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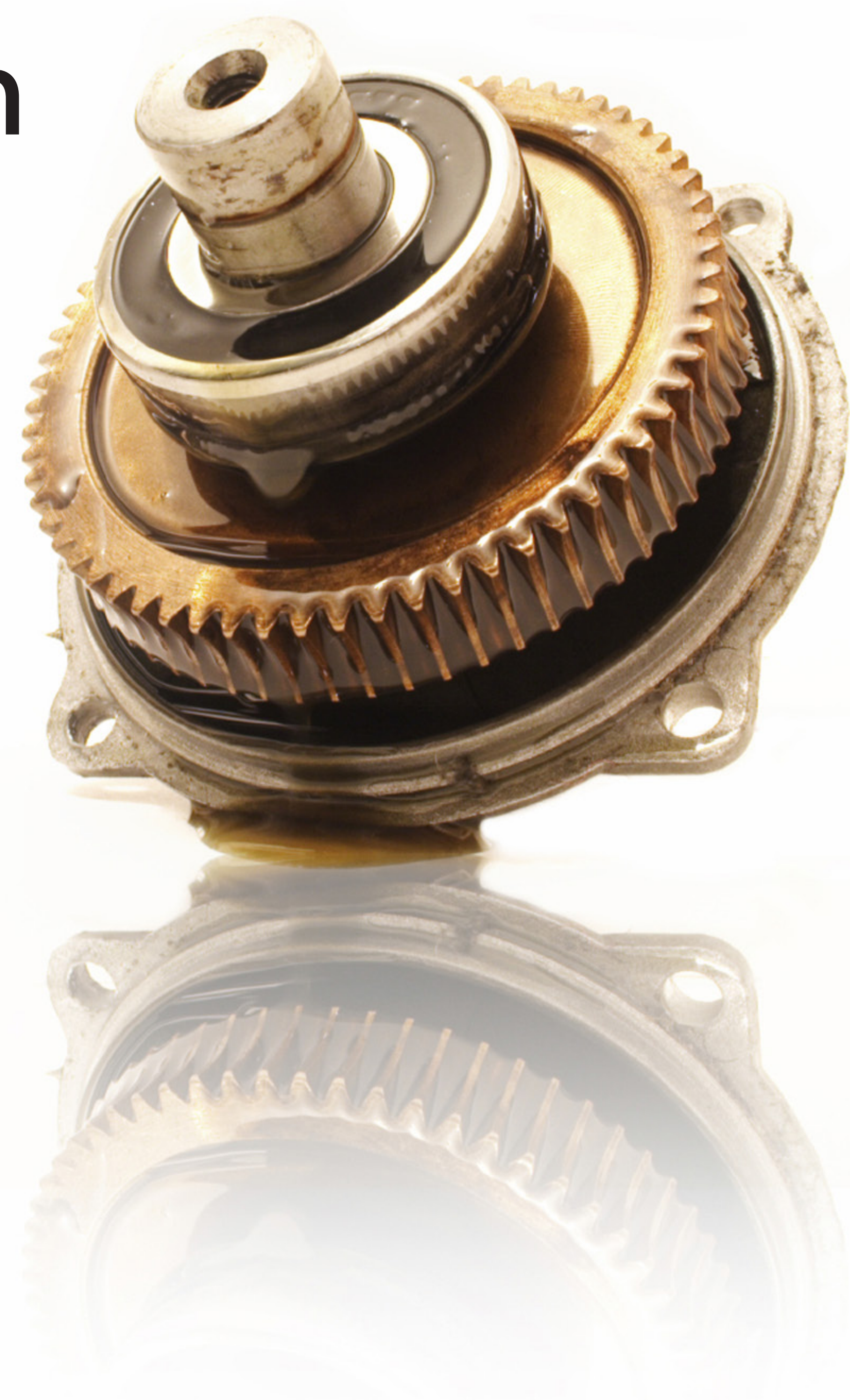
aug/sep 09

Lubrication

Nothing Moves Without It...

But Is Your Program Truly Effective?



On-Line Tests for Medium Voltage Switchgear • Using Torque in Motor Diagnostics • Speeding Up Low RPM Data Collection • Remote Condition Assessment Monitoring

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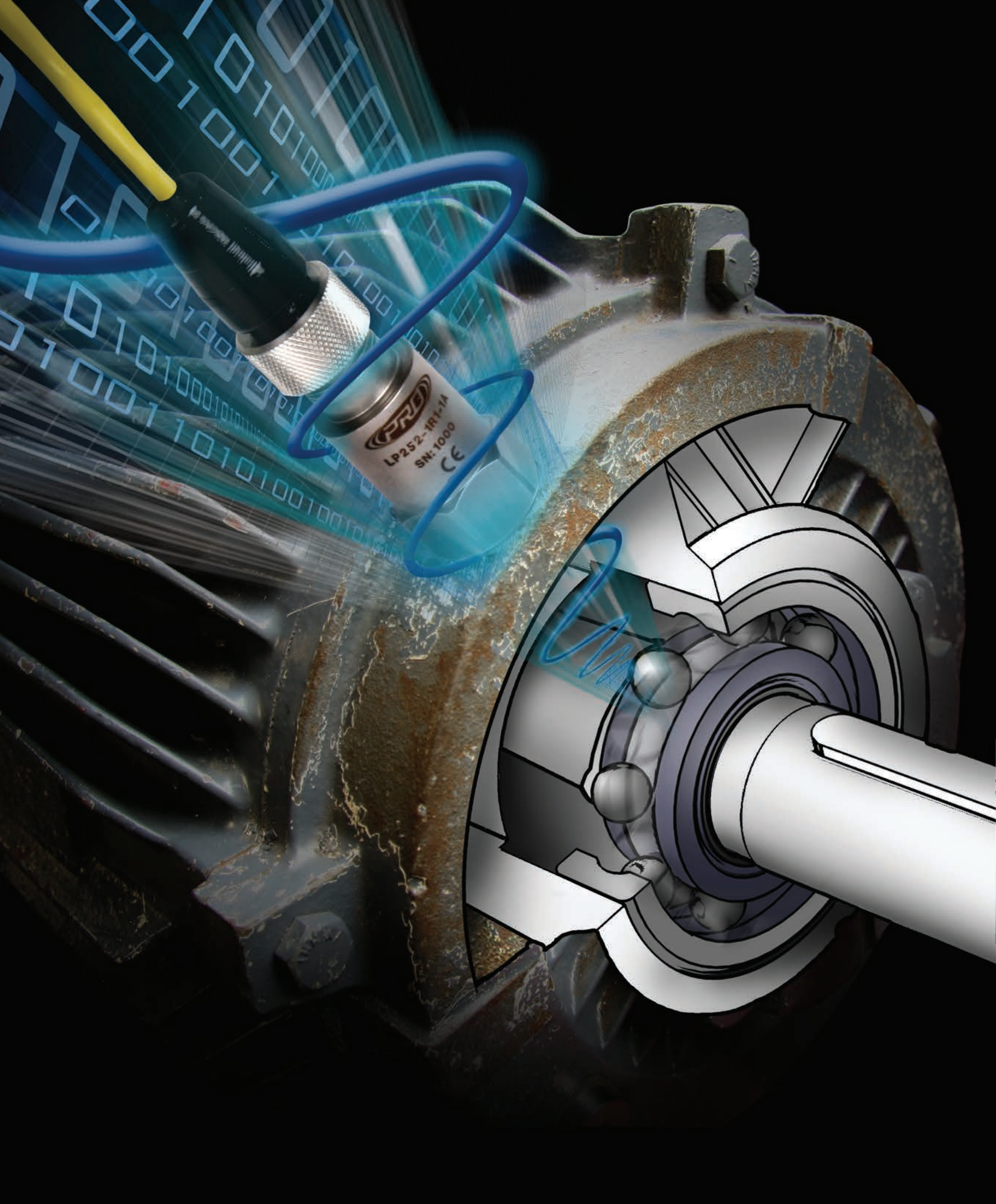
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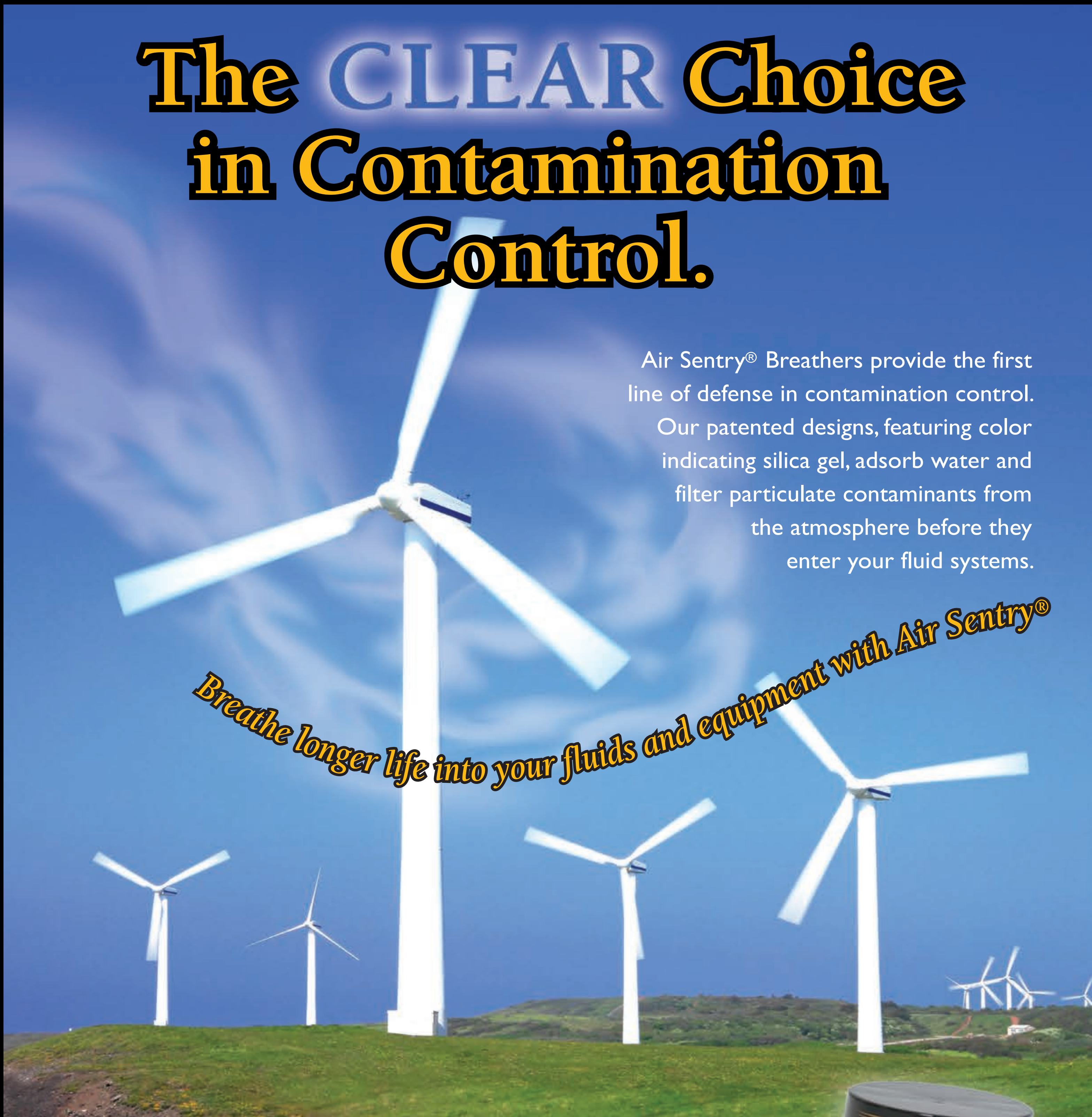
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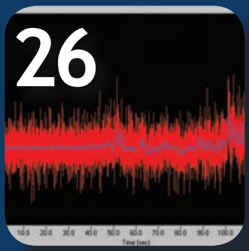
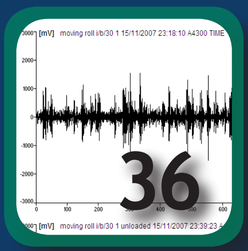
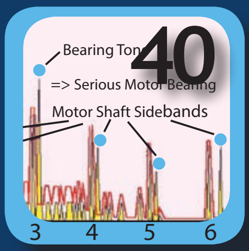
What Exactly is a Maintenance Manager and What Do They Actually Do?
In this humorous article, you will learn where maintenance managers come from, how they got there, what most people (including themselves) think they do and what they should be doing.

