ELECTRIC POWER RESEARCH INSTITUTE

Applications of Predictive Maintenance (PdM) Technologies

2013 TECHNICAL REPORT

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Abstract

The traditional predictive maintenance (PdM) methodologies make use of a fairly mature set of technologies, and extensive knowledge and understanding regarding their conventional deployment now exists in the power generation industry. With the changing landscape of the industry, however, new types of equipment and systems are being acquired and operated, and new applications of existing systems and equipment are being implemented. This EPRI technical update report on applications of predictive maintenance technologies reviews existing technologies used in PdM programs and presents two case studies that demonstrate novel applications of a widely used conventional technology (infrared [IR] thermography). In the first study, IR thermography was used to evaluate heat-up profiles and overall thermal profile of printed circuit boards in a root-cause investigation. In the second study, IR thermography was used to evaluate thermal behavior of grease to obtain information that could lead to better sampling techniques, which in turn might support the expanded use of grease monitoring as a diagnostic tool for PdM.

Keywords
Data collection
Fossil plant maintenance technology
Infrared thermography
Lubrication monitoring
Predictive maintenance

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Section 1: Introduction

The traditional predictive maintenance (PdM) methodologies make use of a fairly mature set of technologies, and extensive knowledge and understanding regarding their conventional deployment now exists in the power generation industry. With the changing landscape of the industry, however, new types of equipment and systems are being acquired and operated, and new applications of existing systems and equipment are being implemented. This EPRI technical update report on applications of predictive maintenance technologies reviews existing technologies used in PdM programs and presents two case studies that demonstrate some novel applications of a widely used conventional technology (infrared [IR] thermography).

This introduction provides background information and a summary of the types of equipment currently being deployed in standard PdM applications. Section 2 of the report presents the two case studies. In the first study, IR thermography was used to evaluate heat-up profiles and overall thermal profile of printed circuit boards in a root-cause investigation. In the second study, IR thermography was used to evaluate thermal behavior of grease to obtain information that could lead to better sampling techniques, which in turn might support the expanded use of grease monitoring as a diagnostic tool for PdM.

1.1 Background

PdM is a process that involves acquiring data on plant equipment, assessing that data to derive information, and then using that information to make decisions regarding corrective actions and appropriate timelines for performing maintenance (see Figure 1-1).

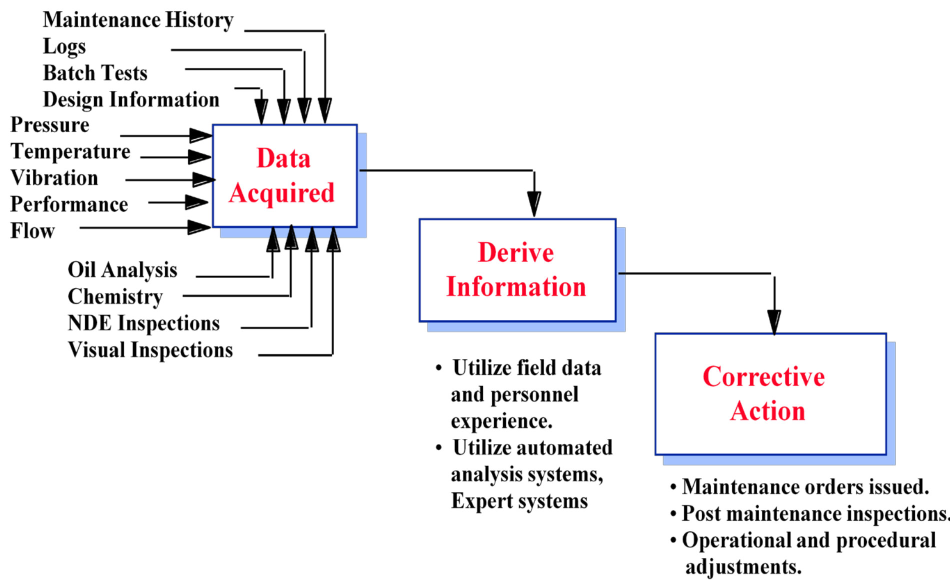

Figure 1-1
Predictive Maintenance: From Data to Information to Action

PdM programs have been a part of the landscape in the fossil power generation industry for many years now. Using PdM procedures to investigate the health of plant machinery saves money and improves plant reliability. PdM supports both better equipment condition and better overall system health condition.

Early PdM programs used condition monitoring techniques such as vibration analysis, infrared thermography, and lube oil analysis to collect data used to support maintenance decision making. Over the years, these technologies have matured and programs have evolved, incorporating new approaches such as on-line and off-line motor testing and ultrasonics. In order to gain maximum value from their PdM programs, utilities must keep a watchful eye on technology improvements and methodology enhancements and periodically acquire new equipment or extend the use of their existing equipment. With organizations constantly being pressed to do more with less, optimal deployment of technology is an essential way to stretch program budgets and utilize staff resources to their maximum advantage.

The evolution of PdM data collection devices over the past twenty years has had a significant impact on the utility industry. Devices used in the early days of PdM data collection were often large, bulky, and time-consuming to deploy, and in many cases they failed to provide sufficient data to enable a clear determination on a component. Examples of older technologies include single-channel vibration analyzers and shortwave IR cameras.

