Thermography and PdM:
How to Maximize Your ROI

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Introduction

Thermography or thermal imaging for industrial plant maintenance applications is a rapidly developing market because:

- the equipment, software and training are becoming more and more affordable,
- the technology is becoming easier to learn and use,
- the applications are intuitive and numerous in an industrial maintenance environment,
- success stories from leading companies are being shared amongst industry professionals,
- and competition amongst suppliers of thermal imaging equipment is heating up.

The great advantage of thermography over some other technologies is that inspections can take place while the equipment is running. In fact, most inspections can only be done with the equipment running. Fortunately, the non-contact nature of infrared also provides an element of safety not found in other inspection techniques.

It is an excellent time to be in the market for thermal imaging equipment. However, companies need to do their homework before making any large investments in equipment, software or training. They must make sure they are investing in the right solutions that will address their needs, and they must make sure that the maintenance program they plan to implement will deliver the return on investment management expects.

The Investment

The challenge with any NDT or PdM technology (thermal imaging, vibration, ultrasound, motor circuit testing, power quality, etc.) is that the initial investment is substantial; typically measured in thousands or tens of thousands of dollars. Without the proper analysis, companies and/or maintenance organizations:

- may decide not to implement a PdM program because they are unable to identify all of the savings, causing them to miss out on operational efficiency improvements,
- may invest in a suboptimal solution that does not best meet their needs,
- may spend significantly more money to establish the program than is necessary,
- and/or may not achieve a return on investment.

Companies need to consider not only the initial equipment costs for the test tools and accessories, but also the software costs, training costs, typical service and calibration costs and overall labor costs associated with performing periodic inspections of critical equipment.

It is very important for companies and maintenance organizations to thoroughly understand their needs. In the case of thermography, companies can spend as little as a few thousand dollars or as much as $1,000,000 to establish an infrared predictive maintenance program. Clearly not every company needs the million dollar solution, but is the $2500 solution really sufficient? Finding the proper balance is the goal.

The Return
The primary objective of any maintenance or reliability manager is to improve operational efficiency. In short, they want to keep things up and running for the lowest possible investment.

Operational efficiency is often measured by labor productivity (both production direct labor and maintenance staff indirect labor), equipment productivity or processing rate, product quality or yield rate and equipment availability or percentage of uptime. In Total Productive Maintenance (TPM) programs, this operational efficiency is often discussed in terms of OEE (overall equipment effectiveness) where:

OEE = % available uptime x % maximum processing rate x % quality yield rate

(NOTE: An OEE = 1.0 or 100% would indicate that the equipment is available 100% of the time, can run at the maximum output rate and never produces a defective product.)

Other measures of operational efficiency include amount of unplanned downtime, inventory turns and average equipment life span.

Regardless of how performance is measured, it is clear that an effective predictive maintenance program using thermal imaging will improve results; especially if the current situation can best be described as “run it until it breaks.” By matching the company’s predictive maintenance needs and applications to the right thermography solution, companies will achieve maximum return in the shortest period of time. In fact, most companies that have invested in the proper thermal imaging solution for predictive maintenance find that they can achieve payback on their initial investment in well under one year.

Analyzing the Investment

Infrared PdM Needs Analysis
Assessing a company’s PdM needs starts with understanding the costs and most common sources of downtime. PdM programs are designed to keep equipment up and running and allow companies to schedule the necessary downtime during periods of production inactivity (off shifts, weekends, periods of slower demand, etc.).

Step one is to identify the most critical equipment in the plant. This can be done through a simple process walk, starting at the beginning (raw material end) of the process and proceeding to the end (finished goods shipment) of the process. Maintenance records and equipment failure data can also help identify those pieces of equipment that are most prone to failure. Evaluating urgent maintenance work orders can also be quite useful, since those “emergency” repair situations are often caused when the most critical equipment in the plant goes down. It is important for the maintenance team to discuss this with the production team. Production/manufacturing often has a very different view of what equipment is most critical to the operation.

