uptime

july 2006

the magazine for PdM & CBM professionals

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Discover
The New P-F Curve

Flying High with Infrared Imaging

Putting The Precision Back Into Alignment

Vibration: Smart Switch Provides Automatic Protection

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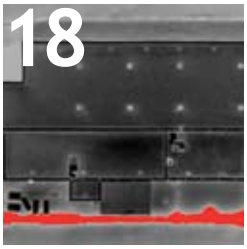

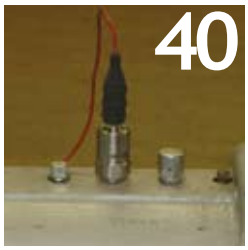

Ahead of the Curve

Welcome to the July issue.

As you probably know by now, Uptime is a big proponent of predictive technologies and strong predictive maintenance programs. PdM helps companies in a number of ways. From an accounting perspective, by investing in an effective PdM program, companies make their maintenance money work harder for them. There is no doubt that proactive and predictive maintenance activities are more efficient than reactive maintenance activities. The more of a maintenance budget that a company shifts to proactive/predictive maintenance, the better their return on that investment will be. Higher throughput, lower costs, less downtime and smoother operations are just some of the dividends.

Continuing education keeps you at the forefront of the industry, and is a big part of successful PdM programs. The pace of advances in technology and the continued evolution of best practices demand it. If we don't continue to learn, we fall behind, which can be catastrophic in today's competitive marketplace.

PdM-2006 is the premiere conference for predictive maintenance professionals. No other conference provides such a wealth of knowledge from each of the main predictive technologies. I highly recommend this conference for anyone involved in maintenance. If you are new to predictive maintenance, you will find PdM-2006 an excellent place to gather information about not only how to start your program, but more importantly, how to start out in the right direction. If you are a seasoned veteran of PdM and CBM, you will learn the latest advances and techniques in the industry. Rookies and veterans alike will find many high-quality sessions facilitated by industry experts as well as plant personnel. In these interactive sessions, you will benefit by learning from their experiences - both mistakes and successes.

You will also be able to meet the winners of Uptime's 1st Annual PdM Program of the Year awards. This will give you a chance to chat with and learn how PdM's top performers run their programs.

Uptime magazine is also a part of the continuing education process, and we strive to make each monthly issue a valuable resource for you. If you know of anyone else, either in your facility or elsewhere in the industry, who may benefit from receiving Uptime, please pass our information along to them.

Thank you for reading. If you have any questions, comments or ideas that would make Uptime more useful for you, please let us know.

All the best,

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Need help finding the road to maintenance success?



Use Our Roadmap.

The Reliability Roadmap™ - a series of free web workshops hosted by Uptime® Magazine and Reliabilityweb.com™ has been a big hit. By going beyond the typical "webinar", participants have been able to continue their learning beyond the hour that each workshop runs. With two of the six web workshops in the books, you shouldn't pass on the opportunity to attend the next one.

Visit the link below to hear the last two presentations.

http://www.reliabilityweb.com/rroadmap/playback_reg.htm

Once you listen, we think you will agree with the other 95% of attendees that responded that they learned at least one thing that will improve their work.

Each workshop features two presentations - one covering management aspects and one covering technical aspects. Each presentation will be followed by a Q & A session, and you can choose to continue the discussion with other participants via the web for days, weeks or months. Our goal is to create a community of shared knowledge that will lead maintenance & reliability professionals to a better understanding of reliability principles.

Web Workshop #4

August 18th 11 am – noon EST

6 Steps to an Effective Motor Testing Program by James Taylor
plus Motor Testing Basics by Howard W Penrose, PhD

Space is limited so enroll in this FREE workshop today!

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www.reliabilityweb.com/roadmap.htm

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Expanding

Moving Your Maintenance Effort Beyond the"P" in the P-F Curve

by Douglas J. Plucknette

My first introduction to equipment reliability came in 1988 at Eastman Kodak Company in Rochester New York. Jerry Haggerty, one of the founding members of the Society of Maintenance and Reliability Professionals (SMRP), had begun to assemble a steering committee of Kodak Maintenance professionals who would begin working together sharing information on equipment reliability. As a member of this team, I remember well the emphasis Jerry put on understanding the P-F curve and the P-F interval. Jerry knew that if we could get our managers to understand the P-F curve we could begin to make the transition into predictive technologies and reduce the amount of reactive maintenance being performed at our plants.

Nearly twenty years later, I can now say with confidence that Jerry was, well, somewhat correct. Understanding the P-F curve, the P-F interval, and the scheduling of predictive technologies is fundamental in building a sound Predictive Maintneance (PdM) program. The understanding of the P-F curve, as most of us know it, will help a maintenance or reliability manager to sell the need for predictive technologies such as vibration analysis, lubrication analysis, ultrasound and infrared inspections. If properly implemented, this will also reduce the amount of reactive maintenance being performed at your plant. What the original P-F curve will not do is maximize the benefit of your PdM program.

The Curve

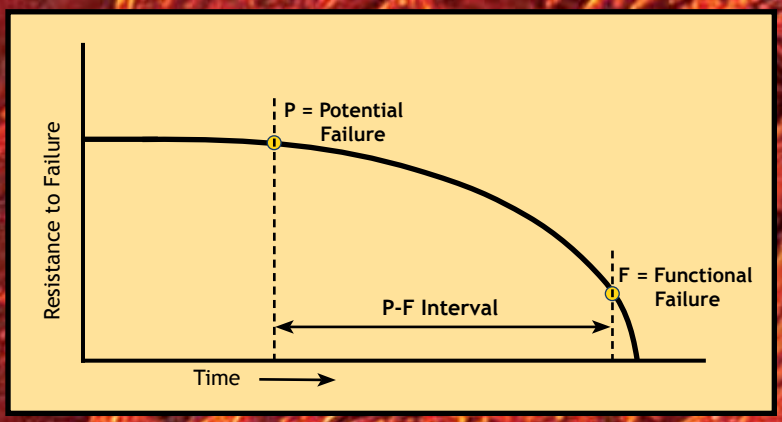

Figure 1 - The Classic P-F Curve

Figure 1 shows the P-F curve most people are familiar with. The x-axis of the curve represents Time or Operating Age, and the y-axis represents Resistance to Failure. Starting at the top left part of the curve and moving right we encounter point P, known as Potential Failure. This is the point in time that, when using some form of Predictive Technologies, one can first detect resistance to failure. As we continue to move right along this curve, resistance to failure continues to fall until we encounter point F, known as Functional Failure. This is the point in time when the component's resistance to failure has deteriorated to a point where it can no longer perform its intended function

The time elapsed between point P and point F is known as the P-F interval. The value of knowing the P-F interval of a component for a specific failure mode is that we can now set the interval of the condition based (PdM) inspection. In setting the interval we should now, with a high level of confidence, be able to detect the failure of this component, plan a replacement or restoration task and repair the component before the failure occurs. In doing so, we have now replaced what once was a reactive task with a PdM task.

The introduction of the P-F Curve and on-condition PdM tasks provided a much needed innovative change into a world where Preventive Maintenance was viewed as the only option to avoid emergency/demand maintenance. Excitement around the P-F Curve quickly evolved the world of maintenance into a new age of "proactive maintenance" for companies who could afford the new and costly predictive technologies associated with Predictive Maintenance. Companies who invested in technologies such as Vibration Analysis, Lubrication Analysis, and Thermographic Analysis paid large sums for the equipment and training to develop in-house Predictive Maintenance groups and, not long after making these investments, began sharing stories of success and the savings that could be generated from detecting failures, and avoiding costly secondary damage associated with emergency maintenance.

Today, it would be no stretch to make the connection between the P-F Curve, Predictive Maintenance and the birth of SMRP, ReliabilityWeb.com, IMC, Marts and many other companies and conferences. As word on Predictive Maintenance spread around the world, PdM course offerings and PdM service providers exploded, making the new technologies both more attractive and affordable. By 1995, if you were benchmarking your company's maintenance organization you could not be world class if you were not involved in predictive maintenance.

Detecting potential failure is simply not enough to consider your PdM program a success.

Something is Missing

Several years after working with Jerry Haggerty I left Eastman Kodak to form Reliability Solutions, Inc. a consulting firm that specializes in training people in reliability tools and measures. As part of our company's services we also offer on-site consulting and mentoring. It was at one of these on-site visits that I learned the P-F curve was incomplete.

Our client had invested a substantial amount of money to develop a Predictive Maintenance Program over the past two years and, while they were quite proud of that program. However, at the same time, they also revealed that they were disappointed their PdM program was not delivering the savings at a rate they had hoped for. Our client's PdM service provider collected data from hundreds of pieces of rotating equipment around their plant. They prepared reports for our client that showed nearly all of their rotating equipment was in the process of failure (someplace between points P and F). As trained, our client would then open a maintenance work order to schedule replacement of the asset prior to failure. Using precision alignment techniques, the rotating equipment would be replaced and, to their extreme disappointment, months later they would be informed that the same asset was again failing. The P-F curve detailed in Figure 2 represents our client's experience with Predictive Technologies and the P-F Interval. Notice the saw tooth effect that designates each time the asset is replaced or repaired.

While the Saw Tooth P-F Curve still effectively eliminates running costly rotating

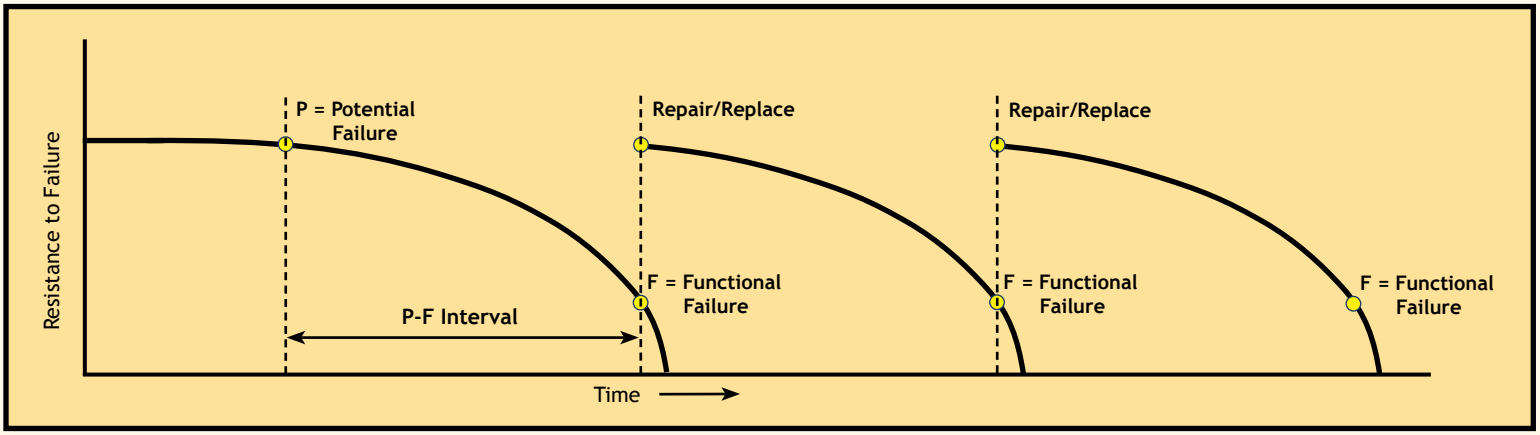

Figure 2 - The Saw Tooth P-F Curve
Resulting from Failure to Identify Specific for Failure Modes

equipment to failure, it can lull maintenance managers into the illusion that PdM is all maintenance has to offer regarding these types of failures. While we could celebrate that this company successfully detected and responded to three potential failures over a short period of time, and avoided the costly secondary damage associated with each failure, I would want them to question why each failure occurred. The most important thing we need to understand about the P-F Curve and the Saw Tooth P-F Curve is this; Today Detecting potential failure is simply not enough today to consider your PdM program a success. For each detected potential failure we must also determine the specific cause of failure. We need to know what has caused this potential failure and most importantly, can this cause be eliminated?

If we ask and answer the above questions, our maintenance organization, PdM service providers and our company are ready to gain the full benefit of the Modified P-F Curve utilizing not only Predictive Maintenance but Pro-Active maintenance techniques and Reliability Tools.

Some failure modes that result in the Saw Tooth P-F Curve are as follows:

- Misalignment
- Soft Foot
- Pipe Stress
- Lack of Lubrication
- Improper Lubrication
- Lubrication Breakdown
- Undersized Foundations
- Improper Belt Tension – Too Tight/ Too Loose
- Over Torque of Electrical Connections
- Dirt/Dust/Moisture Contamination of Electrical Connections
- Improper Sized Wiring, Overloads or Heaters
- Improper Torque of Piping Connections that Result in Leaks
- Improper Gasket Materials
- Improper Design or Application

While each of these failure modes could be detected using some form of Predictive Technologies, and then corrected prior to total failure, if the failure mode is not properly identified the failure will occur again.

The above should clearly highlight the need to take your Predictive Maintenance program a step further by asking these questions each

time a component has been determined to have reached point P in the P-F Curve. In doing so we can now pinpoint the specific cause of each failure and use RCM decision logic and sound Proactive Maintenance techniques to eliminate these causes and the saw tooth effect.

Completing the P-F Curve

As we performed an RCM Blitz™ analysis of several assets at our client's facilities, it became clear why some were not having the success they had expected from their PdM program. In working with their PdM service provider to set up their PdM program ,they had simply generated a list of assets for each specific technology, which was used to identify critical assets and set up PdM routes and intervals for each asset based on the provider's recommendations. In most cases, Vibration Analysis and Airborne Ultrasonic tasks were performed on a monthly basis, Theromgraphic inspections were set up on a quarterly basis, and Motor Current Evaluation was performed every six months. Not one single PdM inspection detailed the failure modes the tasks were looking to detect.

While we all understood the P-F curve and the P-F interval, we failed to understand or determine why the assets were failing over and over again.

While the technologies our client had invested in were successfully detecting failures, our client had never asked the service provider why some assets continued to fail over and over again. This is where the addition to the P-F curve comes in. Note the difference in the P-F curve illustrated in Figure 3. Starting at the far left at point I (Installation) and moving right we have a very long flat line going between point I and point P (Potential Failure). This is what we call the I-P interval. The I-P interval represents the time it takes to move from the point of installation to the point where Potential Failure is first detected. The objective of all world-class maintenance and reliability organizations should be to work to maximize the I-P Interval. This can only be achieved through a thorough understanding of your assets, proactive maintenance techniques and reliability tools. In viewing the P-F curve in this manner it became clear to our client that a large percentage of the failure modes they

Reliability Tools & Proactive Maintenance Techniques to Extend the I-P Interval

Reliability Centered Maintenance (RCM)

Falure Modes & Effects Analysis (FMEA)

Design RCM Blitz

Five Rights of Reliability

Select Supplier Agreements

Requirements Documents

Design Standards

Precision Alignment

Precision Balancing

Installation Standards

Torque Specifications

Precision Tools

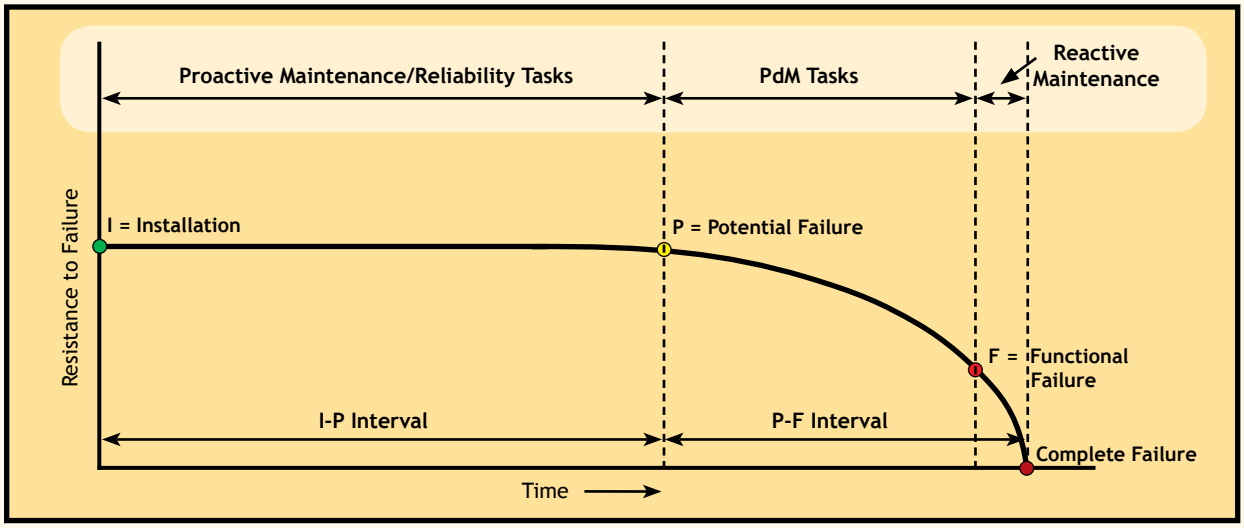

Figure 3 - Completing the P-F Curve

The Modified P-F Curve and I-P Interval are intellectual property of Reliability Solutions, Inc (patent pending)

were detecting through the use of predictive technologies could, in fact, be identified and eliminated using RCM and proactive maintenance techniques. As an example, one of the failures our client was seeing repeatedly was on a blower that was mounted to an undersized foundation. Each time they replaced the blower they used precision alignment to ensure the blower and motor sheaves were properly aligned. However, without the proper foundational support, continued stopping and starting of the blower over time resulted in misalignment and degradation of the blower and motor bearings. Hence, our client experienced the boomerang effect of recurring failures and repeated repairs. In performing the RCM Blitz analysis of this asset, we listed all of the probable failure modes for the blower and determined that the blower base and foundation would need redesign to eliminate the failure mode. The result – a blower that had failed three times in eighteen months has not failed in over four years.