The advent of new applications in PdM can be beneficial to organizations, because the technology potentially requires less time for data collection, allows more data to be collected from a single device, uses smaller instruments, and so on. These improvements can be especially advantageous when there are personnel changes in PdM groups—for example, in cases of staff retirements and/or new hires. The new applications can ease transitions for PdM personnel who may not have intensive training and experience to support condition evaluations on components.

1.2 Vibration/Balancing

Equipment used to collect vibration/balancing data has seen vast improvements over the years. Not only is it possible to collect more data from a single device to support condition assessment of a component, but currently available vibration/balancing data collectors have a wider range of capabilities and more automated functions than some of the older models. In addition to being able to perform conventional functions for components such as motors, fans, and blowers, the new generation of data collection devices can also detect the root cause of mechanical failures—for example, bearing problems, misalignment, unbalance, and looseness.

Many devices now have severity criteria and diagnostic capabilities that can be beneficial to new PdM personnel who may lack extensive experience or knowledge about the technology. Such devices can offer repair recommendations to address specific problems, which can assist in the prioritizing and planning of maintenance repairs. Among the available offerings are small, handheld units that are equipped with severity criteria along with a spot IR sensor for temperature measurement.

1.3 Infrared Thermography

Infrared thermography equipment, like vibration measuring equipment, has seen major improvements over the years. Whereas early IR equipment tended to be unwieldy and require inconvenient warm-up times, new products are compact and easy to use, with features such as hands-free focus, point and shoot capabilities, built-in laser pointers and flashlights, and sophisticated electronics that enable high image resolution and processing ability. Some units can be used in conjunction with a smart phone or tablet device. Along with the development of the technology, a competitive marketplace has made it more practical for organizations to supply IR equipment to a larger number of personnel for use in the field, including maintenance and operations staff performing routine inspections of equipment.

In power plant applications, IR thermography is used on many different types of equipment and components, including the following:

- Motors
- Pumps
- Motor control center (MCC) cabinets
- Breakers
- Bus ducts
- Transformers
- Substation equipment
- Boilers

A few example applications illustrate the wide range of uses of IR thermography in the power industry:

- Determination of heat loss from HVAC systems
- Inspection of flames in a boiler
- Detection of gases such as SF6 and carbon monoxide
- Post-maintenance testing to confirm elimination of IR anomalies

Organizations making purchasing decisions need to take a number of considerations into account. What are the intended applications for the purchased equipment? Will it need to operate in a high-temperature environment? Does it need to provide digital as well as thermal imagery? Will it be used at a distance or close up? Such questions help decision makers narrow down the suitable possibilities from among the large array of choices.

1.4 Ultrasonics

Ultrasonic testing is another technology that has taken major strides over the years and has become an indispensable technique for a number of power-industry inspection situations. One of its primary uses in PdM is for detection of electrical and mechanical anomalies in places where an IR camera cannot be used. For example, in most power stations there are high-voltage breakers that would ideally be imaged with an IR camera, but because of safety issues the breaker compartments cannot be opened. If there are no IR windows to enable use of an IR camera, then ultrasonic testing is the next best thing. Scanning around the compartment door with an ultrasonic device can detect arcing inside, and if an anomaly is found, the breaker can be scheduled for maintenance. Besides being useful in electrical and mechanical inspections, ultrasonic testing can be used to detect leaks in valves and piping and to inspect steam traps. It can also be used to prevent over lubrication in motors.

Many vendors supply ultrasonic equipment to the energy industry. Equipment that is available for PdM applications can analyze conditions, pinpoint locations with a laser pointer, and store collected data. There are also applications for remote monitoring utilizing ultrasonics.

1.5 Remarks

There is a great deal of data collection equipment on the market today that can be beneficial to a plant PdM group, but before purchasing new devices it is important to evaluate already existing equipment in the context of the overall PdM program to determine exactly how new equipment can assist the program. New equipment may entail the need for specialized training, additional software, and so on, but it can potentially reduce data collection time substantially, and it may also provide more data that can be used to make better determinations on components.

Section 2: New Applications of Existing Technologies

2.1 Context

This section of the report presents case studies illustrating two novel applications of existing PdM technologies.

One way to expand the applications of PdM data collection technologies is simply to extend the PdM program itself to cover equipment, whether new or existing, that was not originally covered by the program. In most power stations, the PdM group collects and interprets data on critical equipment such as pumps, fans, motors, breakers, MCCs, and transformers. Plants can consider whether there is other plant equipment and/or technology that should be included in the PdM program.

Every organization today is faced with the situation of needing to do more with less. This typically means fewer personnel doing more data collecting on additional equipment. The overall objective is the reliability of the plant, which depends on keeping equipment failures as infrequent as possible. As new plant equipment is acquired, plants need to evaluate it for possible inclusion in the PdM program, and any implications of added equipment on the program need to be considered.

Three key technologies—vibration, infrared thermography, and oil analysis—are being used at the majority of the power stations as part of the PdM program. In addition, there are other technologies that can be used on equipment, such as motor testing (both on-line and off-line) and ultrasonics.