Optimized Planning and Scheduling
Explore how a small reduction in unplanned and emergency work can lead to significant cost reductions and improvement in real-world resource availability and productivity.







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information technology
implementing EAM successfully... the top 7 critical pitfalls to avoid

lubrication
what you need to know about filter element ratings

reliability
RCM2 and the building blocks of a maintenance philosophy

Solutions

I'd like to bring your attention to the Solutions 2.0 conference that will take place Nov. 17th-19th in Daytona Beach, FL. This conference is going to be quite unique. I know that budgets are tight these days, but if you can go to only one event this year, this is the one.

The breadth and depth of the speakers and presenters is simply unmatched, including over 50 Uptime® PdM Award Winners, Book Authors, Subject Matter Experts, Operations Executives, Maintenance and Reliability Professionals and some of the most innovative thinkers in Operational Performance Management and Sustainability.

Perhaps the most unique feature of Solutions 2.0 is that it includes the Operations Performance Summit - a specific track dedicated to operations excellence in manufacturing. Yes, that's right....operations personnel will be attending this maintenance conference, which will make for some outstanding opportunities for meaningful dialogue.

Go to www.maintenanceconference.com to learn more about this ground breaking event. With its dedicated Twitter page, MaintenanceForums.com thread and Maintenance Professionals group (www.maintenance.org) you can start your conference experience through social networking as soon as you register.

You might notice that we have made some changes to the magazine in this issue, making some articles available exclusively in our digital issue. We are very much enamored with all of the possibilities and opportunities that digital publishing has to offer, and would like for some diehard print readers to take the digital version for a test drive. So please check your e-mail inbox for the digital issue to access even more articles.

Of course, digital publishing is the future, for both environmental and technological reasons. It's funny to think that when I was growing up, there were no cell phones, and, in fact, you were tethered to a cord when talking on your home phone. Now, you can read Uptime articles from almost anywhere in the world right on your cell phone. My kids started creating Powerpoint presentations in the 3rd grade, so who knows what the technological landscape will look like when they are ready to enter the workforce. No matter where technology takes us, Uptime strives to stay on the cutting edge.

I hope you enjoy this issue. As always, thank you for reading. We appreciate your support, and hope you find value within these pages, the digital issue and on our website. If you have any questions, comments or suggestions that will make Uptime more useful to you, please let us know.

All the best,

Jeff Shuler
Editor In Chief
jshuler@uptimemagazine.com

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Please address submissions of case studies, procedures, practical tips and other correspondence to

Jeff Shuler, Editor In Chief
Uptime Magazine
PO Box 60075
Ft. Myers, FL 33906
888-575-1245 x 116
jshuler@uptimemagazine.com

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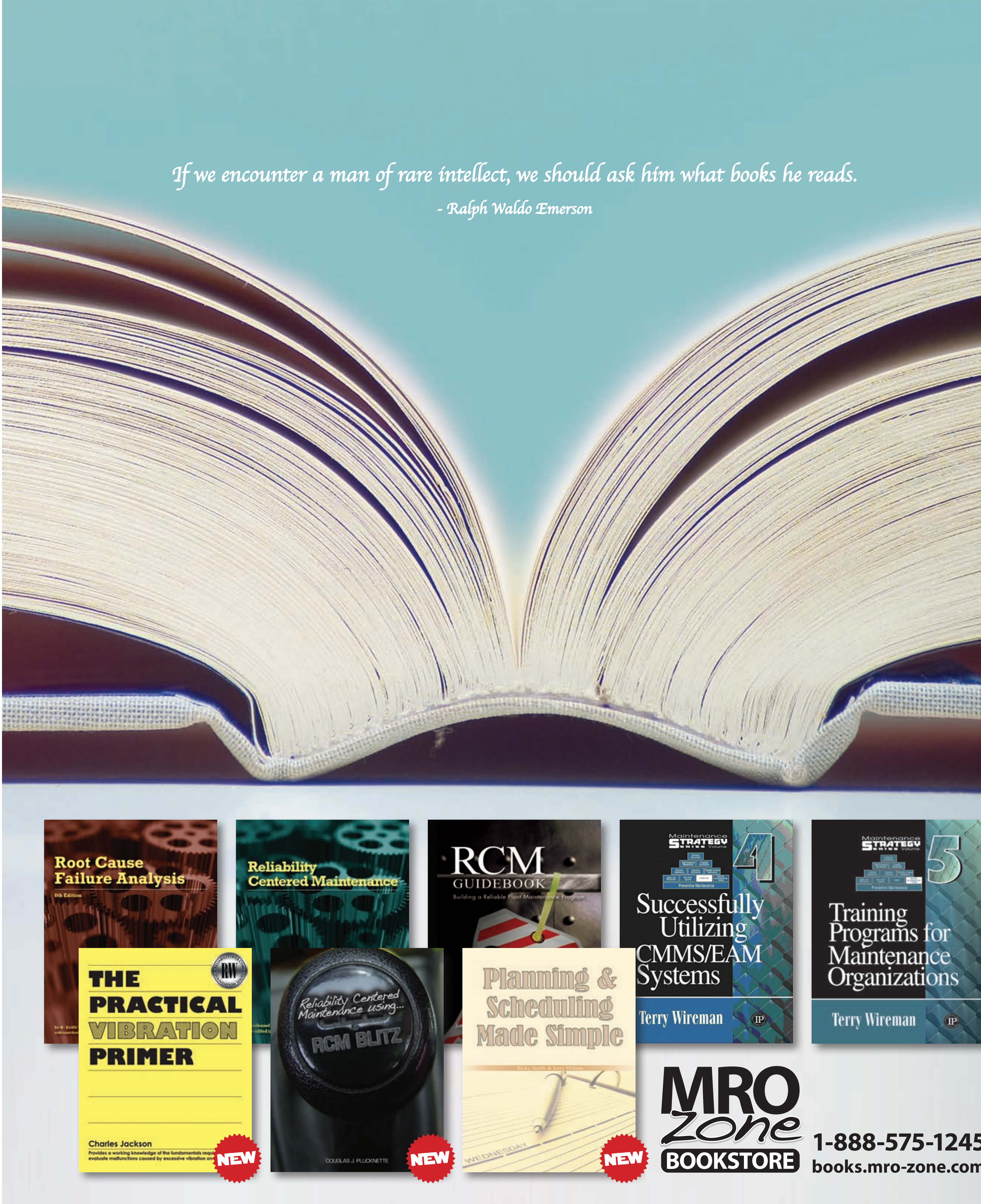

If we encounter a man of rare intellect, we should ask him what books he reads.
- Ralph Waldo Emerson
Root Cause Failure Analysis
6th Edition
Reliability Centered Maintenance
RCM GUIDEBOOK
Building a Reliable Plant Maintenance Program
Maintenance Strategy Series Volume 4
Successfully Utilizing CMMS/EAM Systems
Terry Wireman
Maintenance Strategy Series Volume 5
Training Programs for Maintenance Organizations
Terry Wireman
THE PRACTICAL VIBRATION PRIMER
Charles Jackson
NEW
Reliability Centered Maintenance using... RCM BLITZ
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Lubrication

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Effective Guidelines for Implementing a Well-Engineered Lubrication Program

by Kevan Slater, CLS

A global recession, combined with intense global competition, is forcing many companies to review and search for a "proven" method of reducing their overall maintenance costs while increasing the reliability of their aging equipment. Despite the continuous preaching of the benefits of implementing an effective lubrication program, many organizations still lack the formal direction and understanding required. This article will provide a proven methodology and direction to obtain the benefits of a Well-Engineered Lubrication Program.

Many companies' maintenance departments throughout the world have undergone radical changes over the last ten years in how they perform maintenance on plant equipment. Increasing energy and raw material costs are forcing another round of creative measures to produce a reduction in overall operating costs while increasing the reliability and plant equipment availability just to remain competitive in the growing global economy. Many of these organizations jumped into implementing and using the latest maintenance technologies at enormous expense, all with a promised and expected immediate return on their investment. In many cases, those changes have not led to significant improvements and the technologies have not produced the benefits, despite the quality of the implemented technologies.

For decades, these same organizations have been bombarded with information and endless case studies of the benefits of implementing an effective lubrication program. The benefits associated with this program reach out wider than the equipment reliability, plant availability gains, and the reduction in operating costs in most industrialized plants. These gains can also increase the entire business effectiveness by improving risk-safety, environmental integrity, energy efficiency, product quality, and customer service to mention a few.

It appears that despite the efforts in awareness, many plants still ignore, disbelieve or just struggle to define and comprehend the requirements of a quality lubrication program. While the basis of an effective lubrication program is to provide; the right product, in the right location, in the right amount, at the right time, in the right condition and by the right person – there are many other factors required. To successfully implement these lubricant related activities within a plant, it requires that all of the lubricant related activities fit into and become a part of the work process. It cannot stand on its own as a separate or extra task, but must be fully integrated and be part of the work culture.

As with all effective maintenance programs, a review should be performed to understand and improve the effect of implementing, integrating and immersing these controlled activities within your facility. The four main categories that require review are:

Management and Work Culture – A successful maintenance program requires a management team and an organizational structure that, through good communication and informed knowledge, can provide effective maintenance decisions. Management must set forth a business plan that includes the organization's goals, objectives and expectations. By providing a clear understanding of all maintenance rolls and responsibilities, the individuals involved in the maintenance activities can be held accountable.