Performing reactive maintenance...is costly and minimizes maintenance effectiveness to less than 10 percent.

The Value in Understanding the Modified P-F Curve

While many companies and maintenance organizations around the world have seen the value in understanding the original P-F curve, I want you all to understand the additional value provided by our Modified P-F Curve. To do this we start at the far right end of the P-F Curve at the point of complete failure (where the P-F curve contacts the x-axis). Moving from here back to the left and up to point F (Functional Failure), this interval between Functional Failure and Failure is the interval where reactive maintenance takes place. It's the area if time where this piece of rotating equipment starts smoking, shaking, stinking, and squealing. As a result we quickly send someone out to shut the asset down so that it can be replaced. Performing maintenance in this area is costly and minimizes maintenance effectiveness to less than ten percent.

Moving back to the left and up from point F we encounter point P, this is the well known P-F interval, the time frame where Predictive Maintenance (PdM) is employed. The

value of performing maintenance here is we can detect that failures are in the process of occurring, then plan and schedule repair or replacement to minimize equipment damage and reduce operations down time. Performing maintenance in the P-F interval provides a cost benefit that increases maintenance effectiveness to as high as fifty percent.

Finally, we now move left on the P-F curve from point P (Potential Failure) back to point I (Installation). The I-P interval is the time frame from installation (I) to potential failure (P), this interval should take years to elapse provided the correct Proactive reliability tools are employed and precision maintenance techniques and tools are used at installation. Performing these Proactive Maintenance techniques will provide a cost benefit that increases maintenance effectiveness to one-hundred percent!

To reach this level of effectiveness one will need to understand how Proactive Maintenance Techniques and Reliability Tools can increase the I-P interval of your assets.

Performing Proactive Maintenance techniques will provide a cost benefit that increases maintenance effectiveness to as much as 100 percent.

Understanding Proactive Maintenance Techniques and Reliability Tools

In completing the P-F curve we have identified several proactive maintenance techniques and reliability tools that can be used to extend the I-P Interval. While it would take a full text book to completely explain the value of each technique and tool, I will list each here and provide a summary of how each can extend your I-P Interval.

Reliability Centered Maintenance – RCM is a Reliability Tool that uses a structured team approach to analyze a process or piece of equipment. In performing an RCM analysis your team will assess all likely failure modes for the asset and develop a maintenance strategy to mitigate the consequences for each failure mode. The value in performing RCM is the proactive assessment of these failure modes and the resulting tasks developed

get proactive

Make the shift...

Your organization wants to stop putting out fires. You want your guys to take charge before things become costly. Making the shift from reactive to proactive is not straight forward but it needs to start somewhere. So why not start with the basics...Asset Basic Care?

Asset Basic Care records the condition (sight, smell, touch, sound) of your assets using an electronic checklist on a handheld computer. It's an excellent way to start recording what's going on with your machinery and changing the mind-set from reactive to proactive. In a very short time, your equipment database becomes populated with information that can prevent failures before they happen—putting you in control AND saving money.

Built on a multi-tiered pyramid approach to reliability, **MAINT*elligence***™ provides a simple start toward becoming proactive with a solid foundation in Asset Basic Care, (operator inspections and total lubrication management). Then when you are ready to expand your reliability program, **MAINT*elligence***™ will support you each step of the way at a rate that suits your organization.

Talk to a DMSI reliability specialist to ask how we can assist you in meeting your reliability goals.

MAINT*elligence* > helping you become proactive!

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to eliminate reoccurring failures.

FMEA – Failure Modes and Effects Analysis – Similar to RCM, FMEA is a Reliability Tool used in the design phase to identify likely failure modes. In performing FMEA your design team will discuss these failure modes and attempt to design out failure modes that result from poor design and installation decisions.

The Five Rights of Reliability – Design it right, purchase it right, build it right, operate it right and maintain it right. An overall reliability program focused on educating employees at all levels and organizations overall on the importance of reliability. The five rights of reliability develops a reliability plan across engineering, purchasing, construction, operations and maintenance that clearly describes how each business unit can improve reliability.

Select Supplier Agreements – Often a part of your reliability plan, select supplier agreements should be made with consulting engineering, operations, maintenance and purchasing. These agreements should be developed using your company's reliability data while working with suppliers to provide the most robust and reliable assets. Inferior parts or components are a common cause for reoccurring failures.

Requirements Documents – If this is not part of your company's capital design and engineering program it needs to be. Requirements documents are binding agreements written to ensure the highest level of reliability in design and installation. As an example, many companies now have requirements documents written for the acceptable level of vibration on start up of new rotating equipment. The document will clearly state what that acceptable measure will be and the resulting action taken if the requirement is not achieved. Again, the intent of these documents is to eliminate failure modes inherent to poor design or installation practices.

Design standards – Company design standards should always be used as a tool to improve equipment reliability. Used in combination with select suppliers, and requirements documents, design standards will help your company ensure that all new installations are safe and reliable. Some examples of design standards that will eliminate reoccurring failure modes; standard mass requirements for pump foundations, standards requirements for piping supports, standards for starter panel installations.

Precision Alignment and Balancing – Precision maintenance tools known for increasing the life of rotating equipment. While these tools have been available for several years few of us have taken advantage of their use. Precision alignment and balancing will both dramatically reduce vibration that results in reoccurring failures of bearings, seals and couplings.

Installation Standards – Used for both new installation and maintenance, these standards are put in place to ensure proper craft skills are used when working on equipment/assets. Some examples of installation standards would be the identification of the proper type and grade of flange hardware and gasket material. Developing installation standards eliminates reoccurring failures such as leaks caused by using incorrect gasket material.

Torque Specifications – While almost everyone working in maintenance knows what a torque wrench is and what torque specifications are, they are seldom used. Leaking connections, loose rotating equipment, and sight glass failure are often the result of improper torque. While using a torque wrench and following the specifications may take more time, the resulting reliability will increase your I-P Interval.

Precision Tools – If you want to ensure proper maintenance and installation practices, your people will need precision tools to do the work. As I work with companies, I can quickly assess the level of understanding concerning reliability with a quick look in the tool boxes of their maintenance people. Hammers, channel-locks, pry bars and screw drivers alone will begin to ensure reliability. Precision work requires precision tools and if your people don't have these tools, don't expect your results to improve.

RCM is the most effective way to develop a complete maintenance strategy that includes both Proactive and Predictive maintenance tasks...

Some Things to Work On

For those of us who have been directly involved in creating cultural changes by moving from reactive maintenance to predictive maintenance, we understand these changes take training and time. These changes do not take place overnight; they come in the form of small victories as people learn these techniques do work. As we now look to move back on the P-F curve to include and employ proactive maintenance techniques, a first step in the transition should be to require PdM Technologists to list the Failure Mode associated with failures resulting from equipment entering the P-F curve. Simply by taking the time to list the failure mode, PdM Technologists will increase their value to the PdM team. Their value increases because they will make it possible to identify and

Correctly applied and implemented RCM will always provide a substantial return on investment.

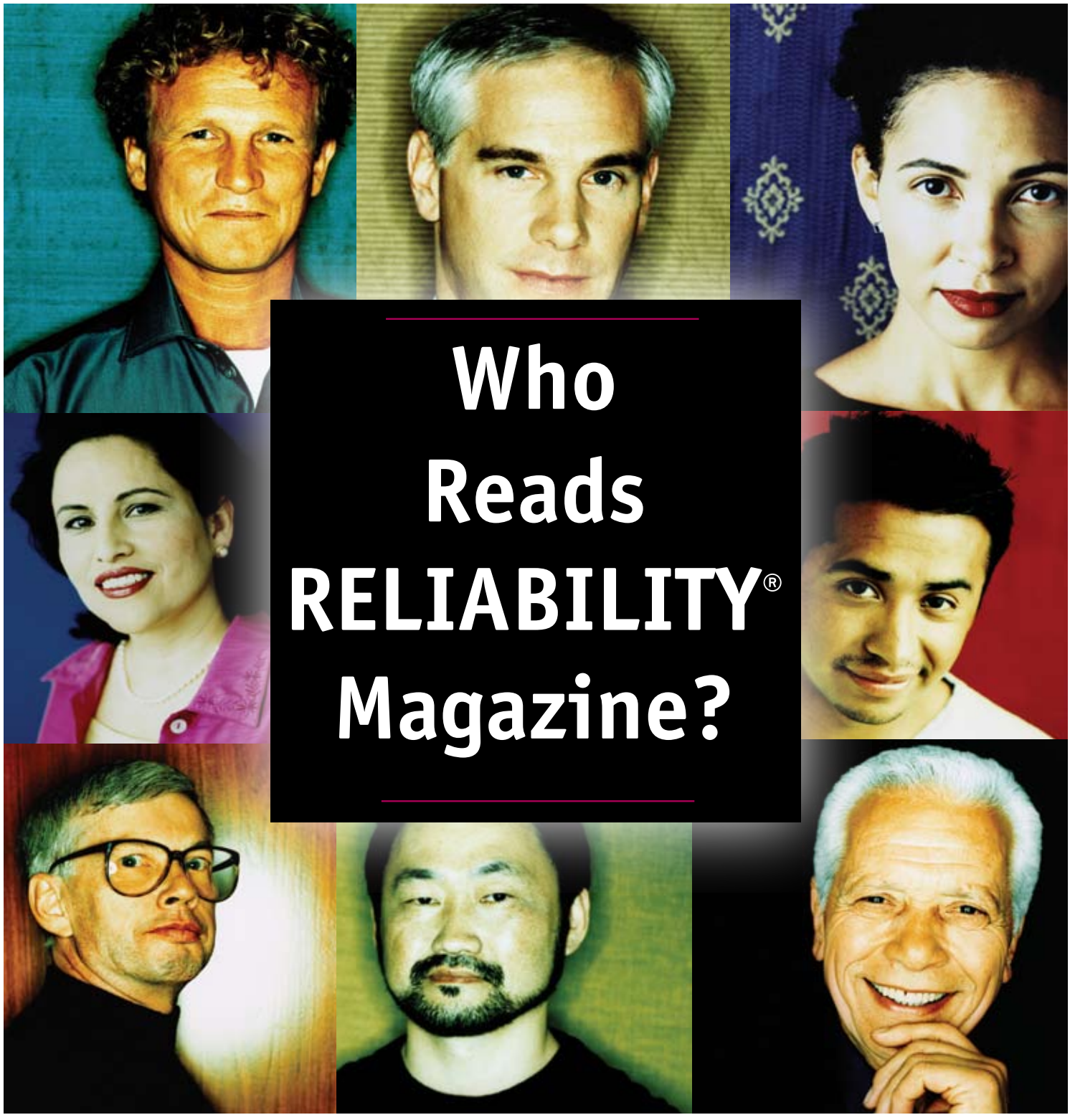
eliminate the failures that result in failure reoccurrence or the saw tooth P-F curve.

The most effective way to enter into and employ Proactive Maintenance techniques is to become involved in Reliability Centered Maintenance. RCM is also the most effective way to develop a complete maintenance strategy that includes both Proactive and Predictive maintenance tasks, and it should be applied to all critical process equipment. RCM is the only way to quickly identify and eliminate reoccurring failures through redesign and effective preventive maintenance tasks. Correctly applied and implemented RCM will always provide an effective, and substantial, return on the money invested for training, analyses, and implementation.

By taking the time to identify a list of all failure modes using RCM, many modes detectable with Predictive Technologies can simply be eliminated altogether. While it is extremely important for all maintenance organizations to celebrate the detection of potential failures through Predictive Technologies it is far more important for us to eliminate failures whenever possible. Failure identification and elimination offers the greatest savings and presents your maintenance group as a truly world-class maintenance and reliability organization.

In closing, I would like to thank my colleague Mr. Terry Harris for his help in providing information on maintenance effectiveness regarding the different zones associated with the P-F curve.

Doug Plucknette is the President of Reliability Solutions, Inc. In business since 1999 Reliability Solutions, Inc. offers training, mentoring and facilitation of reliability tools such as RCM Blitz™, FRACAS, Condition Based Asset Management (CBAM) and Reliability Measures. Mr. Plucknette can be contacted by phone at 585-349-7245 or by e-mail at doug.plucknette@reliabilitysolution.com



Fill Your Predictive Maintenance Toolbox at PdM-2006

by Terrence O'Hanlon, CMRP

Please join us for 4 days of focused learning in a community of knowledge at the Predictive Maintenance Technology Conference and Expo held September 12th through the 15th at the Chattanooga Convention Center in beautiful Chattanooga Tennessee.

Maintenance and reliability professionals use reliability centered maintenance to develop strategies that prevent functional failure. World class companies devote close to 35% of entire maintenance effort on predictive maintenance and machinery condition monitoring. They devote another 15% of the maintenance effort to respond to the findings of the condition monitoring program. That is half of your maintenance labor budget!

50% Percentage of entire maintenance effort spent on Predictive Maintenance by maintenance teams performing at world class levels.

Why so much Predictive Maintenance?

Because, as stated from the very first issue of Uptime Magazine and repeated in almost every issue since, studies show that only 11%-17% of failures are time related on average. If you are spending more than 17% of your maintenance effort on time based preventive maintenance – you need to ask yourself – what specific failure mode is this maintenance task preventing?

Attend the Predictive Maintenance Technology Conference to learn how others are moving away from reactive maintenance and applying predictive technologies to increase reliability and generate superior returns on maintenance investments.

17% Percentage of time related failures. You could be wasting time and money if you are spending more than 17% of your maintenance effort of time-based preventive maintenance.

The Multi-Technology Approach

Many companies use just one Predictive Maintenance technology as part of their PM program. The most common predictive tool for rotating equipment is a vibration data collector. These devices are portable; battery operated and can store vibration readings for later analysis. As powerful as this technology is – it is simply one tool in the Predictive Maintenance Toolbox and does not make a complete PdM program. Much like a Doctor collects condition based information from multiple sensing technologies such as a stethoscope, a thermometer, a blood pressure instrument, EKG and even by drawing various fluid samples to assess human health, maintenance professionals should use industrial sensing technologies such as Infrared, Ultrasound, Motor Circuit testers and Oil Analysis to assess equipment health.