New applications can also take the form of finding different ways to use existing PdM equipment. The two case studies presented in this report document interesting examples of the use of IR thermography. In the first study, the technology was used to evaluate heat-up profiles and overall thermal profile of printed circuit boards in a root-cause investigation. In the second study, IR thermography was used to evaluate thermal behavior of grease to obtain information that could lead to better sampling techniques, which in turn might support the expanded use of grease monitoring as a diagnostic tool for PdM.

2.2 Case Study: IR Thermography of Printed Circuit Boards

2.2.1 Motivation and Overview

The prospect of utilizing IR thermography to evaluate printed circuit boards (PCBs) has attracted interest from a number of different organizations. One particular incident identified at a facility was the failure of a +24V power supply. A root cause investigation was recommended, and the IR thermographer proposed that thermography could aid in the investigation.

The thermographer recommended a technique utilizing dynamic thermal monitoring to evaluate heat-up profiles and overall thermal profile of the printed circuit board as the best method of inspection for the printed circuit boards. It was the intent of the thermal study to subtract the images using the ThermaCAM Researcher professional software from T0 through Tn. The two test cases were recorded and compared. Unfortunately, the equipment/PCB set-up allowed the test board to shift position during the testing, which rendered signal processing futile. However, even though the two tests could not be combined to one image, the data did allow for a direct comparison to be conducted.

2.2.2 Approach

Multiple points of reference (see Figures 2-1 and 2-2) were chosen on the PCB to relate the temperatures of the two boards at peak temperatures within the +24V circuit, +24V regulator module, and -15V circuit. The temperature profiles from T0 through T2:20 were reviewed for heat-up rates and temperatures (see Figure 2-3).