Step two is to evaluate what inspection technologies and techniques are available for the critical equipment and the most common failure modes experienced on that equipment. If electrical connections are the most common problem, thermography would be the ideal technology to implement. More importantly, an affordable thermal imager would most likely answer the needs as well or better than the most expensive imagers on the market. If the biggest problem is with high RPM rotating equipment, a combination of vibration and thermal imaging may be in order. The first priority must be to have alignment between the most critical equipment / failure modes and the inspection equipment / technologies that will be used.

Now that the most critical applications for thermography have been identified, it is time to list all of the other possible applications in the facility or company. It is still important to have a sense of priority in the list of possible applications. The applications for thermography are endless, since anything which has a thermal signature can be inspected with a thermal imager. While it would be nice to purchase a thermal imaging solution that addresses every possible inspection need, it may not make sense to spend an additional $50,000 in order to be able to perform inspections that will only occur every three years or where the probability of finding a problem is very small (or just not that important). Also remember, that for a relatively small investment, infrequent or specialized inspections can still be performed by outside consultants who own the more expensive, more versatile and more complex equipment.

Finally, think about possible applications outside of maintenance. Processing plants often have quality control plans based on regular temperature level inspections at critical points in the process. Manufacturing / processing engineers often have applications for thermal imagers in the development of new production processes (plastic thermoforming mold development). The facilities maintenance team may have a desire to complete a thorough roof inspection every other year. Research, development and design engineers also often have a need for measuring temperatures accurately as they develop new products. The advantage of sharing this technology across an organization is that it becomes easier to justify the initial investment, it speeds the payback time and it lessens the budget impact on any single department.

Thermal Imagers

Thermal imagers come in all shapes and size, with various features and benefits and with a very wide range of price tags. Luckily, the process of evaluating imagers is simplified significantly if the critical equipment and applications are known. Some of the key performance specifications for a thermal imager are listed below:

- array size and type (example: 160x120 uncooled focal plane array)
- thermal sensitivity of the array (example: NETD = 200 mK or 0.2 °C)
- optics field of view options (example: 17° x 12.8° fixed)
- optical resolutions or distance to spot ratio (example: D:S = 90:1)
- form factor including size and weight (example: pistol grip form factor, < 1 kg)
- radiometric accuracy (measures absolute, calibrated temperature; example: +/- 2°C or 2%)
- temperature measurement range (example: -10 °C to 250 °C or 14 °F to 482 °F)

- image and data storage capacity (example: internal flash memory stores 100 images and corresponding data)
- battery life (example: five hours in continuous use)
- manufacturer's length of warranty (example: one year)

Array size and type – The larger the array, the more resolution (pixels) in the thermal image. Costs for imagers are directly proportional to the size of the array, since these components contain the core infrared imaging technology. While larger arrays do, typically, produce nicer images, for predictive maintenance customers the picture quality from a 160 x 120 array is more than sufficient in most applications.

Thermal sensitivity or NETD – This is the smallest temperature difference the thermal imaging camera can resolve. 200 mK or 0.2 °C indicates that the camera can resolve two tenths a °C temperature difference. Some cameras can resolve as little as one tenth or half a tenth °C temperature difference. Again, these cameras produce very high quality images, but also, typically, come with a higher price tag. For maintenance applications, there are very few applications, if any, requiring the ability to resolve less than 0.2 °C temperature difference.

Field of view and Optical Resolution –
The optical system in an infrared camera has a limitation to how much the camera will "see" of a given object at a given distance. This is determined by the field of view. If many of the applications involve small objects (< 2 inches in diameter) at large distances (50 or 100 feet), then a narrow field of view (12° x 9°) with a larger D:S (> 250:1) will be required. If many applications are close up looking at large objects (electrical panels in narrow passage ways or building inspections), then a wider field of view (40° x 30°) and smaller D:S (60:1) may be required/sufficient. For most maintenance applications (both electrical and mechanical), a field of view between 16° x 12° and 30° x 22.5° is appropriate; especially if there is flexibility with most inspections to move closer to or farther away from the target. D:S performance of 75:1 or higher is also usually sufficient, although some smaller electrical components may be difficult to measure accurately at this level.

