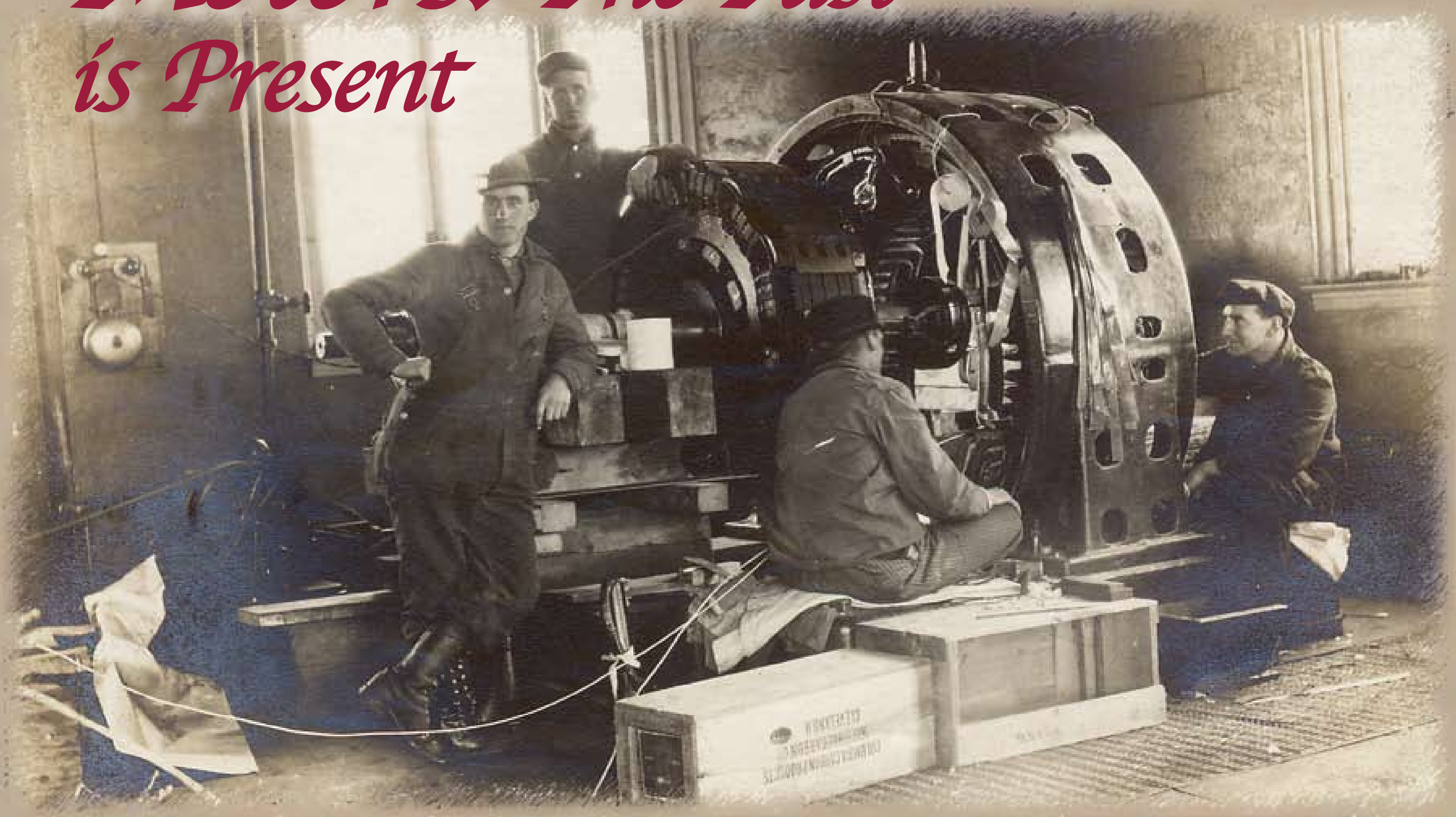
uptime

feb 2006

the magazine for PdM & CBM professionals

Motors: The Past is Present



Hunting in the Haystack

Windows to the IR World

Alignment: Fountain of Youth for Bearings

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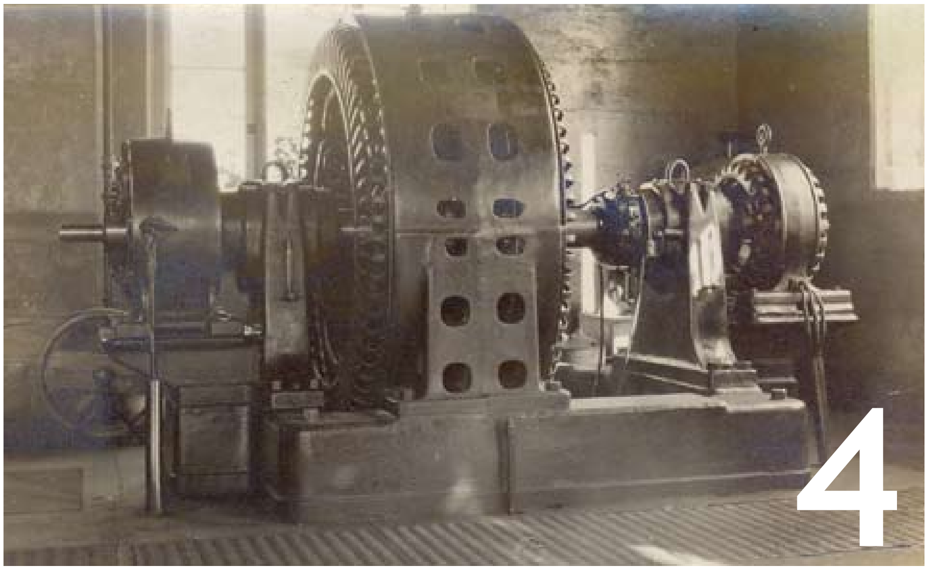
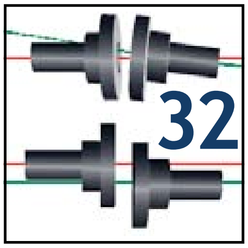
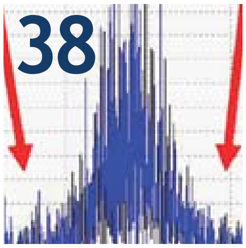
uptime contents



On the Cover:

Synchronous Motor Overhaul at Welland Canal, Thorold, Ontario, 1912





Get Predictive, Get Healthy

This month we will host our first web based workshop in the Reliability Roadmap series, which is co-produced with Reliabilityweb.com. I am excited about this series, and hope you will join us as we journey down the many roads leading to maintenance & reliability excellence.

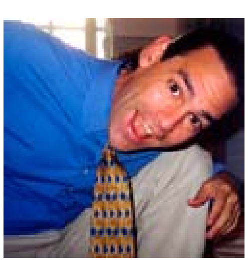
Of course, here at uptime®, we have a particular fondness for the predictive technologies. We like them so much because we strongly believe that companies (and other organizations) simply cannot be performing their best without a robust predictive maintenance program. A well thought out and well executed maintenance program will make any company healthier. We like healthy companies because they are better for employees (from custodians to CEOs), better for government (more tax revenue), better for shareholders and better for consumers.

In this month's feature, Dr. Howard Penrose does an excellent job of laying out the process of implementing a motor management program. Determining which predictive technologies your facility will benefit from is one of the steps. Notice the decision is which technology to use, not whether to use predictive technology or not. That is an important distinction.

In his excellent piece on controlling contamination, Dr. Leonard Bensch says that with the technology that is available today, there is no reason to let dirt decrease the reliability and life of your machines. The same basic idea can be translated to any of the predictive technologies.

There is really no reason for companies not to utilize the technology out there to increase uptime, lower maintenance costs, increase production and increase the bottom line. A healthy maintenance program makes for a healthy company.

Please contact me with any ideas and suggestions you have for us.



All the best,

Jeff Shuler
Editor In Chief
jshuler@uptimemagazine.com

PS - I am fascinated with the photos accompanying the feature. They are from some major overhaul projects that Howard's great grandfather Henry Bulbrook took part in from 1911 to 1929 while with Westinghouse Canada. Howard's grandfather also worked for Westinghouse Canada as a winder and then a welder.

Correction
On page 6 in our January issue, we misspelled the name of the company in the caption of the photo. It should be Eastman Chemical Facility in Kingsport, TN.

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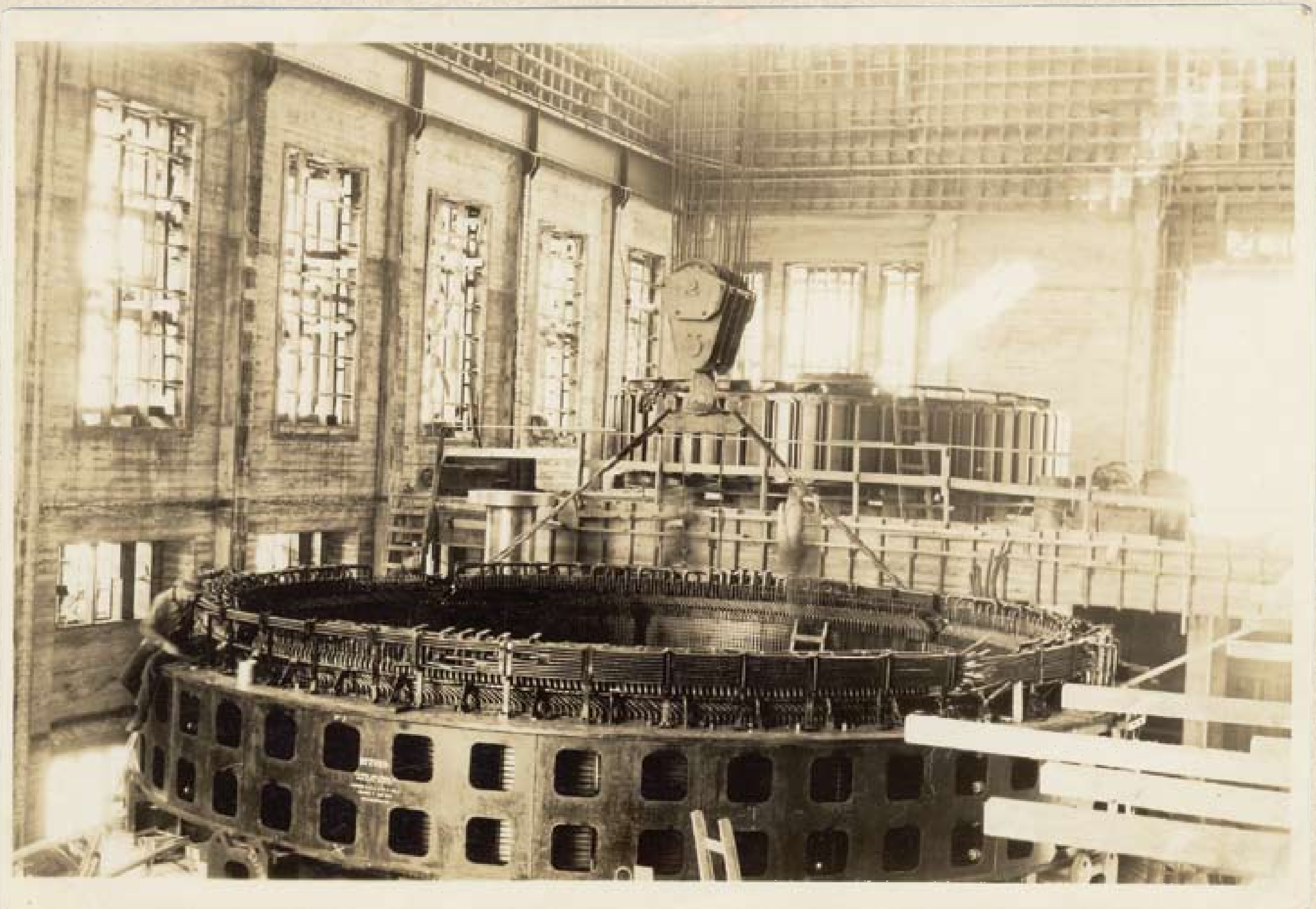
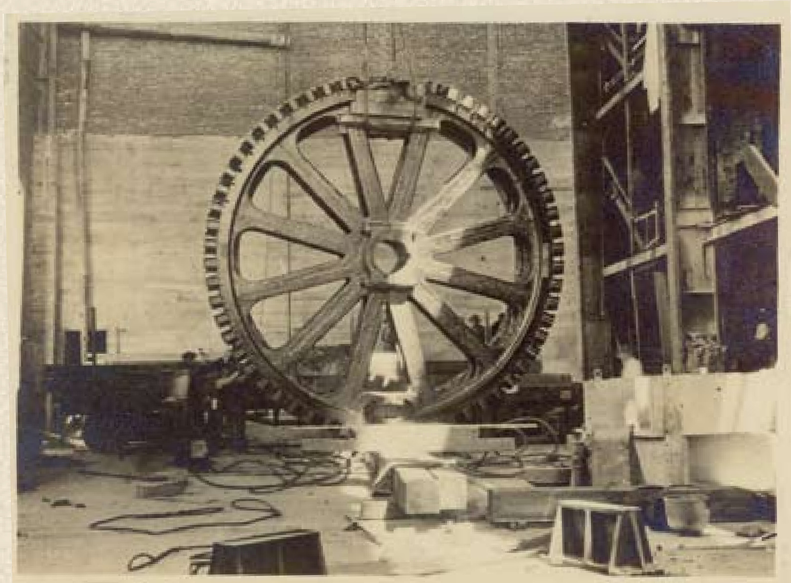
Back to the Future

Electrical Motor System Maintenance and Management

by Howard W. Penrose, Ph.D., CMRP



1929 BC Hydro Generator Overhaul, Ruskin, British Colombia



1915 Laurentide Co. Generator Armature, Grand Mere, Quebec

Electric motors and related systems. They are things we often overlook when thinking about factors that allow industry and manufacturing to compete in a modern economy. Yet electrical motors are, figuratively *and* literally, the engine that drives our economy. In production facilities and processing plants, electric motor systems consume approximately 90%, or more, of the electrical energy used by the facility. The invention of the AC induction motor, and the ability of AC power to be transformed and delivered over long distances, gave the industrial revolution a major shot in the arm following the development of the steam engine. Its greater efficiency and robustness reduced maintenance headaches that older power systems generated.

Yet, here we are, over 118 years following the invention of the AC electric motor system, AC power generation and transformation and distribution systems by Nikola Tesla, and we are still maintaining these vital components of our economy much the same way that they were managed in the early 1900's. In fact, an associate of mine gave

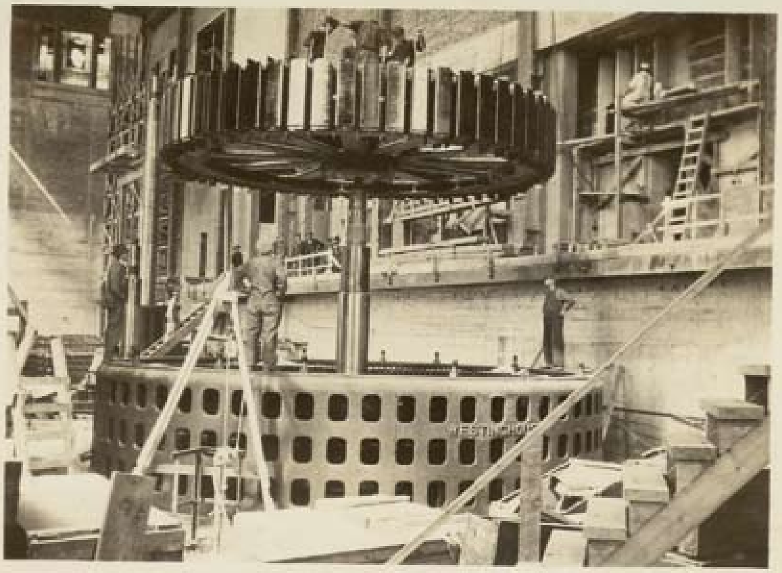
Electrical motors are - figuratively and literally - the engine that drives the economy.

me a book called "The D'Este Steam Engineers' Manual: Electrical Appendix"[1] written by Charles Penrose, EE, in 1913. It describes the same systems, functions and basic maintenance for rotating machines that I can find in books and manuals on motor system maintenance as late as 2005. The electrical generation and distribution system of the early 1900's, both internal and external to the facility, appear very similar to those that we deal with today.

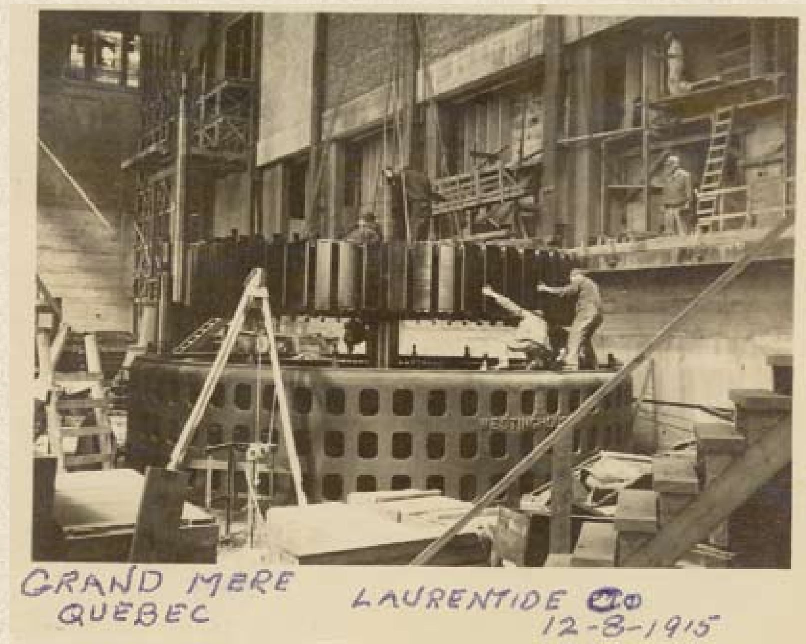
1915 Laurentide Co. Powerhouse

Between 1910 and 1920, technical papers were published in how to provide specialty testing of rotating machines (motors and generators) and their insulation systems. These tests are the ancestors, the great grandfathers, if you will, of more recently introduced test methods, including surge comparison testing, then motor circuit analysis in the 1980's and motor current signature analysis and electrical signature analysis, also in the 1980's. Additional advances in vibration analysis, infrared analysis, ultrasonics, partial discharge, and a great many other tests, along with advances in computer technology and software systems, have all provided us with opportunities today that our predecessors could only dream of.

The electric motor system has not remained stagnant, either. From



1915 Laurentide Co. Re-installing Hydro-Generator Armature



insulation systems made of tar then oil and paper, we have made staggering improvements to electrical insulation systems that have only accelerated over the past four decades, to advanced electronic controls such as variable frequency drives and machine tool systems. Improvements in materials have improved electric motor efficiency while decreasing weight, dimensions and expense to manufacture and purchase.

For all of this technological improvement, the philosophy of *managing* the electric motor system has lagged far behind. It is fascinating to think that we have created, adapted and evolved on the technological side, but have made so little progress in our management skills of overall motor systems programs. Why is this?