Maintenance Work Processes – The maintenance work processes must start by identifying the correct maintenance activities while providing a path to include work initiation, work execution and work completion. This workflow process must also include the integration of procurement and scheduling of parts that will be used in the maintenance activities.

People Skills and Human Resources – A well-trained work force is a prerequisite for any maintenance approach to be successful. The work culture, management and staff 'buy-in,' training requirements, and people skills are all critical for success.

Technologies – This category focuses on the tools required to support the staff. There have been significant advancements in the technologies that can help an organization meet its goal of keeping the plant commercially available. These can range from maintenance and diagnostic systems to information integration systems.

Lubrication Management

The Lubrication Program needs to begin in ensuring all equipment-specific information regarding the critical equipment; maintenance, procedures, and technologies that are presently in place are accurate and up-to-date. By evaluating these issues, timely and beneficial recommendations can be made which focus on elements essential for immediate benefits as well as targeting medium and long-term reliability goals for your lubrication program.

An effective lubrication program should produce significant benefits in plant reliability and equipment availability. Conducting an internal or external assessment of your existing lubrication program and comparing it to industry "Best Practices" will provide a needed gap analysis for identifying both strengths and weaknesses. Once identified, a focus on improvements can be made that yield optimal performance from your lubrication program. The areas for review in a Lubrication Program Assessment would be:

- Standards, Consolidation & Procurement
- Storage, Handling and Disposal
- Lubrication and Re-Lubrication Practices
- Contamination Control
- Sampling Methods and Collection
- Lubricant Analysis Program
- Safety Practices
- Procedures, Guidelines and Training
- Program Management
- Program Goals or Metrics

Although an assessment is a subjective process, the use of a visual graphic spider chart will provide a dynamic overview of the company's strengths and weakness in its existing lubrication program. A spider chart can quickly identify the current status for each section of a lubrication program, which will allow effort to be focused on weaknesses. By improving weaknesses quickly, the lubrication program will be strengthened quicker. Remember, you are only as strong as your weakest link.

Lubricant Selection

The first, and most important step, is selecting and using the correct equipment-specific lubricants. By simply selecting the proper lubricant, the life of both the equipment and lubricant will be extended, which should be a cornerstone goal of the lubrication program.

Many organizations think that the task of selecting the correct lubricant ends at either the directions outlined in the Original Equipment Manufacturers (OEM) manual or general recommendations from a lubricant supplier. This information is only the starting point and should be considered along with current operating conditions, the operating environment, equipment criticality, historical information, reliability requirements, and the chosen maintenance strategies (CM, PM, PdM, PaM, etc).

Manufacturers of rotating equipment utilize powerful computerized programs that optimize finite element analysis and logarithmic contact profiles to assist in the design of the equipment bearing rollers, roller raceways, gearing sets, etc. This is intended to improve the quality of the materials that, in turn, improves the operating efficiencies of the components.

These elements or components move by sliding, rolling, approaching and receding or a combination of these actions and require a lubricant designed to avoid contact between the surfaces. The specific lubricant (viscosity, basestock and additive package) used will ultimately be based on the equipment design, the material, the surface finish, the geometry of the components and the operating conditions (i.e. load, speed, and temperature). To generalize based on the equipment design, the lubricant viscosity and additives must create an acceptable film thickness to maintain a separation of the moving elements (See Figure 1). If contact of the surfaces occurs, then high frictional forces will lead to high temperatures, lubricant degradation and unacceptable wear of the components.

The Original Equipment Manufacturers (OEM) plan the life expectancy of their equipment based on many of the areas or elements listed above. Since the average person or company operating the equipment does not typically have access to this design criterion, we must ensure that we follow and understand the lubricant requirements based on our equipment specific operating conditions, which are outlined in either the Operating and/or Maintenance Manuals. Equipment that is operating outside the average operating conditions outlined in these manuals will require active communication with the OEM's technical service engineers in order to achieve the expected reliability of the equipment at an acceptable operating cost.

Lubrication is an essential design principle of the equipment and is accentuated by modern machines that operate at higher speeds, under heavier loads and with closer mechanical tolerances.

Building the Foundation

An effectively installed Lubrication Program benefits most departments within a facility, including engineering, operations and maintenance. It manages the process of lubricant selection, assessment, procurement, storage, handling, monitoring, and disposal, to ensure the safe, reliable and economic operation of lubricated equipment. Identifying the equipment-specific lubricant requirements creates the foundation of this program. This includes OEM design features, operational parameters, maintenance activities or implemented modifications. This data is referred to as the "technical basis" for lubricant selection. Once collected, this data should be maintained within a controlled database (a Lube List) that provides a direct link between the equipment identification and justification for lubricant selection.

Experience has proven that many Computerized Maintenance Management Systems (CMMS) or Enterprise Asset Management Systems (EAMS) do not contain the actual or required detailed equipment information for obtaining this lubricant technical basis. Lack of information within these management databases appears to be due to various reasons, including the initial equipment data installation methodology, upgrades or changes in the software platforms and/or changes of the installed plant equipment. The most common reason identified is lack of manpower along with the associated costs of field verification. Field verification and recording of the installed equipment base and the actual environmental conditions in which the equipment operates is a necessary starting point for all lubrication programs. Figure 2 is an example of a basic walkdown form, which identifies the equipment, the operating conditions and the operating environment. This completed form should provide the necessary information required to review the OEM operating and maintenance manuals.

This walkdown information must include as much information as possible about the equipment, including its internal design, the system design, and the current operating and environmental conditions. Failure to gain full understanding of the equipment's

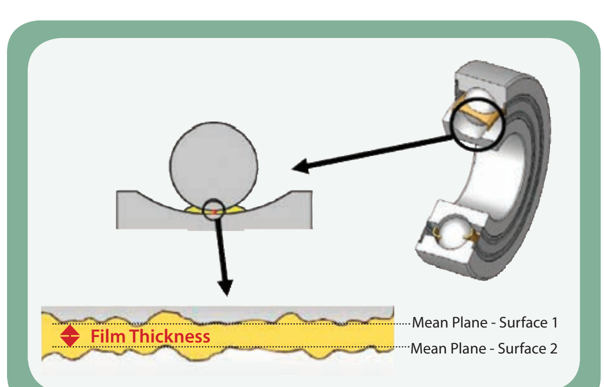

Figure 1 - Measuring Film Thickness

Description of Equipment	Walkdown Information
Equipment Code	JP-S12345
Equipment Location	Level 1 Column 6B
Component Type	Horizontal Reducer
Manufacturer	Any Company
Model	1235
Serial Number	ABC123
RPM (input/output)	Input 1775 / Output 500
Lubricating Method	Splash
Operating Temperature (C/F)	125˚C
Ambient Temperature (C/F)	30˚C
Expected Ambient Temp Range (C/F)	-25˚ to +35˚C
Moisture/Steam Exposure	90% RH and wash downs
Dust Exposure	N/A
Other Contaminants	N/A
Safety Requirements	Slip Hazard

Figure 2 - Basic Walkdown Information

operating needs and conditions undermines the program's effectiveness. The following sections highlight the most basic information that is required as a reference to determine the correct lubricant to be used, along with the information required to set equipment targets and limits.

Equipment Mission Criticality – Safety, environmental concerns, past historical problems, reliability as well as the cost of downtime and repairs must all be taken into consideration when determining the equipment to be included in the lubrication and analysis program. The equipment to be monitored, the frequency and the selections of all health monitoring tests should be determined by the above criteria.

Equipment Component and System Identification – Collecting, categorizing and evaluating all design and operating manuals including schematics is required to understand the complexity of modern equipment. OEM's assistance in identifying the original bearings, wear surfaces and component metallurgy will take the guess work out of selecting lubricants, setting targets and limits and will also assist in future troubleshooting. Equipment nameplate data with accurate model and serial numbers allows for quick and easy identification.

Operating Parameters – Equipment designs and operating manuals reflect the minimum requirements for operating their equipment. These include operating temperature, recommended lubricants, pressures, duty cycles and filtration to name a few. Operating outside the recommended values could require modifications and/or additions to the system to allow the component to run within an acceptable range.

Operating Equipment Evaluation – A visual inspection of the equipment is required to examine and record the equipment components used in the system including filtration, breathers, coolers, heaters etc. This inspection should also record all operating temperatures and pressures, duty cycle times, rotational direction and speeds, filter indicators etc. Temperature readings of the major components are also required. This information verifies that the OEM supplied equipment is still in operation and also reflects the current operating characteristics of the equipment.

Operating Environment – In most cases, hostile environments or environmental contamination are not taken into consideration when the OEM designs the operating parameters. Environmental conditions can influence the degradation of a lubricant, which eventually results in damage to the equipment. All environmental conditions such as mean temperature; humidity and all possible contaminants must be recorded.

Maintenance History – Past reliable history that relates to wear and lubrication related failures can assist in decisions pertaining to lubricant selection and frequency of application. It can also provide guidance when adjusting and tightening targets and limits. These targets should allow

Equipment ID	Name	Ambient Temp (1-20-05)	Operating Temp (1-20-05)	Temperature Rise (F)	Projected Summer Operating Temp (F)
BL107-B	Yellow Vacuum Blower	59	72	13	102
BL304-A	Blower for Airline under Drier	67	150	83	180
BL305-A	Blower for Rework Station	60	125	65	155
AC603-A	350HP Centrifugal Compressor	79	140	61	170
PU106-A	Breakwater Pump FPS	60	101	41	131
PU202-A	Ammonia Pump	67	97	30	127
PU719-A	Primary Mix Tank	45	65	20	95

Figure 3 - Projected Operating Summer Temperatures

for early advanced warnings of historical problems and possible root cause detection.

By combining the information collected during the equipment walkdown with a practical understanding of the plant specific operating conditions, an evaluation can be conducted to determine if there are any items or conditions (i.e. wash downs, temperature changes, summer/winter temperature extremes) that should be taken into account when reviewing the OEM manuals. Figure 3 is an example of a plant that projected their typical summer operating temperatures based on the installed temperature regulating devices (air only). In their case, the OEM referenced the actual operating temperatures for the lubricant selection. Manufacturers tend to provide a reference to either an ambient temperature range or an actual operating temperature in the manuals as the reference for lubricant selection. Once evaluated, this information can also be used in determining some of the lubrication maintenance activities based on the typical life expectancy of the installed lubricant.

Manufacturer's Recommendations

In their operating or maintenance manuals, manufacturers may recommend lubricants by brand name or by specifying the lubricant characteristics required for a particular operating condition. Figure 4 is an example of a manufacturer that provides good detail of the equipment conditions, but little detail on the lubricant requirement itself. Using the information in Figure 4, we can determine that a parallel shaft unit at an operating speed of less than 250 RPM and operating within an ambient temperature range of 90° to 125°F (32° to 52°C) will require a lubricant that is an ISO VG 320 with a mild EP additive. This information and lubricant selection is based on this particular unit with these specific operating conditions. Please note: If identical units are used throughout the plant and they are either in an area that has a different ambient temperature range or are operating at different speeds, then these units could require different lubricants in order to meet and perform within the OEM specifications.