Proactive maintenance is not only more effective than reactive maintenance – it is actually less expensive!

Predictive technologies allow for the early detection of potential failures – which supports proactive planning to mitigate the negative consequences. Proactive maintenance is not only more effective than reactive maintenance – it is actually less expensive!

Learn from those who have already done it

You will hear how companies like Southern Company Services, Tennessee Valley Authority, Alcoa, Cargill, Dofasco, Boeing, The US Navy, Unicem and the US Air Force have used predictive maintenance technologies to increase machinery reliability and lower costs. These are the people who are already on their reliability improvement journey and willing to share their techniques with you.

Subject matter experts like Jack Nicholas Jr. CMRP, Howard Penrose, Ph.D. CMRP, Ray Thibault, OMA,CLS, pump reliability expert Ross Mackay, Mike Johnson, CMRP, Dan Ambre, Dr. Tim Nadasdi and many more will share information that you can take back for immediate use at your company.

Meet the PdM Program of the Year Winners

At PdM-2006 you will also have a chance to meet the PdM Program of the Year award winners and learn more about how they reached their maintenance and reliability goals with predictive maintenance. A special area on the Expo floor is designated for displaying details of winning teams and winning programs and the PdM practitioners

have taken time to participate in the Predictive Maintenance Technology Conference. We hope you will take the time to meet them and learn more about what it took for them to achieve success.

Networking and Information Exchange

We believe that PdM-2006 conference attendees have as much valuable information to share as any of the formal presenters so there are several opportunities for attendees to meet each other. Name badge ribbons based on subjects of interest are available to all attendees and our "Birds of Feather" program makes it easy to meet up with those who share your interest. The conference will also feature a special "problem solving sessions" to get everyone involved!

Professional Development at PdM-2006

Certification demonstrates both knowledge and experience. At PdM-2006 SMRP is offering an opportunity to sit for the CMRP exam and STLE is offering the OMA and CLS exam as well. The Vibration Institute is offering exams for Category I, II and III Certification. If you have been considering earning your certification – PdM-2006 offers a perfect opportunity.

PdM-2006 Plant Tour

Take a plant tour of one of the most unique Department of Defense facilities in the world at Arnold Engineering Development Center (AEDC). The AEDC Reliability Team will share its experience and tell you how they manage maintenance and reliability in this unique environment.

Ramesh Gulati, CMRP is the leader of this excellent program and has encouraged over 64 team members to earn Certified Maintenance & Reliability Professional (CMRP)at AEDC . The Certified team members are not limited to Maintenance and Reliability specialists, they also includes designers, investment/capital project engineers, Air Force managers and AEDC executive management. This tour will provide a lifetime of memories of a very special team who successfully manage a very unique facility.

Space is limited at PdM-2006

Like our other learning events, attendance at PdM-2006 is limited to 500. Our last event on Reliability Centered Maintenance sold out a full month before the start date – so we encourage you to register early to ensure your space. We even offer a $200 early bird discount to make your early effort worthwhile.

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Aerial Infrared

IR Imaging Identifies Problems Not Seen From The Ground

by Gregory R. Stockton

Aerial thermal mapping of your facility, complex, campus, military base or city every few years will reveal leaks in all types of systems, like steam and condensate return lines, hot water lines, chilled water lines, supply water mains, distribution pipes, storm water drains, building heat loss and moisture leaks into your roofs. Aerial photographs should be taken every few years as well. They are inexpensive and can be a great asset when discussing future building additions with management, planning utility repairs and improvements, drawing CADs of the facilities and for uses as simple and handy as showing outside contractors where not to park.

The methodology for taking infrared (IR) thermographs is similar in many ways to taking aerial photographs. To collect the data, the aircraft flies over a given area with a camera mounted to the airframe and oriented looking straight-down (NADIR) to the ground. Oblique or lower angle shots are taken out the side of the aircraft by pointing the camera at the desired angle. The imagery is stored on film or a computer hard drive and later copied to a convenient deliverable format, such as a DVD. Obviously, aerial photos are taken during the day because the sun provides brilliant visible light so one can see features on the ground, like buildings, bridges, roads, etc.

Where aerial infrared thermography differs from aerial visible photography is the time of day when the survey occurs and the wavelength of the imagery that the detector collects. IR thermography of ground objects is performed at night because the sun and its effects on objects is a tremendous distraction in the imagery. Thermography reveals sources of heat and the relative differences in heat from one object to another. Infrared imagery is a grayscale picture whose scales (or shades of gray) represent the differences in temperature and emissivity of objects in the image. Objects in the image that are lighter in color are warmer and darker objects are cooler. No object in an IR image is detected via visible light wavelengths (400-700 nanometers) rather, only from thermal infrared wavelengths in the 3000-5000 nanometers or 8000-14000 nanometers range. Lights and other relatively hot objects are very evident, but as a result of their heat emissions, not their light emissions. Collected IR imagery may then be modified in a number of ways to enhance its value to the end user, such as digitally adjusting the imagery to find particular anomalies and zooming in on different areas of interest (see figure 1). These post-processed images can then be used to prepare predictive maintenance reports on the various systems.

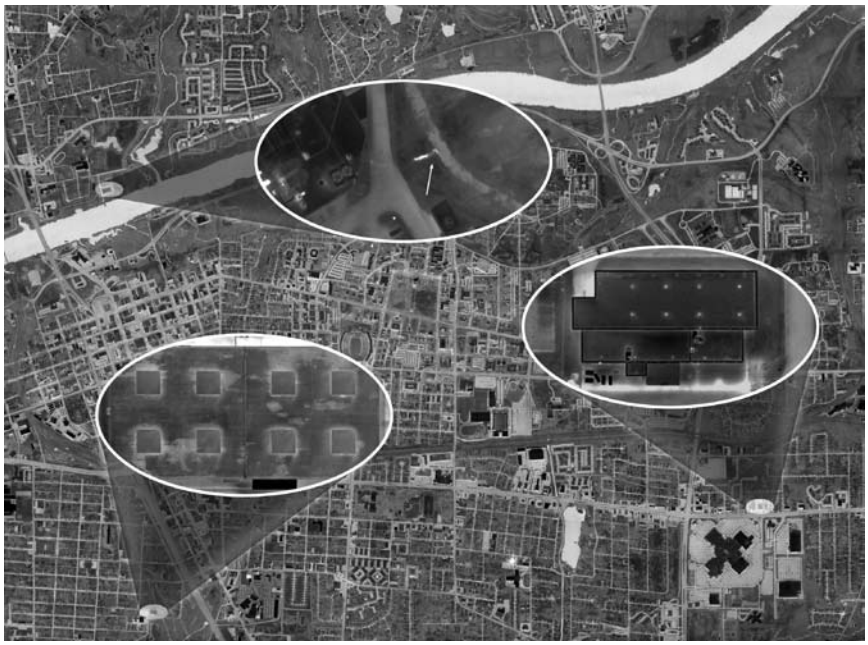


Figure 1 - Ortho-rectified, geo-TIFF mosaic thermal image of a small city.

Thermal Mapping and Ortho-Rectification

Using an aerial high-resolution imager, surveying a couple of buildings or a mile or so of underground lines can be completed by flying over and locating the target(s) in the imagery, saving the data and putting it together into a report. Scale information can be gathered by taking off the existing CAD drawings or having someone walk over the area with a tape measure. This works fine for small areas, but it is not possible to make precise thermal maps of a whole complex, campus, military base or city without ortho-rectification of the imagery.

In order to produce ortho-rectified thermal maps like the one in Figure 1, which are the most useful product, much more information must be gathered and tagged to the IR imagery. During the flight, the aircraft flies straight, smooth lines on a pre-planned grid, allowing 25% side lap of the imagery. The IR operator manages the sensor data-acquisition (shown in Figure 2) following a structured checklist for orderly data file management. The imagery must be collected with a precise direct-digital timing system, a 3-axis ring-laser-gyro and an inertial navigation system (INS), which is tightly-coupled to a real-time differential GPS satellite positioning system that provides x, y, z positioning of the aircraft at all times. After imagery is collected and QC is verified, the digital infrared imagery is then processed into a series of ortho-rectified image tiles, which are stitched together to create a giant mosaic image. An on-board computer system puts all this information together using a digital elevation model (DEM) of the scene that consists of a uniform grid of point elevation values and the position and orientation of the camera with respect to a three-dimensional coordinate system. The result is presented as a high-resolution IR image in the form of a geo-TIFF, which is compatible with any GIS software such as ESRI ArcView, AutoCAD 3-D Map, Global Mapper, MapInfo, etc.

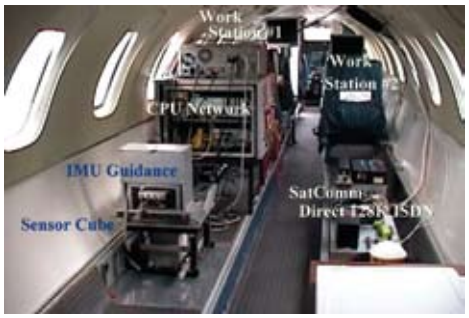


Figure 2 - Data Acquisition Equipment Installed in Aircraft

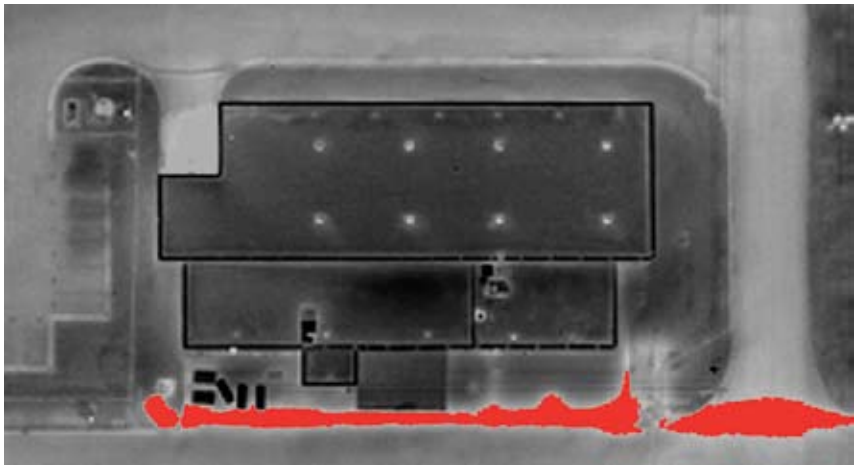


Figure 3 - IR Thermograph showing a leaking steam line (highlighted in red).

Applications for Thermal Mapping

Once high quality digital thermal and photographic ortho-rectified maps are created, these can be added as layers to existing CAD and GIS systems and to other data sets. By post-processing the imagery, many wasteful conditions can be found and reported. The maps and reports help facility managers keep up with their assets in a very efficient manner. Below, some of the low-hanging fruit of back-end post-processing of the information is discussed.

Steam and condensate return lines (see figure 3) are almost always readily visible with infrared imaging, even when no notable problems exist. This is due to the fact that no matter how good the insulation, there is always heat loss from the lines which makes its way to the surface. Problem areas are generally quite evident, having brighter infrared signatures that exceed the norm. Steam line faults normally appear as an overheated line or as a large hot spot in the form of a bulge or balloon along the line. Overheated lines often occur when the steam line is located in a conduit or tunnel. If there is a leak in the line, it will heat up the conduit with escaping steam. If a steam line is buried directly in the ground with an insulating jacket, a leak will usually saturate the insulation, rendering it largely ineffective and begin to transfer heat into the ground around the leak, producing the classic bulge or balloon-like hot area straddling the line. Some leaks may show up as an overheated manhole or vault cover. Manholes or vaults that contain leaking steam system control apparatus will often heat the covers

to warmer than normal temperatures.

A leaking sewer line or water main (see figure 4) may go undetected for years, especially if the leaking liquid is flowing into a storm drain or a stream that no one monitors. Leaking sewage collector lines, storm water drain discharges, water mains and taps into storm water drainage lines can often be identified by their thermal infrared signatures during cold times of the year. As these sources of waste or pollution leak, seep or empty into creeks, streams, rivers and lakes, their thermal signatures vary from their surroundings because the liquid from under the ground is relatively warm. As it flows across the ground and into a realtively cool stream, the warm plume of liquid is detectable due to the difference in temperatures. Late fall, winter and early spring are well suited to this type of inspection because of the cooler water temperatures (ground and surface waters) and because the interference to view by foliage is minimized. Ground water seeps and outfalls of all types are also easily distinguishable for similar reasons.

Roof moisture survey reports (see figure 5) are made by capturing IR and visual images and making scaled drawings of the wet areas, so that surgical repairs can be accomplished. Almost all roof insulation materials discarded in the US annually are dry. Why throw away 95% of the insulation when it is not damaged? With a thermal map of a group of buildings one can narrow down the roofs that have problems from the ones that do not…on a wholesale basis. This allows facilities management to concentrate on those roofs that need to be repaired, while keeping a trend-quality image of the good roofs.

Figure 4 - Thermograph of a storm drain (highlighted in red) leaking wastewater down the bank and joining the flow of a creek. The leak is coming from the adjacent building.

Subsurface wet areas in a flat or low-sloped roof show up as lighter areas in the IR imagery at night because the latent heat (from daytime heating) in the trapped water mass is greater than in the dry, functioning insulation or roof substrate. Areas of roof moisture contamination can be nebulous in shape and sometimes mottled in appearance, although they are commonly found in linear or puddle-like shapes. The linear shapes many times follow low areas, drainage routes, roof edges and seams. Puddle-like round or oblong shapes often form around roof penetrations such as mechanical equipment, standpipes, vents and drains. After sunset when

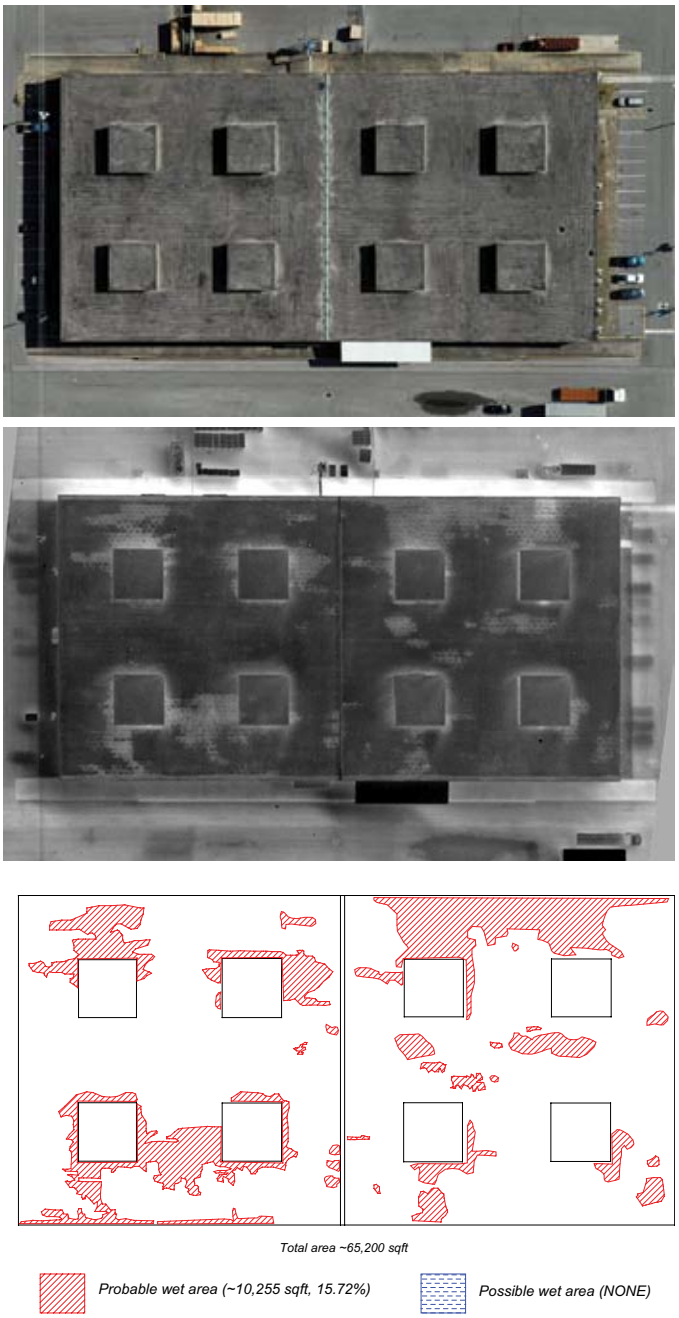


Figure 5 - Photograph, thermograph and CAD drawing of a flat roof with moisture contamination.

the entire roof structure cools down, wet areas of roof insulation and other materials continue to radiate heat because of their higher mass.