Perhaps it is because a great many people see the motor as a mysterious method of converting electrical energy to mechanical torque, and, therefore, view it as a system that either works, or does not. That is, until something in the distribution system, control, motor, coupling or driven equipment stops providing some vital function. Of course, then we see a mad scramble to fix the system – to get the engine of production moving again, at basically any cost. The result has been patched fixes, increased motor system spares inventories, increased downtime, reduced efficiency, wasted money and far more.

In the early 1990's, the US Department of Energy, in collaboration with industry, motor manufacturers and vendors, developed motor management strategies with the focus on improving electrical energy consumption. This was given 'teeth' with the Energy Policy Act of 1992 (EPAct), and was expanded, based upon recommendations of industry, to include the full motor system - from incoming power to driven equipment. Many other companies, in particular, motor repair vendors, developed differing flavors of motor management. The one that I developed, the 'Dreisilker Total Motor System Maintenance and Management Program' (DTM2), in 1993, was one of the first that took responsibility for complete system and manpower issues. In fact, the first site that we concentrated on was a paperboard company with over 26% unplanned downtime. By focusing on just the motor system alone, and using a percentage of the savings to bolster the maintenance budget, we were able to decrease the unplanned downtime to about 6% without a negative impact on profitability! In fact, the program improved throughput, inventory and profitability significantly.

1915 Laurentide Co. Generator Control Conduit Run

The Impact of a Motor Management Program On Business and the Environment

Overall, the implementation of condition-based maintenance programs has a significant, some might say major, impact. The related maintenance costs are reduced by 24 - 30%; associated breakdowns by 70-75%; related downtime by 30-40%; throughput increases by 20-25%; planned maintenance tasks reduced by 33-66%; and man-hour utilization by 40-50%. Through the monitoring of several successful motor system maintenance and management programs, these results can be considered average to conservative.

In addition to the above CBM potential, motor system maintenance and management programs have had the following impacts:

- Troubleshooting and evaluation time improved by over 50%
- Motor repair costs decreased by over 30%
- General motor system related labor reduced by up to 50%; and,
- Motor system related inventory reductions by over 50%.

1915 Laurentide Co. Henry Bulbrook on completed generator overhaul

In general, successfully applying and sustaining a motor system maintenance and management program will have simple paybacks of well under two years from the initial investment, with a majority seeing under one year simple payback.

The United States generated over 3,848 billion kWh of electricity in 2003,, of which approximately 2,270 billion kWh (59%) were consumed by electric motor systems. The application of motor system maintenance and management programs has the potential impact of saving industry an initial $26.5 billion in electrical energy costs while reducing greenhouse gas emissions by over 3,000 Giga-Tons per year, most of which would be directly related to the emissions by power plants of all types. An additional positive impact of these energy savings would be reducing the need for building additional power plants.

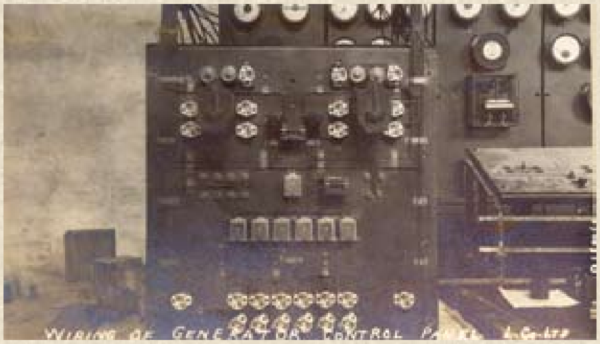
Laurentide Co. Generator Room During 1915 Overhaul

Defining Motor Management

"Modern management practices often do not take into account the importance of motor systems maintenance and management requirements. Through efforts in cost control, many industrial and commercial firms will reduce maintenance staffs, take least cost approaches to corrective actions, and sacrifice preventive maintenance programs. The result has been increased energy costs and downtime resulting from equipment not operating to full potential and failing unexpectedly. The problem results in billions of dollars of additional energy consumption and lost revenue." [2]

As noted in the "Motor Diagnostics and Motor Health Study" (MDMH)[3] , 68% of those surveyed felt that they had a motor management program in place. Of those programs in place, 72% failed and less than half of the remaining programs were considered effective. Of the effective programs, 66% of the program recommendations were ignored. These results mean that overall, 7% of those surveyed had effective motor management programs.

In properly applied programs, over 91% identified immediate returns on investment. These high quality programs were found to be fairly consistent in their outline and implementation. Defining the philosophy of motor management is an issue in and of itself. Many view motor management as energy management, others view it as motor testing, storage, greasing or some other individual function(s). The programs that were formed under these belief systems have been found lacking as they are not long-term strategies. A true motor management program, one that has an overall strategy and holistic philosophy, will have both immediate impact and long term results.



Laurentide Co. Generator Control

The definition of motor management put forward by the Institute for Electrical Motor Diagnostics is: "Motor system maintenance and management is the philosophy of continuous improvement of all aspects of the motor system from incoming power to the driven load. It involves all components of energy, maintenance and reliability from system cradle to grave." [4]

This provides the outline for any true motor management program which is intended to extend the useful life of the motor system combined with continuous improvement of the system. In addition, the focus is where it should be; on a systems approach where the system includes: incoming power and distribution, controls, motor, coupling, load and, process.

The successful motor management program will partner with company departments and outside vendors in covering condition-based maintenance and reliability-centered maintenance, commissioning, repair standards, spare management, condition testing and other strategies. The result is a philosophy that reduces motor system related unplanned downtime in such a way that it is non-intrusive and provides a significant return on investment.

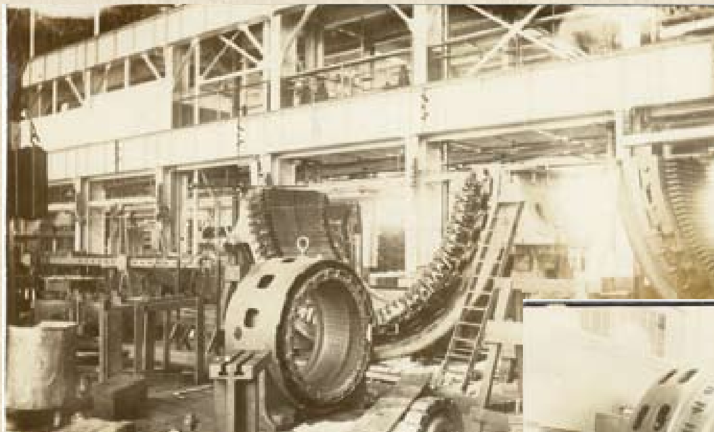
Motor System Management Overview

One of the most common questions in any new program is: Where do I start? My favorite answer is, "From the beginning." In order to start any successful program, you must know what you have and where to focus your energy. The answer to this is quite simple: You must survey your assets in order to determine your areas of responsibility. Then, you must identify critical machines and equipment. There are many different methods of determining criticality. However, typically, criticality is determined from a combination of four basic criteria:

1. Systems that impact safety;
2. Systems that impact regulatory requirements;
3. Systems that impact production; and,
4. Systems that have a high repair or replacement cost. This value averages about $25,000, in the USA.

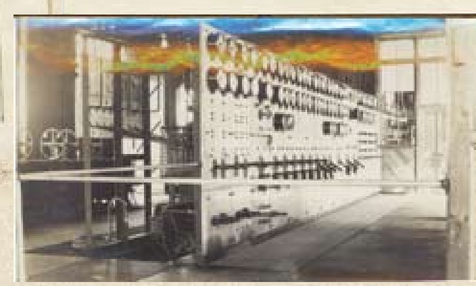
You will also want to include equipment that has a high rate of failure, if your CMMS/EAM

1911 Hydro-Generator Overhaul, Shawenegan Falls, Quebec



Generators, Shawenegan Falls, Quebec

1912 Overhaul Crew, Wellard Canal, Thorold, Ontario.



Wellard Canal Generator Switchgear

and/or equipment histories are accurate.

Once you have selected your critical systems, you will want to concentrate on a reasonable sized pilot area. A great many motor management program failures occur because companies took on far more, initially, than they could handle. The programs would then lose momentum because you can expect to see an average of one in four to one in six systems with issues that should be addressed. By starting with a more manageable grouping, the motor management team can gain experience in setting condemning criteria and prioritizing corrective actions on the systems.

Develop your motor management team. The team should include stakeholders from both within and outside the company, including:

1. System and component vendors;
2. Associated maintenance staff;
3. Maintenance management and senior management;
4. Purchasing;
5. Engineering;
6. Production; and
7. Others with a stake in the operation of the equipment.

Vendors can be an important part of the team. In particular, you will find that some vendors will be willing to take responsibility for associated inventory, on or off-site. This is considered good business as the vendor then has responsibility for the condition of the equipment, right up to use, and they are guaranteed the business. For instance, with the electric motors themselves, there are motor repair and distribution vendors that will alter internal inventory, maintain customer inventory on and off-site and some that will even consign motors to a facility.

By this time, or even before knowing what assets are owned, many companies will purchase, or will have purchased, condition-based monitoring technologies. The most common are vibration analysis, infrared, ultrasonics, insulation resistance, motor circuit analysis, motor current signature analysis, electrical signature analysis, etc. Unfortunately, while good for the instrument vendors, it can end up as 1000's of dollars worth of equipment sitting on storage shelves, or testing being done just for the sake of testing. In reality, the next steps should be *understanding* planned maintenance and condition monitoring needs.

There should be a fairly rigorous overview of the existing planned maintenance program, any existing condition-based testing, motor purchasing and repair specifications (if any) and lubrication program. With a careful eye on planned maintenance, it is possible to reduce unnecessary planned maintenance by 1/3rd, or more, before even adding condi-

tion testing. Then, utilizing a tool such as Reliability-Centered Maintenance (RCM), that meets MIL-P or SAE specifications, review the selected critical systems. This will identify which planned maintenance can be used, eliminated or replaced with condition testing, and which condition testing will provide the best information. You will also find that this process will evaluate the abilities of your CMMS/EAM systems as you gather necessary information, or will help identify those needs, if one does not exist.

Once technology requirements have been identified, and at least rudimentary condemning criteria, through the analysis, you will have enough information to develop a specification for your testing technologies. This can be used as a comparison, along with 'The Multi-Technology Approach to Motor Diagnostics,'[5] to select appropriate test technologies, skills requirements, training and associated requirements. The cost of the technologies is almost always a concern.

Laurentide Co. Generator Room During 1915 Overhaul

However, startup cost should be less of a concern than it usually is. This is because, if properly selected and implemented, most condition testing technologies will have returns on investment measured in days, weeks or months.

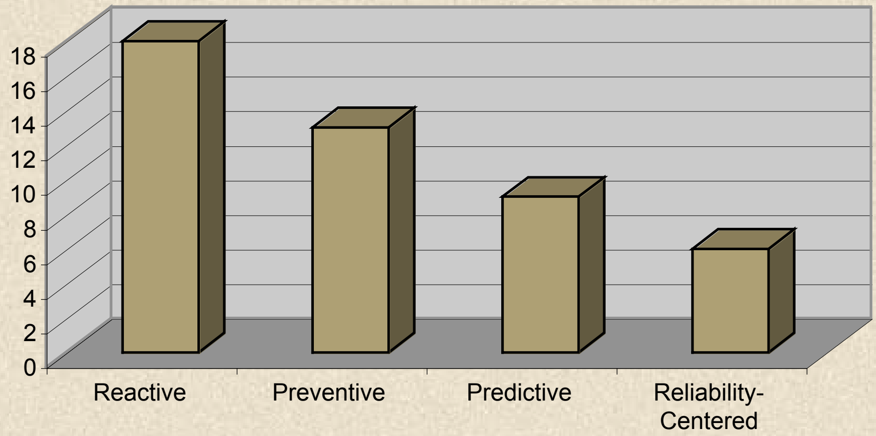
Following the purchasing of equipment, and associated training, baselines must be performed on the selected systems. This will provide both the beginning of trending and a good overview of the general condition of the associated systems.

The next step is the development of specifications for reconditioning, corrective actions and the purchasing of new equipment. It is important to communicate and set the conditions for commissioning new and repaired systems. For instance, if you have selected to perform motor circuit analysis testing on all electric motors that are repaired or purchased, you will want to communicate, in writing, what you will be performing and your acceptance criteria. This will reduce conflict should a motor not pass the commissioning inspection. According to an Electrical Apparatus and Service Association (EASA) study, over 81% of motor repair shops modify the windings of your electric motors through the repair process[6], with most of them performing the change for ease of rewinding and speed.

Implementation of a Root-Cause-Analysis (RCA) program for critical systems and systems that have repetitive failures. This should be a full RCA program that will identify the actual root cause, not just the component that failed. There are several different flavors of RCA programs, select a process that meets the requirements of your process and industry. Ensure that all findings are recorded and shared amongst each facility that has similar systems and in your CMMS/EAM system.

Ensure that scheduled, corrective and proactive maintenance tasks are managed through the CMMS/EAM system. This is critical for the Maintenance Effectiveness Review (MER) process which is the continuous improvement portion of the program. Periodically, systems are to be selected for review and the MER process. Outlined in "Your Maintenance is Effective… Isn't It?"[7] article in the December issue of Uptime, this process reviews the existing program for effectiveness and

Figure 1: Cost Impact of Maintenance $/hp/yr



provides a means for improvements to the program based upon new findings, inspections and technologies.

The Key to Success

One of the key issues to the success of any program is to ensure that it does not suffer from 'Maintenance Entropy.' This is the case when a program has become successful and there are few opportunities that show new short-term simple payback, so resources are cut. Simple payback identified through maintenance is a score of things which are not being done, or completed correctly, in the existing maintenance program. In effect, the maintenance program should be ordered as:

1. Proactive Maintenance
2. Preventive Maintenance
3. Corrective Maintenance
4. Reactive Maintenance

Unfortunately, most companies' maintenance programs are ordered:

1. Reactive Maintenance
2. Corrective Maintenance
3. Preventive Maintenance
4. Rarely: Proactive Maintenance

There is a cost associated with this order of doing maintenance, as shown in Figure 1.

In effect, the implementation of a full motor system maintenance and management program should reduce associated maintenance costs by about 1/3rd.

Conclusion

The implementation of a motor system maintenance and management program will have a significant impact on your company's bottom line, inventory, costs, profitability, energy and uptime. The motor system consists of the power distribution, control, motor, coupling, driven equipment and the process itself. A full program consists of selecting

Laurentide Co. Generator Turbine

critical equipment, putting together a motor management team, setting up a pilot project, a rigorous review of the existing PM program and an RCM analysis, selecting equipment, setting up repair and new equipment specifications, starting an RCA program, ensuring that the associated CMMS/EAM program is being properly utilized and implementing a MER process.

Howard W. Penrose, Ph.D., CMRP, is the President of SUCCESS by DESIGN, a reliability and maintenance services consultant and publisher. He has over 20 years in the reliability and maintenance industry with experience from the shop floor to academia and manufacturing to military. Dr. Penrose is a past Chair of the Chicago Section of the Institute of Electrical and Electronic Engineers, Inc. and is presently the Founding Executive Director of the Institute of Electrical Motor Diagnostics. For more information, or questions, related to this article or SUCCESS by DESIGN services, please contact Dr. Penrose via phone: 860 575-3087 or email: howard@motordoc.net.

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Find Your Hidden Plant at the Reliabilityweb.com Pavilion

Plant Engineering & Maintenance Show
National Manufacturing Week

Rosemont (Chicago), Illinois

March 20-23, 2006

In most manufacturing plants, maintenance is often viewed as a "necessary evil" and a "cost center". Evolving strategies to ensure reliable plant operation by using proactive maintenance techniques and technologies are generally not well understood by company management so most maintenance activities are driven by cost decision which eventually leads to a reactive culture.

Unfortunately, companies that have been driven to reactive maintenance by cost based decisions or inattention to a comprehensive maintenance strategy often end up with a higher overall maintenance cost than competitors who use "best practices" maintenance.

Maintenance has also been largely left out of manufacturing initiatives such as 6 Sigma and Lean, often to the detriment of these programs. Manufacturing managers need to learn that you cannot get "lean" without having equipment reliability.

In early 2001 Reliabilityweb.com approached Reed Exhibition, the National Manufacturing Week organizers with a concept designed to bridge the gap between reliability, maintenance and operations or manufacturing. An agreement was reached that created a special Reliabilityweb.com pavilion on the Manufacturing Week show floor so busy manufacturing executives could quickly learn more about the importance of maintenance to company profits.

Each spring the Reliabilityweb.com pavilion has attracted the most important maintenance and reliability solution providers to Chicago for one of the world's largest manufacturing trade shows.

In 2006, Reliabilityweb.com added an educational track to the mix that begins with a one day pre-conference workshop called the Reliability Game presented by MRG. Whoever said Reliability can't be fun has not experienced the Reliability Game. This workshop effectively demonstrates the financial impact and importance of equipment reliability.

The next three days include sessions by maintenance experts including:

- Best Practices in Maintenance Management by Terry Wireman, Mastering Maintenance.com
- Managing a Successful Maintenance Improvement Project by Dick DeFazio
- The 7 Secrets of Maintenance Excellence by Bob Baldwin, CMRP, Edtron.com
- Keys to Successful EAM/CMMS Software Implementation, A Panel Discussion with Terrence O'Hanlon, Keith Mobley, Robert C. Baldwin, Dick DeFazio and Terry Wireman
- Reliability – Centered Leadership by Terrence O'Hanlon, Publisher, Reliability Magazine
- Achieving Reliability, Integrated Enterprise Asset Management vs. Best of Breed CMMS, A Panel Discussion with Terrence O'Hanlon, Robert C. Baldwin, Keith Mobley, Dick DeFazio and Terry Wireman
- Zero-Breakdown Machine and Production Systems: tools and techniques by Jay Lee, Professor in Advance Manufacturing, NSF Intelligent Maintenance Systems Center, University of Cincinnati

In addition, we suggest that you make a check list of the solutions you can use because over 50 leading maintenance and reliability solution providers are demonstrating new technologies, software, services and training for uncovering the "hidden plant" that is typical in most manufacturing plants. Exhibit passes are available online at no cost at www.manufacturingweek.com.

Reliability Pavilion Exhibitors include:

- Chevron, best known for as one of the most successful oil companies in the world, now offers a full suite of reliability services to help clients achieve competitive advantage in global markets. The full range of products and services will be on display.
- Easy-Laser is demonstrating a line of Laser Alignment instruments designed to ensure reliability rotating equipment operation.
- GE Energy provides equipment reliability and maintenance services.
- Life Cycle Engineering (LCE) is a company specializing in reliability and maintenance solutions with focus in both industrial and government markets.
- Ludeca, Inc., the exclusive distributor and factory authorized service and training center for Prüftechnik AG laser alignment product line and vibration analysis instruments in the United States, Caribbean and Venezuela.
- SPM Instruments will demonstrate a wide range of bearing testers for predictive maintenance
- UE System offers a full line of Ultrasonic leak detectors and bearing monitors

Manufacturing management is invited to stop by the Reliabilityweb.com booth #34039 for a free Reliability Roadmap package that includes:

1. A Best Practices Maintenance Bench marking self assessment form
2. A Reliability Roadmap™ White Paper
3. A Reliability Resources Tutorial CD
4. Many more reliability resources

Expo passes are free so please consider paying us a visit so you can find your hidden plant.