SPEED In RPM					Viscosity, 100°F (38°C)	
Hypoid Units (Pinion)	Spiral Units (Pinion)	Differential Units (Lineshaft)	Parallel Shaft Units (Pinion)	3100 & 4100 Series (Pinion)	Ambient Air Temp 50-90°F (10-32°C)	Ambient Air Temp 90-125°F (32-52°C)
			Above 750		400-500 SUS 86-108 CS	600-750 SUS 129-163 CS
Above 400*	Above 300*	1000* and Below	250-750	1000 & Below	600-750 SUS 129-163 CS	900-1150 SUS 194-249 CS
200-400*	Below 300*	Below 500*	Below 250*	Below 500*	900-1150 SUS 194-249 CS	1300-1600 SUS 280-346 CS
Below 200*					1300-1600 SUS 280-346 CS	1600-2000 SUS 345-432 CS

* - "Mild" extreme pressure additive suggested. (Mild EP)

Figure 4 - Beloit Lubrication Selection Chart

When an OEM suggests or recommends a specific lubricant, these lubricant specifications may become restrictive, or they may be very general, allowing considerable latitude. Regardless, at this point, we must start to research the OEM recommended and preferred oil producers. This product information is published in brochures, pamphlets, handbooks, or on the product container or packaging. Although the amount of information varies from each oil producer, it generally includes the intended use, the additives (AW, EP, R&O), oil type (i.e., paraffinic, naphthenic, synthetic, compounded), and some of the technical specifications or test results. Understanding and comparing lubricant qualities and the provided test results (i.e. Pour Point, "C - ASTM D 97 or 4 Ball EP Test - ASTM D 2783) can become very difficult without a prior knowledge of the test methods and the expected results. Figure 5 is a very basic lubricant comparison chart that can have specific test method results added to assist in the selection or substitution process.

	OEM Recommended Lubricant	Substitute Lubricant	Potential Concern
Lubricant Type Lubricant Name			
Lubricant Manufacturer			
Operating Temp Range (C)			
API Base Oil Group			
ISO Viscosity Grade			
Viscosity Index			
Hydrocarbon or Synthetic Type			
Additive Types			
Shelf Life			
Compatibility			
MSDS Concerns			

Figure 5 - Basic Lubricant Selection Chart

Companies that have very specific lubricant requirements outside the typical OEM recommended lubricants (e.g., "Food Grade" applications), will have to proceed with extra caution when selecting or crossing a lubricant. The selection process must ensure that the lubricant not only meets or exceeds the physical, chemical and performance properties required by the equipment for reliable service, but also meets the food grade qualifications.

Armed with the equipment specific OEM advised lubricant, it does not mean that we have necessarily chosen the best lubricant for the application. This selection is just the starting point, as the final selection should include a process of past operating experience and the equipment criticality outlined within the facility's maintenance strategic objectives.

Operation and maintenance activities that have historically utilized a lubricant which provides acceptable equipment reliability within the desired operating costs could remain the lubricant of choice. However, to remain globally competitive, avenues for continued improvement should be explored. These improvements could be in the direction of:

- Advanced equipment protection
- Improvements in Worker Health and Safety
- Compliance with environmental regulations
- Lower yearly energy requirements

The next step requires an understanding that all effective maintenance and/or lubrication programs require plant equipment to be categorized into criticality levels. This strategy determines a numerical ranking of the plant assets (systems and equipment) according to their commercial availability, safety, environmental, cost and efficiency requirements. Reliability Centered Maintenance (RCM) is one method that is a conceptual exercise identifying the most effective and applicable maintenance tasks for each piece of equipment. A full classical RCM study involves an exhaustive investigation of all failure modes and their effects. This approach can be streamlined by investigating the common known failure modes and the effects analysis (FMEA), as well as determining effective and applicable maintenance tasks to address these conditions. Regardless of the method used, understanding and utilizing this ranking system should allow focus on selecting lubricants that provide:

- Cooler operation or lower operating temperatures (less heat from friction)
- Longer equipment and mechanical components life (due to lower friction and wear)
- Increased oil life (lower wear metals and reduced oil oxidation)
- Lower maintenance cost (fewer oil changes and disposal costs)
- Energy Savings (less energy lost to friction)

In many instances, these same lubricant requirements for critical equipment should be reviewed for the equipment deemed to be less critical and moved into the run-to-failure mode. An example would be a gearbox or reducer that, if filled with clean, dry high performance synthetic gear lubricant and then allowed, as per the maintenance strategy, to run-to-failure. This gearbox should provide an increased life expectancy coupled with a reduction in overall energy usage for a very small investment in the synthetic lubricant over a lower priced commodity gear lubricant.

Finally we move into the facility's consolidation of the lubricants. This definitely has advantages, including reduced inventories and reduced storage requirements due to the overlap of "like" lubricants. In too many cases, the sole criterion for consolidation is cost. Often times, decisions to take advantage of price breaks given for bulk purchases result in overlooking the technical requirements, quality implications, or the effects of interchangeability of lubricants. These all have a significant adverse effect on equipment reliability. Consolidation should be accomplished through the services of a lubricant specialist or a facility employee who has knowledge of the equipment's operating characteristics, the lubricating requirements, and has an ability to understand the lubricant producer's technical data sheets.

Lubrication Management

Equipment reliability requires that the selected lubricant meets and maintains specific physical, chemical and cleanliness requirements. A detailed trail of a lubricant is required which begins with the OEM (lubricant supplier) and ends after disposal. Sampling and testing of the lubricants is required to validate the condition of the lubricant through all these phases.

Lubricant Supplier – Quality control programs implemented by the lubricant manufacturer should be questioned and recorded when evaluating the supplier. Sampling and testing new lubricants before dispensing ensures that the vendor has supplied the correct lubricant.

Lubricant Storage – Correct labeling (including MSDS) must be clearly installed to ensure proper use of the enclosed contents. Proper stock rotation and storage methods must be taken into consideration to prevent the degradation of the physical, chemical and cleanliness requirements of the lubricant throughout the storage and dispensing phase.

Handling and Dispensing – Handling and dispensing methods must ensure that the health and the cleanliness of the lubricant meet the specifications required by the equipment. All opportunities for contamination must be eliminated. Pre-filtering of all lubricants must be performed to meet the specific equipment requirements. Information for all Preventive Maintenance activities involving oil drains, top ups, sweetening, flushing or reclaiming, should be recorded and forwarded to the individual responsible for the oil analysis program group in a timely manner. Record keeping of any activity involving lubricant consumption, lubricant replacement and/or lubricant top-ups performed must be implemented and maintained. Visual management techniques should be utilized to ensure the correct lubricant is being used for each lubrication point.

Oil Sampling Location(s) – A sampling location should be determined to allow for trouble-free, repetitive and representative sampling of the health of the equipment and the health of the lubricant. The sampling method should allow the equipment to be tested under its typical operating condition and allow a safe sampling procedure for the technician.

Tests – As a general rule, oil analysis encompasses four categories of tests: (1) Fluid physical properties, (2) Fluid chemical properties, (3) Fluid contamination, and (4) Machine health. A general routine group of tests does not necessarily take into consideration the machine specifics. Equipment specific testing will supply the required data to effectively monitor and trend the health of the lubricant and the equipment, while exception tests verify a root cause of change.

Targets and Alarms – OEM operating specifications or a recognized governing body can be used in setting the minimum alarms. These alarms must be set taking into consideration all of the above collected information. These settings must provide early detection of contaminants, the deterioration of the lubricant and the current equipment health. These achievable targets should be set to supply an early warning of any anomalies, which will allow corrective actions to be scheduled and performed with little or no effect to production schedules.

Waste Oil – Oil deemed unfit for equipment usage must be disposed of in the correct storage container for that type of lubricant and properly marked and labeled. The lubricant must then be classified for the proper type of disposal and removed from the property without delay. Long storage times allow for the introduction of contaminants (e.g. water) and other fluids, and could in some cases result in re-classification.

Database Development – A database should be developed to organize equipment information, the collected data and the equipment specific targets and alarms. This database must allow for smooth operation of data entry as well as have excellent capabilities for performing the analytical work. The end user must have control of the targets and limits in order to reflect the true equipment specific conditions within the plant.

Contractor Overhaul Templates – Components which are not overhauled in an in-house program should have a guideline or template of the overhaul procedures and required component replacement parts. These templates are a quality control measure to ensure the information in the audit database is kept up-to-date, but also to ensure compatibility of components and lubricants currently used.

The Lube List

After collecting, calculating, and evaluating the technical basis for lubricant selection, we need a controlled repository for this information. Microsoft Access and Excel are both flexible enough to accommodate this task, allowing custom fields and entry screens that can be accessed by all required plant personnel. While this Lube List doesn't have to be part of a work management system, an individual that is competent in lubrication management should control it.

At this point, the lubricant specifications are now based on equipment-specific requirements. These consist of the OEM recommendations, the actual environmental and operating conditions, historic and equipment criticality evaluations and an effective consolidation review. This information, the "Lube List", is stored in a controlled location. The final step is to create a document to define these lubricant specifications, the purchasing criteria, and the actual receipt of new lubricants to ensure the quality of the lubricant.

Training

Any high quality lubrication program requires individuals with world-class reliability skills. The operators and mechanics that are directly responsible for lubrication must be properly trained, and individuals that are indirectly involved in the lubrication program should also have at least a basic awareness of the program's goals, primary benefits, and its procedural requirements. In order for the organization as a whole to increase equipment reliability through lubrication excellence, it's vital that a lubrication skill development program be put in place to meet the needs of all individuals who have responsibility for lubrication tasks, or that may have input into the lube program.

Mechanics are most intimately familiar with the internal workings and condition of the plant's equipment, and they need sufficient technical knowledge about lubrication fundamentals to spot and accurately diagnose lubrication-induced abnormalities. These fundamentals also prove the importance of maintaining or restoring cleanliness during repairs and/or lubricant related activities.

Operators typically perform lubrication tasks and conduct inspections of equipment condition. This is a great opportunity to collect simple, inspection-based lubrication information. Beyond the level gauges, the operators should regularly inspect for filter and desiccant condition, evidence of water contamination, foaming and air entrainment, leaks, darkening of the oil, sludge, smoke or fumes exuded from vents, and a host of other easy-to observe conditions. These activities should be set up as a routine and controlled by the work management system to promote accountability and activity adherence. Operator Driven Reliability (ODR) lubrication training should be provided to ensure competency in performing these functions.

Measuring The Program

The establishment of meaningful goals and metrics remains a key element to implementing or improving your lubrication program. The maturity of the program will determine which key performance indicators should be used to move the lubrication program towards lubrication excellence by meeting or exceeding lubrication industry best practices.

The Lubrication Assessment process will assist in identifying the current status of the program, but a focus and vision of your organizations specific goals will ultimately direct the development of the key indicators. These indicators should steer the lubrication program to meet the overall operating and maintenance requirements of the facility.