Advantages of Aerial IR Imaging of Roofs

- High-angle, straight-down infrared images capture large areas at once, making the imagery easier to analyze and the report clear and concise. Because infrared images, visual images and AutoCAD® drawings are reconciled, it is less expensive to produce detailed reports.

- Plan view imaging allows for accurate marking of areas of suspect roof moisture contamination. AutoCAD® drawings are made by drawing 'over' the captured visual and infrared image on the screen.

- Logistical, image quality, access and security problems, which are common when performing on-roof IR surveys, are eliminated. The printed AutoCAD® drawings can be used on the roof to paint areas of moisture contamination directly on the roof, if desired. There is never a time when on-roof IR produces better results than aerial IR.

With the roofs surveyed and existing CAD drawings corrected, updated, saved and layered into a GIS or CAD system, the facilities operator takes control of all of the roofs. Knowing the condition of all of the roofs allows for better life-cycle preventive maintenance, warranty enforcement, budget planning and improved roof asset management.

Conclusion

The farther one can get from the subject of any imaging survey, while maintaining the resolution to achieve the needed image quality, the more useful the data becomes. This is the aerial advantage. But, one needs to obtain very high resolution imagery in order to survey large areas.

It is true that a picture is worth a thousand words; so get the big picture of your facilities and start speaking volumes about its condition.

Gregory R. Stockton is president of Stockton Infrared Thermographic Services, Inc. The North Carolina-based Corporation operates seven application-specific divisions performing many different infrared services in the US, Canada, Central and South America. Greg has been an infrared thermographer since 1989, and has published numerous white papers and articles on infrared thermography. He can be reached at 336-498-4734 or by e-mail at gregsits@northstate.net

Fishing with FTIR

To Catch Symptoms of Change

by Mike Johnson

Fourier Transform Infrared Spectroscopy (FTIR) is a powerful analytical tool and widely used in oil analysis as one of various methods for identifying changed lubricant conditions. It has strong usefulness as a clear indicator of a few specific conditions and a vague indicator of a wide variety of conditions that justify a closer look. The purpose of this article is to review the FTIR test method and reinforce its importance as a broad screening tool in an oil analysis program.

Screening for Clues

There is a variety of commonly recognized test methods used by oil analysis practitioners to screen samples. The screening process allows the laboratory to quickly assess the nature of a given sample and determine if additional, more specialized testing is warranted. Results from the screening methods are central to the decision to accept the status of the machine as it is or to proceed with more sophisticated testing either onsite (OSA) or through a commercial facility (CLA).

Given the high cost of, and associated difficulty of justifying, commonly used laboratory instruments for in-house use, the on-site laboratory would be a logical place to see qualitative screening methods used extensively in lieu of quantitative instruments. Various scan methods that could be used are shown in Table 1.

If one or more parameters point toward a likely condition, such as the presence of moisture in a sample, then condition specific methods are used to provide quantitative results. The OSA lab would then select the specific test, or choose a package of tests, including the specifically intended test, to be run at a commercial lab to create a more comprehensive basis for judgement.

Commercial laboratories, with access to more sophisticated and often more automated instrumentation, are less likely to depend on the variety of screens, but may choose to use some for very specific direction. FTIR spectroscopy provides substantial value as a preliminary screen and as a terminal test method.

Inside the FTIR Spectrograph

It is helpful to have a basic understanding of what the instrument is reading. Infrared (IR) energy is one of several types of energy that make up the electromagnetic (EM) spectrum. Humans enjoy the benefits of the various electromagnetic frequencies in the forms of various colors of visible light, and in the form of energy waves that carry television and radio programming. However, humans cannot observe the entire EM spectrum. Within the electromagnetic spectrum – infrared energy is just beyond the visible range.

The infrared portion of the spectrum covers an area where the EM waves range from .00008 cm to .04 cm. Physicists and chemists refer to a Wavenumber when referring to a specific wavelength, or more correctly wave frequency. Infrared instruments use the 'mid-range infrared' portion of the IR range, which includes wavenumbers between 4000 and 400 (the wave number gets smaller as the EM range moves further away from visible light energy). The wave number is a calculated value, derived by dividing one by the wavelength, and expressing this in centimeters, as follows:

$$\text{Wavenumber } (\text{cm}^{-1}) = \frac{1}{\text{WAVELENGTH (cm)}}$$

Lubricants are complex hydrocarbons. The atoms in the hydrocarbon molecule are bonded through polar attraction. The bonds are in a constant state of expansion, contraction and relative movement. IR energy at different wavenumbers can excite the bonds, based on the type of each bond.

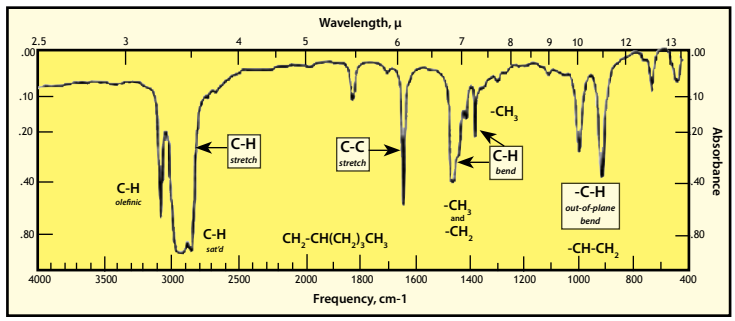
Table 1- Scan Methods & What They Find

Test Method	Item(s) To Identify	Likely Used
Filter Gram/ Patch Test	Concentration of Solid Contaminants Type of Solid Contaminants Evidence of Metallic Wear Debris	OSA - Yes CLA - No
Blotter Spot Test	Evidence of Oxidation (non-engine) Evidence of Soot Concentration Evidence of Glycol/Fuel Contamination	OSA - Yes CLA - Yes[1]
Crackle Test	Presence of water contamination Presence of air (versus water)	OSA - Yes CLA - Yes
FTIR	Additive integrity Base oil integrity Presence of some contaminants (water, chemicals, additives, fuel, glycol, soot, oxidation, nitration)	OSA - Yes[2] CLA - Yes
Color Comparison	Oxidation Evidence of solid contaminants Evidence off liquid discontinuous contaminants	OSA - Yes CLA - No

OSA = On-Site Analysis \CLA = Commercial Laboratory Analysis

1. This is dependent on sample processing volume, and inclusion of specialized blotter methods in the test package.
2. Cost of instrumentation is high, but size dependent. For very large facilities it may be justified.

Figure 1[1]



Specific types of bonds are stimulated by specific infrared energy intensities. When the element and bond type is known, IR analysis can provide direction to answer questions about lubricant change.

When IR energy is passed through a given molecule, the molecule absorbs some of the energy at a specific wavenumber (dependent on molecule size, bond structure and composition). As shown in Figure 1, the specific area and degree of absorption is noted at the wavenumber and by the degrees of intensity.

None of this information is particularly useful by itself, but it does help you to know how the technology works in order to understand the relative strengths and weaknesses of IR technology.

Using FTIR to Identify Lubricant Change

Armed with knowledge of the EM spectrum and how IR energy affects molecules, we begin to understand that the different molecular components and their respective concentrations within the lubricant can be identified based on a response at a given wavenumber. Figure 3 shows common components of an engine lubricant identified on an IR scan. As long as nothing causes the molecules to change, then the signature will remain steady from analysis to analysis.

Unfortunately for the lubricant user, the lubricant sump is a cauldron full of forces that change the lubricant, causing some additives to fracture, some to change chemical form, some to be absorbed, and even causing new molecules (species) to form. Common catalysts promoting lubricant change and degradation include:

- Wear metals (primarily Iron and Copper)
- Atmospheric chemicals
- Process chemicals
- Moisture
- Heat
- Air (primarily oxygen and nitrogen)

The forces noted above work synergistically to produce a wide variety of degradation by-products than can include aldehydes, ketones, acids, sulfates, carboxylates and polymeric compounds. The formation of these degradation species is accelerated by heat and the concentration of the other catalysts present. The type of base stock and the type, quality and stability of the additives will also have an influence on the formation of unwelcome chemicals.

As the molecules change, their respective intensity and wavenumber (location) on the IR spectra also changes. Most of the changes are not to the benefit of the lubricant, and it certainly makes sense to understand which changes have the potential for creating problems. The IR scan provides evidence of molecular change that can be used to make lubricant management decisions well in advance of the actual collapse of lubricant health. As shown in Figure 4, when the scan of the original sample is compared to the same lubricant in its current condition it is possible to identify changes, some with stark clarity. Even without knowing the types of molecules that correspond to the wavenumbers, it is obvious that changes to the lubricant have occurred.

The spectrum in Figure 2 represent scans on new and used oil. The black line represents new oil and the red line is a scan of the same oil after a period of use. The analyst in a lab would compare the two scans and look for significant changes. Differences at

known wavenumbers can point out specific conditions, and provide for specific remedies – i.e. the need for an oil change.

In the course of conducting routine lubricant analysis, the analyst will conduct the scan, identify the wavenumbers based on insightful guesswork and the use of a library of known compounds, measure the degree of change from the previous result, and offer a judgment call, which should be displayed in the form of a notice on the oil analysis report.

Case Example: Verifying Additive Degradation with FTIR

Herguth Laboratories in Vallejo, California, provides premium quality routine and investigative oil analysis support for multiple industries. Recently Herguth performed experiments to confirm the potential for UV energy (sunlight) induced degradation of turbine oils.

In this experiment, four oil samples were subjected to UV energy for a period of 5 days, and were then analyzed for evidence of change due to exposure to UV energy. As seen in Table 2[3], several tests were conducted on each sample before and following exposure to identify any evidence of lost stability. The most distinct change occurs in Sample A oxidation stability test results, which is a key indicator. FTIR scans were performed on the samples, with specific interest in evidence of change in oxidation inhibitor integrity.

The scans revealed a noteworthy change in Sample A, as seen in Figure 3[4]. The blue line represents new oil condition and the red line represents the oil condition following exposure to UV. There is a change at a wavenumber that corresponds to a nitration compound (1688). The specific compound is not identified but the results point toward types of Nitrogen containing compounds, such as a rust inhibitor or primary amine antioxidant.

Product	Acid Number ASTM D974	Viscosity @ 40oC cSt ASTM D445	Oxidation Induction Time by PDSC Minutes 190 oC ASTM D6186	Rotating Pressure Vessel Oxidation Minutes ASTM D2272
"A" New	0.07	30.19	19	1707
"A" Aged	0.11	30.21	11	916
"A" Aged (Glass)	--	30.18	--	--
"B" New	0.04	29.81	10	367
"B" Aged	0.07	28.88	13	409
"C" New	0.07	30.18	22	1840
"C" Aged	0.11	30.27	22	1530
Hydraulic, New	0.1	43.78	17	566
Hydraulic, Aged	0.13	43.94	17	474

Table 2 - Multiple data sources are useful to confirm suspicions of a problem, or to provide weight to a confirmed problem. Many lubricant based test methods provide information on more than one condition.

Whenever there is a pronounced spike at a particular wavenumber (as seen in Figure 3), this is a clear signal to investigate with further tests. In fact, IR analysis often points to a need for more narrowly defined analysis. As such, IR analysis can be a powerful screening tool.

The evidence of change in a specific wavenumber alone identifies an area for a search, but does not prove anything conclusively. If the laboratory conducting the analysis also benefits from having confidential information on the construction and

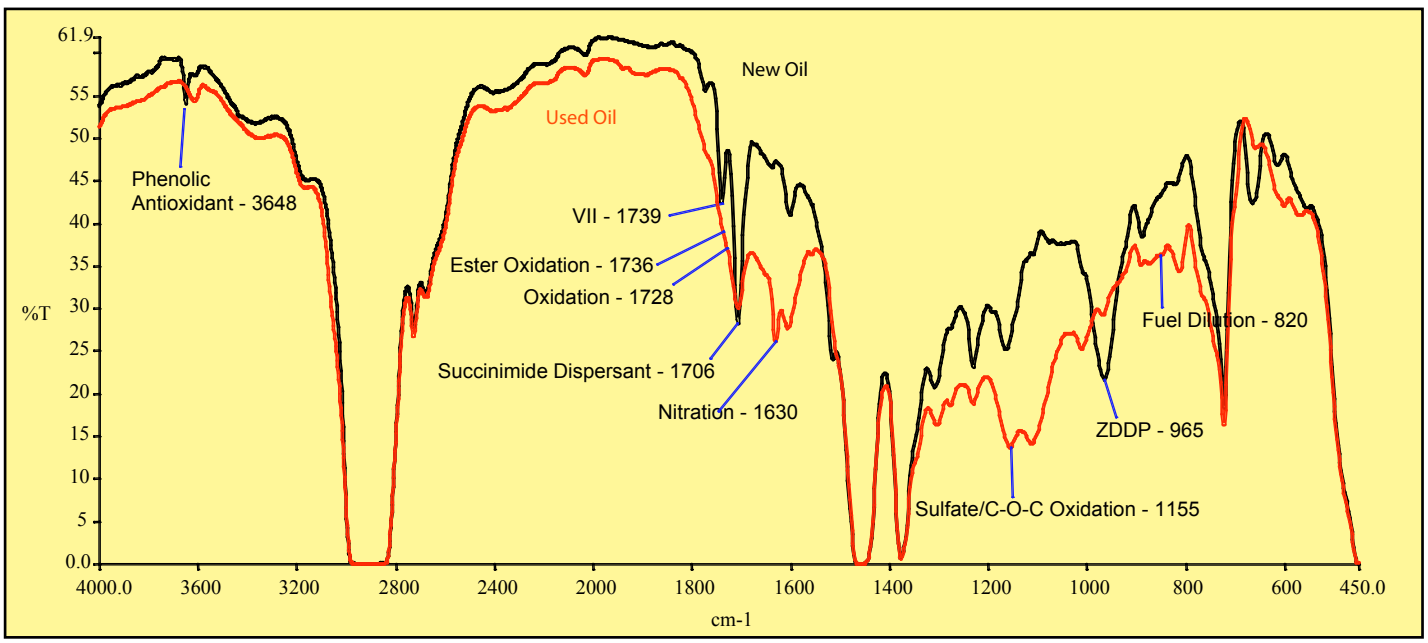


Figure 2[2]- Comparative FTIR scans on new and used oil.

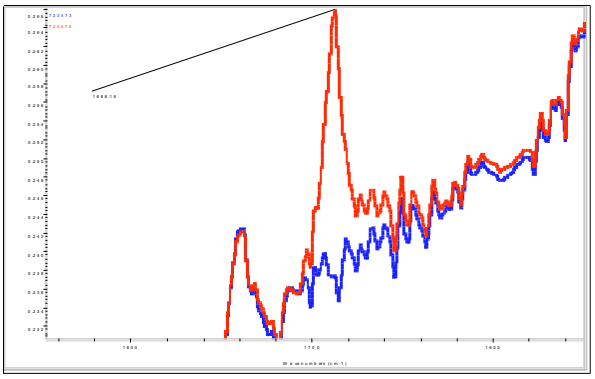


Figure 3 - FTIR scan of Sample "A' in Herguth Lab's experiment. Notice pronounced spike.

specific raw materials used in the lubricant, then the clues shorten the process to discovery, which is most likely when the manufacturer of the lubricant is conducting the analysis.