Register online at www.manufacturingweek.com

Seeing IR Windows Clearly

Common Misconceptions

by Martin Robinson

The majority of thermographic cameras are based on digital camera technology and therefore require a direct-line-of-site to record an accurate image. Surveys are hampered by cabinet designs that obscure the target components being imaged and thermographers are put at risk by having to open cabinets or doors in an attempt to gain access to the internal components that they wish to image. Even the most comprehensive risk assessments and method statements cannot avoid the obvious risks involved.

The use of Infrared Inspection ports is becoming more common place, in fact electrical panel manufacturers are now fitting Infrared inspection ports, grills, mesh screens, etc. in an attempt to make their panels infrared friendly.

As an IR inspection port is a permanent fitting in an electrical panel, the thermographer has to give careful consideration to several issues prior to deciding what type of IR Inspection window best suits their individual requirements.

The ideal IR window is one that would allow all the infrared radiation to pass through it with zero losses. Unfortunately, with the materials currently available, we cannot achieve the perfect transmission rate of 100%. We can, however, get very close with some materials (coated Zinc Selenide has a peak IR transmission rate of 99%).

We have to try to keep emittance and reflectance values as low as possible to achieve as high a transmittance value as possible. This is achieved in a number of ways such as coating materials with an anti reflectance coating to reduce reflectance and choosing the correct material for the IR wavelength suitable for your camera. However a high transmission rate is not the most important property of an Infrared window, in fact there are many other issues that can have a very detrimental effect on the results gathered through infrared windows.

Transmission Rates

The graph in Fig 1 demonstrates the transmission rates of the chosen materials and where they fall into the Longwave (LW) and Shortwave (SW) infrared wavelengths. You can see that it is imperative to consider the type of equipment being used, as some materials will be unsuitable for use with a LW camera (Sapphire Al2O3) and SW cameras (Germanium Ge). Some materials are suitable for use with both LW and SW cameras (ZnSe), though these materials tend to be more expensive for that reason.

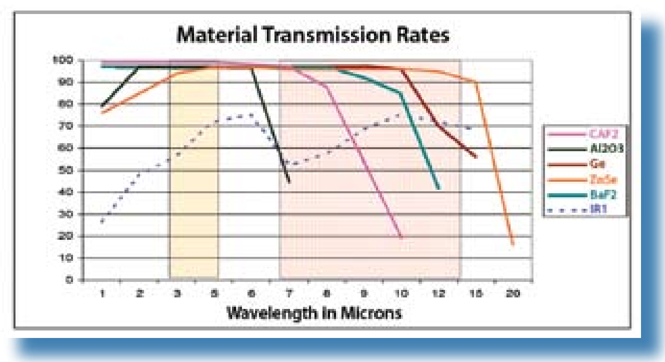


FIG 1 – Transmission Rates of IR Window Materials

Note: When deciding on the transmission rates of IR materials ensure that the supplier quotes against a known wavelength. Our research has shown that in the PdM field the majority of LW thermography is at approx 9 μm and SW is at approx 4 μm. You should ask for the IR transmission at these wavelengths.

The most important thing to remember regarding IR transmission rates is that you must know what the transmission rate and wavelength that your IR window is operating in. It is irrelevant to the measurement whether it is 99% or 50%, as the camera/software will calculate the temperature based on the transmission rate that you put into the calculation. Therefore you must be confident that the transmission rate is correct.

Fig 2 shows how calculated temperature readings change when you vary the transmission rates. The transmission rates were changed from 99% to 50% using the same image. This gave a difference of 11.8 °C. The significant thing to note, other than the temperature difference, is that the calculated temperature increases when the transmission rate decreases. So, if your transmission rate is too high, the calculated temperature is too low! This will cause real problems if you are using temperature as the means of categorizing faults or

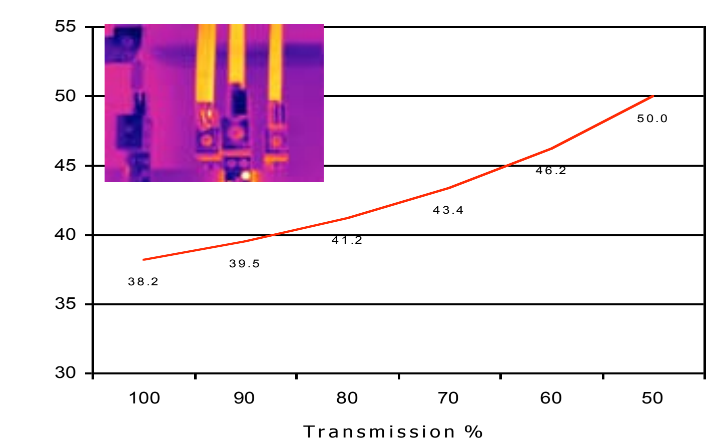


FIG 2 - Transmission vs. Temperature

scheduling maintenance.

Material Mechanical Properties

From Fig 3, you can see that the materials' physical properties vary considerably. Other areas you need to consider are:

Environmental Considerations

Is the window for indoor or outdoor use? Will it be submitted to severe environmental conditions? (UV, rain, snow, sea water, acids or alkalis, extreme temperatures, etc)

Operational Considerations

Some materials are less robust than others, the Knoop hardness number indicate the resistance to local penetration. Rugged materials such as Sapphire (Al2O3) have a high number; fragile materials like Barium Fluoride have a low number. Therefore operators must give serious consideration to the operating environments in which they intend to use IR windows as choosing the wrong material would be a very costly exercise!

Note: Manufacturers place too much importance on providing IR window material with a very high infrared transmittance value. More consideration must be given to the environmental and operational conditions in which the window will be used. You want a window that will be functional for the life of the panel in which it is fitted. Never trade off mechanical properties for higher infrared transmission rates. You don't need them, but you do need a window that will last.

Emissivity or Emittance

The emissivity of an object is the ratio of radiant energy emitted by that object divided by the radiant energy which a blackbody would emit at that same temperature. If the emittance is the same at all wavelengths, the object is called a gray body. Some industrial materials change their emissivity with temperature and sometimes with other variables as well. Emissivity always equals absorption and it also equals 1 minus the sum of reflectance and transmittance (E = A= 1 - T - R).

Electrical cabinets, etc are full of different materials of varying emissivity. They can range from .95 to 0.15 and, as stated, these values can change with age and temperature. Fig 4 shows, as with transmission, how calculated temperatures can be adversely affected if you get them wrong and, as with transmission, if your emissivity is too high the temperature is too low! Therefore it is imperative that the thermographer know the emissivity of the target components within the panel. Another method used by thermographers is to cover or coat all targets with a material of a known emissivity (i.e. electrical tape, barbecue paint, etc)..

Material	Chemical Symbol	Wavelength µm	Reflection (Two Surfaces)	Knoop Hardness	Soluble in H2O
Calcium Fluoride	CaF2	0.13 – 10	5%	158	Yes
Sapphire	Al2O3	0.15-5.5	14%	2000	No
IR Polymer	N/A	0.15 – 22	21%	n/A	No
Germanium	Ge	1.8 – 23	53%	780	No
Zinc Selenide	ZnSe	0.5-22	29%	120	No
Barium Fluoride	BaF2	0.15 – 12.5	7%	82	Yes

FIG 3 - IR Material Properties Comparison

The Coffee Cup Test

Measuring IR Window Transmission With An Infrared Camera

Specialized instrumentation is used to measure the spectral transmittance of IR window materials. However, as the majority of thermographers are unable to access this type of instrumentation, we have to derive methods of using our IR cameras to calculate the approximate transmission rates. I have used this method in the field many times and it has proven to be accurate and reliable. I call it the "coffee cup test".

Method 1: IR camera with external optics transmission compensation:

1. Using electrical tape mark a low emissivity target onto a coffee cup and fill the cup with hot coffee.
2. Set the transmission rate to 0.99 and the emissivity to 0.95.
3. Measure the temperature of the emissivity target on the coffee cup.
4. Place window in front of target.
5. Calculate the IR window transmission by adjusting the camera transmission rate until the temperature reads the same as the temperature without the IR window.
6. Mark transmission rates on IR windows.

Method 2: Using IR camera reporting software:

1. Using electrical tape mark a low emissivity target onto a coffee cup and fill the cup with hot coffee.
2. Set the transmission rate to 0.99 and the emissivity to 0.95.
3. Take an image of the coffee cup measuring the temperature at the emissivity target.
4. Place window in front of target.
5. Take an image of the coffee cup through the IR window measuring the temperature at the emissivity target.
6. Save both images into your reporting software
7. Calculate the IR window transmission by adjusting the transmission rate within the reporting software on the image taken through the IR window until the temperatures read the same as the image without the IR window.
8. Mark transmission rates on IR windows.

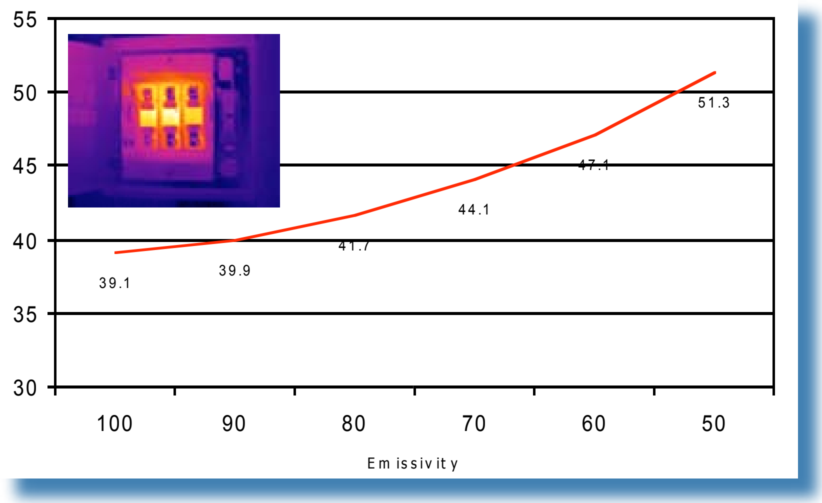


FIG 4 - Emissivity vs. Temperature

Fig 4 illustrates how calculated temperature readings change when you vary the emissivity rates. The emissivity rates were changed from 99% to 50% using the same image. This gave a difference of 12.2 °C

Note: Worse case scenario would be to get the emissivity and the transmission totally wrong. In the example shown in Fig 4, the temperature with emissivity and transmission set to 0.95 is 39.1 °C. If you now change both the emissivity and transmission settings to 0.50 the calculated temperature now changes to 73.6 °C, an increase of 34.5 °C - almost twice the original apparent temperature. Again, just as with transmission, this will cause real problems if you are using temperature as the means of categorizing repairs or scheduling maintenance.

Positioning Your IR Windows

Once you have decided on the viewing material that best suits your requirements and operating environment, the next step is to decide where you want to position your IR windows. The thermographer must first identify the target components that he wishes to measure during his inspection program. Once this has been completed the following areas will need investigating prior to finalizing the IR window specifications:

Field of View

The window diameter needed is a function of the lens field of view and the distance from the window to the component in which the thermographer needs to see. Traditionally, the total field of view is calculated by multiplying two times the distance by the tangent of one half the angle.

The calculations from Fig 5 show that, using an 82° FOV lens in a fixed plain, up to 8.41 square feet can be seen inside the panel. However, during an inspection a thermographer does not hold a camera at a fixed angle, and can manipulate a camera to various angles while looking through an IR window. This substantially increases the field of view. We recommend that the camera angle of incidence where possible never exceeds 30 degrees from a perpendicular target, which equates to increasing the FOV by up to approx 3 times. (We recommend that if you need to work to extreme angles, you should consider using wider angled lenses if possible.)

Fig 6 shows how the FOV is increased by multiplying the calculated FOV figure by up to 3 times.

Although these figures may look impressive, the operator must be aware that it is impractical to use a multiplication factor in excess of 3, as correlating the images to their actual positions within the panels can cause problems and give poor results due to extreme angles, internal obstructions, etc. It is therefore advised that a maximum multiplication factor of 2 is used to maintain the image integrity and identifying any fault locations.

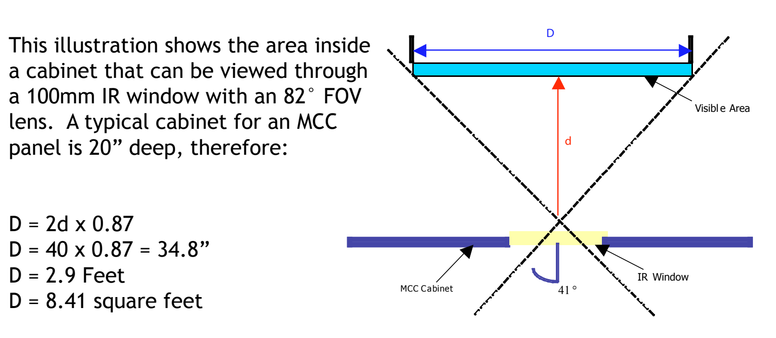


FIG 5 - Standard Field of View calculation with fixed viewing angle

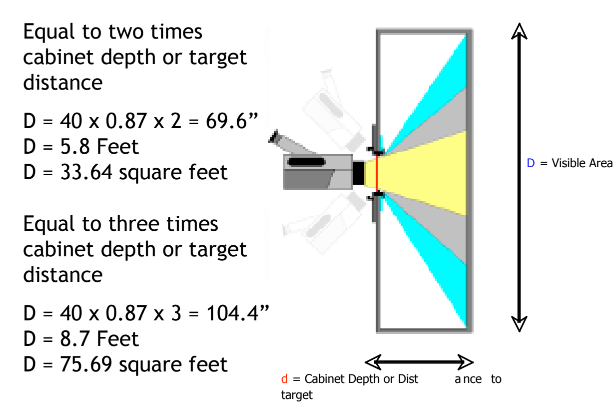


FIG 6 - Standard Field of View calculation with no fixed viewing angle

Dielectric Clearances

A very important area of concern is the maximum safe distance between the IR window and any live components; this is called the “dielectric clearance”. The recommended minimum dielectric clearance is as follows:

5 Kv Equipment no less than 4 inches!!
15 Kv Equipment no less than 6 inches !!

It must be noted that under no circumstances can the minimum clearances be compromised.

Pressure Ratings

The operator must be aware of any IP ratings within the panels in the scope of the scheme; under no circumstances must a panel’s integrity be compromised. If the panel is an IP rated panel then the chosen IR window must match that IP rating (preferably better), otherwise issues with safety and warranties may arise.

Certifications

If the panel that you intend to fit the IR window into carries any certification marks then, where reasonably practicable, these should not be breached in any way. In the case of a panel with UL certification, you should only consider using UL recognized components; a question that is regularly asked is how does field installation of IR windows affect the UL status of the panel?

- The component (in this case, IR window) can be field or factory installed. The issue is the listing of the product in the field to which it is installed. Installing this product in the field does not negate the listing mark. Customers often modify assemblies that are UL listed and marked. Any modification done in the field is not covered by an existing UL mark. Therefore, UL is not responsible for the certification of these listings.
- When changes are made to listed assemblies that affect the rating of the equipment, UL will do a field inspection of the modified product to re-certify the equipment, ensuring it meets UL requirements. A customer may request this to be done. The IR window would have to be added to the UL procedure for that piece of equipment. If it is not covered in the UL procedure then UL could not re-certify.
- In cases where the IR window is not part of a product's UL listing, there is another option, the field evaluation by UL. Since the IR window is a UL recognized component, UL should be able to provide a UL mark that would verify the modified product had been evaluated. However, this would probably not be required in most cases.

IR Window Design

The thermographer now has all the information that he requires and is now left with one final decision to make. That is the design or type of IR window that he intends to use. An IR window sounds more complicated than it really is. Although there are several types of windows available, there is nothing stopping the thermographer from designing a window for use in any particular inspection that he may wish to complete. An IR viewing window is basically an optical crystal and a holder. There are innumerable optics manufacturers available to the thermographer and most optics companies will be able to advise on the best crystal to use for the particular task at hand.

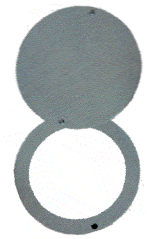
You may decide not to use a crystal, if the component that you are interested in is some distance from the cover and a protective grill can be used in place of the crystal. However, you must ensure that the grill is IP2X certified, that is that the grill size must offer protection against foreign objects with diameters larger than 12mm. This method can significantly reduce the capital expenditure required and has the additional benefits of allowing ultra sound inspections of the electrical switchgear as well as thermographic inspections.

Now it's time to decide upon the optics holder design. The field of view, equipment lens and window size are all functions of the design and must meet all the required parameters before the holder is manufactured. You should also include a protective cover in the design as crystals are very expensive and in some cases extremely fragile. Be aware that when adopting this approach the IR window is not tested or certified (as discussed in certifications) to any recognized standard and local approval must be gained to certify their use.

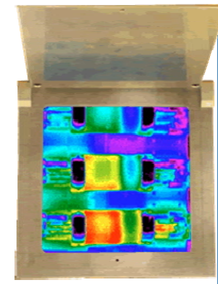
If you decide not to involve yourself in this process there are a number of manufacturers who sell tested and certified IR windows

Round Plastic
Fixed Optics

Round Plastic
Grill



Round Aluminum
Fixed Optics



Square Aluminum
Fixed Optics

Fig 7 - Samples of IR viewing ports.

and will be able to advise you on the best IR window to suit your particular application and specifications.

Fitting an IR Window

Before fitting IR windows into any component it is important that the thermographer ensures that all local electrical enclosure construction regulations and health and safety regulations are strictly adhered to and not breached in any way.

The following points must be strictly adhered to when fitting an IR window:

1. The IR window must be installed and serviced only by qualified electrical personnel.
2. Disconnect the power source before working on or inside the equipment.
3. Always use a properly rated sensing device to confirm that all power is off
4. Once the IR window is fitted, replace all doors and covers before turning on power to the equipment

REMEMBER FAILURE TO COMPLY WITH THESE INSTRUCTIONS WILL RESULT IN DEATH OR SERIOUS INJURY.

Fitting IR windows will disrupt the day to day operations of a company so be sure to schedule their installation during scheduled shutdowns.

Using IR Windows

An important thing to remember when using IR windows is to identify the window with a unique number. This will be invaluable, especially when you have multiple windows on electrical panels, etc. It is also advisable to identify the type and wavelength of the crystal.

The most essential data to record is the transmission rate of the crystal and also the emissivity of the component or components that you are measuring through the IR window. The most effective way of using IR windows is to, where possible, prepare all components that are inspected with electrical tape or paint so they have the same emissivity. This way all components being inspected will have the same transmission rate and emissivity readings, consequently the results gathered will be more accurate.

It should be noted that there may be multiple targets through the IR window. These need to be recorded on the ID label. The most common method of locating the targets required is by using the clock face method, (i.e. Bus Bar connections at 4 O'clock, etc).. This data can all be placed on labels, examples of which are shown in FIG 8.

Alternatives To IR Windows

The reason that we as thermographers want to use IR windows have been discussed in this paper, however there will be times when we will not be able to implement their use, and need to look at some other methods to facilitate a direct temperature measurement.