The primary goal during the early development of the lubrication program is the identification of overall program needs and the development of roles and responsibilities. As the lubrication program matures, the focus of the lubrication program goals and metrics should move from the development process to more proactive measurements. These might include refining lubrication limits and alarm levels, determining root causes of lubricant-related equipment failures, extending or eliminating lubrication PM tasks, improving the lubrication consolation process and reducing oil consumption. The fol-


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lowing is a simplified list of potential key indicators that could be used as the lubrication program matures:

Reduce Lubricant Costs – In a lubrication optimization program, the goal is to minimize the purchase of new lubricants through the consolidation of products, the elimination of time-based oil changes, and to minimize waste and leakage. When properly done, all of these measures should have a measurable effect on the dollars being spent annually on lubricants.

Improve Compliance to Scheduled Lubrication PM Tasks – All lubrication tasks need to be scheduled activities - from the daily level checks, sampling for oil analysis, regreasing, top-ups, and scheduled oil changes. Measuring the percent conformance of PM's that were scheduled and completed, to that of PM tasks that were not completed within the required parameters (time, date, frequency, etc) allows for a quick and accurate view of PM compliance.

Adjust or Redefine Analysis Alert or Alarm Limits – Initial temperature, pressure and oil analysis alarms must be reviewed to ensure that the original target values are correct and that they appropriately reflect the equipment-specific operating condition of the equipment components. This is often accomplished by incorporating feedback from the maintenance activities and using lessons learned resulting from root cause analyses of failed components.

Improve Equipment Reliability – Performance indicators that relate to equipment reliability and availability remain significant to the effectiveness of the lubrication program. The goal is to minimize or reduce the number of lubrication-related equipment failures or significant events, but this remains difficult to determine if the actual root cause of an anomaly is not correctly identified.

Improve Oil Cleanliness Levels – It has been well documented that by improving the cleanliness levels of a lubricant, it will have a direct effect on the life of the component. Improvement in handling, storage, dispensing and filtration methods will assist in reducing the acceptable cleanliness levels, which will result in improved equipment reliability with the associated reduction in maintenance costs.

Tracking and Trending Lubricant Disposal Costs – Understanding total consumption, leaks, top-ups, and oil changes, helps drive the efforts and behaviors needed for the effective implementation of the lubrication program.

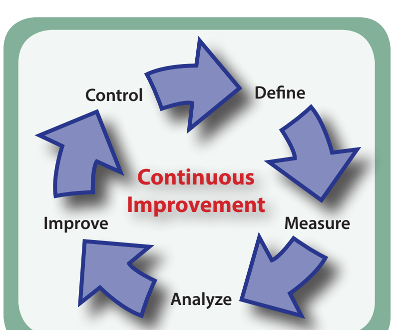

Figure 6 - Continuous Improvement Loop

Many organizations ignore the fact that lubrication is an essential design principle of the equipment and only a dedicated, consistent and enduring effort to increase the plant's lubrication knowledge and maintaining the design requirements of your equipment will dramatically improve equipment reliability, uptime and profitability.

Kevan J. Slater is an independent senior reliability consultant. Kevan has spent the last 20 years as a senior technical consultant developing, advocating and implementing technical, business and operating strategies for improving the reliability of industrial equipment to numerous companies throughout North America. Kevan's expertise focuses on improving and building maintenance foundations that promote continuous improvement of equipment reliability by ensuring people; technology and processes align in achieving a balanced reliable cost effective maintenance program. He can be reached at 416-759-0870 or at kevan.slater@sympatico.ca

No Outage Inspections

Which Tools Are Best For Medium Voltage Electrical Inspections

by Don Genutis

Although there are many useful electrical 'on-line' predictive maintenance technologies available to assess equipment condition, this article will outline and discuss the most effective tools for determining the condition of medium and high voltage equipment. A brief application summary is included for each technology in order to enhance your understanding or, if you are already familiar with the technologies, to serve as a review.

Visual Inspections are very useful but may be limited due to equipment construction. However, it is always recommended to conduct thorough visual inspections in conjunction with any of the other 'no-outage' technologies. Visual inspections may indicate unusual conditions that other technologies may not directly detect.

Infrared (IR) technology is primarily used to detect conductor problems and can be useful for inspecting any equipment where connections are visible. It is important to realize that insulation problems rarely create a detectable temperature rise, so other technologies should also be employed. IR is probably the best on-line tool for detecting low voltage problems.

Partial discharge (PD) testing using electromagnetic signal detection is very useful in identifying problems within switchgear, cables, dry-type transformers and other devices. PD testing is not as effective as Airborne Acoustic or Corona Camera surveys when inspecting "open" constructed equipment. A new handheld PD detector (shown in Figure 1) has been developed that combines ultrasonic and electromagnetic sensor technologies into one easy-to-use instrument which allows medium voltage insulation to be surveyed for defects in an efficient and cost-effective manner.

Figure 1 - A technician applies a handheld PD Detector against the medium voltage switchgear enclosure to detect electromagnetic activity associated with internal breakdown.

Airborne Acoustic (AA) or ultrasonic listening can be useful in detecting direct line-of-sight surface insulation problems or when the acoustic signal escapes the equipment enclosure through openings. One advantage of using ultrasonic inspections is that surveys can be conducted quickly.

The Corona Camera detects direct line-of-sight surface insulation or conductor problems very effectively by producing an image of the problem that is normally invisible during daylight conditions. This technology is perhaps the best for outdoor substations or high voltage applications, but also supplements the other no-outage technologies by providing visual proof of surface problems. Just as every apparatus with connections should be scanned with IR, all medium & high voltage equipment should be scanned for Corona.

Oil/Gas sampling and analysis is an effective tool to indicate both the condition of the insulation and the condition of the equipment. Unfortunately, solid insulation cannot be sampled in the same manner, so other on-line technologies must be employed to evaluate equipment constructed with solid dielectrics.

Comparing the No-Outage Technologies

Remember the old saying – "a picture is worth a thousand words"? Below we will display the differences in some of these technologies pictorially to better help identify their differences.

First, we should briefly explain the differences between two popular inspection methods, infrared and partial discharge technologies. Infrared technology detects heat that is generated by current flow or amperage related problems that are often caused by loose connections. So, infrared detects the condition of the conductor. Partial discharge, ultrasonic and corona surveys detect voltage problems that occur from the partial failure of the insulation. So, these technologies detect the condition of the insulation. In order for partial discharges or corona to occur, typically voltages greater than 2,000 volts must be present. Therefore, these technologies are not effective for low voltage applications.

Figure 2 - The Test Set-Up. The thicker conductor is an unshielded, single conductor cable and the thinner conductor is at ground potential. The AC hypot is at the far left of the picture.

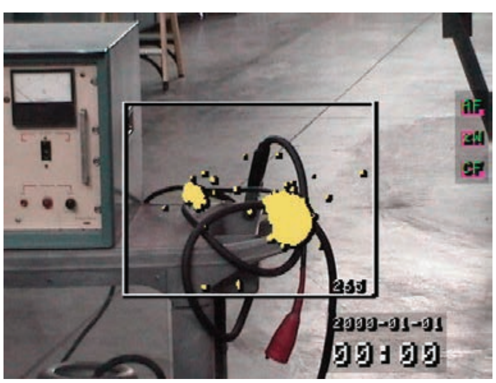

Figure 3 - The yellow areas of this photo show the ultraviolet light associated with the corona that is occurring between the energized and grounded conductor.

Figure 4 - This infrared image of the same event does not show any appreciative temperature rise.

Now, back to the pictures. We created simple, surface discharges in the laboratory by applying an AC hypot to an unshielded medium voltage conductor that was placed upon a ground conductor. We then performed several types of tests as shown in Figures 2-6.

What conclusions can be made from this simple experiment and our previous knowledge of these technologies?

- Infrared is the best tool for low voltage equipment assessment. This should be a "minimum" annual test requirement, especially for low voltage equipment.
- For medium voltage switchgear and dry-type transformers that have surface tracking or corona problems, the Ultrasonic tester provides a quick and relatively inexpensive solution that will detect many problems.
- A Partial Discharge test set using a capacitive sensor can detect "deep" or non-surface insulation defects in medium voltage switchgear and dry-type transformers and should be used to supplement the ultrasonic test set in order to detect additional problems.

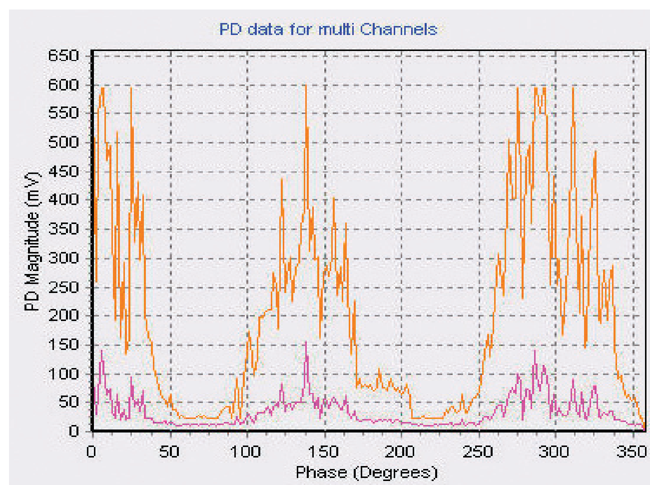

Figure 5 - Partial discharge test results clearly show a dangerous problem. The larger signal was obtained using a high frequency current transformer placed around the ground conductor and the smaller signal was obtained using a capacitive sensor placed on the test set control unit.

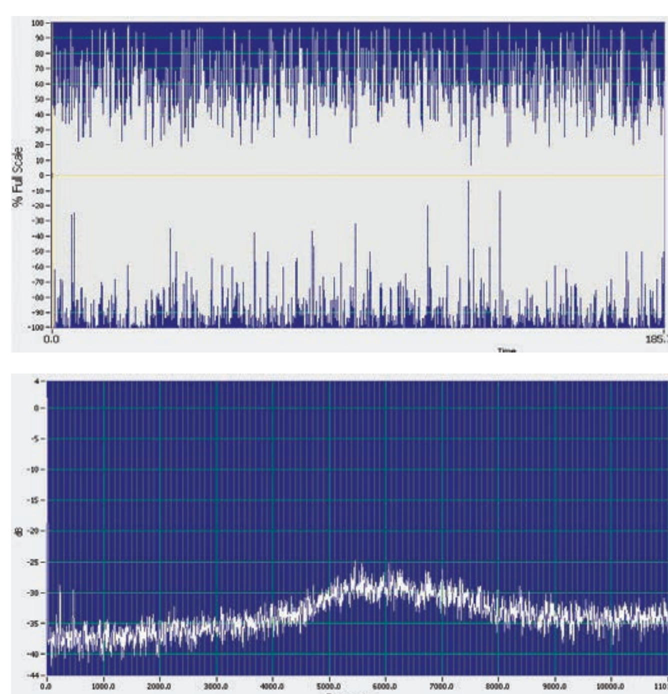

Figure 6 - Magnitude vs. time and magnitude vs. frequency graphs obtained from recording the audio output from an Ultrasonic test set. In this case, the graphs are not very useful but listening to the audio output certainly was.