The prospect of a degraded amine inhibitor itself does not mean the lubricant is compromised, but it certainly points the way for future predictive activity, and helps to set a timetable for corrective action. In this particular case, there is evidence of change (color, viscosity) and evidence of lost oxidation resistance from Sample A (PDSC and RPVOT), but no similar evidence in the other samples.

Summary

This brief introduction to FTIR analysis should whet the appetite for users of lubricant analysis to incorporate this method into their routine analysis. The added extra cost, particularly on critical machines, produces real value when the data is used for long-term reliability management.

Whether standing alone as a preliminary 'screen' or coupled with other meaningful data, the FTIR analysis provides meaningful clues that help the skilled analyst identify the root causes that may yet lead to trouble. In some instances, the clues are compelling (such as soot concentration measurements) and in other instances, the clues only offer direction for additional analysis.

Special recognition to Bill Herguth of Herguth Laboratories for information and guidance on some of the IR details found within this article.

Mike Johnson is the founder of Advanced Machine Reliability Resources Inc., a firm that provides precision lubrication program development, consulting and training. He has written and presented numerous technical papers at symposia and conferences throughout North America about how to use machine lubrication to drive machine reliability. Mike is happily married, plays and coaches soccer, and has 3 young children that consume his remaining time and attention. He can be reached at mjohnson@amrri.com, or 615-771-6030.

1 Geach, Alistair. "Infrared Analysis as a Tool for Assessing Degradation in used Engine Lubricants". Wearcheck, S. Africa. http://www.wearcheck.ca/literature/techdoc/WZA002.htm
2. Wooton-Consulting, Dave_Wooton@att.net
3 Herguth, W., Adams, H; "Sunlight Degradation of Lubricants". Herguth Laboratories. 2005.
4. Ibid 3.

AC Motor Testing and PdM

Helpful Standards Hopefully on the Way

by Howard W. Penrose, PhD, CMRP

The key to fully understanding condition-based monitoring of AC electric motors is to determine the capabilities and limitations of each technology. With this knowledge, the maintenance and reliability technician can make decisions with a known degree of reliability. In this article, we will discuss some of the primary methods of motor testing along with their capabilities, how they are applied and pass/fail (where possible) as well as trending limits. The basis for this discussion will be "IEEE P1415: Draft Guide for Induction Machinery Maintenance Testing and Failure Analysis."

Introduction

The requirement for an inclusive AC induction machinery standard that outlines known condition-based testing technologies and their capabilities has been needed for quite some time. For the past nine years, an IEEE Power Engineering Society Standards Committee has been in the process of developing the "Guide for Induction Machinery Maintenance Testing and Failure Analysis," designated IEEE P1415. At the time this paper was drafted, IEEE P1415 was in the final stages of voting to become an IEEE Standard.

What makes this particular standard unusual is that it provides an overview of both electrical and mechanical test methods and provides test limits where possible. In many cases, it splits a particular technology into sub-tests. For instance, a Motor Circuit Analysis test that involves resistance, impedance, inductance, phase angle, current/frequency and insulation to ground is broken into individual tests such as: Winding Resistance, Insulation Resistance, Phase Angle, Phase Balance (Inductance and Impedance) and Variable Frequency. The purpose is to both cover existing technologies and provide room for future technologies that may use different combinations.

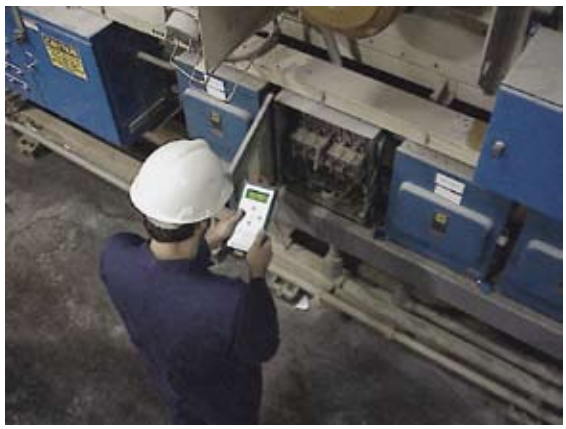


Figure 1 - Motor Circuit Analysis through a Motor Control

Electrical Motor Diagnostics Defined

One of the most troublesome areas that has come along with our modern times is keeping track of definitions. For instance, on-line can mean using the internet or while equipment is running. Lately, the concept of Electrical Motor Diagnostics has been considered as only the technologies of Motor Circuit Analysis (MCA) and Electrical or Current Signature Analysis. However, in 2004, the Institute of Electrical Motor Diagnostics (IEMD) defined Electrical Motor Diagnostics as all technologies used to test or evaluate the condition of the electric motor system or capable of being used in motor system maintenance and management programs.

Motor system maintenance and management was then defined:

"Motor system maintenance and management is the philosophy of continuous improvement of all aspects of the motor system from incoming power to driven load. It involves all components of energy, maintenance and reliability from system cradle to grave."

The result of these definitions is that a broader scope of

technology is encompassed, providing the concept of a broader range of tools available for electric motor health diagnosis. This definition, combined with the IEEE P1415, gives us the slate of technologies that are to be explored with this paper. However, the focus will be on the motor only, including:

- Stator winding and core
- Rotor winding and core
- Vibration and noise
- Bearings and shafts
- Structure and frame
- Ventilation
- Accessories

Figure 2- Motor Circuit Analysis of a Submersible Pump

Condition-Based Technologies

The following technologies are covered by the proposed standard:

- AC High Potential: Is a pass/fail test applied at twice the rated voltage plus 1,000 volts for new insulation systems and 125-135% of motor nameplate voltage for existing insulation systems.
- Acceleration Time: Increased or decreasing starting times may indicate problems with power supply, motor or load.
- Bearing Insulation: Evaluation of the insulation integrity of the bearings for purposes of reduced shaft currents and resulting bearing damage. Performed following IEEE Std 43-2000.
- Bearing Temperature: Measured by RTD, thermocouple or bulb-type thermometer. Temperature limits vary but generally fall in the range of 90-100°C for alarm and 105-120°C for shutdown.
- Capacitance: Measurement is trended and values to ground increasing over time indicate surface contamination, high humidity, high temperature or insulation breakdown.
- Core Loss (Loop Test): Test performed during motor repair to evaluate the interlaminar insulation of the stator core. No spot should be greater than 10°C than the ambient core temperature.
- Coupling Insulation: Performed to ensure that no shaft currents flow into driven equipment. Performed following IEEE Std 43-2000.
- Current Demodulation: Used in motor current signature analysis as a method of removing the fundamental frequency from current FFT spectra.
- Current Running: Can be used as an indication of load. Pulsating current, measured with an analog current probe, is an indicator of rotor bar problems.
- Current Signature Analysis: Used to provide analysis of electro-mechanical condition and driven equipment condition. Requires analysis of current FFT spectra.
- Current Starting: Inrush and starting current is evaluated for anomalies.
- DC High Potential: DC High Potential is a trendable test when leakage is recorded. Uses twice the voltage plus 1,000 volts time 1.7 as the maximum applied. If, while increasing voltage, the leakage value increases very quickly, then the test has failed.
- Dielectric Absorption: Is a ratio of the DC insulation resistance readings of the 60 second value to the 30-second value. A ratio of 1.4 or greater, in pre-1970 insulation systems, is considered acceptable. Otherwise, trending is required. Reference IEEE Std 43-2000.
- Dissipation Factor and Power Factor: Are both tests that use an alternating current voltage at the rated voltage of the motor being tested. The trended value should not exceed a change of 2% over the period of test.
- Grease Analysis: Used to trend and evaluate deterioration of lubrication properties of grease.
- Growler: Used to evaluate the condition of rotor bars when the rotor is removed from the electric motor.
- Insulation Resistance: Measures the insulation value between conductors and ground after 1 minute. The applied voltage is less than the motor rated voltage with a temperature corrected result of 5 MegOhms for random-wound machines and 100 MegOhms for form-wound machines. Reference IEEE Std 43-2000.
- Oil Analysis: Used to evaluate the degradation of the lubricating properties of oil. Can also be used to detect excessive mechanical wear in equipment.
- Partial Discharge: Is a measurement of capacitive discharges within the electrical insulation itself. This value is trended generally on machines over 6,000Vac.
- Phase Angle: The timed measurement between the peak voltage and current at about 7Vac applied to a coil. When two coils are compared, the value should be within one digit of both results.
- Phase Balance (Inductance and Impedance): Used to detect severe winding unbalances or to compare in order to detect winding contamination. Test results are compared phase to phase to determine if the pattern is the same, or not.
- Polarization Index: The ratio of the 10 minute insulation to ground test and the one minute insulation to ground test. A ratio of 2 or more is required on pre-1970 insulation systems. Reference IEEE Std 43-2000.
- Single Phase Rotor Test: 10 percent of the motor nameplate voltage is applied across one phase of the motor. The rotor is turned

Figure 3 - Failed motor being prepared for testing on the shop floor

and current values taken. Variations of 3%, or more, of the current value through 360 degrees of rotation identify probable broken rotor bars.

- Shaft Grounding Current: A measurement of the shaft current. Can identify that shaft currents are not flowing through the shaft grounding system.
- Shaft Testing: Magnetic particle, liquid penetrant and ultrasonic examination are used to evaluate the condition of the motor shaft material.
- Shaft Voltage: Voltage measurements taken from the shaft of the motor. Variations in the voltage value indicate problems with the motor.
- Speed: Uses measurements of motor RPM in order to determine if potential motor or load problems exist.
- Surge Test: High frequency, high voltage impedance-based test used to check the turn-to-turn dielectric strength of the insulation system. Waveforms compared with deviations indicating faults.
- Surge PD: Variation of the surge test, evaluates partial discharges that result from the high voltage, fast rise-time test.
- Thermography: Utilizes an infrared camera to compare the background (ambient) to the test component. Defects can cause a high temperature rise at the point of fault.
- Torque Analysis: Uses three phases of voltage and current in order to calculate torque. The value is then displayed and analyzed as torque FFT spectra.
- Ultrasound/Ultrasonic: Used to detect bearing and other electro-mechanical defects on motors. Also used to detect other motor system opportunities.
- Variable Frequency: Using about 7Vac, the motor current is measured then the applied frequency doubled and the resulting current compared to the initial current result. The value should be no more than one to two digits different between phases.
- Vibration: FFT spectra of vibration information is used to trend and detect mechanical and some electrical faults.
- Voltage Balance: Voltage measurements used to detect voltage unbalance defects in the supply.
- Voltage Distortion: Harmonic content of voltage. If this value is too high, rotor and stator heating will occur.
- Voltage Drop: Is a trended measurement of the voltage drop when starting a large electric motor. Changes may indicate electric motor defects.
- Voltage Level: Voltage measurements are used to ensure that the supply voltage remains within +/- 10% of nameplate voltage.
- Voltage Spikes: Monitoring voltage spikes allows the ability to evaluate supply and control conditions.
- Winding Resistance: Used to detect broken wires and loose connections.
- Winding Temperature: Winding temperature can be trended over time in order to determine if overload conditions or insulation failure is going to occur.

Each of the tests is described, effectiveness determined (i.e.: Effective for trending?), online or offline, typical test frequencies, any precautions or considerations and related standards cited.

Application of Combined Technologies

As previously mentioned, the technologies cited can be used both individually and in combination with one another. The use of multi-technologies allows for a more accurate analysis of the condition of a machine.

An important part of understanding the application of any testing technology is also the knowledge that findings represent a probability of the type of fault being diagnosed. For instance, an insulation resistance test that shows a very low test result may be a failed insulation system, winding contamination, high humidity, improper testing procedure or a damaged instrument. It is common that the call is made based upon the experience of the user. For instance, if a 480Vac motor tests at 0.5 MegOhms to ground, based upon the experience of the user, they may state that the insulation system has failed or that there is high humidity. The corrective action taken, if any, may be incorrect as a result.

Instead, by understanding the technologies and practices available, how they are applied and what the results may mean (including the probability of the different results), the maintenance and reliability technician now can se-

lect the combination of tools to improve confidence in findings. For instance, using the above example, a combination of insulation resistance, phase balance, phase angle and variable frequency testing are used. The low insulation value is coupled with out of tolerance phase angle and variable frequency and the impedance and inductance phase balances do not match. The most likely result would be an insulation failure with the corrective action being a rewind or motor replacement.

Another benefit of evaluating condition, or trending, with multiple technologies is the ability to more accurately estimate remaining life. As a result, many technology manufacturers now combine multiple technologies into single package solutions.

Case #1: DC Thruster Analysis

Electrical signature analysis of DC machines provides a solid picture of both the driven equipment, motor and DC drive. In the case of marine thrusters, the DC allows for variable speed to propellers that are used to position a vessel. The challenge of analyzing thrusters is the ability to detect problems in the gears, bearings, seals and propeller with resulting cavitation, which directly affect vibration test results.

By using a combination of Voltage Signature Analysis and Current Signature Analysis (Electrical Signature Analysis - ESA), the results can be compared and the driven equipment evaluated. In one recent case, vibration analysis was performed on a thruster followed by ESA. ESA identified a strong running speed signature that would signify an extreme unbalance, severe misalignment or bent shaft. A review of vibration data provided additional input that suggested the result was a bent shaft.

Case #2: Generator Analysis

An operating generator on board an ocean-going vessel tripped offline due to high temperature several times during loaded operations. Infrared thermography determined that the cooling system was operating satisfactorily. MCA was utilized and it was determined that a developing winding short coupled with an insulation to ground fault was developing. Following an online test, performed with ESA, it was determined that there was a rotating field problem, as well. Another MCA test was performed and the rate of insulation failure was determined.

Utilizing the information provided by these tests, it was determined that the generator could operate in a derated condition for approximately three months. This allowed the vessel to fulfill its next mission. The generator was rewound, due to insulation failure, during the next dry-dock period, as scheduled.

Conclusion

The identification of technologies available for motor condition-based testing, their limits and capabilities provides a powerful tool for electrical motor diagnostics. The hoped for publication of IEEE P1415, "Draft Guide for Induction Machinery Maintenance Testing and Failure Analysis," addresses the need for a full electrical and mechanical test standard for electric motor condition testing. By utilizing the combined capabilities of the technologies, early and accurate analysis and remaining life estimation can be performed.

Dr. Penrose is the President of SUCCESS by DESIGN, a maintenance and reliability consulting firm. Dr. Penrose has over 20 years in the industrial electrical motor industry and is the Executive Director of the Institute of Electrical Motor Diagnostics. He can be contacted via e-mail at howard@motordoc.net

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Precision Alignment 2006.5

Are We Where We Need To Be?

by Ron Sullivan

The title of this article is drawn from an observation by a colleague. In a recent conversation he observed that today, midway through the year 2006, the state of precision alignment knowledge is still very lacking among maintenance practitioners. There certainly is no shortage of alignment equipment suppliers. A quick internet search would confirm that one can get dial indicator kits or laser alignment systems from a multitude of sources. However, the knowledge level and acceptance of precision alignment is still sorely lacking.

I will share a recent experience that promoted this article. I was hired to deliver a 2 day training class to a customer who had bought one of our laser alignment systems. On the first day of the class there was a maintenance technician (let's call him Stan) who openly voiced disapproval of his company's purchase of the laser system. Why? Because Stan said he had always done alignments with dial indicators and he saw the laser system as a waste of money (about $1,200 for a dial indicator kit, and $4,100 for the laser system). Stan was quite experienced and influential among his co-workers. I knew that I had to prove to Stan and his co-workers that the investment in the laser system was worth it. If I didn't get their "buy-in" to the laser system, their time in the training class would have been far less effective.