Screens and modified panel designs

Some panel manufacturers have thought of this and included diamond lite covers. These are covers that have a series of holes drilled or punched into the cover, allowing the thermographers to see the components inside the panel to take direct temperature measurements. This is better than taking indirect temperatures from the covers. Though you can detect high temperatures, the main drawback with this type of panel is that it is very difficult to identify precisely where the high temperatures are.

Specialist Lens Alternative

There are also special lenses available that allow for images to be taken through a small hole drilled into the panel. The end of the

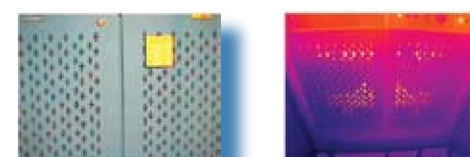


FIG 9 - Transformer Covers

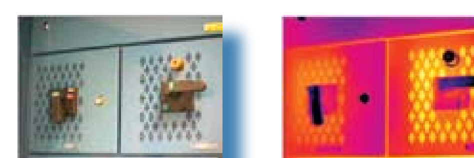


FIG 10 - Panel Isolator Switches

lens has a small diameter (approx 16mm) and a wide FOV, the featured example "Spyglass" has a 53°H x 40°V (66° Diagonal) FOV and a focus range of 4" to 45". This allows for components to be easily seen and does not have a detrimental effect on the structural integrity of the panel being inspected.

Summary

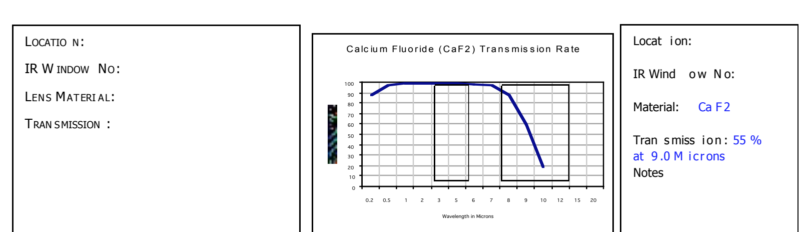


FIG 8 - Samples of IR window ID labels

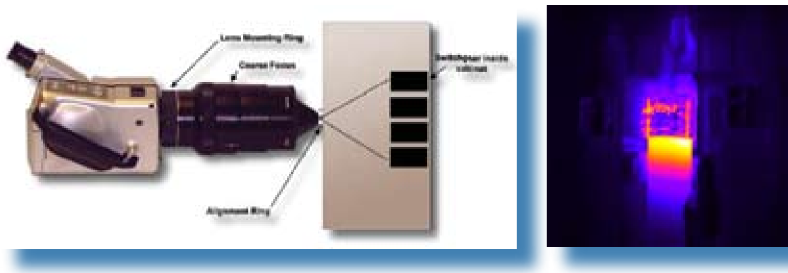


FIG 11 - Spyglass Lens (photo courtesy of Mikron)

To a thermographer there are many benefits to using IR windows. Direct temperature readings will always be the preferred medium for gathering information, especially on critical plant machinery. IR windows are an asset to any inspection program and remove the necessity of:

- Complex risk assessments and method statements prior to an "open panel" inspection.
- Opening panels and exposing manpower to potentially hazardous live components.
- Permits to isolate and shutdown panels.
- Restarting plant after shutdown.

The additional benefits of using IR windows are:

- Improved thermographic survey results, as they are direct temperature measurements.
- Improved plant reliability.
- Safer working environment for thermographers.
- Reduces the amount of time and costs involved in a thermographic survey, as no shutdowns are required.

IR windows make our work safer, faster and more accurate, but only when installed and used correctly. If careful consideration is not given to the issues discussed in this paper the inspection port will give inaccurate results leading to poor diagnosis, thus negating the reason for fitting them in the first place.

Martin Robinson is the sole owner of G M Technologies. He is the designer and manufacturer of the IRISS Infrared Window System and thermographer accessories. Martin is an advisor to several large switchgear companies on IR windows.

He is a member of the British Institute of Non Destructive Testing (BINDT) thermograph work group, currently involved in establishing the ISO training standards for thermographers in the UK. Martin is a level 2 Vibration analyst and a level 3 thermographer.

Prior to opening G M Tech, Martin was in the Army for 16 years. He then worked for the Ford Motor Company as a diesel engineer on their prototype engines supporting component suppliers all over the world. It was during this time that he was first introduced to IR - on Exhaust catalysts and manifolds, He used it in all of his R&D projects and was hooked!

Martin lives with in Chelmsford, UK, where he is happily married. He and his wife Debbie are the proud parents of eight children.

Keeping It Clean

Contamination Control in Hydraulic and Lubricating Systems

by Leonard E. Bensch, Ph.D., P.E.

Contamination in hydraulic and lubricating system fluids is generally recognized as the single most important factor in reducing the reliability and longevity of equipment. The sensitivity of a component to particulate contamination is dependent to a large extent on the lubricant film thickness and the size and quantity of contaminants in the fluid. Any decrease in reliability because of fluid contamination has a major impact on maintenance costs as well as machine productivity. In order to increase system reliability, a program should be established for cleanliness control. In this article I hope to provide you with a fundamental understanding of contamination control principles, starting with particulate contamination, including common methods of measuring and reporting contamination levels. I will discuss typical damage caused by contamination as well as benefits achieved by controlling contamination to desired levels. Finally, I'll provide guidelines for determining cleanliness requirements, filter selection, and filter location.
Oil contamination poses a serious threat to the performance and reliability of hydraulic and lubricated systems. Failures of hydraulic and lubricated components or systems are, more often than not, related to an excessive amount of contamination. Tribological failures of machinery cost industry billions of dollars per year, but they can easily be minimized. This offers the prospect of achieving real savings and, at the same time, improving the efficiency of the operation and the service provided. Numerous studies have been conducted over the years to quantify the impact of contamination on component life and reliability [References 1-4, see page 48 for all references]. These studies report that 50% to 80% of failures and wear problems in lubricated machines are caused by oil contamination. These findings tell us - without a doubt - that there is still an enormous amount of improvement to be made in this area. They also tell us that facilities operating today can cut maintenance costs dramatically, and improve production output significantly, by correctly applying proven contamination control techniques.

In order to increase reliability of hydraulic systems, a program should be established for cleanliness control [References 5-6]. A total cleanliness control program involves good machine design to minimize contamination sensitivity and exclude built-in and ingressed contaminants, proper filter selection to maintain the operating cleanliness, and good practices to ensure minimal contamination is introduced or remains after maintenance is performed. Also important is setting cleanliness targets and monitoring to ensure the cleanliness is being maintained at the desired level.

Contamination In Lubricated Systems

Contamination in hydraulic and lubrication systems can be particulate in nature such as silica (sand), metals, fibers, participates, etc. Particulate contamination, because of its severe impact on component wear and fatigue, is the primary focus of this article and is discussed in detail. Other fluid properties, which affect system operation and reliability, include viscosity, additive and acid levels, and water contamination. Heat, moisture and catalytic metal wear particles all contribute to fluid degradation. Any good contamination control and fluid-monitoring program should include periodic evaluation of these other fluid properties.

There are four primary sources of particulate contamination in hydraulic and lubricating systems. Built-in contaminants come from components, fluids, hoses, reservoirs, etc. Generated contaminants result from assembly of systems, break-in and operation of a system, and fluid breakdown. External ingressed contaminants enter a system through reservoir breathers, cylinder rod seals, and valve and bearing seals. Maintenance related contaminants are introduced when equipment is disassembled or assembled and make-up oil is added.

Effective flushing, on-board filtration and conscientious maintenance practices will slow ingression of contaminants from built-in, generated, and maintenance related sources. Effective reservoir breathers and external component seals are a must for controlling external ingression.

Measuring Particulate Contamination

The particulate contamination level of a fluid can be measured by a number of methods. Table 1 lists several methods of monitoring contamination as well as some of the benefits and limitations of each method. Probably the first method used to assess particulate contamination in a fluid was to simply look at the oil with the naked eye and make a qualitative judgment about the cleanliness. Using a vacuum to draw down a quantity of fluid through a filter patch was a significant advance because this allowed the contaminant particles to be separated from the oil and examined for quantity and type. This technique, commonly called the patch test can be performed quickly and on site and is still a popular method to obtain a qualitative estimate of the contamination level.

The first method to quantify the size and number of particles in a lubricant extended the patch test by applying a microscope to actually size and count the particles. The microscope method, ISO 4407, [7] has been improved over the years, sometimes with the addition of automated computer image analysis, but the basic principles are still the same. Microscopic counting is still required when actual particle counts are needed on non-homogeneous fluids such as water contaminated oil or fluid with free air bubbles present.

Automatic optical particle counters, first developed for hydraulic fluids in the late 1960's, are now the most common method to quantify the amount of particulate contamination in hydraulic and lubricating fluids. These devices, when properly calibrated, per ISO 11171 [8] and ISO 11943 [9] will give a fast, accurate and repeatable assessment of the size and number of particles as well as applicable contamination codes such as ISO 4406 [10], or others. Modern automatic counters are portable, battery operated, and can easily be used in the field either for on-line analysis or if necessary, a bottle sample.

The mesh obscuration monitor, although not a particle counter, is also able to measure relative contamination codes with good accuracy. These monitors are based on the principle that particles larger than a specific mesh pore size, when captured by that mesh, will result in an increased differential pressure (or reduced flow) proportional to the number of particles captured.

Method	Units	Benefits	Limitations
Patch test and fluid contamination comparator	Visual comparison or cleanliness code estimate	Rapid analysis of system field cleanliness levels; also helps to identify types of contaminants	Provides approximate contamination levels; not quantitative
Microscopic particle count	Particles/mL	Provides accurate size and quantity distribution	Long sample preparation time
Automatic particle count (on-line or bottle)	Particles/mL	Fast, accurate, repeatable	Sensitive to non-particulate contaminants, e.g. water and air
Mesh obscuration monitor (bottle or on-line)	Contamination code	Fast, repeatable, OK with water and air contamination in oil	No particle counts

Table 1 - Primary Fluid Particulate Contamination Analysis Methods

Units that use multiple mesh sizes are able to measure the contamination at and above these sizes and report a cleanliness code accordingly. Because these units use no optics, they are insensitive to non-particulate contamination, e.g., water and air, and can be applied in most instances. Like the modern portable particle counters, they can be transported and used in the field for on-line or bottle analysis.

Although spectrometry, ferrography and gravimetric analysis methods are sometimes used, they are used less frequently for particulate contaminant measurement than the other methods discussed.

Damage Caused By Contamination

Nearly all studies found in the literature, for example, references 1-4, conclude that most problems in hydraulic and lubrication systems are caused by contamination and mechanical wear. There are four primary types of mechanical wear mechanisms: abrasion, erosion, fatigue, and adhesion. Abrasive wear occurs when particles enter a clearance space between two sliding surfaces separated by a lubricant film, as shown in Figure 1. Contaminant particles at or above the size of this clearance space can cut, rub or scrape one or both surfaces. The particles may become embedded in one surface, and act as cutting tools, scraping away material from the opposing surface. The wearing away of one or both surfaces results in sloppy fits, increased internal or external leakage, reduced operating efficiencies, higher temperatures, and of course, more contamination from the wear particles.

Erosion occurs when hard particles carried by the lubricant at high velocities impact onto a component surface. The momentum of the particle translates into a force at impact that can erode away the component surface. The result is similar to abrasive wear and results in increased internal leakage, lower efficiencies, and more contamination. Erosion can be found in hydraulic components such as pressure control or servo valves, where the fluid velocity is high when passing through a control orifice.

Fatigue wear of rolling contact surfaces is initiated when particles the same size or larger than the dynamic lubricant film thickness enter the load zone of anti-fric-

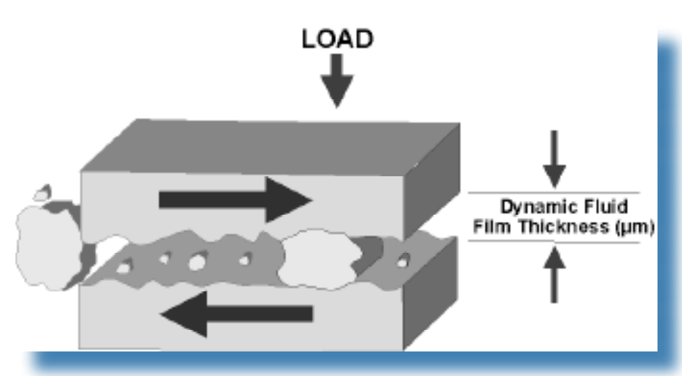


Figure 1 - Abrasive wear

tion bearings. These particles momentarily bridge the lubricant film gap and create small dents and micro-cracks on the rolling surface. Under repeated loadings, the micro-cracks grow until they undermine the surface, eventually causing spalling and fatigue failures.

Adhesive wear is metal-to-metal contact between two moving component surfaces. Particles contribute to adhesive wear when they roughen surfaces through abrasive or fatigue wear, forming surface asperities that extend through the lubricant film thickness. Of course, particles generated due to adhesive wear become contaminant particles, which if left unchecked, can cause subsequent abrasive or fatigue wear.

Effectively Controlling Contamination

An effective contamination control program starts at the system design stage. This is when components are selected for their insensitivity to contamination where possible, reservoir breathers and component seals are selected to control contaminant ingression, and a filtration system is selected, ideally to provide control of fluid contaminants larger that critical clearance spaces. Dynamic clearances of a wide range of components are shown in Table 2, adapted from reference 11. A good flushing program on newly built equipment is also critical to prevent early damage due to built-in contaminants.

Component	Clearance
Servo Valve	1 - 4 µm
Proportional Valve	1 - 6 µm
Directional Valve	2 - 8 µm
Piston Pump	
Piston to Bore	5 - 40 µm
Valve Plate to Cylinder	0.5 – 5 µm
Gear Pump	
Tooth to Side Plate	0.5 - 5 µm
Tooth Tip to Case	0.5 - 5 µm
Roller Bearings	0.4 - 1 µm
Ball Bearings	0.1 - 0.7 µm
Journal Bearings	0.5 - 25 µm
Gears	0.1 - 1 µm
Dynamic Seal	0.05 – 0.5 µm

Table 2 - Typical Dynamic Operating Clearances

A total cleanliness control program also includes the establishment of operating cleanliness targets and monitoring to ensure the cleanliness is being maintained at the desired level. A target contamination level can be established by consulting with component suppliers or based on established recommendations from individual studies or standards. References cited earlier as well as, Ref 12-17, can be consulted for cleanliness level guidance. One of the more modern and more comprehensive industrial standards addressing the establishment of target contamination levels is BFPA P5 [Ref 18]. This standard establishes weighting factors based on the sensitivity and criticality of the components and system. Taken into account are the operating pressure and duty cycle, the type of components, life expectancy, economic and safety liabilities, and operating environment. Based on a combination of these weighting factors, a target cleanliness level is recommended. Knowing the desired maximum contamination level and operating conditions allows the filter supplier to make more intelligent recommendations on the proper filtration system and filter locations for contamination control.

The final stage of an effective contamination control program involves monitoring the operating fluids to ensure the cleanliness is being maintained at or below the desired level [Ref 19]. Such a monitoring program includes either in-line continuous monitoring, or regular sampling and sample analysis by means of portable on-line analysis equipment, or through the use of in-house or contract laboratories.

Conclusions

The application of total cleanliness control and a proactive cleanliness monitoring program to hydraulic and lube systems offers the prospect of maximizing their useful life and reliability and hence realizing substantial savings in total operating costs. A comprehensive total cleanliness control program includes several aspects:

1. Establish a target cleanliness level for system operation. The BFPA guidelines are recommended.
2. Determine the proper filter and other contamination control techniques that will achieve the target cleanliness. Consult BFPA/P5 or your filter supplier for guidance.
3. Establish how the system fluid is to be monitored. The use of an on-line automatic particle counter or mesh obscuration monitor is recommended.
4. Set action levels and corrective action plans to occur whenever cleanliness targets are exceeded; then conduct periodic reviews of the cleanliness-monitoring program and make necessary adjustments as experience is gained.

Historically, fluid contamination has been the major cause of component and system failure. Today, contamination control is much more a science than several years ago. Through proper implementation of a total cleanliness control program, supplemented by a proactive monitoring program, the goal should be to reduce or eliminate contaminated related failures. With the state of the art technology available today, there is no reason to continue to allow dirt to be the major machine life limiter.

Dr. Leonard Bensch is Pall Corporation Vice President responsible for global fluid power applications. He has had numerous roles within Pall for over 26 years, always engaged in the area of contamination control. He received his degrees in mechanical engineering from Oklahoma State University, where he conducted and led research projects for 12 years in hydraulic filtration and contamination control and was instrumental in the development of most modern hydraulic filter test methods and contamination analysis techniques. He has authored over 120 technical papers in the area of fluid power filtration and contamination control. He participates actively on industrial technical committees, is chairman of the USA Technical Advisory Group to ISO for contamination control and convener of the ISO filtration test methods working group. He serves as liaison to the Board of Directors of the National Fluid Power Association.

Electrical Troubleshooting

Getting Back to the Basics

by Peter Bechard

A boiler feed pump being powered by two 3500 HP induction motors appears to be developing a problem. Failure of this pump will result in the loss of a generator currently producing half of the station's power output. Operators are complaining that a large compressor on several occasions has failed to start. A controller just doesn't sound the way it used to. A cooling fan has developed an audible "beat" sound during operation. One of the most enjoyable aspects of working as an electrician is taking such compelling evidence as "appears to be developing a problem," determining what is actually going on, and making a sound decision on the correct course of action. Successfully troubleshooting a complex piece of equipment gives a technician a tremendous sense of satisfaction. If you like that feeling of satisfaction, and would like to experience it more, having an effective troubleshooting plan, and following it, is your best bet.

The following is a short discussion concerning basic electrical troubleshooting. It is a broad overview of what has proven to be a simple, but effective, method of investigating an electrical problem. Use this seven-step process to get yourself organized when presented with a complex problem.

Seven-step process

1. Gathering information
2. Understanding the malfunction
3. Identifying which parameters need to be evaluated
4. Identifying the source of the problem
5. Correcting/Repairing the component
6. Verifying the repair
7. Performing root cause analysis

1. Gathering information is a logical first step in any troubleshooting endeavor. The saying "look before you leap" always holds true.

Therefore, ask yourself about or perform the following: What technical documentation about the equipment is available? How exactly is the equipment supposed to operate? Are there any previous lessons learned? Review any material history that exists for the equipment. Identify similar equipment to which you can compare the malfunctioning equipment. This can be especially helpful if there is limited technical data available for the equipment that is malfunctioning.

Let's apply step 1 to the boiler feed pump example.

For a high cost repair, like a boiler feed pump, the importance of answering or performing as many of the above listed items before considering a repair activity is vital. Applying the first step resulted in a review of the equipment's current signature analysis (CSA) and vibration analysis material history. During this review it was noted that the amplitude of the pol pass frequency in the CSA had increased for of both of the motors powering the pump. However, vibration analysis did not indicate any possible problems, either mechanical or electrical.

Now that you have identified technical resources and equipment operation, you are in a position to understand the malfunction.