Form factor –
It is important not to underestimate the form factor, size and weight of professional tools. Thermal imagers should be comfortable to carry around and use all day long. They should be well balanced in the hand and easy to grip. They should not be too heavy. The aiming and display angles should feel natural. The buttons, wheels and switches should be easy to access and intuitive to use. This overall ease of use factor could mean the difference between the tool sitting on the shelf or constantly being in use on the factory floor.

Radiometric accuracy –
Some very low cost imagers are non-radiometric or only partially radiometric, meaning the pixels are not measuring an absolute temperature. They are only showing temperatures relative to one another. So while a hot spot might be visible, the camera

cannot tell you what the real temperature of the hot spot is. This is a significant disadvantage in PdM applications, where so much of the equipment being inspected will have rated operating ranges for temperature. Also, trending of temperatures over time is only possible if the imager measures absolute temperature.

Temperature measurement range –
The needs for temperature are a direct correlation to the applications present within the industrial environment in question. In most manufacturing and facilities environments, the temperature range needs for the electrical and mechanical equipment will not exceed 250 °C. However, in the metals industries and some others, temperatures over 250 °C are quite common. If this is the case, a camera with a higher temperature range may be necessary. If the higher temperature requirement is more of the exception than the rule, this may be where an outside consultant can help supplement an internal program. Another option for higher temperatures is to use an infrared filter to reduce the IR energy reaching the detector. This allows the camera to "see" higher temperatures, although the camera may no longer be able to measure accurately those temperatures.

Image and data storage capacity –
Internal memory has some advantages over external options such as memory sticks or flash media cards. The user doesn't have to worry about losing the external memory devices and the user interface is not complicated by selecting the memory location for the camera to use. The important question is whether the camera holds enough images for a full day of testing or will the stored images need to be downloaded to the PC several times each day. In most environments 100 (or even 50) memory locations is sufficient to support a full day of uninterrupted inspections.

Battery life –
Similar to internal memory capacity, battery life is a convenience issue. Does the camera's battery life provide for a full day of uninterrupted inspections? This will require only four or five hours of continuous use battery life (since during a day of inspections, the camera is typically not continuously in use). Is the discharge time faster or slower than the charging time? It should be at least three times faster to charge the battery as it is to discharge, otherwise you will need multiple batteries and chargers, which can be quite expensive. Is there a convenient power option besides a customer rechargeable battery pack? It can often be a life saver if "off the shelf" alkalines can be substituted instead of the custom rechargeable battery pack. With batteries, think convenience, cost and reliability.

Advanced features like voice recording and heads up displays –
For some users, including professional thermographers and consultants, advanced features like voice recording and even heads up displays with Bluetooth technology are considered valuable and well worth the additional investment and added complexity. For a person who is using the camera all day, every day, who has the time to spend learning how to use all of the advanced features and is most concerned about producing a thorough inspection report at the end of the day or week, these features can be beneficial. However, for the person who shares a camera amongst their work group, and who values

simplicity (they won't use the camera if they have to relearn how to use it every time they pick it up) and durability (the more bells and whistles, the more things there are to break), these features tend to be a distraction.

To summarize, it is important for companies to invest in a thermal imaging camera that fits their needs. This means the camera should be appropriate for the majority of their intended applications, but not be over specified or loaded with complicated and expensive extras. These high end specifications and extras will definitely increase the up front investment, so it is important for the decision maker(s) to validate the company's true needs.

Thermal Imager Accessories

Before purchasing a thermal imaging camera, consider the additional accessories that may be needed. Depending on the battery life, extra batteries and charging stations may be needed to get through a full day of inspections. Extra batteries can cost several hundred dollars a piece. Also consider the need for a transport/carrying case. Buying a camera with optional lenses provides a more flexible imaging solution, but it is also significantly more expensive. Make sure the optional lenses are truly needed and will be used. Ideally, the company will receive everything they need in one convenient package, and they will not have to buy lots of extras just to get started.