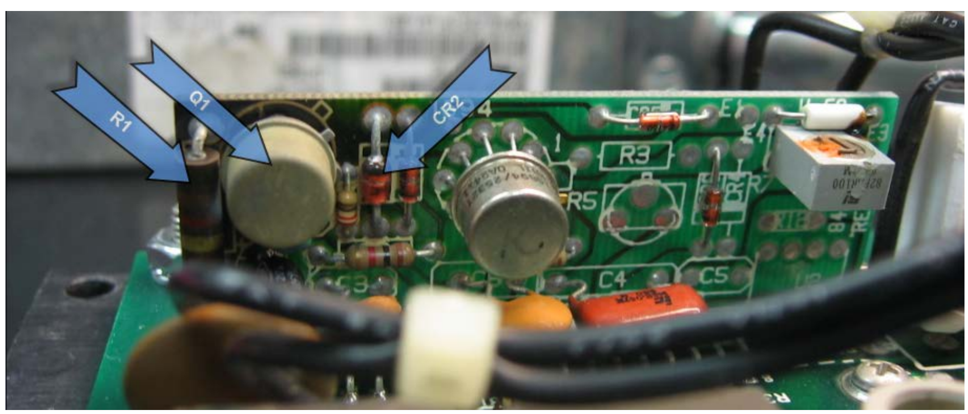

Figure 2-1
PCB showing points of reference

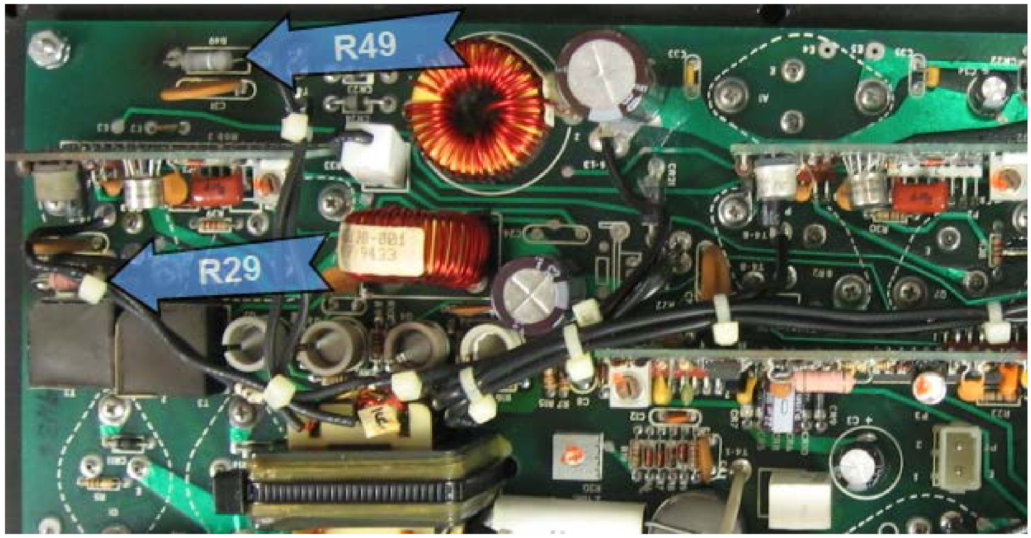

Figure 2-2
PCB showing points of reference

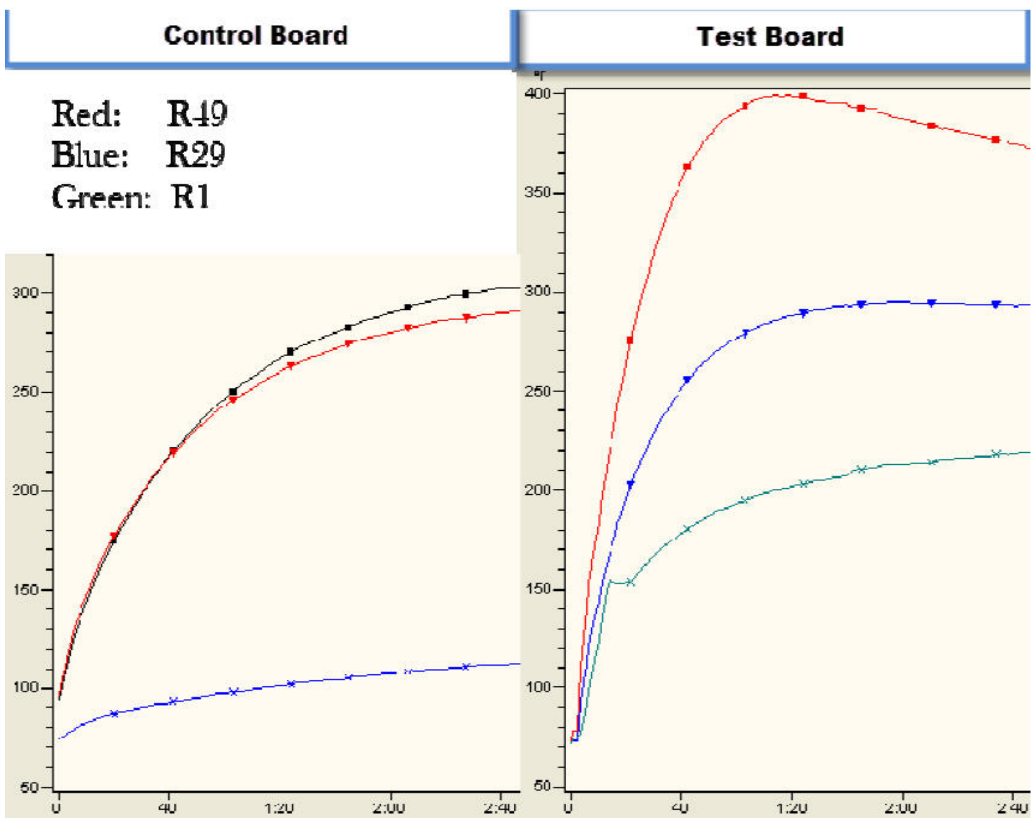

Figure 2-3
Temperature profiles of the two boards

2.2.3 Observations and Conclusion

It was immediately evident that the test board heat-up rates were significantly elevated and that R1 in the +24V regulator module was heating abnormally, in both heat-up profile and temperature levels. The heat-up rate initially mimicked that of R29 in the 24V circuit and then ceased heat-up at T00:14–T00:16. After the pause, the resister then continued to heat up with a normal heat-up profile. In an attempt to understand what happened at T00:14 with R29, Q1 and CR2 were profiled on the regulator (see Figure 2-4).

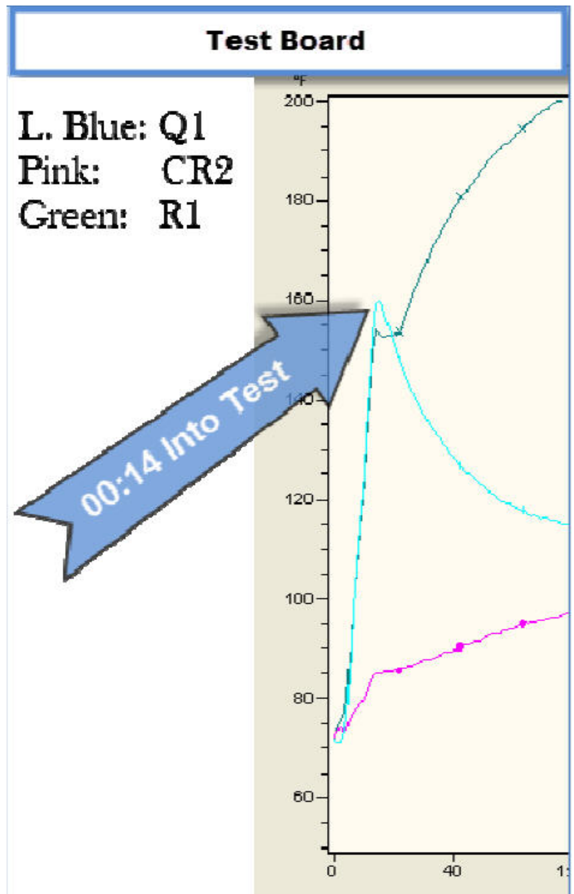

Figure 2-4
Heat-up profile on the test board

At T00:14 it is evident that Q1 stopped conducting through the emitter, as it immediately began a typical cool-down profile. At the same time, CR2 exited a normal heat-up profile for a conducting component with a resistance and began a heat-up that is more indicative of a heat-up due to the influence of nearby components or that of a component with little to no resistance. The zener diode (CR2) was identified as shorted.