2. Understanding the malfunction means that you understand how or what the process is and what portion of the process is operating incorrectly.

Answer these questions:

How is the process supposed to work? What is not functioning as it should? What would cause these results or malfunction?

Applying step 2, the boiler feed pumps in question have not been reported by operations to have a problem but the field technicians, through the use of predictive tools, have trended a possible anomaly. Rotor defects, bearing misalignment, magnetic offset, or abnormal load fluctuations were determined to be possible causes of the pole pass frequency trending upward.

3. Identifying which parameters need to be evaluated requires the clear understanding of the discrepancy and which signals affect the suspected component. Which input signals control the component? What is the expected output from the suspect circuit? Is there a timing delay, sequence, or set point that can be verified? Identify the parameters that need to be recorded which could either confirm or refute your suspicions regarding the problem.

Identify the following:

What parameters can you measure? What are the expected values for any measurements that are to be taken? What test equipment is needed? Is there access for the required readings? Is there an alternative method to gather the required readings? Could other components have been affected by this fault?

For step 3, gaining access to the high voltage cables supplying the boiler feed pump motors would prove to be difficult. However, testing from the current and pote transformers (CT's and PT's) offers an easy alternative method in gathering the required voltage and current signals to assist in troubleshooting (see Fig 1).

Fig 1 - Using an MCEMAX to Test a High Voltage Meter

Having performed these first three steps -- gathering information, understanding the malfunction, and identifying which parameters need evaluation - it is now time to perform the required measurements and observations to identify the faulty component. Ensure that all required safety procedures are adhered to while performing any test.

4. Identifying the source of the problem requires the technician to:

- Isolate components and evaluate circuit parameters.
- Isolate the circuit by group when dealing with a complicated circuit (half step approach)
- Identify the malfunctioning component using the recorded data

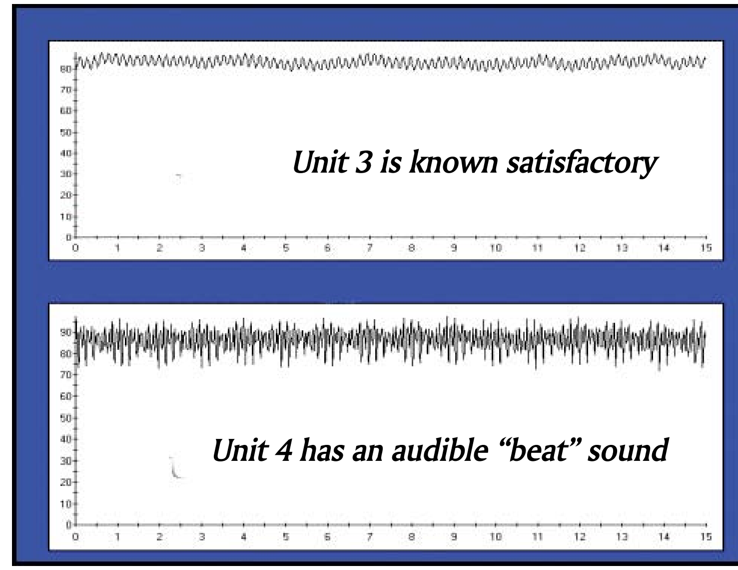


Fig 2: RMS Current Captures

One test recommended in confirming a possible anomaly and establishing a severity is a current profile comparison between two like machines. This is sometimes referred to as a process analysis test. Figure 2 shows current samples from two identical machines. The MCEMAX In-Rush/Start-Up test is a capture of a single channel of RMS enveloped current for up to 60 seconds. The test has a sampling rate of 3600 samples per second and produces a digital strip chart of RMS current.

In this example there is a considerable difference between the unit 3 and 4 motors. With this limited information, a technician would at least have strong evidence that further investigation and possible action of the unit 4 motor is necessary.

The current modulations seen in Figure 2 will create torque variations and possible degradation of electrical and mechanical components if left alone. Step 4 calls for more detailed analysis of the data available to isolate the source of the problem. To provide further analysis from the current spectrum PdMA has developed Advanced Spectral Analysis (ASA). ASA utilizes current demodulation to identify and separate each of the specific frequencies that are modulating the current. By correlating these frequencies to the electrical and mechanical components of the motor pump assembly, the technician can determine which component is creating the largest impact.

An example of ASA current demodulation is shown in Figure 3. The demodulation process removes the 60 Hz frequency component from the captured current signal. Removing the 60 Hz component of the current sample allows repetitive torque variations developed by mechanical items such as belts and gears, which were previously lost in the signal-to-noise ratio of the spectrum, to be identified. These mechanical frequencies are transmitted to the current signature via the air gap flux of the motor during operation.

Applying step 4 to the boiler feed pumps,

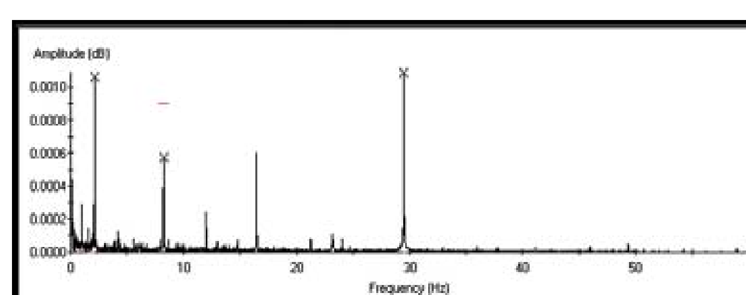


Fig 3 - ASA Demodulated Current Signal Spectrum

Figures 4 and 5 show the demodulated current spectrums from one of the motors taken approximately 1 year apart. The pole pass frequency (F_p) has been isolated for evaluation of the change in amplitude over time. The other motor had similar results. It was the increase in the F_p amplitude that raised concern over the condition of the equipment. Additional testing was performed with particular attention to evaluating the condition of the motor's rotor. It was determined after gathering additional vibration, motor circuit analysis, and current signature data that the equipment needed to be removed from service for repairs. What made this decision especially difficult was that the vibration data was inconclusive. Of several surveys taken on the equipment at different times, only one showed any signs of increased vibration levels.

Armed with data, you can now determine what needs to be done with the suspect component. Many times after the first round of troubleshooting, the first three steps may need to be repeated; however, now you have additional data to work with.

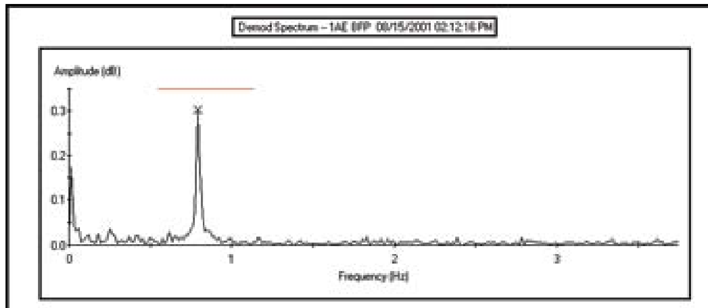


Fig 4 - ASA Demodulated Current Signal Spectrum

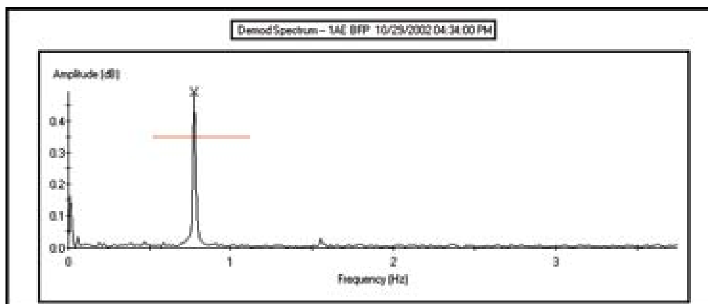


Fig 5 - ASA Demodulated Current Signal Spectrum

5. Correcting/Repairing the component identified as damaged based on the recorded data. Perform the required repairs to the circuit. Completing step 5 can range from simple adjustments to a complete component replacement.

For the boiler feed pumps, when inspecting the two motors, the technicians found that one motor had bent/damaged rotor bars. The damage to the rotor was no surprise due to the elevated pole pass frequency indications during the current signature analysis. But, why only one of the rotors when both of the motors had elevated values?

Technicians felt that since both motors were mounted to a common shaft, it would not be unusual for the elevated pole pass frequency of one motor to be transmitted through the shaft to the other.

In addition to the rotor bar degradation, technicians discovered severe damage to the load end bearings of each motor. The arrow in Figure 6 shows the damaged area of the bearing shell. During initial installation, the magnetic center was not properly set for one, or possibly both of the motors, which led to axial thrusting of the drive shaft, causing the bearing damage. Technicians conducted inspections of similar boiler feed pump installations to ensure that both motors were properly aligned with regard to magnetic center.

6. Verifying the repair after completion. Ensure the equipment is operating as designed. Perform another round of testing to verify the equipment is in fact running correctly and that no other discrepancies exist.

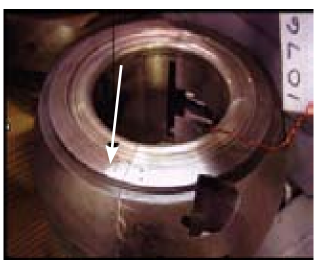


Fig 6 - Damaged Bearing

Following the repair and installation of the boiler feed pump motors, or the installation of replacement motors, retest to ensure the installation will not result in the same failure mechanism in the future. Looking at another example, in Figure 7 an MCEMAX was used to identify a high resistance joint in the connection box of a 460v AC induction motor. The motor lugs were replaced and re-taped resulting in a 3% reduction in resistive imbalance and a cleared alarm.

7. Performing root cause analysis, even though mentioned last, began in the first step of the troubleshooting process. You should use the knowledge gained throughout the troubleshooting process in determining what could have possibly caused the component to fail. Did the component fail prematurely? Why are the motor windings failing after only four years of service? These are just a few of the questions that may come to light when evaluating the whole repair process. Without identifying the possible cause that led to the failure, the repair will always be only temporary. While working through the troubleshooting process, ask yourself, "Is this the root cause or just a symptom of the problem?"

Fig 7 - High Resistance Connection and Test Results

Test Date	7/13/1998	7/16/1998
Test ID	1651	1685
Voltage	500	500
Motor Temp	28	35
Measured M ohm	>2000	1100.0
Corrected M ohm	OVR	780.0
pF Ph 1 to Gnd	34250	34500
ohm Ph 1 to 2	0.07700	0.07500
ohm Ph 1 to 3	0.07700	0.07450
ohm Ph 2 to 3	0.07300	0.07500
m H Ph 1 to 2	1.590	1.590
m H Ph 1 to 3	1.580	1.585
m H Ph 2 to 3	1.585	1.595
% Res. Imbalance	3.52	0.45
% Ind. Imbalance	0.32	0.31
$ Power Loss	63.23	7.90
Condition Code		Good

When attempting to determine the cause of increased motor running temperature, a technician recorded the RMS current to the motor. The process powered by the motor involves constantly changing speeds and loads, shown in Figure 8. With the MCEMAX In-Rush/Start-Up current capture providing a graph of current throughout the repetitive cycle; it was readily apparent why the motor temperature was running so high. The level horizontal line indicates nameplate full load current.

Using this data, the technicians determined that the motor was undersized for the varying load it was driving. Repairing the heat-damaged motor would not have been a permanent solution to the problem. Installing a motor only slightly larger than the original resulted in an installation where motor operating temperature is well within the temperature ratings of its insulation system.

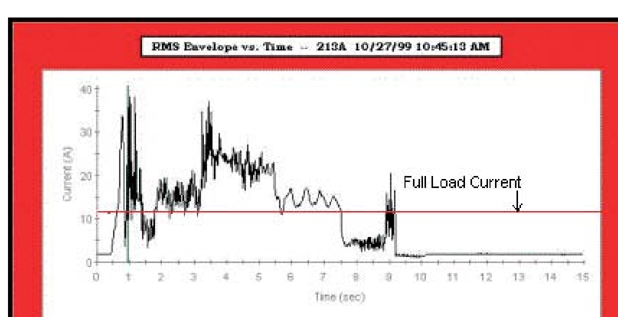


Fig 8: Graph of RMS Current

Summary

By following a well thought-out systematic process when challenged with an electrical troubleshooting problem, you will greatly enhance your effectiveness. Invest a little time up front doing your research and determining your troubleshooting plan of action. A benefit of newer test equipment packages, which combine multiple testing technologies in one unit, is how much they increase the flexibility and capability of a technician's troubleshooting toolbox.

Inventory your test equipment and determine what you have available when the opportunity to use the seven step troubleshooting process presents itself.

Peter Bechard, PdMA Corporation, is a native of California and has been living in Tampa, Florida since retiring from the United States Navy seven years ago. He graduated from Columbia College with a degree in Business Administration.

While with PdMA Peter has completed formal qualification requirements as an Instructor/Facilitator through Langevin Learning Services. He has also completed formal training in Servo Motor Operation and Repair, and Harmonic Current/Power Quality in Industrial Distribution Systems. His travels with PdMA have sent him as far away as Singapore for motor reliability workshops and as close as The Florida Aquarium in Tampa where PdMA provides MCEmax services as part of their predictive maintenance program.

During eleven years of his Naval career, Peter was lead supervisor for maintenance, repair and operation of AC and DC rotating equipment. He also spent three years as a Quality Assurance Officer for nuclear submarine repairs conducted at the Pearl Harbor Submarine Base. Pete can be contacted at (813) 621-6463 ext. 104 or at pete@pdma.com

Longer Living Bearings & Seals

The Impact of Precision Alignment on Lifespan

by Michael Snider & Gary L. Phillips

Precision alignment of rotating machinery shafts is one of the key factors in reducing "parasitic" loads on bearings, seals and shafting. Thus, it stands to reason that precision alignment increases overall machine uptime, Mean Time Between Failure (MTBF) of machinery components, and profitability of the organization - all of which are worthy goals and something we all seek. The primary focus of this article is to show how misalignment affects the machine components of both the driver and driven machines once coupled and under operation.

While the concepts discussed here apply to all types of rotating machinery, let's start by considering the chart below that relates to failures of one very important type of equipment throughout industry, the centrifugal pump. The results if a recent statistical analysis of which components generally fail in a centrifugal pump are shown in Fig 1. As you can see, approximately 69% of failures involve a sealing device, most commonly a mechanical seal.

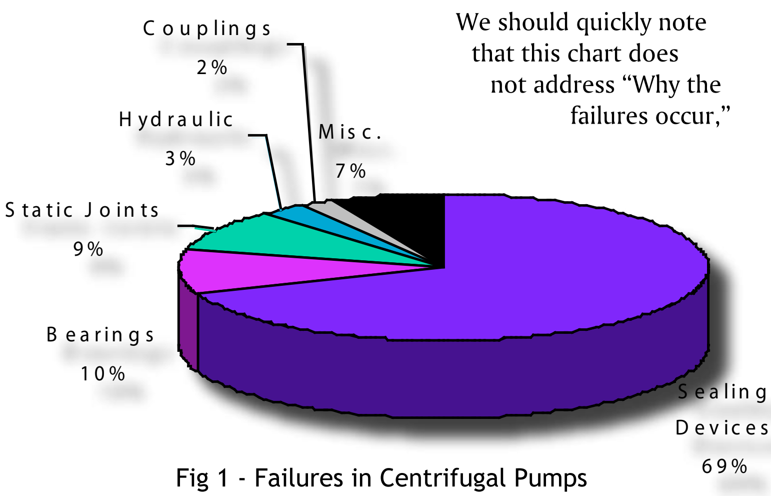


Fig 1 - Failures in Centrifugal Pumps

We should quickly note that this chart does not address "Why the failures occur," but simply "What fails?" While the analysis of all the specific root causes of these component failures is beyond the scope of this article, it is clear that mechanical sources of failure such as shaft misalignment contribute significantly. From this study, we can conclude that elimination of the root causes of bearing and seal failures would resolve approximately 79% of the pump reliability challenges that resulted in this study.

Basics of Alignment

Rotating equipment misalignment is defined as the deviation of relative shaft position from a collinear axis of rotation. The term collinear, illustrated in Fig 2, is defined as "containing elements that correspond to one another and that are arranged in the same linear sequence."

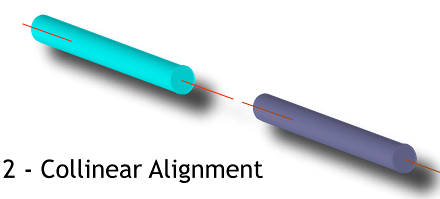


Fig 2 - Collinear Alignment

When applied to rotating equipment, the coupled shaft centerlines of both the driver and driven machines form one line while the machines are operating, thereby reducing the "parasitic" loads imposed on the machinery components. These machinery components include the shafts, bearings, seal, rotors and coupling.
Note that loads imposed by imbalance, assembly errors, and operating conditions are separate subjects.

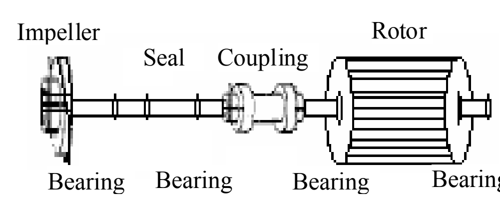


Fig 3 - Collinear Aligned Machine

For coupled machines, shafts are misaligned when their rotational centerlines are not collinear when the machines are operating.

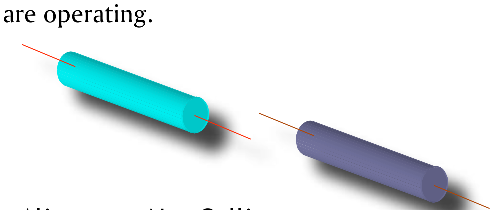


Fig 4 - Alignment Not Collinear

Most discussions of shaft alignment begin by defining two types of misalignment: offset misalignment and angular misalignment. These two types of misalignment are typically illustrated as shown in Fig 5.

Common Challenges and Misconceptions Regarding Shaft Alignment

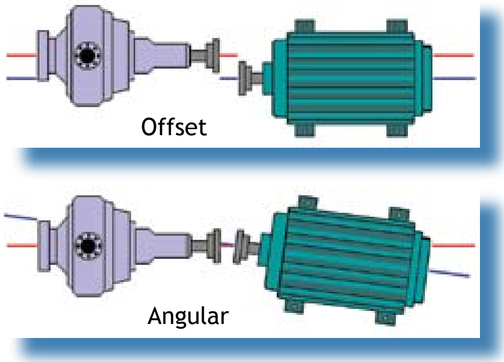


Fig 5 - Types of Misalignment

A wide variety of challenges and misconceptions exist regarding the subject of machine installation and shaft alignment. In addition, many of these issues remain subjects of debate. Among the issues are the following:

1. What is the correct set of alignment tolerances?
2. If aligning to more precise tolerances doesn't reduce machinery vibration levels, is there a real benefit?
3. What is the impact of "flexible" couplings on alignment tolerances?
4. If a machine is subject to considerable movement due to pipe strain or thermal growth, and even changing operating conditions, what is the benefit of "precision tolerances?"
5. How do various equipment-specific variables such as operating speed, bearing type, seal type, etc. impact the degree of precision required?