Equipment	Most Effective On-Line Tests					
Switchgear	Visual	IR	PD	AA	Corona	
Transformers, Dry-Type	Visual	IR	PD	AA	Corona	
Transformers, Liquid-Filled			PD			Oil
Cables, Medium- and High-Voltage		IR	PD	AA	Corona	
Metal-Enclosed Busways		IR	PD			
Switches, Air, M-V, Metal-Enclosed	Visual	IR	PD	AA	Corona	
Switches, Air, M-V and H-V, Open	Visual	IR		AA	Corona	
Switches, Oil, Medium-Voltage			PD			Oil
Switches, Vacuum, Medium-Voltage			PD			
Switches, SF6, Medium-Voltage			PD			Gas
Switches, Cutouts	Visual	IR		AA	Corona	
Circuit Breakers, Air, Medium-Voltage			PD			
Circuit Breakers, Oil, Medium-Voltage			PD			Oil
Circuit Breakers, Oil, High-Voltage			PD		Corona	Oil
Circuit Breakers, Vacuum, M-V			PD			
Circuit Breakers, SF6			PD		Corona	Gas
Circuit Switchers			PD		Corona	Gas
Instrument Transformers		IR	PD	AA	Corona	
Regulating Apparatus, Volt Regulators		IR	PD		Corona	Oil
Regulating Apparatus, Load Tap-Changers		IR				Oil
Rotating Machinery, AC Motors			PD			
Rotating Machinery, AC Generators			PD			
Motor Control, Motor Starters, M-V			PD	AA		
Motor Control, MCC, M-V			PD	AA		
Surge Arresters, Surge Protection Devices	Visual	IR	PD	AA	Corona	
Capacitors and Reactors, Capacitors	Visual	IR	PD			
Capacitors & Reactors, Reactors, Dry-Type	Visual	IR	PD	AA	Corona	
Outdoor Bus Structures			PD			Oil
Capacitors & Reactors, Reactors, Liq	Visual	IR		AA	Corona	
Automatic Circuit Reclosers, Oil/Vacuum			PD			Oil

Figure 7 - No-Outage Testing Matrix

- A Partial Discharge test set using a high frequency current transformer is the best tool to detect cable, termination and splice problems
- A Daylight Corona camera is excellent for pinpointing surface discharges in medium voltage equipment and is the best tool for high voltage equipment

Conclusion

So what is the "best" No-Outage technology? The answer is the one that will detect the problem. While none of the technologies discussed in this article can single-handedly detect every type of problem, by employing all of these technologies as part of an annual predictive maintenance program, many problems will be detected and many failures will be prevented.

The matrix shown in Figure 7 has been created to help identify the best "No-Outage" technologies available for various types of electrical equipment.

Don Genutis received his BSEE from Carnegie Mellon University, has been a NETA Certified Technician for 15 years, and is a Certified Corona Technician. Don's technical training and education is complemented by twenty-five years of practical field and laboratory electrical testing experience. Recently, Don co-founded and acts as President of No-Outage Electrical Testing, Inc. a Group CBS affiliate that focuses on new inspection technologies that are performed while the equipment remains in service. He can be reached at DGenutis@groupcbs.com or 813-752-6051.

Why PdM Programs Fail

Misuse of Technology

by Alan Friedman

Every good mechanic knows that you need the right tool for the job, but a common problem with PdM programs is that sometimes people acquire the tool before fully understanding what problem needs to be fixed. Of course, when you have a hammer all of your problems look like nails, and what follows from this mistaken view is a whole list of reasons why PdM programs fail. The biggest lesson I learned from engineering school is that the solution to a problem is most often found in its correct definition. That is, solutions become obvious when you really understand what the problem is.

We laugh when we read the exchange between the tech support person and the new computer owner who calls to say his wireless Internet is not working. After the tech support person laboriously goes through all of the steps to verify that the hardware and software are all installed and functioning, she asks who the person's Internet service provider is – and, in the pregnant pause that follows, we suddenly know what the real problem is!

One reason PdM programs fail is because the goals of the program are not well defined or well understood. A company purchases a technology like a vibration analysis system or infrared camera and then they get trained to use the tool, but not what to use it for. What they often fail to do is change processes and procedures in the plant to take advantage of the information this new tool provides. In other words, you buy a screwdriver, you learn how to loosen and tighten screws but you somehow fail to see how this does or doesn't relate to the plant's overall operation.

So, what are the goals of a successful program? Depending on your background, experience or role in your organization, you may have differing ideas about this, but how you view this will have a large impact on how you employ the technology and on the sorts of benefits you will receive. It will also ultimately dictate your view of what is the best tool for the job. To reiterate, I believe that the failure of many PdM programs can be traced back directly to confusion or disagreement on this core question: what is the goal of the program? Why are we purchasing this tool (or service), how will we use it and how will we measure our success? In many cases, the tools are purchased before these questions are answered, if they are ever answered. In other cases, the benefits one hopes to achieve are not in line with how the technology is actually being employed.

Let's consider two common viewpoints regarding the goals of a vibration analysis program. One typical view is that vibration analysis is one of the best non-destructive technologies available to detect and diagnose mechanical faults and degradation in rotating machinery. The goal of using the technology is to detect and diagnose faults in rotating machinery – period.

Another common view is that because vibration analysis can be used to detect wear in rotating machines, one can utilize this machinery condition information to better plan maintenance actions. This leads to an increase in uptime, quality and plant performance and a decrease in unplanned maintenance, catastrophic failures and accidents. These benefits, loosely defined as Overall Equipment Effectiveness (OEE), lead to higher profitability. In this view, the lofty goal of the vibration analysis program is higher plant profitability.

This is the crux of many failed programs. Perhaps a manager agrees to purchase a vibration monitoring system or a monitoring service. In his mind, he imagines a 30:1 return on his investment. Maybe he hasn't thought it completely through, but when he considers the benefits of such a system, his mind leans towards the goal of higher profitability. He has read plenty of articles about condition monitoring and profitability and he is sold on the idea of it. Now, a product has been purchased, some technicians and engineers have been given some training, but they understand the goal differently. They use the equipment to detect problems in their rotating machinery; perhaps they even become quite skilled at it. But beyond this, no organizational changes have been implemented to schedule maintenance based on vibration test results, nor have metrics been introduced to calculate and measure the impact of the technology on uptime and spare parts and, ultimately, its impact on the bottom line.

From the point of view of the engineers and technicians using the system, it appears successful. They are able to troubleshoot machines and diagnose problems but imagine what happens when a recession hits and upper management goes around looking for programs to cut. How will these technicians make the case that their vibration program should be preserved? Where is the 30:1 ROI? This is one major cause of terminated PdM programs. The original idea was to impact the bottom line, but the technology was actually used in a more limited fashion. The organizational and procedural changes required to utilize machine condition information to meet the goal of higher profitability were not implemented.

Another issue is the tool itself, the actual equipment or service that one purchases. If we consider the two separate goals mentioned above, it will soon be obvious that the equipment we purchase, and how we use the equipment, will vary based on our goal. Again, I will reiterate that most people purchase the equipment first and never fully reconcile the goal.

Here is a common scenario that describes a plant using vibration analysis to troubleshoot machines and determine what is wrong with them. The plant either has a vibration expert on-site or uses an outside consultant. Typically, someone hears a weird noise coming from a machine or they feel that the machine is vibrating too much. Maybe the machine keeps failing unexpectedly or seems to have more problems than a similar unit. Whatever it is, someone in the maintenance department believes there is a problem, and so they call the vibe guy to troubleshoot it.

The on-site expert or consultant will require customizable high tech equipment that allows him to set up a variety of special tests to troubleshoot the machine. The data collection equipment may have a big screen because the analyst will do a lot of his analysis on the plant floor. The equipment may also have many channels and it will likely be complex and difficult to use. Because there is no historical data, the focus will not be on trending or looking for changes over time, therefore, his equipment will not require any advanced alarming or trending capabilities. It would not be uncommon to expect the analyst to spend multiple hours or even multiple days in some cases, diagnosing the problem and submitting his report. This would most likely be a costly, but hopefully, infrequent expense.

Summary Scenario #1

Data collector needs:

- Big screen
- Many test types
- Customizable, multi-channel, magnet mounted sensors
- Intelligence in the analyzer

Does not need:

- Alarming
- Trending
- Reporting
- Intelligent software

Analyst:

- Highly trained
- Highly paid
- Experienced

Program manager:

- Not much program management required

Now let's consider that the goal of the program is to use the technology to better plan maintenance, ultimately leading to a measurable impact on plant profitability. What type of equipment will be best suited to meet this goal?

In this next scenario, the emphasis is placed on trending because the goal is to look for changes in machine condition and then base maintenance decisions on this information. Time is spent up front defining standard test conditions and organizing the program. This scenario calls for a low cost, efficient worker to collect data in exactly the same way, day in and day out, year after year on the same equipment. The data collection equipment would be "idiot proof" with limited or controlled options for the user, or it may be an online system. Test points on the machine would be screw type sensor pads or installed targets for magnet mounts to insure repeatability. Initiation of a standard test should take no more than a button press. Because the data collection tasks, including the required equipment, have been defined in such a way as to ensure repeatable, relevant and historical data, there is no reason for the person collecting the data to look at or analyze the data on the plant floor. This eliminates the need for the data collector's big screen.

The software will have to be very good at looking at trend data in an efficient way because this scenario also calls for testing most of the plant's machines frequently, not only machines with known problems. Therefore, the analysis software will require the sophistication, not the data collector. There won't be time (or need) for an analyst to spend multiple hours looking at data from each machine; a couple of


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minutes will be enough to see if the condition has changed, a couple more will be needed to understand how it's changed and to update the status and add a recommendation in the software. Additionally, because trends based on good data should provide enough information to meet the goals of this scenario, the data collector will not require the capability to perform advanced customized tests, nor will the technician collecting the data require much training.

Lastly, since this scenario is concerned with improving maintenance decisions and relating them to the bottom line, the software should be part of a larger CMMS package or Plant Asset Management program. Linking results to business goals such as improvements in uptime, quality and plant performance allow maintenance managers to accurately quantify their impact on profitability.

Summary Scenario #2

Data collector:
- Easy to use
- Human error proof
- Simple, standard tests or online system

Data collector doesn't need:
- Big screen
- Complex customized tests

Sensor:
- Triaxial sensor and stud mount

Software:
- Intelligent software
- Good alarming
- Trending and reporting features
- Links to CMMS and asset management software
- Metrics calculated from maintenance decisions up to plant profitability

User:
- Data collection technician
- Low skill
- Low wage

Program manager:
- High skill
- High wage

As you can see, the way we define the goal has a big impact on the type of equipment we will purchase and how this equipment is used. It also points to a common reason why PdM programs fail. People often buy the equipment with the most bells and whistles first, with little to no attention on the software and no idea how the monitoring program will be organized. This is to say they buy the equipment defined in the first scenario with a vague idea that they will receive the rewards of using it as described in the second scenario. They focus more on the tool than on program management. When they receive training from the equipment vendor, it is often training in how to use the tool, not what to use the tool for. People who fall into this trap will typically say that they only test "critical" machines, not understanding that they are doing this because they bought equipment that was not designed to test large numbers of machines efficiently.