I asked the group what type of dial indicator method they had been using. No one stated it exactly, but what they had been using is the rim & face method. Led by Stan, they asserted that this was a good method that was "fast" and easy for them. As a way of making my point that there was value in the laser alignment system, I went to the white board and made a sketch of a typical rim & face setup as shown in Figure 1.

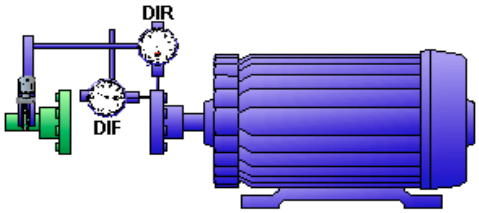

Figure 1 - Typical setup for rim & face method

They all nodded and agreed that this is how they would setup to do an alignment. I then wrote some typical dial indicator values (DIR = -40, DIF = +10) and asked them to figure out where the movable machine was sitting and what would be needed to be done to get it into alignment. There was some rustling of papers as everyone attempted to do some calculations or plotting of the solution. After about 5 minutes no one, including Stan, had offered a solution. The room fell into a painfully dead silence and it was apparent to everyone that they really did not understand this method they had been using all along. Why? Probably because their only knowledge of the method was acquired the same way humans passed on knowledge before writing was developed, by word of mouth. And you all know what happens as a story is told and retold over and over again – it changes over time. These technicians had unfortunately been shortchanged in their training of a basic and essential alignment skill.

As we tried to solve the problem together, a little discussion with the group revealed that what they usually did was to first minimize the DIF (the Face dial indicator) by shimming the movable machine. They would add or remove shims until the new DIF values were very close to zero. Then they would add or remove shims, AGAIN, until the DIR (the Rim dial indicator) value was close to zero. It was very much a trial and error method. But it was they way they were taught. I offered up a more methodical way of doing this.

To measure vertical misalignment, which must be corrected before aligning horizontally, perform the following steps:

1. Rotate the dial indicators to 6:00.

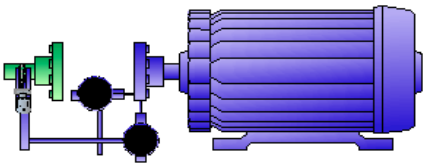

Figure 2 - Dial Indicators at 6:00

2. Set the face dial indicator to read zero.
3. Set the rim dial indicator to the sag value (bar sag would have been measured before setting up).
4. Rotate both shafts to 12:00.

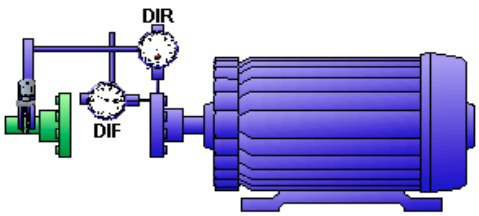

Figure 3 - Shaft Rotated to 12:00

Next, construct a simple graph with the dimensions of the machine (dimensions B & C) laid out to scale as shown in Figure 4.

In the rim-face graph example shown the DIR value is -20 mils the DIF value is +4 mils, and the A dimension is 5".

After setting up the graph, the next step is to divide the Rim Dial DIR by 2 to obtain an offset value. This value is plotted along the vertical line representing the plane that the Rim indicator swept. On the graph in Figure 5 the value of -10 has been plotted.

A second point is obtained from the face dial indicator (DIF) reading and the "A" dimension ('A" is the diameter that the Rim indicator swept). In this example the DIF was +4. A +4 means that the coupling faces are closed at the top and open at the bottom. This means that the movable machine centerline is angled upwards as you move from left to right. And how much is it angled? It is angled by 4 mils every 5 " (dimension A). So on the graph we would plot a second point (offset) that is 4 mils higher than the first point at a distance of 5 inches away.

Once the two offsets are plotted, a straightedge can be used to draw a line between them. If the line is extended until it intersects the planes of the front and rear feet, the position at these feet can be determined.

In the example shown in Figure 6, the front feet of the machine are 2 mils low; shims need to be added. The rear feet are positioned 6 mils too high; shims need to be removed from both rear feet.

All this can be done much more easily than the old "trial and error" approach. They all agreed that this seemed like a better way to use the rim & face method.

Next, I asked how they corrected for horizontal misalignment? Pretty much the same way they did for vertical misalignment, trial & error. Here is a simple technique

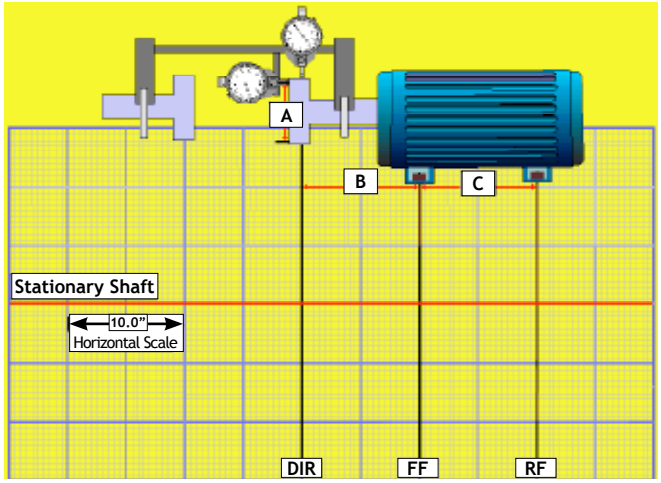

Figure 4 - Graph with Machine Dimensions Laid Out to Scale

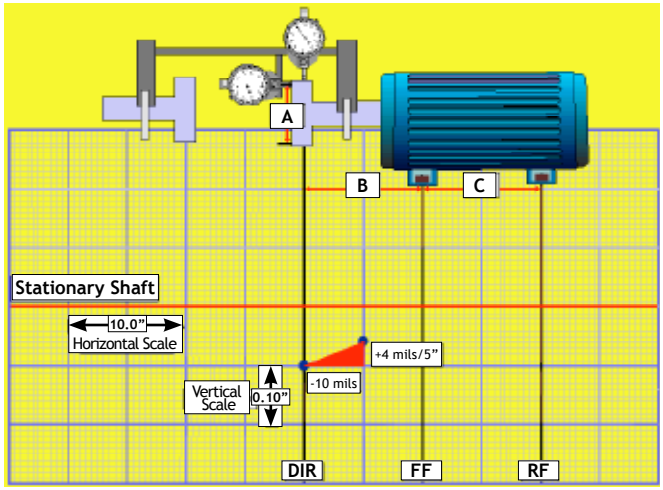

Figure 5 - Offset Value (-10 mils) plotted along vertical line of the plane the Rim Indicator swept.

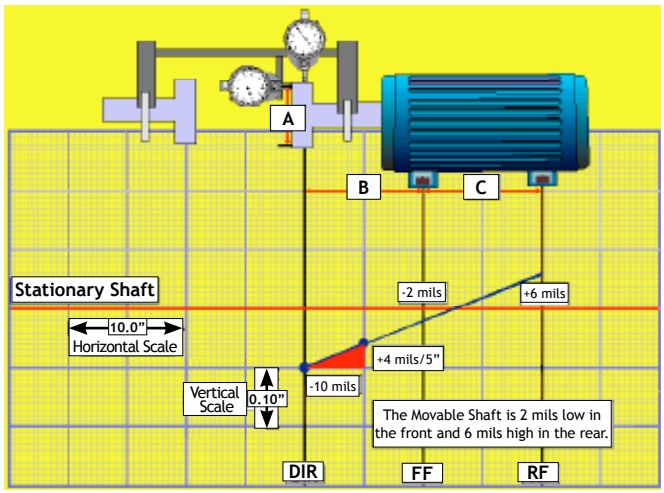

Figure 6 - Line drawn between the two offsets & extended to intersect planes of front and rear feet.

that I presented to them. Zero the indicators at the 9:00 position (as viewed when looking from behind the movable towards the stationary machine). Rotate to the 3:00 position. Adjust the DIR to half of the value. Use the "Near-Near, Far-Far" technique to move the machine into alignment. "Near-Near, Far-Far" means that the front foot will control the near indicator (the DIR), and the back foot will control the far indicator (the DIF).

	Angular Misalignment Mils per inch (000.1/1")		Offset Misalignment Mils (.001")	
RPM	Excellent	Acceptable	Excellent	Acceptable
3600	0.3	0.5	1.0	2.0
1800	0.5	0.7	2.0	4.0
1200	0.7	1.0	3.0	6.0
900	1.0	1.5	4.0	8.0

Figure 7 - General Alignment Tolerances

I asked one last question to the class – when do you stop aligning? Some said "when I get zeros all around". Others said "when I get it to about 1 or 2 mils". Others admitted they stopped when they had had enough of fighting with the machine or it was time for the shift to end! Again, trial & error was ruling. In fact, they really should always work towards a specific tolerance. And since they all work at the same plant, it would make sense for all of them to work towards the same alignment tolerances. Alignment tolerances such as those in Figure 7 are usually achievable and result in smooth running machinery.

So we got back to discussing why the plant bought a laser system. The reason is that most of these maintenance technicians (including Stan) were not performing precision alignments. The fact is that there was a lot of time being wasted. It was a hit & miss proposition whether a piece of machinery got aligned at all, not to mention properly.

What does the laser unit bring to the table? It eliminates the need to plot or calculate the results every time a set of readings are taken. It does the calculations and presents the angularity and offset values, which are the true

Figure 8 - Shaft Hog laser unit on the shafts
(courtesy VibrAlign, Inc.)

objectives of precision alignment. As they would see, the laser system also gives live values that represent the current position of the front and back foot, which will help reduce the time it takes to get an alignment completed.

At the end of the class, there was near unanimity that the laser system was a good idea after all. There was also candid (and somewhat embarrassing) acknowledgement that what had been handed down as dial indicator training over the years was not all that it was cracked up to be. The technicians appreciated learning some fundamentals about alignment, like offset and angularity. This new found understanding would give them confidence in using the laser (or a dial indicator kit) when performing alignments in the future.

So here we are, 2006.5 (midyear 2006). Dial indicator based alignment kits have been around for generations (from the "old days" as my kids would say). Laser alignment systems have been available for almost 20 years. Yet, the vast majority of alignments performed today are still done by "trial & error". Take a hard look at your procedures. Or, at the techniques your technicians are employing. Is there a solid understanding of the fundamentals? Are alignment tools being used effectively? Is everyone working towards the same alignment tolerances, or goals. Are you leveraging the latest technology in precision alignment (yes, laser alignment), so you can get back to focusing on your core competencies? The answer is probably no to several of these questions.

I am sure you have heard a manager say something to the effect of "…well if we spend money for equipment and train them, they will just leave and go somewhere else…". But this question still remains, if they don't get training what kind of job will they be doing for you along the way? Well, don't let 2007.5 catch you in the same place. Don't be stubborn. Don't keep doing things the same way you've done them in the past, and expect a different result!

Ron Sullivan was recently appointed as Regional Manager – Latin America for Commtest, Inc, Prior to this, Ron worked 16 years for VibrAlign, Inc. Starting as a Field Service Manager in 1989, he progressed to the position of President (in 1996). At VibrAlign, Ron supported industrial customers (e.g., aluminum, tobacco, pulp & paper, tire making, plastic films, food processing, defense, and ship building) with predictive maintenance consulting services, including: vibration analysis, training, field balancing, and laser alignment services. Before joining VibrAlign, Ron spent 13 years with Carrier Corporation. Starting as a field service engineer with Carrier Corporation's Machinery & Systems Division specializing in airside equipment & systems. Ron has presented papers at various industry conferences including SMRP, Enteract, Paper Industry Maintenance Conference, P/PM Technology, Vibration Institute, IR/INFO and the GM Symposium. He has also written articles and contributed to several maintenance publications. Ron is a Mechanical Engineer with over 27 years of field experience.

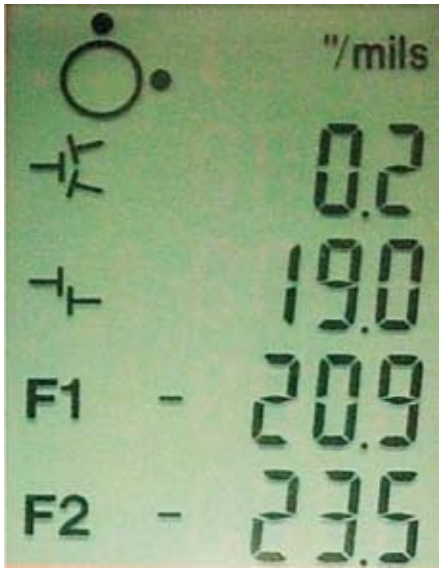

Figure 9 - Screen shot of live values (courtesy VibrAlign, Inc.)

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The Versatility of Ultrasound

One Technology, Many Uses

by Jim Hall

Airborne ultrasound is one of the most cost effective PdM instruments in the marketplace today. For years, many have thought of this instrument as "only" a leak detector. However, today's airborne ultrasound is both an instrument that is to be used for troubleshooting and as a predictive maintenance tool. Today's airborne ultrasound instruments are far too valuable to let sit on a shelf and go "unused". How long has it been since you used your airborne ultrasound instrument, 7, 10, 30, 60 or 90 days? Why? You are simply leaving money on the table if you let your instrument sit too long.

So, now that you have decided to recharge the batteries of your old unit or, have decided to finally purchase an ultrasound instrument, what next?

Air Leaks

Air leaks? Everyone has them in their plant. And they are expensive. Why not find and fix them? The number one answer is, "man-power". The need for man-power to find them and, once identified, the man-power to fix them is usually the problem.

Have you ever thought about hiring a third party to locate the leaks? Many of these third party leak detection companies do not repair, but they do find leaks, mark them, and catalog the leaks. It may take the leak detection service 2-4 days to complete a "leak detection audit" (depending upon the size of a plant). But, remember, those are 2-4 days that you did not dedicate your maintenance personnel to identifying leaks.

If man-power isn't your problem, then arm a technician with an ultrasonic instrument, a parabolic dish, long range horn, a digital camera, a 3 part leak audit tag (find, repair, inspect) and start saving money in two possible ways:

1. The cost of the supply and demand of the leak.
2. An increase in production or an increase the efficiency of a process.

It is possible that your leaks have been starving the air system, creating a production problem or a causing a process to slow down.

A good leak audit should be comprised of the following:

1. Pictures (preferably digital) to aid a technician in locating and identifying leaks.
2. A 3-part leak audit tag (Find, Repair & Inspect).
3. Leak Audit Spreadsheet, a catalog identifying all leaks found and the size of leaks (Small, Medium and Large).

Remember this - What is noisy to you and me is not noisy to the ultrasonic receiver! One of the hardest obstacles to overcome in training technicians on how to use airborne ultrasound is to get them to realize just how much background noise can be eliminated by frequency tuning.

Fig 1 - When using any airborne ultrasound instrument, first scan the area without a rubber cone or isolation tube affixed to the unit. Once the leak is heard, then apply the cone to focus in on the leak or leaks.

Bearing Analysis

Bearing analysis using airborne ultrasound is best achieved when the bearing is trended over a period of time. Testing

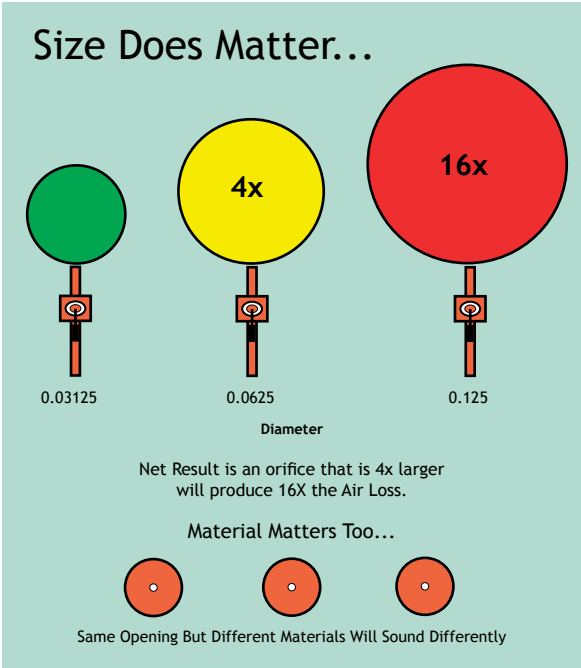

Fig 2 - The size of air leaks does matter, as well as the material from which it is leaking.

a bearing over time is done once a baseline is established.