While each of these are important subjects and, indeed, pose challenges, our focus here is to look at the subject purely from the perspective of the bearings and seals.

Alignment Tolerance Chart Example

While the final decision on alignment tolerances must be made by individual companies based on the nature of the equipment and its criticality to the business, the charts shown in Fig 6 are typical of commonly accepted alignment tolerances.

Charts such as these are very common; however, a few precautions should be noted:

- Angularity and offset tolerances focus the attention on the coupling, not on the length of the shafts or amount of misalignment at the bearings.
- Operating speed is one factor to be considered, but many more factors should be considered as well.

Consider the illustration in Fig 7. Given an 1800 RPM machine aligned to the "excellent" angularity and offset tolerances provided in the chart on the previous page, look at the

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

	Angular Misalignment mm/100mm		Offset Misalignment mm	
RPM	Excellent	Acceptable	Excellent	Acceptable
3000	0.03	0.04	0.03	0.06
1500	0.05	0.07	0.06	0.09
1000	0.07	0.1	0.075	0.15
750	0.09	0.13	0.09	0.19

Fig 6 - Commonly Accepted Tolerances

amount of misalignment present at the machine feet, which happen to be very near the machine bearings.

In summary, what we see is that, though the offset and angularity values at the "coupling" are within tolerances typically considered "excellent," there remain offsets at the movable machine front feet and rear feet of 0.007" (0.175mm) and 0.023" (0.585mm), respectively.

While the misalignment values in this example are obviously not "precise," we need to consider why the misalignment leads to premature machinery failures, particularly components such as bearings and mechanical seals. As we established earlier, by definition "rotating equipment misalignment is defined as the deviation of relative shaft position from a collinear axis of rotation." See illustration in Fig 8.

When operating, the rotating shaft centerlines seek a collinear position, and that is true regardless of the type of coupling, the type of bearings, or the operating speed of the machines. In trying to reach a collinear position in this example, consider the amount of offset at the drive-end feet, also near the drive end bearings, 0.005" (0.125mm) and 0.006" (0.155mm). Why are these offsets an issue?

To answer that question we need to consider the radial internal clearance of the bearings and the clearance between the bearing and the bearing housing. For typical machine shaft diameters of 2 inches (50 mm), the maximum internal clearance of typical rolling element bearings is approximately 0.001" (0.025 mm) and the maximum clearance between the outside diameter of the bearing and the housing is also about 0.001" (0.025 mm), for a total of only 0.002" (0.050 mm).

If, in this example, in trying to reach a collinear position the two shafts need to travel 0.006" (0.155mm) and 0.005" (0.125mm), yet there is only 0.002" (0.050mm) of space available. Not only do we lose the vital space needed for an oil film within the bearings, but the bearings also have no choice but to sustain additional dynamic loading and the shafts sustain bending forces. These additional forces not only cause shaft deflection, which may lead to shaft failure, but also lead to extensive damage to the component most people consider

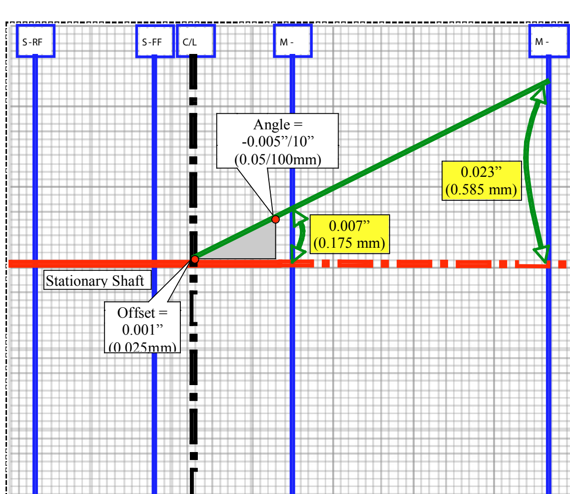


Fig 7 - 1800 RPM Machine "Excellent" Alignment

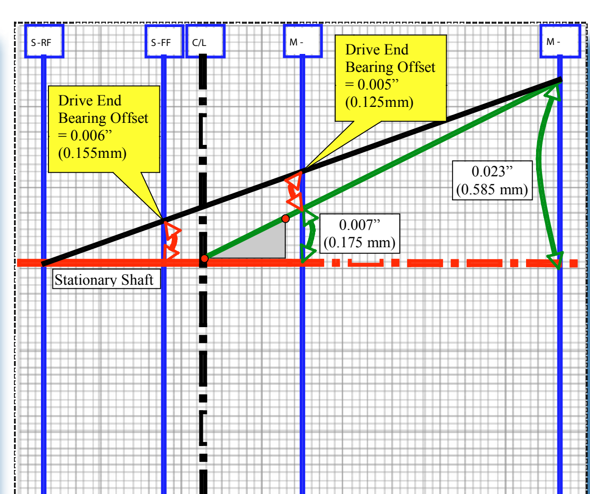


Fig 8 - Offsets Cause Additional Load

Offset Misalignment and Inboard Bearing Life				
Coupling Type	Maximum Offset for 3 Levels of Bearing Life			Maximum Coupling Offset Recommended
	90% Life Expectancy	80% Life Expectancy	50% Life Expectancy	
Link	3 mils (12% max)	5 mils (19% max)	20 mils (77% max)	26 mils
Elastomeric	8 mils (11% max)	21 mils (30% max)	70 mils (100% max)	70 mils
Grid	1 mil (8% max)	2 mils (17% max)	5 mils (42% max)	12 mils
Gear	5 mils (10% max)	10 mils (20% max)	35 mils (70% max)	50 mils

Fig 9 - Misalignment & Reductions in Bearing Life

the weakest link in the machine, the mechanical seal.

A recent study performed at the University of Tennessee found that even small amounts of misalignment could significantly reduce bearing life. The study found that if, on average, a motor was offset misaligned by 10% of the coupling manufacturer's allowable offset, there was a corresponding 10% reduction in inboard bearing life. Furthermore, if a motor was offset misaligned by 70% of the coupling manufacturer's allowable offset, there was a corresponding 50% reduction in inboard bearing life (Hines et al). The results of the study are summarized in Fig 9.

A Different Perspective on Alignment Tolerances

Many companies have realized significant improvement in bearing life, seal life, and overall machinery reliability by implementing alignment tolerances such as those below which focus not on coupling angularity and offset values, but on the maximum offsets that are permissible at the coupling and at the machine feet.

Given our previous example, let us consider the value of such "precision alignment tolerances" on shaft, bearing and mechanical seal life. Consider the illustration in Fig 11. Per the values in Fig 10, given a maximum offset at the coupling of 0.001" (0.025mm) and a maximum offset at the feet of 0.002" (0.050mm), the graph below shows the worse case scenario.

Maximum Offset at Machine Feet	Maximum Offset at Coupling Centerline
0.002" (0.05mm)	0.001" (0.025mm)

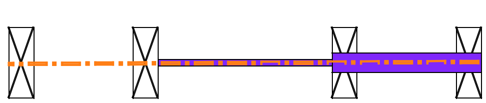


Fig 10 - Max Offsets at Centerline & Machine Feet

With the shafts in this position, if we now look at the distances the two shafts would need to travel to reach a collinear position, you can see the value of such tolerances. In this case, the distances the shafts need to travel are less than 0.001" (0.025mm). And, given typical bearing clearances, you can see that these distances are not only tolerable to the bearings; but the reduction in bearing loading, increase in lubricant life, decreased shaft stress, and finally mechanical seal life is now realized.

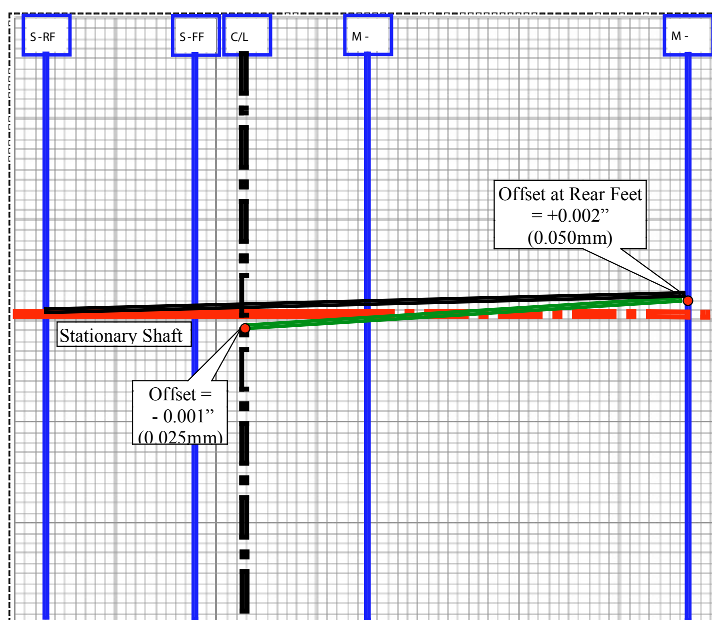


Fig 11 - More Precise Precision Alignment

Conclusions

Alignment tolerances have often been treated with a halfhearted "just get it close" attitude. However, alignment tolerances are actually the measurement of a job well done and they provide the definition of what close actually is. There are two reasons to use tolerances. The key reason is to establish goals. If you do not have a goal, how do you know when the job is finished? If there is not a goal, there cannot be a quality alignment. The second purpose of alignment tolerances is to establish accountability. Accountability is the evaluation of alignment quality. If there is no tolerance to compare an alignment to, how can the quality of the alignment be judged? Accountability can create competition, driving a mechanic to get the job done better.

While adherence to such strict alignment tolerances poses a variety of challenges, and while meeting these tolerances is not always practical or necessary, it is clear that meeting them whenever possible will contribute positively to meeting or exceeding the design life of bearings and seals. In turn, this will help to reach those goals we are all striving for - increasing machine uptime, increasing Mean Time Between Failure, and increasing the profitability of the organization.

Michael Snider is the founder and CEO of the Universal Technologies companies, including operations in the US, Europe, and Latin America. Michael has over 23 years experience in the fields of machinery reliability, technical training delivery, training and task qualification program design and development. He received his B.S. and B.A. degrees in Philosophy and English in 1981 and 1982, respectively, from St. Andrews Presbyterian College and completed graduate studies in Physics and Mathematics at the University of North Carolina in 1987. Michael is the proud father of five children and one grandchild. Hobbies include travel, reading, snow skiing, and writing.

Gary Phillips is Senior Instructor at Universal Technologies with 28 years experience in vibration analysis & technical training related to machinery reliability. His expertise extends to troubleshooting and problem-solving, root cause failure analysis, shop & field balancing, reliability program evaluation, implementation & management, quality control & quality assurance, advanced precision machinery alignment using laser & dial indicator methods. Gary received his BS in Mechanical Engineering in 1969 from the University of Saskatchewan, Saskatoon, Saskatchewan. He lives in Duncan, BC Canada.

Safe & (Ultra)Sound

Ultrasound & Infrared Imaging Make Safer Electrical Inspections

by Jim Hall with contributions from Jim Brady

Airborne ultrasound is more than just a leak detector. It is a versatile and important tool that should be in the toolbox of every company that has a Predictive Maintenance (PdM) program. Airborne Ultrasound is versatile enough that if you are just using it for predicting failures of bearings or steam traps, you are not taking full advantage of it. You should seriously consider using ultrasound as a part of your electrical PdM program as well. Airborne ultrasound can be used to hear arcing, tracking and corona discharge when scanning or surveying switchgear, without opening panels or doors of electrical switchgear. Airborne ultrasound is also used in substations to survey transformers, breakers, overhead lines and switches for corona, tracking or arcing.

Airborne Ultrasound Compliments Infrared Imaging

Since corona under 240 kV is not in the infrared spectrum, infrared imaging cannot recognize or see it. Airborne ultrasound can detect corona at 1 kV or higher.

What is corona? Corona is the faint glow adjacent to the surface of an electrical conductor at high voltage (1 kV or higher) as a result of the ionization of gases due to the high electrical stress. Stress can be caused by contamination, poor insulation values, design defects and/or poor installation.

Why Airborne Ultrasound?

- Airborne ultrasound hears high frequency sounds above the human hearing range of 20,000 Hz (20 kHz) and above.
- Ultrasound can hear corona under 240 kV.
- Ultrasound is very directional.
- Short wave and typically 1/8" to 5/16" of an inch in length.
- Portable (handheld).
- Cost effective and a high "Return-On-Investment".

Safety First

For safety reasons alone, airborne ultrasound should be part of your infrared pdm program. If used before opening all electrical doors or panels, airborne ultrasound could in fact prevent injuries and, quite possibly, save lives. Airborne ultrasound can hear corona, tracking or arcing around or through the panels or doors alerting the technicians of potential danger before opening.

Even a novice using an airborne ultrasound receiver for the first time would not mistake arcing if it were present. The ultrasound receiver amplifies and heterodynes the signal. Sound is then received into the headphones as a low-frequency signal that we can hear and understand.

Early on in my airborne ultrasound career I learned what to listen for by going into the field and scanning switchgear and substations with engineers and technicians. This included scanning for radio/tv interference, listening for internal arcing of oil-filled transformers, bearing analysis of transformer pumps and fans, scanning for nitrogen blanket leaks as well as for SF6 gas leaks on breakers.

13KV Rectifier Panel

I received a request from an electrical technician in eastern Tennessee who was interested in implementing an airborne ultrasound program within his infrared imaging PdM program. He had just received his Level One Thermographers Certification and during his training he was introduced to airborne ultrasound as a means to hear corona in closed metal-clad switchgear.

The electrical technician and I proceeded to a vault were there was a row of fifteen 13.8 kV Rectifier Panels. We started at one end and everything was quiet as we worked our way up the row of panels - until we reached panel number thirteen. From the lower right side of this panel, where the vacuum breaker is stored, the noise in my headphones sounded like thunder and lightening in a trash can. It was enough noise that I immediately told the technician, " The demo is over, I'm out of here". However, prior to leaving the area I recorded a wave file of the cabinet.

(If you'd like to hear what a bad vacuum breaker sounds like, you can listen to this wave file at www.ultra-soundtech.com).

That evening at my hotel I loaded the wave file take of the 13.8 kV rectifier panel onto the hard drive of my laptop. I then emailed a few seconds of that file to an electrical engineer of a local utility. The electrical engineer played the wave file and suggested the electrical technician remove the vacuum breaker from the rectifier panel and apply DC current to see if the breaker had failed. The breaker had, indeed, failed. The breaker was replaced and the customer never had an outage due to a failure of this panel.

Afterwards, the technician went to the department head to ask for funding to purchase an ultrasound receiver. Unfortunately, he was turned down. The department head believed that the recent $60k purchase for the infrared camera was "all" the technician needed. Another $4k for an ultrasound receiver was not available. I strongly believe that had a catastrophic failure occurred, it would have cost much more that $4,000 in downtime, loss of production and repairs. Not to mention the possibility of an injury to someone who may have been in the area at the time of a catastrophic failure.

Another Perspective

For a different point of view, I asked Jim Brady of Brady Infrared Inspection Services of Stuart, Florida, to tell me about any recent case histories using airborne ultrasound during an electrical survey. Jim has been using airborne ultrasound with infrared imaging for several years. He is a firm believer in the use of airborne ultrasound because of stories like this...

During a recent inspection at a downtown substation for a utilities provider, a series of 13kV rack-in breaker cabinets were being scanned with infrared and ultrasound. One of the rack-in breakers was completely removed from the main bus cabinet following a recent flash-over (Fig 1). Because of the "no load" conditions inside the cabinet, infrared was ineffective for detecting any thermal anomalies present in the equipment.

However, while scanning with the ultrasound receiver, I heard what sounded like tracking (i.e…build-up of intensity, discharge and start over again) on the B-phase stationary bus contact (Fig 2). The most logical explanation for the tracking condition was that the problem that caused the initial flashover was still present. The presence of carbon-rich flash residue only compounded this situation by providing very conductive material for tracking paths to ground (Fig 3). It was only a "matter of time" until another flash-over occurred in the cabinet, this time possibly damaging the main bus responsible for five additional feeder breakers.

Fig 1 - Presence of carbon-rich flash residue.

Fig 2 - Back of side of cabinet.

Fig 3 - Front side of cabinet with carbon residue, Rack-In Breaker had been removed.

All photos courtesy of Brady Infrared Inspection Service

What needs to be understood is that corona and tracking conditions are voltage problems, not load/current related problems. They can occur in electrical equipment that is energized but not operating. The use of infrared alone in this particular situation would have revealed no problems when in fact a serious problem was looming.

So, I believe that implementing the use of airborne ultrasound within an infrared PdM program can prevent injuries and possibly save lives. No matter if your current Infrared PdM program is outsourced or run in-house, airborne ultrasound is a must for electrical scanning. If a company does currently outsource the Infrared PdM program they should seek out those Infrared service companies who are familiar with and currently offer airborne ultrasound as a complimentary service during the infrared survey.

Thanks for the story, Jim.

Conclusion

This article touches on only a couple of the many anomalies companies such as Brady Infrared Inspection and I, have seen over the past few years. Granted, some of the anomalies we have seen are very subjective. But, one fact remains, if you have corona activity - take action - do not wait for an incident report to spark your attention.

Remember, SAFETY FIRST, review the NFPA 70B before starting a program to survey electrical switchgear and substations.

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 online presentations at ReliabilityWeb.com and is a contributing editor for UPTIME Magazine. 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). He can be contacted at (770) 517-8747 or at jim.hall@Ultra-SoundTech.com

Acceleration Enveloping

A Key Element in Aggressive Condition Monitoring

By Greg Lee

Acceleration Enveloping, sometimes referred to as Demodulation, Shock Pulse Spectrum, or Spike Energy Spectrum, is a highly useful signal processing technique primarily used for the detection of rolling element bearing problems in the early stages of damage. Often acceleration enveloping is overlooked as a key analysis tool because little is known about the measurement and how it is derived. The purpose of this article is to explain how Acceleration Enveloping is derived and to show its usefulness in the early detection of rolling element bearing faults.

We typically use a velocity spectrum to analyze machinery faults and rolling element bearing problems. Unfortunately, the bearing frequencies are hidden in the midst of a host of other machinery fault frequencies and their associated harmonics. A rolling element bearing can have significant damage, yet the amplitudes at the bearing frequencies can be quite low when compared to other vibrating components, such as imbalance, misalignment, looseness, blade/vane pass, and electrical frequencies. Because of this it is sometimes difficult, if not impossible, to detect a bearing in its early stages of failure using a velocity spectrum (see Figure 1). What we need is a way to see the bearing frequencies independent of the other machine fault frequencies. Acceleration Enveloping provides a signal processing method which accomplishes this.