PC Software for Data Storage, Data Analysis and Report Generation

There are various software solutions available, which accompany thermal imaging cameras. Some software is very basic, only showing images (picture files) with no ability to analyze data or even create a report. Some software will store and analyze data and create reports. Some software will also integrate with other PdM technologies and even automatically generate work orders in the CMMS system. Again, understanding the company's needs is critical to making the correct choice. With some of today's affordable thermal imagers, advanced storage, analysis and reporting software is provided at no additional charge, as part of an overall PdM solution.

For predictive maintenance, having the ability to analyze images and data and create reports is very important. Sometimes, just seeing the image is not enough to make a determination of the existence and/or cause of a problem. Also, advanced software packages provide additional flexibility to the end user while in the field. If the end user sets the wrong emissivity or gets back to their office and wants to see an image in a different palette, this is no problem. They do not have to go back into the field and retake the image. The software allows them to change the image and data settings after the fact, in the comfort, quiet and safety of their office.

Another consideration for software is whether there is a license agreement. Can the software be loaded on unlimited PCs or does the company have to pay a license fee for each additional user?

Also, what about software upgrades? Are they offered periodically, and if so, how much must the company pay to gain access to the new features.

The investment for thermography software can range anywhere from "free" to thousands of dollars for each individual user. Once again, matching the needs of the company / applications with the solution is very important to make sure the investment will generate the maximum return in the shortest period of time.

Training

Training is an important consideration when starting any new initiative or improvement program. Predictive maintenance and thermal imaging are no different. In order to maximize the return on investment in cameras, accessories and software, the engineers, technicians, mechanics and/or electricians must be trained on:

- how to use the equipment
- what applications will provide the greatest return on investment
- the limitations of infrared inspections based on the laws of physics
- how to properly perform inspections to achieve consistent and reliable results
- how to interpret results and generate meaningful reports
- how to safely conduct thermography inspections in an industrial work environment

Some manufacturers of infrared cameras provide free training with the purchase of the thermal imager. This training may only cover the basic use of the camera or it may be more involved, touching on applications as well as best practices for establishing an effective infrared PdM program.

There are also opportunities to send personnel to more extensive training, which will result in a level of certification based on the ASNT standards. Through certification, an employer can ensure that their personnel are fully trained and qualified to perform thermography inspections.

Depending on the sophistication of the PdM program, more or less training may be required. Regardless, it is recommended that companies consider their investment in training prior to launching a new PdM program. Any investment in hardware and software can quickly be lost if people are not properly trained. In fact, an untrained technician performing inspections can actually increase maintenance and operational costs compared with doing nothing at all.

Service and Calibration Costs

Before making any investment decisions in thermal imaging equipment, consider the ownership costs associated with service and calibration over the life of the instrument. There is a very wide range of costs from camera manufacturers for basic service and calibration of thermography equipment. Depending on the brand and model of camera, costs for an annual calibration could be as little as $350 or as much as $2000.

Proactive/Predictive Maintenance Inspection Routing

Finally, once the equipment is in hand, the software has been installed and the training has been done, it is time to actually perform regular inspections of the critical equipment in a facility. The effort required to establish a PdM program, identify the equipment, determine the inspection techniques and technologies for each, determine the frequency of inspections required and logically plan the inspections in the form of inspection routes is not at all trivial. Once the program is up and running, the effort involved to collect, store, analyze and report on the data is also significant.

It is helpful if the thermal imager being used supports the concept of inspection routing. Some cameras even provide guidance to the user in the field while they are executing an inspection route. It becomes much easier to manage a broad based PdM program if the tools in use are designed such that the actual electricians and mechanics can easily gather the data on their own, freeing the expert to manage the overall program.

Companies should be aware that PdM techniques often, initially, generate more maintenance work than there was before. Electricians and mechanics will be busy not only executing inspection routes but also fixing potential problems or “finds.” The workload is very different from a “run it until it breaks” approach. Initially the workload will be greater, but if the program is well designed and executed, very quickly the PdM approach will take less maintenance and production manpower and resources, as the activities transition from reactive to proactive. This will most definitely improve the companies overall efficiency and effectiveness.