Figure 2-5 displays some general temperatures of the testing, showing the comparison between the two tests.

		Test Board (F)	Control Board (F)	Delta (F)
Main Board	R49	400	325	75
Main Board	R29	294	305	11
24V Reg Module	R1	225	160	65
24V Reg Module	CR2	120	167	47
24V Reg Module	Q1	158	Undetermined	-

Figure 2-5
Comparison temperatures between the two tests

Visual images were also reviewed, and an abundance of heat damage was identified (see Figures 2-6 and 2-7).

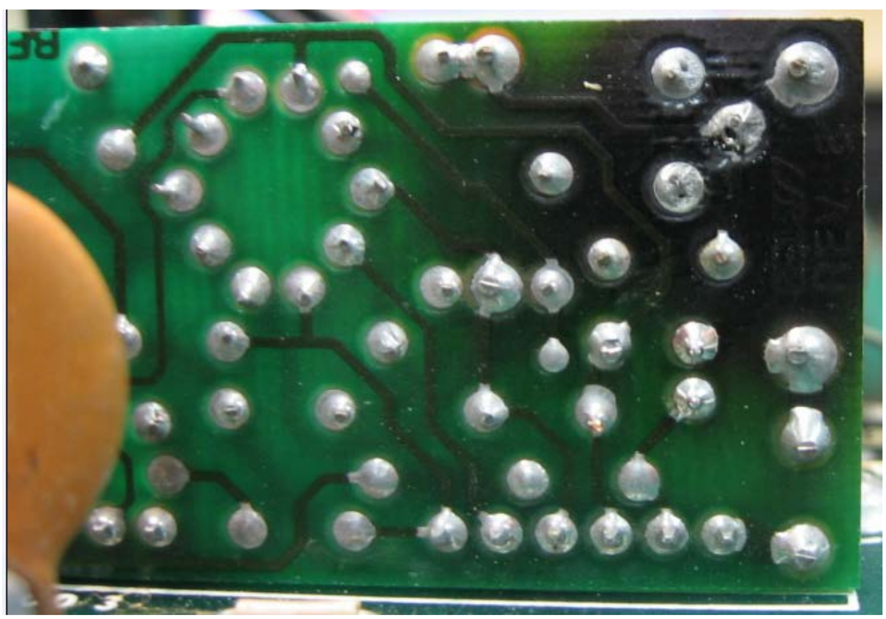

Figure 2-6
Photograph of the PCB, showing clear signs of heat damage

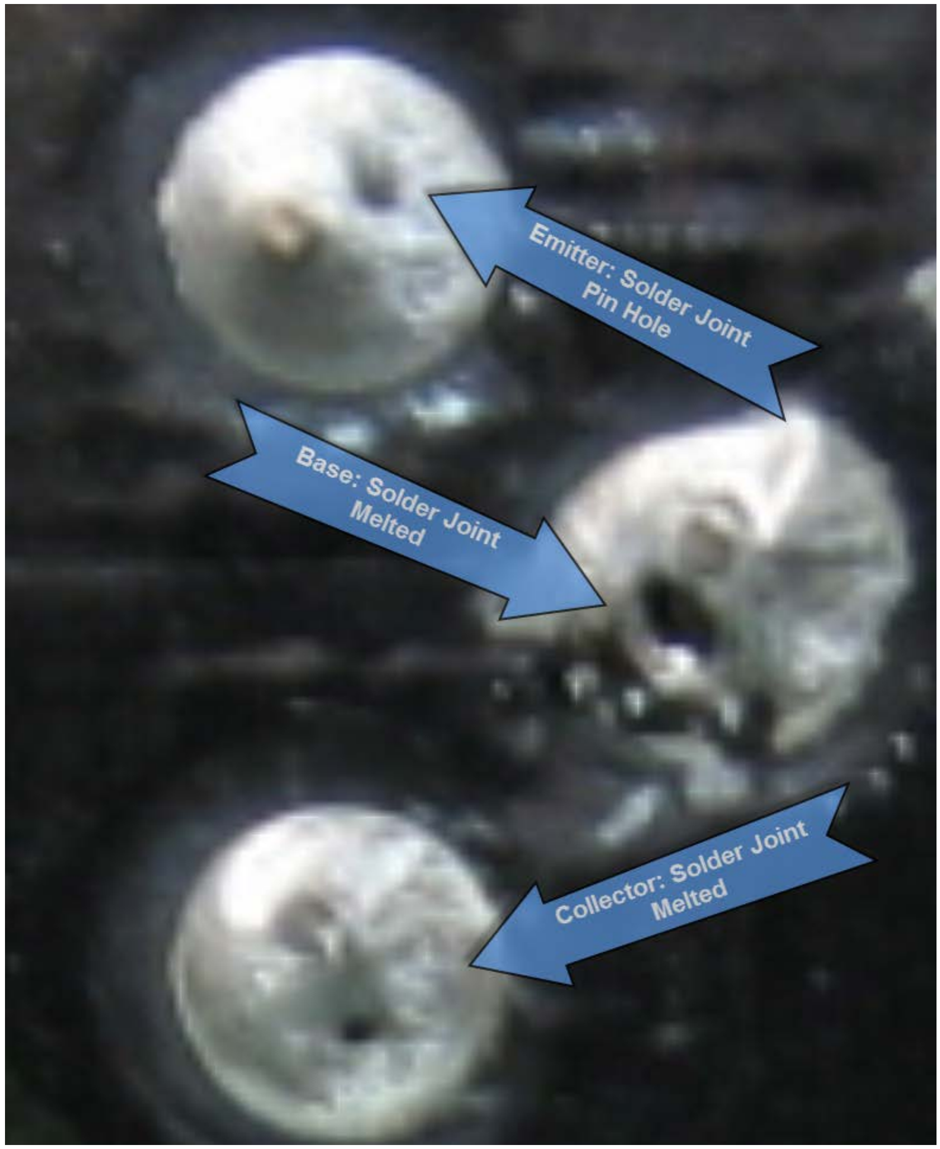

Figure 2-7
Specific areas of damage identified on the PCB

The end result was that it took the technician about one minute with the schematic to pinpoint the problem after the thermal anomaly was identified.

2.3 Case Study: Use of Infrared Thermography to Monitor Grease Migration in Bearings

2.3.1 Motivation and Overview

As part of a comprehensive predictive or condition-based maintenance program, lubricant analysis is an effective complement to other diagnostic technologies such as vibration analysis, infrared thermography, ultrasonic detection, and motor circuit evaluation. Oil sampling and analysis is a well-established diagnostic tool for industrial machinery, providing insight into the condition of the bearings, gears, and other lubricated mechanical components, and into contaminants that have entered the system, as well as the condition of the oil itself. Grease sampling and analysis, on the other hand, has not seen widespread use as a diagnostic tool. Although grease lubrication of rolling element bearings is one of the most common lubrication scenarios in industry, the exact behavior of greases while equipment is in operation is not well understood. The primary barrier to routine use of grease analysis has been the challenges related to understanding and obtaining representative samples.

New tools have been developed for improved sampling techniques, and grease analysis tests have been added to address concerns of sample trending as well as accommodating small sample sizes. These include rheometry of greases, for which DIN (German Standards Organization) and ASTM standards exist and are under development. A better understanding of grease thermal behavior, flow characteristics of non-newtonian fluids, and changes in grease properties in rotating rolling-element bearings can help to support the proper application of these tools and tests.