Now let's return to the original question: Why do PdM programs fail? One reason that I hope is clear by now is the possible confusion between condition monitoring tools and their accompanying goals. The most common stumbling blocks are in understanding what the business goals are, employing the right tools, people and processes to meet those goals and establishing metrics to show how effective the program is in reaching the goals. Often times, plants employ highly trained individuals to use complex equipment solely to troubleshoot machines that are already known to be problematic. This may be a valid use of the technology, but it is not PdM and does not bring the same rewards or ROI. If you begins with the stated goal of increasing profitability and work down the ladder from there, equipment purchases and the way these tools are employed will be very different and the profitability goal will be better realized.

Alan Friedman is a senior technical advisor for Azima DLI (www.AzimaDLI.com). With more than 18 years of engineering experience, Friedman has worked with hundreds of industrial facilities worldwide and developed proven best practices for sustainable condition monitoring and predictive maintenance programs. Friedman contributed to the development of Azima DLI's automated diagnostic system and has produced and taught global CAT II and CAT III equivalent vibration analysis courses. Friedman is a senior instructor at the Mobius Institute, an independent provider of vibration training and certification, and an instructor for the Instituto Mexicano de Mantenimiento Predictivo (Predictive Maintenance Institute of Mexico). He is also the founder of ZenCo, a positive vibrations company. You can contact Alan at 206-327-3332 or at friedmanalan1@gmail.com

What Torque Can Tell You

PdM of Mechanical Failures Using Electrical Measurements for Instantaneous Torque

by Ernesto Wiedenbrug, PhD SM IEEE

Electric dynamic predictive maintenance is a field of continual rapid technology development. The same theoretical background, which made the first torque controlled VFDs possible, is now utilized to monitor the shaft torque by measuring only the stator currents and voltages. The first diagnostic use of the instantaneous torque signal as part of an off-the-shelf solution for field maintenance reached the market in 1999. In the last ten years, it has shown a dramatic increase in the quality of the information obtained over previously used techniques.

The main benefit to predictive maintenance by the use of instantaneous torque signature analysis is the ease of data assessment. This article covers a variety of case studies on a diverse set of motors (1.5hp to 1250hp) in several industries. These studies aim at fault types that relate mainly to the mechanical field for line operated and VFD driven loads. The faults include looseness, impeller deterioration, mechanical unbalance, bearing failures, eccentricity, VFD-regeneration, VFD dynamic overloading and VFD oscillations.

Looseness

Often the motor and driven load are relatively inaccessible. This is also true for automated machinery in manufacturing environments. Due to safety considerations, it is uncommon that maintenance professionals investigate the functionality of automated machines during operation. Most faults are noticed only after a failure causes work stoppages. Mechanical failures that reach this state will require more downtime to repair than if found at an earlier stage.

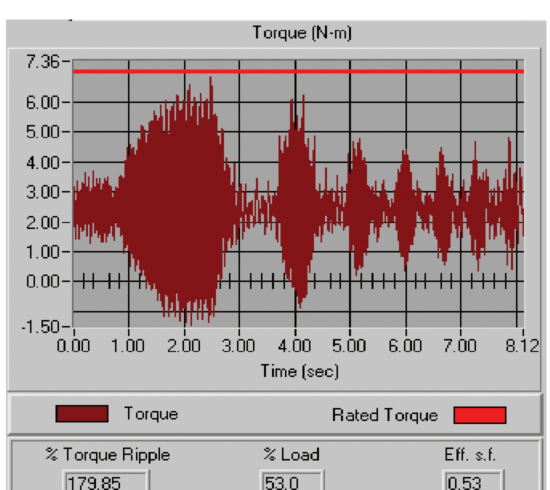


Figure 1 - Torque ripple of load showing looseness. 1.5hp motor, manufacturing environment.

Dynamic technology allows measuring the electrical input to motors, and diagnosing the driven process. This concept uses the motor as a sensor for the driven load. Figure 1 shows the instantaneous torque versus time graph in a manufacturing environment. The load is driven by a 1.5hp, 4-pole motor. Understanding the busyness of the predictive maintenance professional's schedule, clearly, the cost of the motor itself is not sufficient to warrant a line shutdown; however, the cost of potential downtime warrants a closer look.

The red line shows the upper limit of the rated operation or rated torque. This signature shows a steady state average torque, onto which torque band increases are added. These band increases represent fast torque changes. Looking at the size of the highest peak to the lowest valley, we see that this dynamic torque changes in a range of full rated torque. This happens literally thousands of times per second, so frequently, that it cannot be counted in this graph without zooming in. This signature shows that there are extremely large pulsations on the driven load that cannot be explained by the nature of the load. A basic understanding of the mechanical setup of this load, however, allows diagnosing looseness and rattling. The fact that the amplitude of the torque bands are varying from band to band, the changing time intervals between these occurrences, as well as the varying duration of the torque band changes, are hallmark limitations of finding signatures using the frequency domain.

There are no reoccurring patterns in the time domain, hence there are no clear distinguishable peaks resulting in the frequency domain. Random patterns, like this one, only elevate the noise-floor in the frequency domain, and are difficult to diagnose there. Fault signatures containing relatively high transient energy levels are optimally found in the time domain. This fault type may or may not have consistent inner frequencies. If the fault lacked consistent inner frequencies, then diagnosis is difficult in either the frequency or demodulated domains.

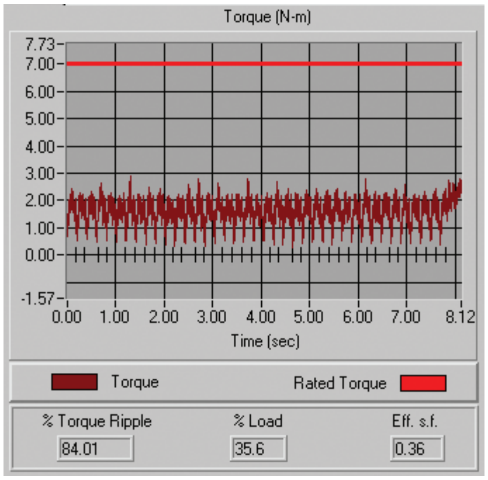


Figure 2 - Adjusted load torque signature of previously loose, rattling load (see Fig. 1).

Finding this fault during general operation and at the MCC was advantageous. It allowed for a safe diagnosis and shortened downtime. Less than one hour was required to readjust the load. Figure 2 shows the torque signature of the same load after the readjustment. The torque band increases are gone, and the torque signature describes a steady state operation.

Impeller Deterioration

Deep well water pumps are used in many community water supply systems. Sand and other foreign materials are pulled into the intake of the pump, which grind inside the pump, causing erosion. The results of this phenomena are shown in Figure 3.

Being able to observe whether foreign materi-

Figure 3 - Sand eroded impeller (Top), sample of sand (Bottom).

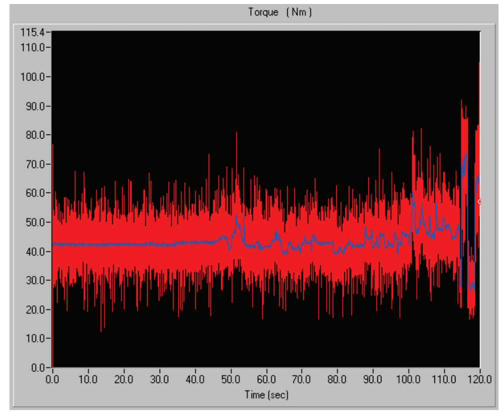


Figure 4 - Instantaneous torque signatures (red) and short-time average (blue) for no sand pumping (0s - 40s) and increasing sand pumping (80s - 120s).

als are being pumped allows for the forecasting of pump degradation. Simple changes such as a reduction in pump speed can help rectify this problem. However, if pump speed is relevant to the process, then an understanding of this deterioration process is beneficial.

A lab setup was used to verify the sand signature of a VFD driven submerged pump. Data was acquired for 120 seconds. For the first 40 seconds the pump operated without sand intrusion into the intake. Increasing amounts of sand were introduced during the remaining 80 seconds. Figure 4 shows the instantaneous torque curve in red, and the short time averaged curve in blue. Notice that the short time average is flat while only water is pumped; however, it shows a strong variation once sand was introduced. Between seconds 100 and 115, the amount of pumped sand is above the acceptable level. After further increases in sand, between seconds 115 and 120, the pump reaches such a high level that it begins to bind.

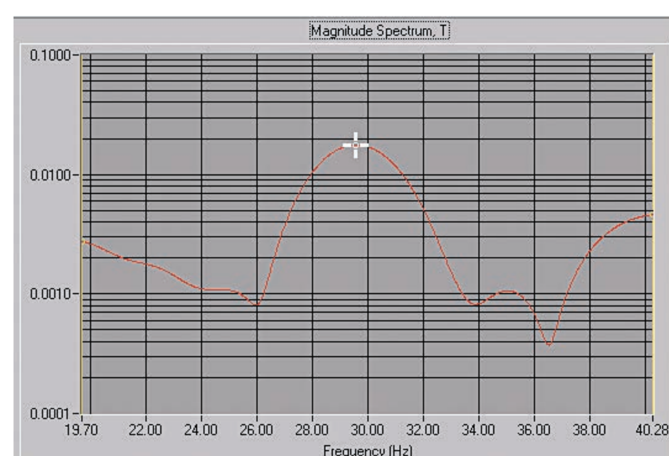
Mechanical Unbalance

Predicting failures of motors or bearings is important in industry. One of the most critical environments for predictive maintenance is the nuclear industry. Over several years, it was noted that in-duct mounted fans were failing due to bearing problems at an unusual rate. The failures were not successfully predicted by using top of the line portable vibration monitoring equipment. Lacking permanently wired sensors on the motor, vibration data is limited to the outside of the air duct in which the motor is mounted. The mounting bars of the motor to the duct were dampening the vibration signatures. These failure modes, which are easily diagnosed on the motor's case, did not reach the outside of the duct. In an effort to find alternate methods of failure prediction, two failure modes were planted onto a duct-mounted fan. The first experiment was comparing the baseline, well-balanced operation of the fan with a mechanically unbalanced operation, shown in Figure 5.

The torque spectrum shows a 1x peak for this 4-pole motor. This peak amplitude was found to be a reliable measure of the severity of unbalance. This technology can be used for baselining and identifying worsening mechanical unbalance conditions.

Bearing Failures

The second failure mode investigated was an outer bearing failure. Figure 6 (following page) shows a typical bearing signature pattern. This bearing had a BPFO of 107Hz. The failure pattern in the torque signature showed a high peak at 107Hz, and its third harmonic at 314Hz (in red). Additionally it showed the sidebands at ±2 x electrical (in green) to the BPFO.