Maximizing the Return

The benefits of investing in thermal imaging equipment, software and training and implementing an in-house infrared PdM program include:

- eliminating existing expenses such as annual or semiannual thermographic inspections by outside consultants
- reduction in unnecessary, preventative maintenance activities
- improve maintenance efficiency and reduce unplanned downtime
- reduce capital equipment expenditures by increasing the life expectancy of capital equipment
- improve production efficiency and quality

Eliminating Existing Expenses

Many companies hire external consultants (rates may range from $750 to $1500 per day) to inspect their facilities on an annual or semi-annual basis. Often, this inspection or survey is required by the company’s insurance company. Unfortunately, there are some limitations to this approach to thermography:

1. Often, the thermographic report gets filed away and no actions are taken.
2. These reports frequently contain images of every piece of equipment inspected, without effectively highlighting those pieces of equipment that have a real problem or need immediate attention.
3. If and when the problems identified in the report are acted upon, there is no way for the company, without the consultant’s help and fees, to verify that the repair actually eliminated the problem.
4. Although the consultant is the one who will capture the images, analyze the data and create the reports, maintenance personnel must typically accompany the

consultant throughout their entire inspection in order to provide access to equipment and identify potential safety hazards, so plant personnel are also involved in these inspections.

5. In order for consultants to reduce their liability, they typically highlight all issues, even if they are marginal problems. It is up to the maintenance team, at this point, to determine what issues really require their attention.

By bringing the inspections in-house, most of the limitations listed above can be eliminated in addition to the consultant fees. Sometimes the consultant may not be eliminated completely but simply paired back to specialized inspections, for which in-plant personnel either don't have the equipment or are not trained. It is clear that, for many companies, simply outsourcing the thermographic inspections on an annual basis to outside consultants is not a solution that will provide the best return on investment.

Eliminating Wasteful Maintenance Practices

Preventive maintenance is based on the idea that regular maintenance of critical equipment will keep that equipment up and running. While this is generally a true statement, often companies are finding themselves investing in manpower and materials to perform regular maintenance on equipment when that regular maintenance really isn't needed. Predictive maintenance techniques are used to assess the "condition" of the equipment before taking maintenance actions. In this way, actions are only taken when the machine's condition warrants the action, not before.

There are even cases where preventive maintenance actions, if taken too soon or too often, can actually lower performance levels. Applying grease to bearings should be done somewhat regularly, but if grease is overdone, the bearings can actually fail prematurely.

Finally, with better tools, maintenance personnel can be more effective and efficient. While a thermal imager is considered the ideal tool for predictive maintenance, it is also very useful simply as a troubleshooting tool. When rotating equipment seems overloaded or is too noisy, inspecting the equipment with a thermal imager can quickly help the user to identify a heat signature and more importantly a source. Many electrical problems can also be more quickly identified with the help of an imager.

Finally, safety is also an important benefit when using a thermal imager. Because thermal imaging is a non-contact technology, users can stay out of harms way while inspecting "live" or "rotating" equipment.

Improving Maintenance Efficiency

As with any predictive maintenance technology, the ultimate goal is to keep equipment up and running. This means we must reduce the amount of unplanned downtime. Unplanned downtime leads to many problems for a production facility:

- maintenance personnel must drop whatever else they are working on to address the unscheduled down time

- often equipment that fails unexpectedly is very expensive to fix versus if maintenance had intervened before catastrophic failure had occurred
- overtime costs increase when downtime events are unscheduled
- customer orders are shipped late
- revenue may be lost forever to the competition, depending on the product (often true for commodities)
- production quality and yields decline
- scrap increases as the production process unexpectedly stops (especially true in processing industries)
- the need to carry additional spare parts and maintenance inventory just in case equipment unexpectedly fails

Each of these problems has a very real cost associated with it. The productivity of maintenance personnel is generally stated in terms of labor hours saved and an average labor rate. With fully burdened (including benefits and overhead) labor rates ranging anywhere from $40 to $100 per hour for maintenance personnel, the savings from productivity improvements can quickly add up. Add on overtime that inevitably increases as unplanned downtime increases (both for maintenance and production personnel) and improved maintenance practices can have a dramatic impact on labor costs.