In accordance with the flow properties of non-newtonian fluids, as a bearing heats up during operation, the yield stress of the lubricating grease drops, and an increasing percentage of the grease in the housing experiences fluid flow. Once the grease begins to move, the boundary between fluid flow and non-fluid flow areas of the grease becomes difficult to observe. Knowing this behavior is important in ensuring that grease samples are taken from circulating and representative areas of the housing.

This case study describes an effort to show thermal patterns of circulating grease in a common electrical motor application and utilize these thermal patterns as well as knowledge of the flow behavior of non-newtonian fluids. The goal is to aid in the establishment of a strategy for utilizing grease sampling tools to access samples of grease that will be representative of the grease condition and the health of the monitored component.

2.3.2 Infrared Monitoring of Bearing Internals During Operation

To allow infrared monitoring of bearing internals during operation of an electric motor, a test stand developed for performing visual observations of grease flow within an operating motor (see Figure 2-8) was modified by replacing the stand's original Plexiglas window with a mounting ring and stretching a 1-mil-thick polyethylene film between the ring and the housing. (This film was observed with an infrared camera and determined to have a very small effect on temperatures measured during bearing operation due to the high transmissivity of the thin polyethylene.) The bearing was hand packed with a polyurea-based grease suitable for electric motor applications, and a small amount of grease was added to the bottom of the housing, as is typical in new installations of this configuration.

Figure 2-8
Motor test stand used in grease study

An infrared camera was used to monitor the bearing from startup, and to trend temperature changes observed on the bearing and the grease within the housing. Although temperatures were monitored and trended, the purpose of this observation was primarily qualitative in nature.

The bearing was first lubricated in the normal manner by adding grease through a hydraulic fitting (zerk) in the top-most position of the housing, and allowing the grease to fall to the base of the housing, where it could come in contact with the rotating parts of the bearing. This contact typically draws most of the grease into the bearing, with some being flung out and away from the bearing. The thermal trend shown in Figure 2-9 illustrates the general increase in temperature during this heatup (initially without grease being added) and then the addition of grease marked at about 700 seconds, after the temperature had stabilized.