Here is an example. One user took readings from several motors and established a baseline of 35 to 55 decibels. Once the reading reached 10 decibels over the normal decibel range, which was established over time, the bearing was considered to be in need of lubrication. After lubrication if the bearing did not return to a normal range the inspection time would be decreased to 30 day instead of 60 day intervals. Once the bearing reached 20 decibels over the normal running baseline, replacement was ordered.

Now, this does not mean that using these numbers will or should work for you. This is one plant and one engineer who spent the time needed to establish his baseline. However, it does provide a good example of the process you should use.

When trending bearings, attention should be paid to the frequency of inspections. If the man-power exists, take readings every 60-90 days. Once a bearing starts trending consistently 8-10 decibels over an established baseline, lubricate the bearing. If, after lubrication of the bearing, readings continue to track high or enter a failure mode of 10-15 decibels over baseline, increase the inspection intervals. If decibels reach 16 or more over normal, removal or replacement should be scheduled at the next convenient time. However, if the bearing spikes upward to 35 decibels or more over the normal readings, it should be considered catastrophic and should be removed and replaced immediately.

Bearing Failure Modes	Decibels Over Baseline (0 db = 1 µV)	Action
Pre-Failure or Lack of Lubrication	8-10 dBµV	Lubricate and Retake Reading
First Failure or Beginning of Failure	10-12 dBµV	Watch over time
Failure	16 dBµV	Schedule Removal/ Replacement (next convenient time)
Catastrophic Failure	35-50 dBµV	Removal/Replacement Immediately

Fig 3 - Bearing Failure Modes and Actions

Ultrasound and Vibration Analysis

Using airborne ultrasound in combination with vibration instruments is not something new. The first time I saw an ultrasound receiver connected to a vibration analyzer was at the Pearl Harbor Naval Station in 1990. A young US Navy 2nd Class Machinist Mate attached to the US Navy Submarine Fleet's Performance Monitoring Team was using his ultrasound receiver and vibration analyzer to detect valve leakage due to unseated and/or worn valve seats. Later this same technician earned a degree in mechanical engineering and is now very active in the vibration analysis industry.

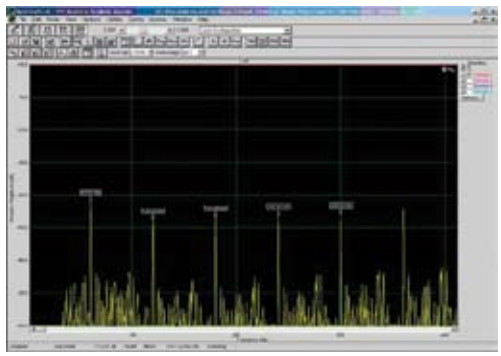

Fig 4 - Corona (60 Hz peaks), 13 kV Oil-Filled Transformer
Spectra-Plus Software courtesy of Sound Technology, Inc

Today, you can purchase an ultrasound receiver from the various manufacturers and receive software that will allow you to perform waveform analysis. Waveform analysis can be very effective when diagnosing bearing problems such as an outer race problem

and/or electrical discharge to identify corona.

Electrical Scanning

Ultrasound is used to scan electrical switchgear and substations for corona, tracking and arcing. But airborne ultrasound is more than just a predictive tool for detecting these problems.

You are probably familiar with the term ARC FLASH. Scanning electrical switchgear with an ultrasonic instrument could possibly save your life. *Before entering an arc flash boundary be sure to review NFPA 70E and remember that anyone working inside an Arc Flash Boundary must wear the appropriate protective equipment.* For electrical switchgear applications, it is helpful to think of using airborne ultrasound for safety reasons first and view the predictive data you gain as an added bonus.

If you are not sure whether what you are hearing is corona or a mechanical problem, you can record a wave file and play it on a spectrum analyzer or use one of the many sound analysis software programs available in the marketplace. Look for high peaks every 60 Hz (120, 180, 240, etc.).

Steam Traps Troubleshooting

Ultrasound alone can be used to diagnose a steam trap. A pyrometer is helpful but not always necessary. When you listen to an inverted bucket trap, you can actually hear the linkage as it moves the bucket. Also, when listening to the discharge side of the inverted bucket trap, if you hear a "continuous" blowby you know that the trap has failed and remains open.

Valve Inspections

Do you have a valve or valves that you suspect may not be seating properly? Or perhaps a valve that can not be easily removed or taken off line? By using airborne ultrasound to inspect valves, you can easily determine if they are functioning properly. Fig 4 shows a typical valve inspection, in which you use your ultrasonic contact probe to check Points A, B, C and D with the valve closed.

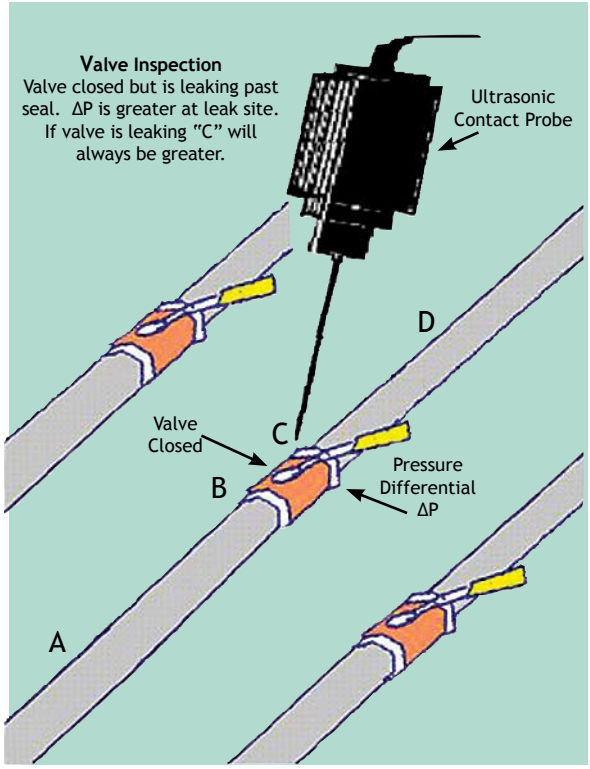

Fig 4 - Typical Valve Inspection

Building Envelope Leaks

Most ultrasound kits have a tone generator device that emits high frequency sound into a volume (room or opening). The ultrasonic receiver then hears the sound that allows the user to locate a leak site. This technology is also used by manufacturers that build vaults, ovens, tanks and even clean rooms to locate leaks. The technology can be used as a pretest before using helium or other trace gases to locate leaks at a much smaller leak rate than the ultrasound receiver (airborne ultrasound sensitivity rated to $1x10^{-3}$ std/cc/sec) that is used for gross leaks. The use of airborne ultrasound first to locate the gross leaks is a "best practice" method application. When using helium to find leaks in the $1x10^{-3}$ std/cc/sec, you could possibly saturate your sensor rendering it useless. It is always useful to find the gross leaks first with ultrasound.

Troubleshooting Hydraulic Systems

Airborne ultrasound is very directional because of the short wave signal. You can detect and diagnose problems by using the contact probe or magnetic sensor to listen to an actuator that has bypassing fluids or pneumatic air escaping from the cylinder and/or to listen for scraping of the cylinder as it is moving in and out of the barrel.

Underground Leak Detection

Airborne ultrasound is commonly used to successfully locate underground leaks of both

Fig 5 - Underground leak located 4 feet below ground. Using ultrasound and steel rods driven into the ground.
Photo courtesy of All Leak Detection, LLC

gas (air) and liquids. I have personally used ultrasound for this application and have been very successful doing so. I suggest reviewing the April issue of Uptime in which you will find an article dedicated to this topic. Please understand that there are limitations in using ultrasound for this application. Your instrument must be able to frequency tune to 20 kHz, and some instruments can even tune as low as 15.1 kHz. Also, you must touch the ground with the microphone, preferably the contact sensor.

Other Applications

There are literally hundreds of applications for airborne ultrasound, of which we have only mentioned a handful. Other applications include:

- Condenser Leaks (waterboxes)
- Heat Exchanger Leaks (on/off-line)
- Expansion Joints
- Acoustic Lubrication
- Automotive, Marine, Aviation (wind/water leaks)
- Boiler Inspections
- Radio/TV Interference

More Than Just A Leak Detector

By now you get the idea that airborne ultrasound is much more that just a leak detector. Your instrument can even do more than just ultrasound related applications. There are instruments in the marketplace that can be used with rpm sensors, an A-weighted decibel sensor and pyrometers (temperature guns). Some of these ultrasound instruments can actually take the reading directly from the accessory and load it onto an onboard data-logger. Sometimes it seems that ultrasound applications are limited only by the users imagination.

A high-quality ultrasound instrument is one of the greatest "Return-On-Investment" predictive maintenance instruments ever made. So why is it sitting in the tool room?

Seek training (on-site is most effective) if you are not familiar with the instrument. A one or two day workshop on equipment orientation and applications will easily pay for itself and will, over time, return huge dividends.

Final Thought

A final thought on the use of airborne ultrasound. One unknown user recently made the following statement during an on-line forum discussion about airborne ultrasound.

"We use ultrasound for bearings, monitoring grease application, valve leakage and air system leaks. The success or failure of the investigation depends on the experience of the user, their familiarity of the instrument and the machine being scanned. Like many users we had a tough time getting enough experience and confidence to make the program effective. Training and experience goes a long way."

So pick up your instrument right now, start identifying and fixing problems. You'll be amazed at how quickly the savings begin to roll in.

Jim Hall is the president of Ultra-Sound Technologies, a "Vendor-Neutral" company providing on-site predictive maintenance consultation and training. UST provides an Associate Level, Level I & II Airborne Ultrasound Certification. Jim is also a regular provider of on-line presentations at ReliabilityWeb.com. Jim has provided airborne ultrasound training for several Fortune 500 Companies in electrical generation, pulp & paper, petro-chemical and transportation (marine, automotive, aerospace). A 17 year civil service veteran, Jim served as an aerospace engineering technician for Naval Aviation Engineering Service Unit (NAESU) and with the Naval Aviation Depot Jacksonville Florida (NADEP).

Smart Switches

A First Line Defense

By Dr. George Zusman, Ray Limburg & Joseph P. Jank

Machinery and mechanical systems face potential failure when their ability to function normally is compromised due to worn components or when their normal operating condition becomes upset in some manner. If the worn component or process upset can be detected, then operator warning or immediate shutdown can safeguard the machinery from catastrophic failure. A simple detection technique can be based on vibration — where an increase in measured machinery vibration is utilized to trigger an alarm or shutdown. It is a known fact that machinery vibration increases when problems such as worn bearings, cracked gears, lack or contamination of lubrication, imbalance, looseness, and misalignment become worse.

For such applications, the mechanism used to detect a vibration increase and trigger an alarm or shutdown is called a vibration switch. A vibration switch can also be used to alert an operator of a decrease in vibration levels — as may be the case when a motor ceases to function.

Continuous monitoring of increasing and decreasing vibration levels helps avoid expensive unplanned shutdowns by detecting machinery faults before they become catastrophic events. Early detection is essential for efficient machine maintenance, as well as protecting equipment from further damage during an upset condition. The advancement in vibration switch technology from mechanical to electronic switches has offered a very useful tool for maintenance engineers, allowing for better planning and less headaches while sustaining equipment performance and longevity.

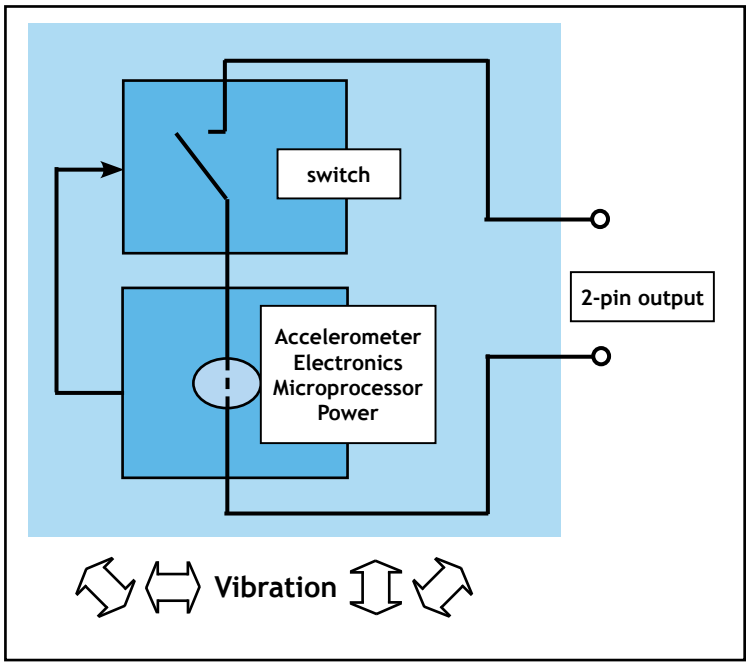

Figure 1 - Intelligent 2-wire Vibration Switch Operating Principle

The classic style of an electronic vibration switch utilizes a built-in, or remotely located, vibration sensor whose electrical signal is conditioned and monitored. The switch mechanism itself is a circuit board with a mechanical relay that is typically housed in an electronics enclosure. The circuitry monitors the sensor's generated vibration signal against a pre-set threshold value and activates the relay when an exceedance is encountered. Such devices are bulky for mounting onto a machine, have a limited range, require a separate power source, and require individual wiring to their respective programmable logic controller (PLC) or alarming device. To overcome some of the complexities and shortcomings of the classical style electronic vibration switch, a new, intelligent, two-wire, solid-state vibration switch has been developed. The operating principle for this new switch is shown in figure 1.

This intelligent, two-wire vibration switch is a new type of device for machinery protection. It has been designed to be a cost effective tool for generating an alarm or initiating shutdown of small to medium-size machinery, such as electrical motors, pumps, fans, and

compressors. The device is entirely self-contained within a hermetically sealed, stainless steel housing. With its 2-pin MIL type electrical connector, the unit's appearance is very similar to an industrial accelerometer. The unit is simple to install and is virtually universally compatible with any type of load, relay, monitoring system, or control device. In many instances the intelligent two-wire vibration switch will be the only device necessary for permanent machinery protection.

The fact that switches now have the ability to be mounted and installed like a sensor (see Figure 2) allows for easy introduction into existing plant machinery. Systems engineers are no longer launching a brand new technology that is foreign to maintenance supervisors, who ultimately will be responsible for their upkeep. The unique two-wire design allows for standard wiring configurations which mirror that of existing accelerometers. In many cases, spare parts and cables are already part of plant inventory.

Functionally, the unit incorporates a piezoelectric accelerometer, signal conditioning electronics, a microprocessor, and a solid-state switch with a 500 mA current capacity. This unit is relatively small in size with a height of 2.75 inches and a 1-1/4 inch hex diameter. Its weight is 7 ounces. The small size and weight offer excellent frequency response and low cross axis sensitivity as compared with alternative devices.

The intelligent vibration switch operates over two wires. It installs in series with a load and its power source to form a loop. In this case, the load is the alarm or shutdown device, such as a PLC, annunciator, or relay coil. To energize itself, the vibration switch scavenges power from the load's power source. When a threshold exceedance is encountered, the switch is activated and the load's power circuit is completed to facilitate the desired alarm or shutdown.

The intelligent vibration switch is installed by screwing into a tapped mounting hole on the machinery surface. During operation, the vibration sensor generates an analog signal that is proportional to the acceleration of the vibration present at the installed location. This signal is amplified, filtered, integrated (to velocity), digitized, and interrogated by the microprocessor. The microprocessor compares the rms velocity signal against the programmed threshold value and activates the switch when an exceedance is encountered.