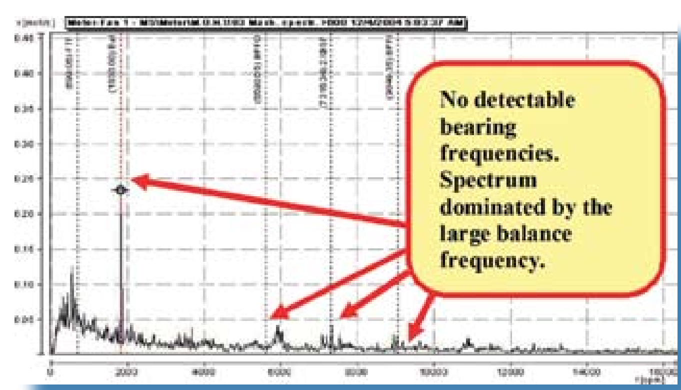


Figure 1 - Bearing Frequencies Not Detectable

Acceleration Enveloping

When a bearing defect is small, the impacts of the rolling elements on the defect cause the bearing components to resonate, or ring, like a bell. This ringing occurs at a much higher frequency than the fundamental bearing frequencies of Cage, Inner Race, Outer Race, and Ball Spin. Visualize an outer race defect, in that every time a rolling element strikes it the bearing components ring, then subside until the next element hits the defect. The forcing frequency is the ball pass frequency of the outer race. The response consists of the resonant frequencies of the bearing components and bearing housing. The resonant frequencies of bearing components vary based on the material, structure, mass, loading, and excitation frequency. Therefore, there is no one frequency to look for but a range of frequencies, often referred to as a “Haystack”. This haystack is best observed in units of acceleration. Haystacks typically occur between 120,000 CPM and 600,000 CPM but the exact frequency is not as important as the fact that they are present. If a haystack is present, the source should be investigated.

If this haystack in acceleration spectrums was all we needed to identify a failing bearing, then that would be the end of the story. However, there are several other possible sources for this haystack of frequencies. Rubs near the bearing, steam running near the bearing, rubbing carbon seals, pump cavitation and other process-related audible noise can also cause a haystack to appear in an acceleration spectrum. Acceleration Enveloping helps us discern if the haystack is being driven by random impacts like a rub, or a repeating impact such as a bearing component or something like a gear.

Steps to Derive Acceleration Enveloping

When using a tool it is always helpful to understand how it works. This understanding enhances your ability to correctly apply the tool and achieve a favorable result. The same is true of acceleration enveloping.

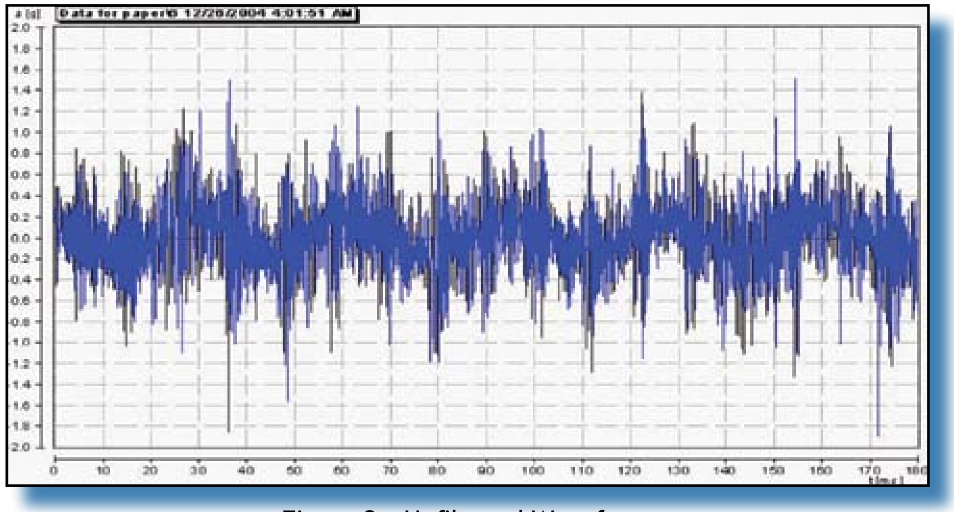


Figure 2 - Unfiltered Waveform

For this explanation/example we are using an SKF 6203 bearing with a known defect in the outer raceway of the bearing. The defect is small enough that it is difficult to see with the naked eye.

Waveform

We will start out by looking at the waveform emitted from the bearing. The raw unfiltered acceleration waveform combines elements of both low frequency vibration and high frequency haystack from the resonating bearing components. As you can see in Figure 2, there is a lot of high frequency in the signal which accounts for the thousands of small peaks. You can also see underlying low frequency vibrations which the high frequencies ride on.

Applying a Band-Pass Filter

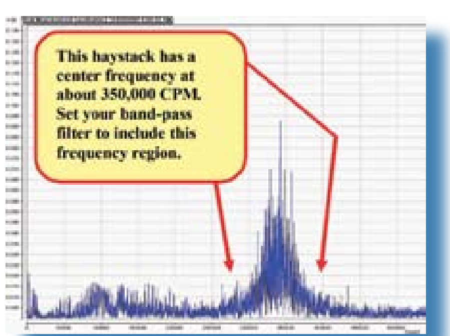


Figure 3 - Setting Band Pass Filter

Different analyzer suppliers have different methods for setting the band pass filter. The key is to set up the filter so that the haystack frequencies are allowed through the filter while the other frequencies, especially below the haystack, are filtered out by the filter (see Figure 3). Now let's see what happens to the waveform when we apply a band-pass filter set to filter out the frequencies higher and lower than the haystack.

You can see in Figure 4 that as each rolling element rolls past the defect in the outer race, the impact causes the bearing components to ring at a high frequency. The application of the high pass and low pass filters eliminates most of the other vibrations from the waveform. This, in turn, allows us to clearly see the impact and ring-down within the waveform created by impacts of the rolling elements on the defect in the outer race of the bearing.

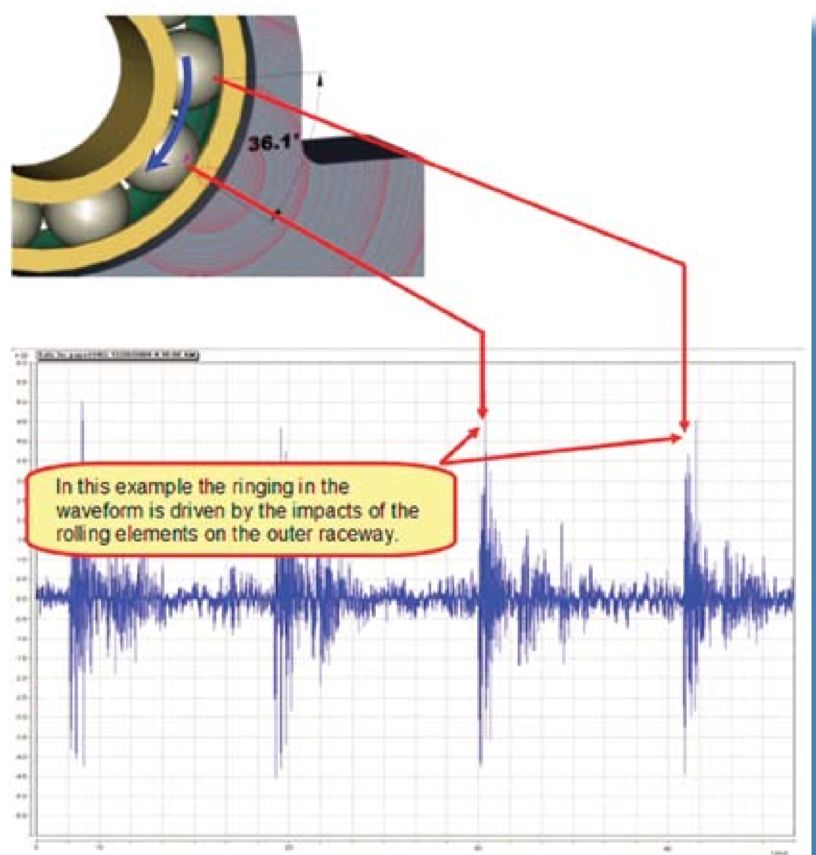


Figure 4 - Waveform After Applying Band Pass Filter

Notice that the time between impacts in the waveform matches the time spacing between the rolling elements.

Enveloping the Waveform

In order to identify the source frequencies of the impacts which cause the reoccurring ringing of the bearing, two processes are required. First the signal is rectified, i.e., the negative portion of the signal is inverted to positive. This is demonstrated in Figure 5.

The rectified waveform is then enveloped by laying a trace or line over the general shape of the rectified waveform (see Figure 6). This envelope line is now used as a new signal. Notice that the peaks and valleys of the waveform still match the spacing between the rolling elements on the outer race surface.

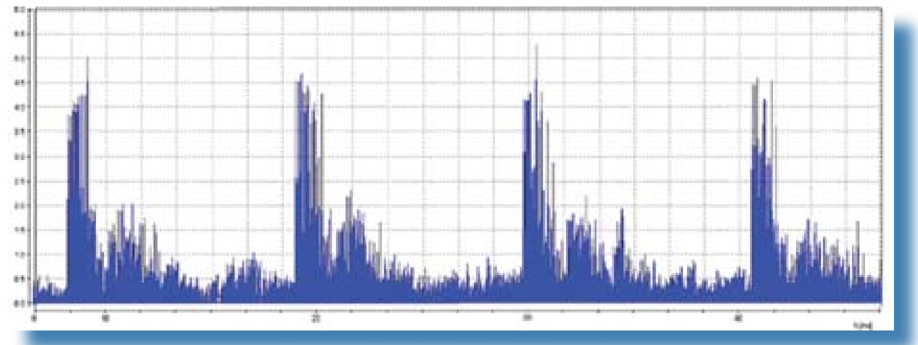


Figure 5 - Rectified Waveform

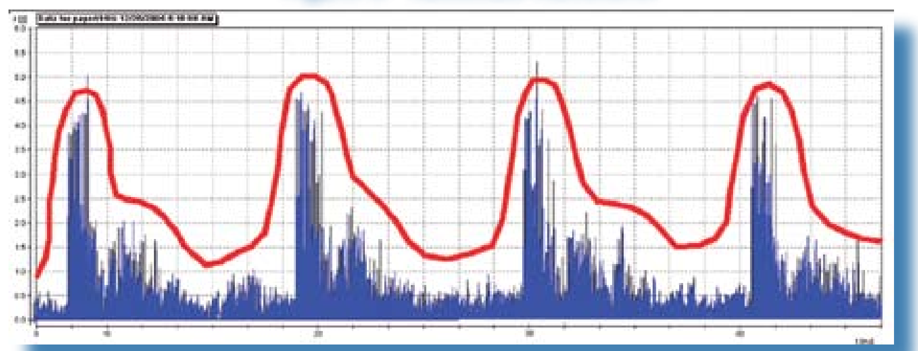


Figure 6 - Enveloped Waveform

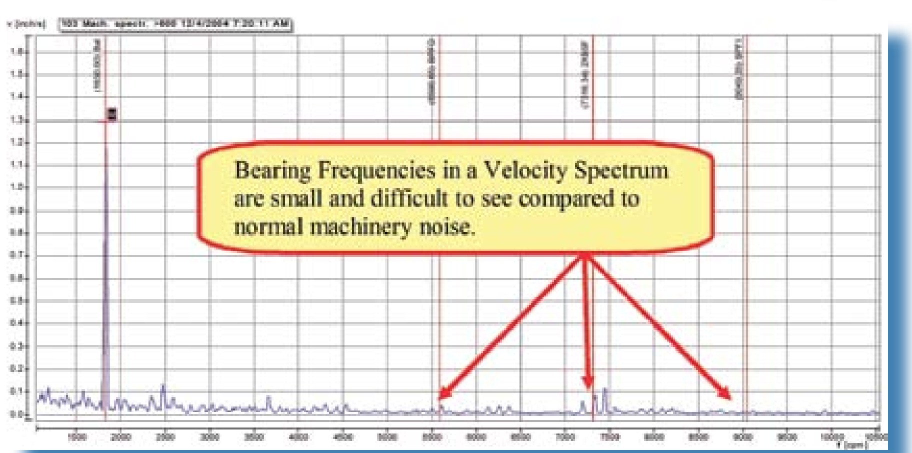


Figure 7 - Velocity Spectrum

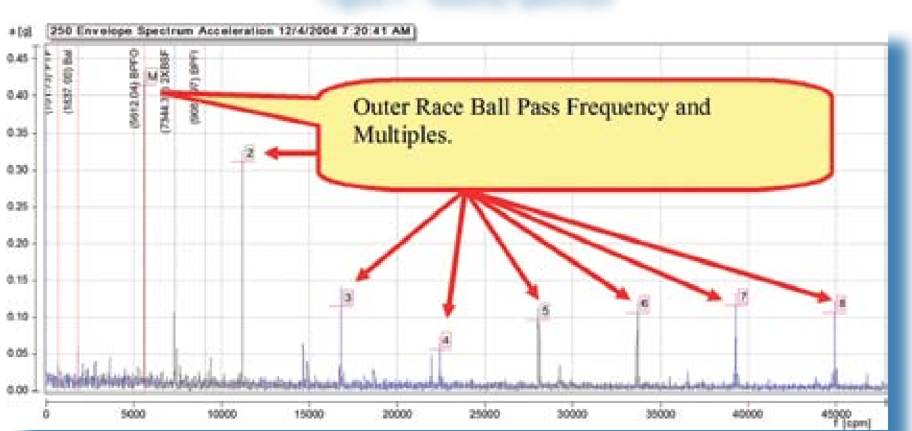


Figure 8 - Acceleration Envelope Spectrum

Calculating the New Spectrum

The envelope line is now used as if it were a true vibration signal. A spectrum is performed on the envelope signal (in red, Figure 6) which will reveal the frequencies of any repetitive pattern in the newly generated signal. You can see the results at left and compare it to a normal velocity spectrum. The bearing defect is all but impossible to distinguish from the other frequencies in the velocity spectrum (Figure 7) but the bearing outer race and its multiples are clearly visible in the enveloped spectrum (Figure 8).

In Figure 9, we have displayed a waterfall of acceleration envelope spectrums and a trend of the bearing's outer race frequency. This helps you track and identify the increase in intensity of the bearing outer race defect over time.

Other Sources of the "Haystack"

If a Haystack is present in an acceleration spectrum, it is important to understand that there are other possible causes aside from bearing damage. As mentioned previously, such conditions as a shaft rub, pump cavitation, steam noise, rubbing seals, process noise, and audible noise can also drive the bearing housing to ring and display the haystack pattern. The big difference is that the source generally consists of random impacts, and not regularly spaced impacts. The envelope can

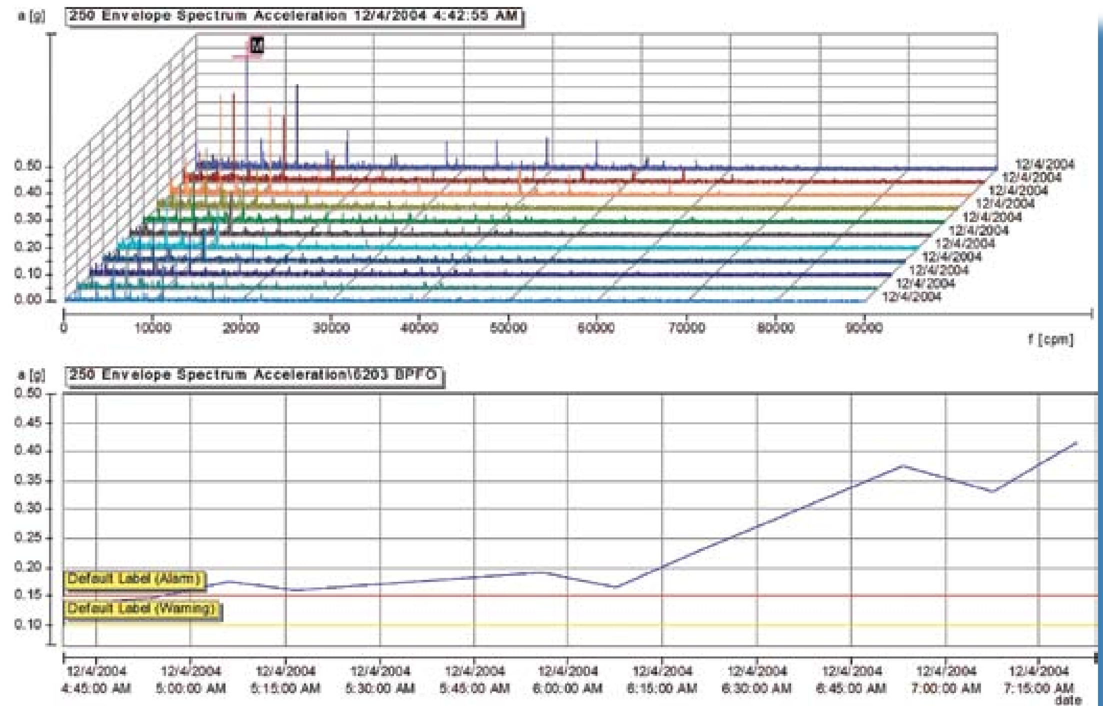


Figure 9 - Waterfall of Acceleration Envelope Spectrums & Trend

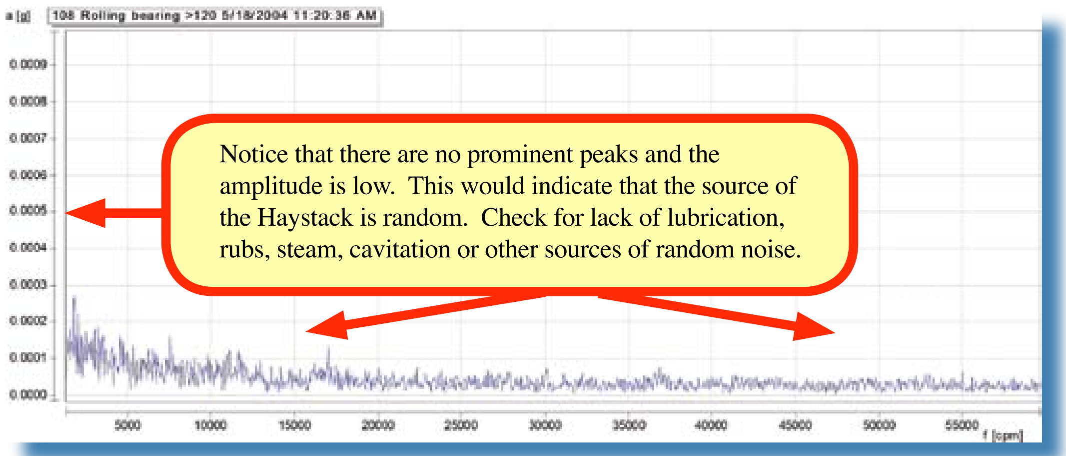


Figure 10 - Envelope Spectrum, Random Source of Haystack

assist you in determining if the source of the haystack is random or impact driven. If the driving force of the haystack is random then the filtered waveform would not have any prominent peaks evenly spaced. The resulting envelope signal would be flat or random. Figure 10 represents an example of a haystack being driven by a small rub, which results in an envelope spectrum that looks noisy and has low amplitudes with no prominent frequencies.

Enveloping Other Vibration Measurements

Envelopes are not restricted to acceleration but can also be used for other measurement types. For example, a Shock Pulse or Spike Energy signal can be enveloped using the same band pass process that was used with the acceleration waveform. If the Shock Pulse signal is being driven by an impact that occurs at a regular frequency interval, it will show up at the driving impact frequency in the Enveloped Spectrum. Other units such as Velocity can also be enveloped using the same technique.