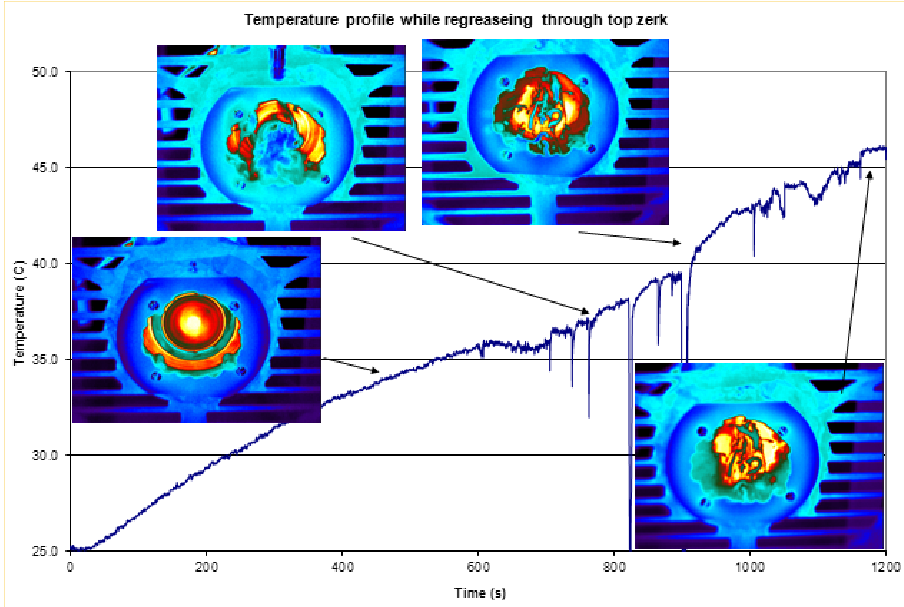

Figure 2-9
Increasing temperature profile on top addition of grease

When grease is added, there are several drops in temperature, which reflect the colder, new grease being placed in the path of the infrared camera. In some cases, this new colder grease is present in the observed pathway (location of the spotmeter) for a longer period of time, which shows as a wider dip. Eventually, these additions of new, colder grease are mixed in with the grease previously added, and the temperature ramp resumes.

Eventually, grease being flung from the bearing began to cover the polyethylene window and impede the ability to observe the behavior of the grease. To prevent this, the drain plug was removed, and the hydraulic fitting was moved to the bottom of the housing, so that grease could be added from this non-typical location. This improved the ability to observe the movement of the grease, and the thermal patterns, but did change the behavior of the grease being added. There tended to be a surge of grease that would contact the moving parts of the bearing, which drew a large chunk of grease into the bearing all at once. This new grease was cooler in temperature than the grease that had already circulated, or was actively circulating. As the amount of grease in the reservoir increased, the area that remained cooler than the surrounding grease increased as well. The profile of the grease temperature, as measured at an area with view of the moving parts of the bearing, is shown in Figure 2-10.

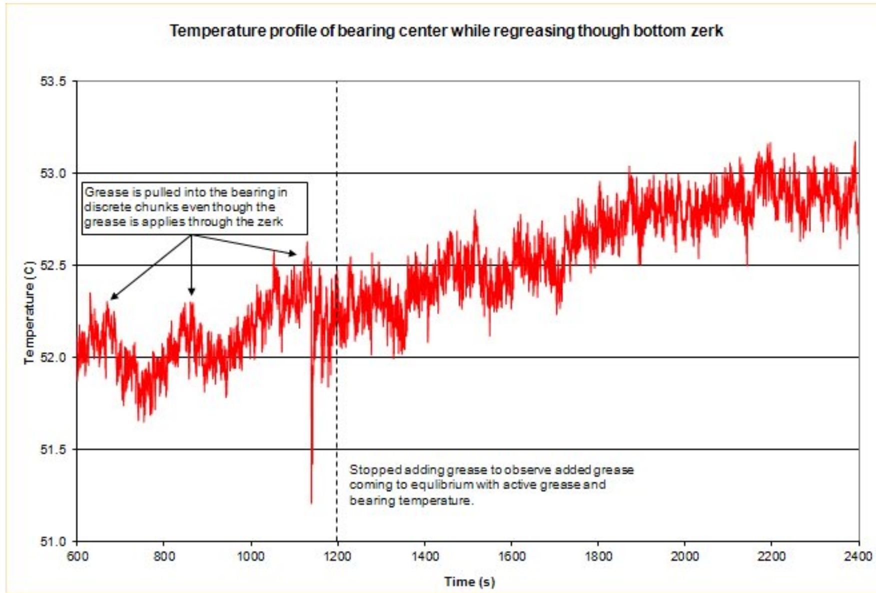

Figure 2-10
Increasing temperature profile on bottom addition of grease

2.3.3 Comparison of Active Zone of Grease to Newly Added Grease

Three spotmeters were placed on the bearing to trend the temperatures at the bearing shaft (Spotmeter 1: little or no grease present), in the active grease zone (Spotmeter 2: grease that is actively moving or has just been flung out of the active zone after being in circulation), and in the non-active grease zone (Spotmeter 3: newly added grease near the hydraulic fitting). Spotmeters 1 and 2 showed a gradual increasing trend in temperature, consistent with the heat-up of the bearing, and the addition of new grease in viscous churning (viscous temperature increase). Spotmeter 3 showed a trend that first had a spike, when the last added grease was swept into the bearing, giving the spotmeter a view of the warmer grease closer to the active zone in the bearing. Then several pumps of new grease were added, dropping the temperature significantly to the new temperature of the added grease. Over time, this grease, without moving, slowly increased in temperature as it was heated by the surrounding grease, and by that portion in active circulation in the bearing. In this test, this demonstrated that slowly, over time, all grease in this housing was influenced by the temperatures and fluid flow of the grease in the active zone.

