdown due to operation of a protection device. Even though the protection device prevented equipment damage, repeated downtime over a period of time can actually amount to a greater total shutdown time than for motor burnout conditions. It is important to inspect these components on a regular basis.

The best overall condition monitoring technique for this type of equipment is infrared thermography.

**Circuit Breakers And Switches**

These are mechanical switching devices capable of making, opening, carrying, and breaking currents, by non-automatic means under normal circuit conditions, and to open a circuit automatically under specified overcurrent or abnormal circuit conditions such as a short circuit. Circuit breakers will trip under severe loads beyond their ratings, providing protection to conductors, motors and other components. They may also trip from high ambient temperatures, excessive heat from poor connections and from poor or improper connections.

Another non-contact technique for certain medium and high voltage circuit breakers is ultrasound. Visual inspections are made of all components of an exposed switch or breaker; burning, arc trails, and deterioration are looked for. Resistance measurements are made to determine contact and connection integrity.

**Starter And Contactors**

Whether magnetically or manually operated, a motor control contactor or starter must repeatedly establish and interrupt an electric power circuit. The operating coil becomes energized, which in turn, closes movable contacts against the stationary contacts of the device. The contacts then connect the motor to the power source. These contacts are held in position by maintaining current through the coil.

The controller combines the function of starting and variable speed control. Both starters and controllers contain a mechanism for automatically disconnecting the motor from the power line should the voltage line fail.

Thermography Inspection would be an early warning test to indicate overheating of internal components such as deteriorated contacts, poor conductor connections, overheating of coils and resistors.

_Not as much attention is paid when it comes to shutdown due to operation of a protection device. Even though the protection device prevented equipment damage, repeated downtime over a period of time can actually amount to a greater total shutdown time than for motor burnout conditions. It is important to inspect these components on a regular basis.

_The best overall condition monitoring technique for this type of equipment is infrared thermography._

_This infrared image shows increased resistance at the bolted connection. Also note that the insulation is burned off and must be repaired as soon as possible._

_Overheating on B phase breaker contact._
Thermal Overloads

Thermal overload protection heaters are used to provide overload protection without the circuit being tripped by large momentary starting currents. The heaters protect the motor from continuous overload and from excessive currents caused by an open phase.

Fuses

A fuse is an overcurrent protective device made of a metal conductor that is deliberately made to melt when an overcurrent is passed through it.

Problems found with thermography are caused by:
- Loose mechanical stab or clips
- Corroded, oxidized external contact surfaces
- Poor internal connections or link

Power supply problems- Another cause for overheating is power supply problems. Low voltage will result in the motor drawing higher current to deliver the same horsepower, and the higher current means higher winding temperatures. A 10% drop in voltage could cause temperature rise. Excessive or sustained high voltage will saturate a motor’s core and lead to overheating as well.

In three-phase motors, phase imbalances can result in high currents and excessive heat, the extreme being the complete loss of voltage in one phase, called single phasing. This happens in a 3-phase motor when one of the three phase legs of the motor circuit loses all voltage. This could be due to one blown fuse. This will cause single phasing, which if correct protection is not in place, will result in motor burnout in a relatively short time.

Conclusion

Predictive, proactive maintenance utilizing infrared thermography on motors has many advantages over reactive, run to failure maintenance. Properly implemented and maintained, condition monitoring as part of a reliability based maintenance program will increase plant reliability and improve operating profit.

A full program will assist in determining equipment and facility maintenance priorities, enhance operational safety and contribute to a stronger bottom line. The savings in reduced overtime, reduced parts inventory, reduced repair costs and reduced production downtime far outweigh the investment required to add infrared thermography to your condition monitoring program.

Ron Newport is President of Newport Solutions located in Kamloops, B.C.