Figure 2 - Intelligent vibration switch installed in a power plant on a 1500 horse power boiler feed pump.

The programmed threshold value is the upper limit of acceptable vibration for the specific machine operating within its particular application. This value may be different for dissimilar machines, or even for identical machines operating under different conditions. If the vibration limit can be determined, then a vibration switch with a fixed threshold value can be deployed. Often, however, this limit is not known, making the ability to adjust the threshold value, in the field, a requirement. To support field adjustability of the threshold value, the intelligent vibration switch offers an option called Magnetically Adjustable Vibration Threshold (MAVT™). This option provides an effective and easy way to change and set the threshold value at any location.

The MAVT option adds a magnetically actuated sensor within the housing of the intelligent vibration switch. This sensor is activated by touching the housing of the switch, at the proper location, with a strong, permanent magnet. This action then initiates a process within the microprocessor to change the threshold value. During this process, the vibration experienced by the intelligent vibration switch is averaged over a fixed sample period of approximately 30 seconds. This average vibration value is then

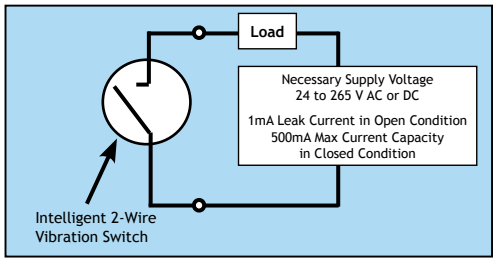

Figure 3 - General hook-up diagram for a system utilizing the Vibration Switch

doubled and this new value (2 x measured average) becomes set as the new threshold value. This process is entirely automatic and requires no additional calibration devices or instrumentation. With MAVT capability, the intelligent vibration switch can simply be installed onto machinery that is operating normally, touched with a strong, permanent magnet, and then, in about 30 seconds, it is all set to begin protecting machinery against potential catastrophic failure. Additionally, to achieve a more precise set-up of the threshold value, the vibration switch may be mounted to a controlled vibration shaker in order to experience measurable vibration amplitude. In this scenario the threshold value will be set to 2 x the shaker vibration amplitude.

The MAVT capability permits easy installation on a piece of machinery; even if nothing is known about its natural frequencies. Never before has switch protection been this easy to install. Integration of this type of technology no longer requires extensive vibration analysis or trial and error to become reliable.

As previously mentioned, the intelligent vibration switch derives its excitation power from the power source used to energize the load with which the switch it is connected in series. This arrangement, which is shown in Figure 3, serves to restrict the amount of current passing through the switch, which is limited to 500 mA.

The power requirements for the switch are very broad, which permits its use with virtually any type of load such as a PLC, annunciator lamp, alarm device, electromechanical relay, or solid-state relay. A variety of application examples are shown in figure 4. Specifically, the switch can be powered by anything from 24V to 265V, AC or DC. With the switch in its open condition there is a leak current of approximately 1 mA, whereby in the closed condition, the switch

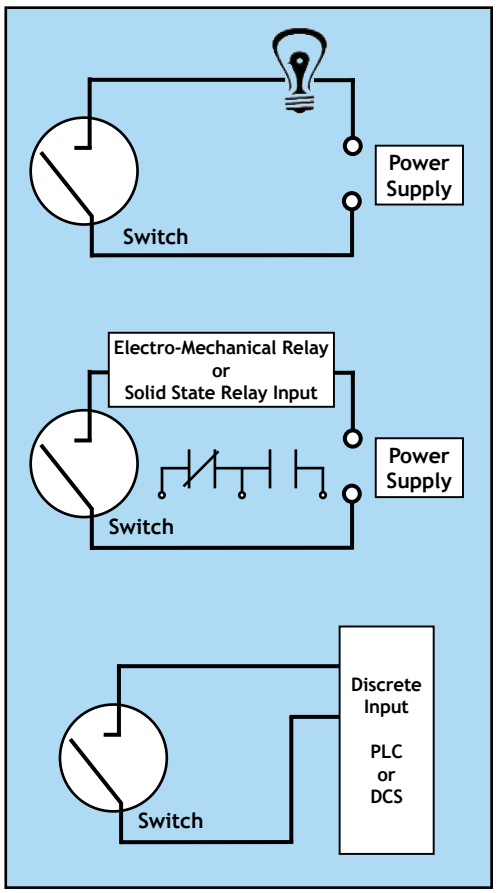

Figure 4 - Application Examples of 2-wire Vibration Switch

can support passing a current of up to 500 mA with a voltage drop of approximately 8V. In circumstances where a lower voltage drop is required, a special switch can be offered, which operates from 10V to 30V DC, and possesses a voltage drop, in the closed condition, of 1.5V DC.

Another intelligent design feature of the vibration switch safeguards its compatibility with electromechanical relays, which are a popular choice for use in machinery shutdown and alarm requirements. Such relays operate with a dropout current that is smaller than their pickup current. For certain relays, the dropout current could potentially be near to, or less than, the 1 mA leak current of the vibration switch, thus compromising successful dropout when the vibration switch becomes open (OFF). To ensure successful dropout of the relay when the vibration switch returns to an open state, the vibration switch will turn itself off for approximately 100 milliseconds. This feature is illustrated in figure 5. During this period of time, there is zero current on the output leads of the switch. This action guarantees proper dropout of the electromechanical relay. For almost all electromechanical relays, their pickup current is significantly higher than the 1 mA leak current of the vibration switch, so there is little chance for incompatibility from this perspective.

Because this unit is universally powered, it can be installed virtually anywhere. Any existing mechanical switch installations can be immediately replaced with intelligent electronic vibration switches, without the need to run separate power to the unit. At less than $500 per switch, it provides an extremely economic solution to online vibration monitoring. The cost of this system can be justified by the reliability of constant

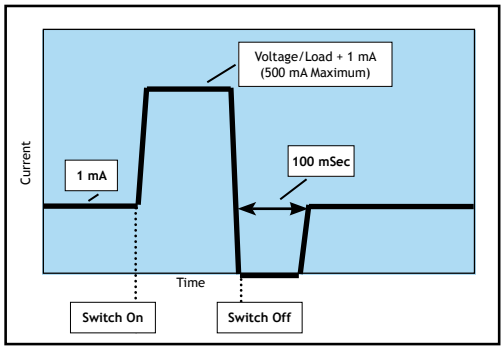

Figure 5 - Plot depicting 100 millisecond turn-off of Switch, ensures reliable dropout of Electro-Mechanical Relays.

24/7 vibration protection. Not only does this allow machinery to be protected around the clock, it can help minimize and better control route based vibration analysis which can only be reliable if utilized effectively and repeatably. This technology is not intended to replace scheduled vibration analysis, but rather to act as a first line of defense against potential machinery failure. This technology serves an important role in any industry where machine reliability is essential to everyday operations.

Figure 6 - Electronic vibration switch installed on a circulation water feed pump at a paper mill.

Dr. Zusman has a Ph.D. in Electronics, an Sc.D. in Vibration Monitoring and has more than 30 years of experience in industrial vibration monitoring instrumentation. Dr. Zusman joined PCB Piezotronics as Director of Product Development in 2005. He was formerly Director of Engineering, and later, president of Metrix Instruments, Co. / PMC-Beta. Dr. Zusman started his career as an R&D engineer at one of the leading universities in Moscow, Russia. Subsequently, he held numerous R&D and engineering management positions. He holds about 20 patents and has authored nearly 100 technical publications.

Ray Limburg is a Technical Marketing Specialist with PCB Piezotronics,Inc., and holds a BS degree in Interdisciplinary Engineering and Management from Clarkson University. Since 1982 he has held various sales, product management, and marketing positions related to sensors and instrumentation for test & measurement and process control requirements.

Joseph P. Jank from Buffalo, NY is the Product Manager for the IMI Sensors division of PCB Piezotronics; specializing in the new line of electronic vibration switches and industrial vibration monitoring equipment.

Thermal monitoring has been dominated by infrared thermography for many years. Now there is a new alternative that provides continuous monitoring.

ExerTherm

Constant thermal monitoring. Just think about that phrase for a minute. A constant stream of data giving you the temperature status of your equipment. That's pretty powerful stuff. That's information that can lead to more informed decisions about your equipment's health. That is what ExerTherm provides. We caught up with Bob Kern, the product manager for Exertherm in the U.S., and a 25-year veteran of the power conversion and control equipment industry. Here is what Bob had to say about ExerTherm - a product that's been aound a while in the UK, but one which is very new to the United States.

Why don't you briefly explain what ExerTherm actually is and what it does?

ExerTherm is a constant thermal monitoring system that uses an assortment of thermocouples that are permanently installed. What makes ExerTherm unique is our miniature passive Infrared (IR) thermocouple (requiring no external power) for non-contact measurement of a target. The IR thermocouple reports the temperature rise above ambient, eliminating the ambient temperature fluctuations in the data as a variable. The system not only monitors and alarms, but also collects and stores data for trend analysis for true predictive maintenance. The system can be used for electrical switchgear and distribution equipment, motors, pumps, bearings and so on.

When did you develop the idea for this product?

Power Service Concepts is the authorized USA distributor and Service Company for ExerTherm. QHi Group in the UK developed ExerTherm about 6 years ago.

How long has ExerTherm been used successfully by industry?

ExerTherm was rolled out in the UK about 5 years ago. With success of over 20,000 sensors and associated ExerTherm equipment installed in the UK, QHi decided it was time to introduce ExerTherm to the US.

What industries is ExerTherm best suited for?

Data Centers, Financial, Telecom, Utilities, Shipping, Media, Petro-Chemical, Large Scale Manufacturing Plants. Really any facility or organization where failure of mission critical equipment will potentially result in significant down time costs.

What type of machinery is ExerTherm being used on currently?

Key joints / connections (the most common cause of failure) in critical electrical enclosures (switchgear, transfer switches, PDUs, UPSs, transformers). In addition, critical mechanical equipment such as HVAC, bearings, gearboxes, motors, pumps, etc.

Is ExerTherm appropriate for any size operation?

Yes. ExerTherm is completely scaleable. A facility can start with an affordable single data card system with up to 8 sensors today, and incre-

mentally install more monitoring as needed by purchasing additional data cards and sensors. Large-scale OEM and "Green Field" (new construction) installations are common, as well as retrofits. The basic ExerTherm System will operate on a PC. ExerTherm can be integrated many different ways in up to 450 different Business Managament Systems as well.

What kind of impact does ExerTherm have on overall plant and machinery reliability?

ExerTherm has two functions, the 1st being predictive maintenance. The software has built in trending and graphing functions so the technician or engineer can review the data and make decisions based on the data that has been collected. From there they can decide how well their equipment is performing and look for problems during a "growth period" or un-usually heavy production period. Are parts starting to fall short of their ratings or expected life? Can components or the system handle the expected growth? Answers only the collected trend data can answer.

The 2nd function is the alarms. The responsible engineer can turn on the alarm function for each channel independently and set the "warning alarm level" and the "maximum alarm level". So in real time ExerTherm will initiate an alarm when one of the levels is tripped on any of the channels. The basic ExerTherm system includes an alarm card with SCADA compatible dry contacts.

Can a business case be made to justify the cost of ExerTherm?

Yes, the trend data collected and stored on the PC, will allow the owner to optimize the time between scheduled preventive maintenance sessions. Preventive maintenance is scheduled on a calendar time or hours of operation. Of course the time interval is based on what the responsible engineer believes will provide the most operating time between scheduled down times for the maintenance work without incurring failures. If the cycle time is too short, there is a waste of time and money. If it's too long and a failure may occur in which the repair cost, collateral damage, and the cost of the unexpected down time will be more than the cost of an ExerTherm System. In the case of electrical switchgear, many companies open the cabinets and perform the torque maintenance once a year, just in case. But if the bus bars are monitored 24/7/365, the data can be reviewed and if no increase in temperature is seen, that maintenance cycle can be extended. So, instead of once a year maybe the torque cycle is once every 3 years or 5 years or as indicated by the data from the ExerTherm System after review.

Photos of Installed ExerTherm Systems

Based on the nature of calendar or operational time based preventive maintenance cycles, unforeseen problems can become failures. The damage caused by a failure will be more expensive and more time consuming to fix compared to an initial repair of a minor problem which would be inexpensive and quick to facilitate – if found in time. Review of the ExerTherm 24/7/365 Trend Data and or the ExerTherm alarms can highlight a problem before it grows into an expensive failure or catastrophic event.

As electrical demands grow in Data Centers and Manufacturing Plants, their electrical switchgear and distribution components need to handle the load. As of now, most companies perform Thermography scans once a year for preventative maintenance. But as the loads grow daily/weekly/monthly, at some point during the year between preventive maintenance intervals, some component of the system may reach a premature limit. As the electrical demand growth occurs, real time trend data can show how the electrical system is handling the growth, allowing a more precise estimate of the expected capacity life span of the electrical equipment, optimizing the original investment of the equipment in place.

All physical maintenance is intrusive to a system. There is always a chance of something happening, such as a mistake that causes failure of the equipment or puts a technician in harms way. With electrical switchgear, at the least there maybe an issue of the system not coming back online timely, at the worst a technician can be killed from an accident or arc flash.

In short ExerTherm is all about mitigating the risks of downtime of mission critical equipment in the high downtime cost environment.

What is the best success story you have heard from the implementation of ExerTherm?

It's extremely hard to describe a "success story". ExerTherm's mission is to highlight issues when they are minor problems, before they become major problems or catastrophic in nature. Since not one system ExerTherm is installed in has reported any major problems or catastrophic events and not a single sensor or data card has failed to date. I would consider that our best success story. Also the majority of our customers that are blue chip organizations have extended the use of ExerTherm following the initial installations. This probably speaks for itself.

How can our readers get more information about ExerTherm?

To get more info, please visit our ExerTherm Web site at www.psc-exertherm.com or, feel free to contact the USA Product Manager directly at 631-736-0593 or bkern@psc-exertherm.com and for the UK contact QHi Group Ltd: 44 (0)1582 461123 or sales@qhigroup.com

The 261A Series Triaxial Force Link Sensors from the Force/Torque Division of PCB Piezotronics, Inc. simultaneously measure dynamic and quasi-static forces in three orthogonal directions (X, Y, and Z-axes). The sensors are used during vibration testing of aerospace structures to match the mechanical impedance of shaker inputs and may be used to force limit the shaker controller to prevent damage to expensive structures. Other applications include cutting tool monitoring, biomechanics feedback, and automobile chassis dynamics.

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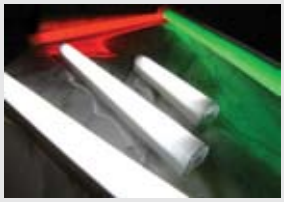
Flowserve Corp announces the launch of new Learning Resource Center (LRC) instructional labs, which offer hands-on technical facilities for pump, valve and seal system optimization and maintenance training. The LRC offers hands-on training in a simulated plant environment that features complete pumping systems and equipment from both Flowserve and other manufacturers.

The LRC, part of Flowserve Educational Services, sets a new standard in technical education, with up to 50 percent of training time spent working in the operational labs with the pump, valve and seal systems plant professionals use every day. Courses are specifically designed to increase participants' skill levels in equipment selection, installation, repair, failure analysis, and troubleshooting. Participants return to work with practical knowledge to improve plant performance, increase machine availability, lower the cost of maintenance, and improve plant safety.

Class size at the LRC is limited, providing ample opportunity for participants to experiment and test the "what-ifs" of the equipment they use every day, as well as ask questions and discuss theoretical topics.

The Learning Resource Center is located in Irving, Texas, in the heart of the Dallas/Fort Worth Metroplex. Courses are also offered at Flowserve Learning Centers across the U.S. and on-site at plant locations around the world.

Juliette Rowe **972-915-1626**
jrowe@flowserve.com **www.flowserve.com/education**



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