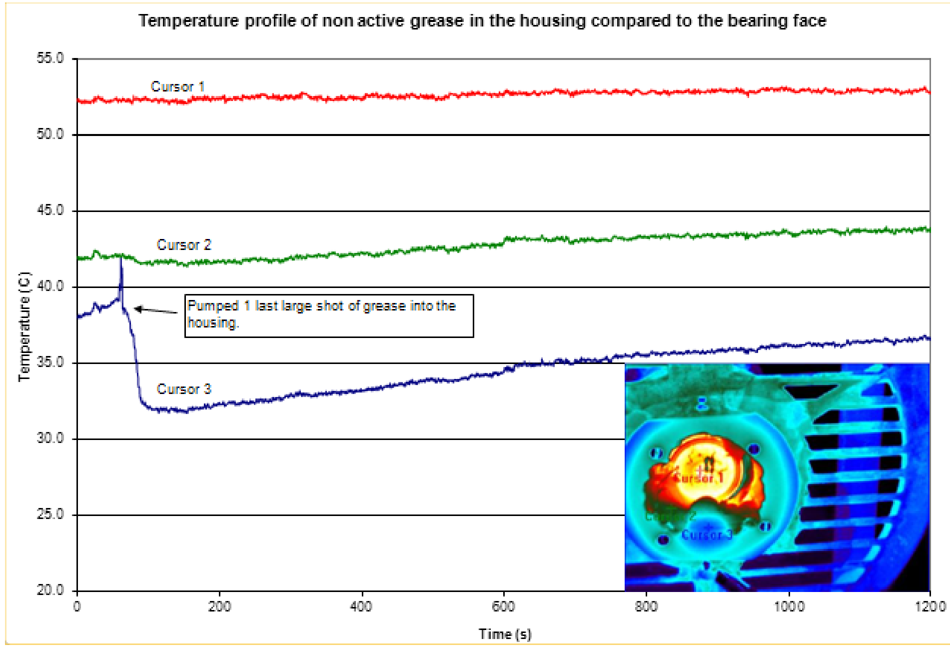

Figure 2-11
Profile of three selected active and non-active zones in the bearing

2.3.4 Conclusions and Applications

The findings in this experiment reflect conditions in a new motor that has been properly lubricated with a single grease of the correct type and quantity. In this configuration, the thermal profiles shown demonstrate a tendency for the grease in the housing near the drain hole to be lower in temperature, and sufficiently far away from the applied forces of the rotating bearing to remain in circulation within the housing. This limits the effectiveness of the drain located in this position to provide an adequate drain point for purged grease. Additionally, any samples taken from this position will likely have spent little time in contact with the bearing, and samples from this position may not reflect the active condition of the grease or the bearing. Designers of such components, and maintenance personnel tasked with sampling, can utilize the thermal profiles shown in this study to adequately position sampling tools (such as the ASTM D7718 compliant tool shown in Figure 2-12), or to retrofit equipment with access points that provide grease samples from the active circulating zone of the bearing to enhance monitoring effectiveness.

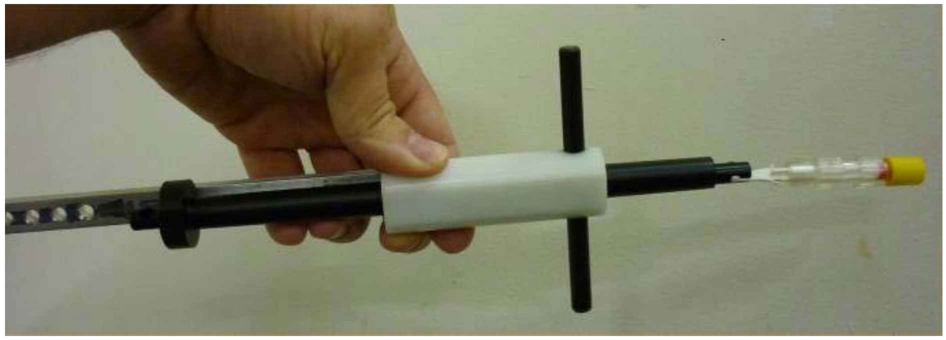

Figure 2-12
T-handle and grease sampler for accessing "live zone" of grease

2.3.5 References

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Wurzbach, R., Williams, L., and Bupp, E., Proceedings of Thermosense XXXIV, "Monitoring and thermal effects of relubrication of greased bearings," SPIE, Bellingham, WA, May 2012.

Section 3: Related EPRI Reports

Condition-Based Maintenance Guideline. EPRI, Palo Alto, CA: 2011. 1022957.

Criteria for Assessing Predictive Maintenance Data. EPRI, Palo Alto, CA. 2012. 1021725.

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