Most problems become much more difficult and expensive to repair after they have catastrophically failed, versus if maintenance personnel had intervened sooner. Fortunately for owners of thermal imaging cameras, most problems associated with electrical and mechanical systems generate heat well before catastrophic failure occurs. Often, parts that cost pennies, if identified early enough, can be replaced in time to prevent damage to equipment that costs thousands of dollars.

Production is impacted heavily by unscheduled equipment failures. Production personnel are unable to continue producing product. Unreliable equipment lowers yields resulting in rework and scrapped material. If the plant is running at capacity in order to meet the demands of the market, then downtime will cost them customers, revenue and profits. For companies that have been operating under the “run it until it breaks” maintenance philosophy, they must have stockpiles of replacement and backup equipment inventory, so that downtime can be minimized. Investing in idle inventory not only takes cash out of the business, but it also involves ongoing costs to store, organize and manage. Companies generally estimate annual inventory carrying costs at between 10% and 25% of the inventory’s value. If there is $100,000 worth of spare parts or back up equipment inventory, it is costing the company somewhere between $10,000 and $25,000 per year to maintain that inventory.

Many process plants and manufacturing companies track downtime very closely and know precisely how much an hour of downtime costs them. This can vary widely by industry (anywhere from a few hundred dollars to tens of thousands of dollars per hour). Obviously, the higher this number, the more effort and investment companies will put into predictive maintenance.

Reducing Capital Expenses
The final benefit to consider when implementing infrared predictive maintenance is simply the increased lifetime of capital equipment that can be achieved. If the average life time of equipment for a company is 10 years and the total value of that capital equipment is $1,000,000, then the company is, on average, spending $100,000 per year to replace aging equipment. If the average lifetime can be extended by 10% due to improved maintenance practices, then the annual costs to replace aging equipment drops to $90,000 per year, saving $10,000 each year in replacement costs.

Another advantage to incorporating thermography into the maintenance tool box occurs when new equipment is purchased and installed. Many companies use thermography to verify the proper installation of new production lines, furnaces, motors, electrical distribution systems, substations, etc. It is always more cost effective to find problems with equipment when it is new, and still under warranty, then once the warranty has expired. Also, equipment is not always installed properly, which can turn a properly running piece of equipment into a failing piece of equipment very quickly.

Conclusion
The primary objective of any predictive maintenance program is generally to improve operational performance. Produce more and higher quality products, on time, with less cost while generating more profits. Any actions or programs that don't generally support this primary objective will quickly fall out of favor with management.

With the proper knowledge and tools, maintenance and reliability managers can easily justify the implementation of an infrared predictive maintenance program. A thermal imager with the necessary accessories, PC software for storage analysis and reporting and professional thermography training form the critical components to any effective infrared predictive maintenance solution.

Before making any investments in thermography, companies should thoroughly assess their critical equipment, applications and organizational needs. Only then, should they investigate the products and solutions available. The market is changing rapidly and products are becoming more affordable all the time. A few years ago, to begin a new infrared PdM program might require an investment of $50,000 or $100,000. Today a company can get started for under $10,000.

Once the right solution has been identified, often lower and mid level managers must sell the investment decision up the chain. Even at the $10,000 investment level, most companies required several approvals. Approvals are more likely, if the discussion is based in a solid Return on Investment Analysis. One must be realistic about the costs of starting an ambitious infrared PdM program. Most good managers will quickly see though any efforts to sugarcoat the initial investment requirements. Fortunately, for most companies, the benefits of an effective PdM program far outweigh the up front investments required. Whether it is the elimination or reduction of annual or semiannual thermographic inspections by outside consultants, the reduction of unnecessary maintenance activities, the elimination of unplanned downtime, the increase in life expectancy for critical capital equipment or the improvement in production productivity, quality and delivery, there are plenty of financial reasons to justify an investment in thermal imaging for predictive maintenance.