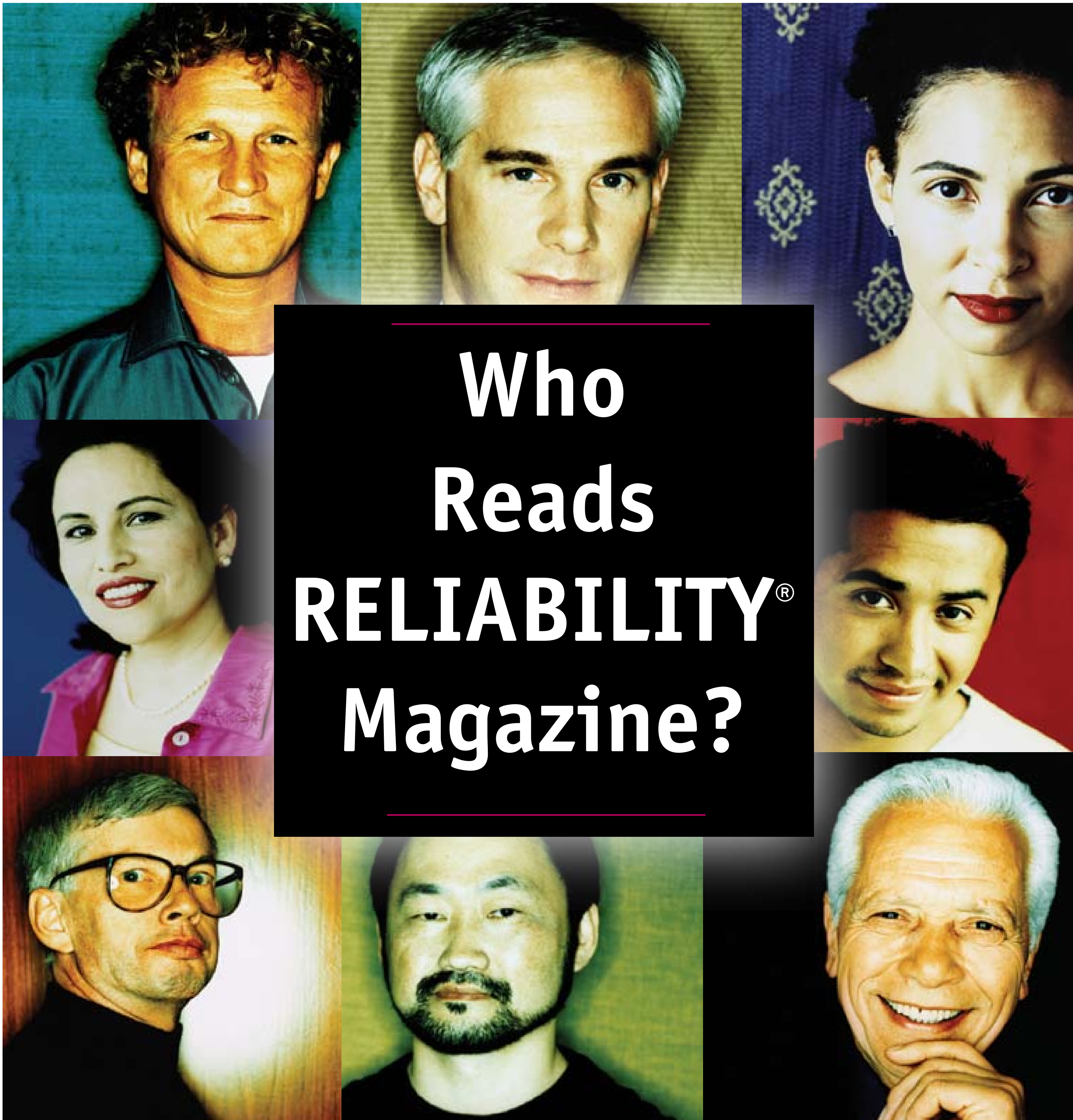
Conclusion

As can be seen, the results are impressive. When comparing the spectrum to the normal velocity spectrum, the bearing frequencies are now prominent. The amplitude of the frequencies is not as important as their prominence above the noise floor. This is the same for multiples of a driving frequency. In our outer race example, more multiples of the outer race frequency indicates that the damage is more severe.

It is also important to note that Enveloping provides early detection of bearing damage. It is not unusual for a bearing fault detected with the enveloping technique to run 3 to 4 months, or even up to a year before it fails. Enveloping is often used as a trigger measurement to activate life extension actions such as changing lubrication and performing precision laser alignment.

Around the world Acceleration Enveloping is fast becoming a key element in the early detection of failing bearings in most aggressive Condition-Based Maintenance Programs. Don't miss using this excellent technique to get ahead of rolling element bearing problems in your facility.

Greg received his BS Degree from Michigan Technological University in 1982 where he was a member of The National Deans List. Since his employment with IRD Mechanalysis in the mid 1980s, he has worked for several major vibration measurement companies as well as provided condition based maintenance programs for a number of mining and paper companies. In 1995, he joined Prüftechnik AG where he helped with product and market development. Since 1999 he has worked with Ludeca, Inc. the exclusive US distributor for Prüftechnik products. Greg resides in Gardnerville Nevada with his wife Cindy where they have 5 children and 1 grand child. He enjoys Skiing, Motocross, and is a Sail Plane (Glider) Pilot. Greg can be contacted at greg.lee@ludeca.com or at (775) 265-6650.


Who
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EyeTank - A Real Eye Opener

Your Fluid Level Management Made Easy

Chevron just introduced a new online fluid monitoring system called EyeTank. After looking at what this product has to offer, it seems to have the potential to dramatically streamline and improve fluid management. We like products that simplify procedures, reduce problems and increase the bottom line for facilities. We sat down recently with John Malone, Reliability Solutions Manager for Chevron, to get a little more insight into the product and the thinking behind it.

Easy access to tank levels and forecasting in the Eyetank system.

What exactly is EyeTank?

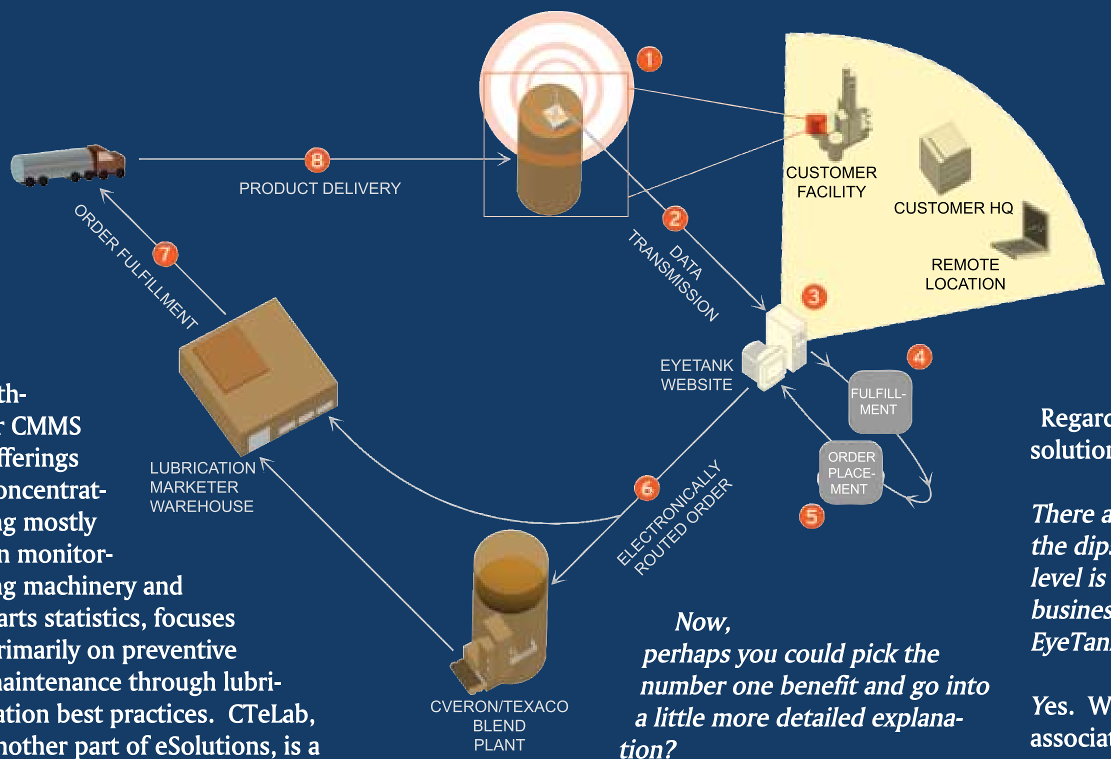
EyeTank is an advanced online fluid inventory management system designed to efficiently and reliably maintain bulk lubricants at optimum levels. EyeTank allows the end user to view lubricant stock levels, forecast the need for replenishment, and schedule deliveries before run-out. EyeTank provides the end user with the opportunity to connect their tank monitors to Chevron's order fulfillment systems, creating automatic purchase order requests, distributor replenishment requests, and total order fulfillment.

Whether you are managing one tank or an entire tank farm, our solution helps to make the job of the maintenance and purchasing departments easier.

EyeTank also allows for a convenient level of flexibility, you can choose the level of service that best fits your operation's needs. From fully automated replenishment to simple online monitoring, the solution helps you manage your fluid and maintenance costs.

What was the mind set behind Chevron, which is established as a high quality lubricant provider, branching out to develop EyeTank?

Chevron has over 100 years of experience in the lubrication market, which gives us considerable insight into how we can improve the bottom-line performance of our customers business , in this case, through lubricant related solutions. The company offers a complete portfolio of Reliability Solutions. One component of this portfolio is our ISOCLEAN® Solutions line, which focus on fluid cleanliness. This line includes ISOCLEAN Solutions Desiccant Breathers, ISOCLEAN Automatic Lubricators, ISOCLEAN Fluid Conditioning Services and the recently introduced ISOCLEAN Fluid ID System, which is a product line of interchangeable lids, storage containers and accessories, intended to prevent fluid contamination and reduce product misapplication. Another component of the Reliability Solutions portfolio is T-REX™, which stands for Total Reliability Excellence. This is our reliability consulting service, where we help our customers become the lowest cost producer, achieve the highest level of asset reliability, comply with federal regulations, improve their safety record and optimize quality. The final component is eSolutions, which is where EyeTank belongs. Besides EyeTank, we have Computex MMS, a fully scalable, web-based Computerized Maintenance Management System (CMMS) that, unlike



other CMMS offerings concentrating mostly on monitoring machinery and parts statistics, focuses primarily on preventive maintenance through lubrication best practices. CTeLab, another part of eSolutions, is a web-enabled solution that allows users manage oil analysis information for multiple pieces of equipment, from multiple sites or geographies and with data coming from multiple labs. It also allows users to register equipment online, graph equipment condition and generate detailed management reports. Finally, there is Lubricants University, which offers online lubricant related training solutions.

As mentioned, EyeTank is the newest addition to Chevron's slate of eSolutions, and has a direct impact on supply chain reliability, where Chevron already provides the link to lubrication.

You would be hard pressed to find a more complete set of reliability solutions on the market.

What do you consider the top five benefits of implementing the EyeTank system?

EyeTank benefits the user by simplifying the fulfillment process, optimizing inventory, reducing the time and labor required to check tank levels, detecting sudden changes in inventory levels, and eliminating run-outs and emergency deliveries.

Individually these are all valuable, but to be able to offer them in a single solution allows Chevron to provide its customers with an incredible advantage.

Now, perhaps you could pick the number one benefit and go into a little more detailed explanation?

Forecasting is the single most unique feature of EyeTank. The forecasting ability of EyeTank calculates when you should place your next order and schedules your next delivery based on tank minimum and maximum levels, lubricant usage, hours of operation, and a number of additional values you can customize. This option also offers direct online access to inventory history, usage patterns, and actual delivery amounts.

Describe, in a nutshell, the impact you think EyeTank can have on a lubrication program of a facility?

EyeTank enables the user to gain complete control of their entire fluid inventory management process. The user can proactively schedule replenishments, automate deliveries and generate reports – all via the Internet. The Internet also facilitates real-time notices and warnings should a problem arise within the tank – such as an unscheduled level increase or a sudden leak. By keeping a close eye on tank levels, you can more effectively manage your fluids, and save money in the process.

Is EyeTank flexible enough to work for facilities of any size?

Yes. EyeTank has the ability to monitor one or more tanks of various sizes, and can monitor fuel as well as lubricant stock levels. As I mentioned earlier, EyeTank also allows for a convenient level of flexibility, you can choose the level of service that best fits your operation's needs. From fully automated replenishment to simple online monitoring, the solution really helps you manage your fluid and maintenance costs. Regardless of the size of your facility, this solution can benefit your bottom line.

There are many organizations that think the dipstick method of monitoring fluid level is the least expensive way to go. Can a business case be made to justify purchasing EyeTank?

Yes. When you look at the basic costs associated with carrying excess inventory, manually checking tank levels, frequency of transactions and emergency delivery fees, EyeTank generates an immediate return on investment. If you also factor in the cost of unplanned downtime due to missed deliveries, product contamination, or catastrophic leaks, the justification for implementing EyeTank is even greater.

Do you have a success story from the implementation of EyeTank?

As you know, we introduced EyeTank in early December 2005, so it's a bit early for case studies on this solution. That being said, we have been working these types of technologies for years and we understand the value they can bring on an individual basis. With EyeTank, we brought these technologies together in a way that benefits the end users by simplifying their business process.

Where is the best place for people to get more info about EyeTank?

EyeTank can be accessed directly through an interactive Web portal at www.eyetank.net. To obtain more information about EyeTank and other products and services available through Chevron, call 1-866-354-4476 or go to www.chevronreliabilitysolutions.com.

PLANT ENGINEERING Magazine Honors the Electrophysics® HotShot® Camera With Product of the Year Award

Voted on by the 100,000 Plant Engineering subscribers, the award is a highly prized recognition of design excellence in the field of instrumentation. HotShot combines superior performance and best in class ergonomic design in a low-cost and highly featured package. Electrophysics is honored to be a part of this award that not only encompasses prestige, but is a symbol of quality and innovation in the industry.

An entirely new concept in industrial inspection data collection, the HotShot is the world's first thermography camera with an integrated data logger functionality and icon-based user interface. The camera was designed for industrial inspection of high voltage electrical systems, production machinery and buildings. The HotShot also features a unique rotating thermal camera head that enables a proper perpendicular view of electrical and mechanical systems from floor level to overhead while maintaining an optimal display angle and hand position, even when operating in tight spaces.

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Ann Arbor Sensor Systems L.L.C. – a Dexter, Michigan company specializing in non-contact temperature measurement – is pleased to announce the launch of the AXT100 series of thermal imaging cameras. At less than $5000, the AXT100 offers features not found in thermal imaging cameras three times the price. The AXT100 provides Power-over-Ethernet, Universal Plug-n-Play, two powerful software applications, shutterless operation, and requires no export license. The camera has full radiometric calibration with a measurement range from -40ºC to 800ºC.

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"Consumers are the true architects of this idea," said Brian Gleason, president of Des-Case, "The FlowGuard™ hand cart series was created to specifically address their desire for a customizable filter cart with superior quality."

The design of the hand cart incorporates the cleaning capability of dual filter media and the sealing capability of the quick disconnects. Pairing it with FlowGuard™ quick connect adaptors makes oil handling even easier and cleaner. By combining these endorsed methods into one cost-effective package, FlowGuard™ virtually eliminates the opportunity for the ingress of dirt and water.

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The Vibration Division of PCB Piezotronics, Inc. (PCB®) introduces Series 3741 New High Sensitivity MEMS DC Accelerometers. Series 3741 offers several models to accommodate various crash sled acceleration profiles, and full scale ranges from 2 to 200 g, up to 2k Hz measurement capability, and sensitivities up to 1 V/g, to accommodate both automotive and aerospace applications.

The Series' rugged, low-profile design allows for mounting on restricted areas of crash simulation sleds, truck axles and aircraft wing surfaces. Their DC response allows for measurements in both static and dynamic environments.

Andrea Mohn 716-684-0002 ext. 2216 mktg@pcb.com

ITT's new PROsmart wireless machine health monitoring system is designed to provide cost effective monitoring of all types of rotating equipment. This new technology brings affordable real-time monitoring to equipment that was previously monitored by manual hand-held type data collection equipment. The PROsmart system continuously monitors and automatically predicts machine health and alerts operators and maintenance personnel of existing and impending problems.

ITT Industries, Inc.
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New 8212 power monitor designed to provide local information on current. Allows you to manage your server loads locally , set and manage alarms for current locally, monitor current per panelboard and per circuit. The 8212 power monitor matches up with PDI's Branch Circuit Monitoring System, a patented system that allows pro-active management of branch circuits, Delivers information to Building Management/Power Monitoring System via Modbus open protocol or SNMP - increasing the reliability of your data center to the server level.

Scott Boyd
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Mikron exhibits two new infrared cameras at National Manufacturing Week

A first in infrared imaging technology for PdM applications, Mikron's new M7800 and M7815 cameras introduce a high-resolution 320x240 UFPA detector with a 60 Hz refresh rate in a package starting at $14,500. With four times the resolution of a standard 160x120 detector, the two cameras provide superior images - free of pixelating - with correspondingly higher resolution in temperature measurement. The cameras include many other professional-level features, such as laser target designator, a measuring range of -40 to 500°C, on-board storage of 1300 images, and a "big screen" 3.5" articulating LCD that allows easy viewing at any camera angle.

Mikron's new 7815B infrared camera is like an x-ray machine for building diagnostics, identifying a wide range of invisible problems that add hidden costs to building ownership. The 7815B combines the highest-resolution microbolometer camera in the industry with a visible light camera and laser target dot to make professional thermal imaging point-and-shoot simple. It can detect air infiltration, moisture intrusion, mold, fungus, energy losses, pest infestations, and other problems.

Jon Chynoweth jon@mikroninfrared.com
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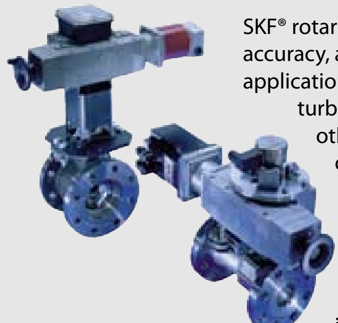

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Global Maintenance Technologies, Inc. (GM Tech) bolsters IRISS (Infrared Inspection Support Systems) product line with the new iR-iD Emissivity Labels, iR-Tk Thermographers Tool Kits, and iR-P IR Camera Lens Covers. GM Tech is a leading provider of Infrared Windows which are used in conjunction with Infra Red cameras to allow thermographers safe access to take images of electrical equipment without exposure to energized components.

The iR-iD label system is a set of Hi Emissivity target labels of various shapes that allow thermographers to mark and identify components, standardize emissivity to 0.95 and remove the problems caused when imaging highly reflective surfaces.

The iR-Tk Thermographers Toolkit provides a non contact spot radiometer, a non contact distance meter, ambient temperature/humidity meter, electricity proximity sensor, panel tools, infrared mirrors and samples of emissivity labels.

The iR-P Infrared Camera Lens Cover protects valuable infrared lenses from damage associated with dirt, dust impact, sparks and more.

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