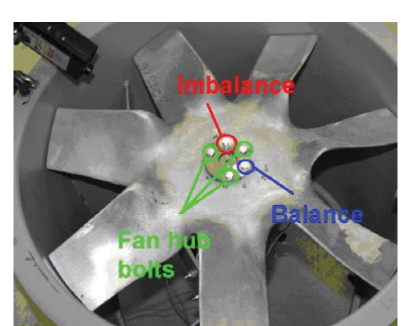


Figure 5 - In-duct mounted fan (left) with fastening, balancing and unbalancing bolts. Torque vs. frequency signature at 1 x rpm (above).

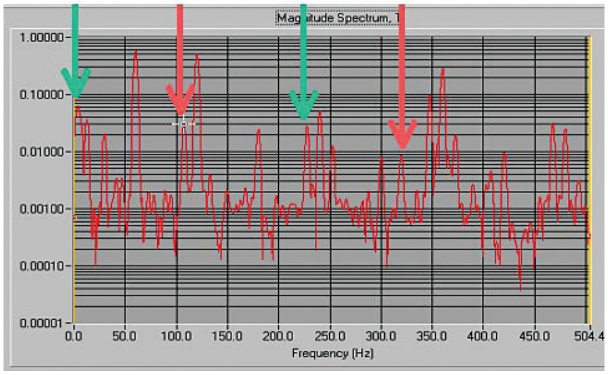


Figure 6 - Torque vs. Frequency signature of 5hp motor with BPFO 107Hz, at stage 3.

The result of this investigation showed that it is possible to find deteriorating bearing failures in this type of application. The measurements of currents and voltages were taken at the MCC.

Eccentricity

According to Peter Vas in his book Parameter Estimation, Condition Monitoring, and Diagnosis of Electrical Machines, it is possible to detect eccentricity by using the stator current's frequency components created by rotor bar pass frequencies. Modern work focuses on the use of these frequencies, taking into account that the amplitudes of the current spectra calculated before are not always visible on every motor design. There are rotor bar-stator slot combinations, which will not show the signatures, regardless of the amount of eccentricity. Babour and Thomson investigated the effects of rotor slot design (open or closed bridge), saturation and skew. Their conclusions were that the frequencies observed by variations due to skew, rotor bar design in combination with stator slot design and saturation, make an accurate assessment of eccentricity based on the rotor bar pass frequencies unreliable. If the maintenance professional does not know what combination of rotor bar and stator slot counts work with the rotor bar pass frequency method, an inaccurate assessment could be made. The analysis of 1x and 2x electrical frequencies in the demodulated torque spectrum is a method that does not require knowledge of rotor bar and stator slot combinations.

Cryogenic pump motors are operated at liquid nitrogen temperatures. These low temperatures can introduce a bend into the rotor if not well tempered. This dynamic eccentricity disappears the instant the motor is removed from these extreme conditions. This situation is challenging to determine with vibration analysis because accelerometers do not function well at cryogenically low temperatures, and the fault does not show when the motor is elevated to normal temperatures.

Our research has shown that the AM demodulated torque signal is a reliable way of identifying dynamic eccentricity. An additional advantage is that dynamic eccentricity shows at the same frequencies that it does for vibration technology: at 1x and 2x electrical. Figure 7 shows the frequency spectrum of the AM demodulated torque signature for a motor with dynamic eccentricity. You will notice a significant amplitude increase at 60 Hz and 120 Hz.

VFD – Regeneration

Variable Frequency Drives (VFDs) are challenging to diagnosis, due to the dynamic changes of operating conditions. Lacking a steady state, the analysis requires the work be performed in the time domain.

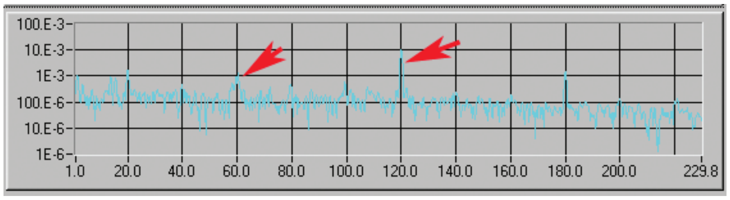


Figure 7 - AM-demodulated torque signature of a motor with eccentricity.

This pulp and paper industry application is a 60 hp conveyor belt, which feeds logs into a saw. When there is no log in proximity to the saw, the conveyor's 6-pole motor runs at maximal rated speed (1200rpm). This is the operation's first 0.7 seconds, and from 3.7 seconds to cycle completion. The blue line shows the constant higher speed at 1200rpm during these times. At 0.7 seconds, the log reaches the saw. This causes the PLCs to slow the conveyor's speed to cutting speed (250rpm.) The deceleration takes 1 second. Cutting the log takes 1 second, and then, at 2.7 seconds, the PLCs accelerate back to 60Hz.

The red line in Figure 8 is the torque signal. It keeps a steady average value during the steady state operations. During the deceleration and acceleration, it keeps constant low and high torque values, respectively. This behavior matches expectations, by remembering that

Force = mass X acceleration

In Figure 9 on the following page, we see the same torque signal, represented at a higher resolution. Typically, the resolution in Figure 9 is used for understanding trends in the system. The resolution in Figure 9 scrutinizes the particulars of the system. It also shows the dynamic rated torque boundary. This is calculated as a function of voltage level, frequency and motor nameplate information. This line represents the equivalent of the full rated operation's temperature stress to the motor.

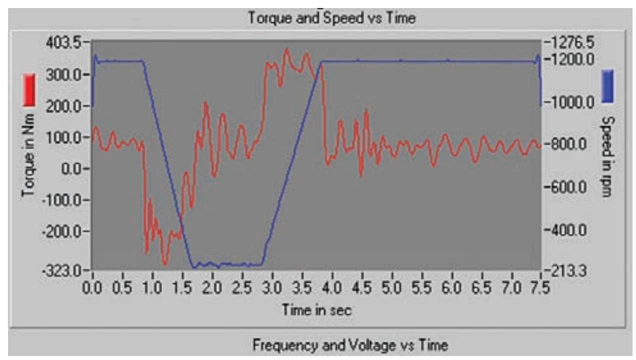


Figure 8 - Torque and Speed vs. time for VFD driven conveyor belt.

Three interesting items were identified in this figure. First, A, shows the torque is negative. This means that during the deceleration, the motor is operating with a negative torque, trying to stop the load from running fast. The negative torque means the motor is operating as a generator, taking energy from the driven load and passing it to the electrical grid.

The motor can operate as a generator without any trouble; however, not all loads can withstand a push-pull type operation. In this case, the conveyor was designed for a push-pull operation.

VFD – Dynamic Overloading

Secondly, B in Figure 9 shows the instantaneous torque surpasses the rated torque. The rated torque is 220 Nm, while the operating torque keeps an average of 300 Nm with a peak surpassing 400 Nm.

Overloading is a fundamental reason why motors overheat. A closer look shows that the motor overloads during acceleration. The solution is simple. Slowing the settings for acceleration (Hz/seconds) will keep the motor from overheating. If the 1-second acceleration from 20Hz to 60Hz is lengthened to a 1.3-second acceleration, the torque will drop by the percentage by which the acceleration time is extended. Again, remember the equation:

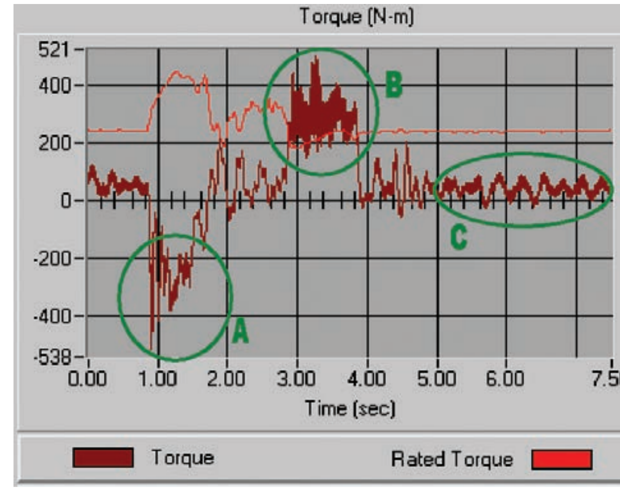


Figure 9 - Dynamic torque and rated torque vs. time

Force = mass X acceleration

Commonly, there is no problem in slowing down the acceleration for such an application. It results in a reduced production of 0.3 seconds per log. If this 0.3 second was prohibitive, the cruising speed of the conveyor could be adjusted higher. It is set at 60Hz, which is a common 'rated' setting. NEMA MG1 allows motors of 4-poles and up to be run up to 110% of rated frequency. The needed adjustment would make up for 0.3 seconds during the 4 seconds of 60Hz speed. Setting the cruising speed from 60.0Hz to 66.0Hz will rectify the lower acceleration rate's lost productivity. This small change in cruising speed will not noticeably affect the health of the mechanical system.

VFD – Oscillation (Hunting)

Finally, section C in Figure 9 shows an inconstant torque while the motor is running at a set speed. The torque is showing a low amplitude oscillation. This type of oscillation is typical within VFDs, and can be explained as the mechanical system 'talking' to the electrical regulation of the VFD. The electro-mechanical system can start swinging, or oscillating. This mode frequently is called 'hunting' by the field. Even though the motor sustains no damage under this operation mode, the mechanical system is constantly accelerated and decelerated. This swinging will stress the entire mechanical system, including the conveyor belt and all parts holding it in place. Such an oscillation represents unnecessary wear on the system.

Most VFD's produced during the last 15 years have adjustable PID settings. The PID settings' function is to counteract the 'talking' between the load and the VFD. Since the VFD manufacturers do not know in advance what mechanical system properties the motor will face, they cannot pre-set the VFD in its optimal state. Ensuring that the PIDs are set to avoid oscillations is the responsibility of field maintenance. They may do this task themselves, deal with the VFD manufacturer's service group, or hire a third party.

Comparing Current And Torque Signals

Current signature analysis has been on the market for nearly twice as long as torque signature analysis. It also has the enticing simplicity of not requiring a synchronous measurement of multiphase currents and voltages, nor does it need additional computation. So why go to the trouble for the added complexity of the torque calculation? The answer is in the commonly used domains of torque analysis: Time and Demodulated.

Time Domain — The same process, in which the cryogenic pump manufacturer checks for low temperature induced eccentricity, is used for overall functioning of the pump.

In Figure 10, it is virtually impossible to distinguish the quality of the signatures of the good and the poor operation.

In Figure 11, the two torque signatures show tremendous differences. Through basic understanding of pump operation, a steady state is expected with nearly no torque ripple. With the use of the torque signature method, the visual difference between a healthy signature and a faulted one makes it unnecessary to compare one signature with the other. The torque signature results in a simple, intuitive and definitive assessment, whereas the current signature offers an unrealistic fault assessment.

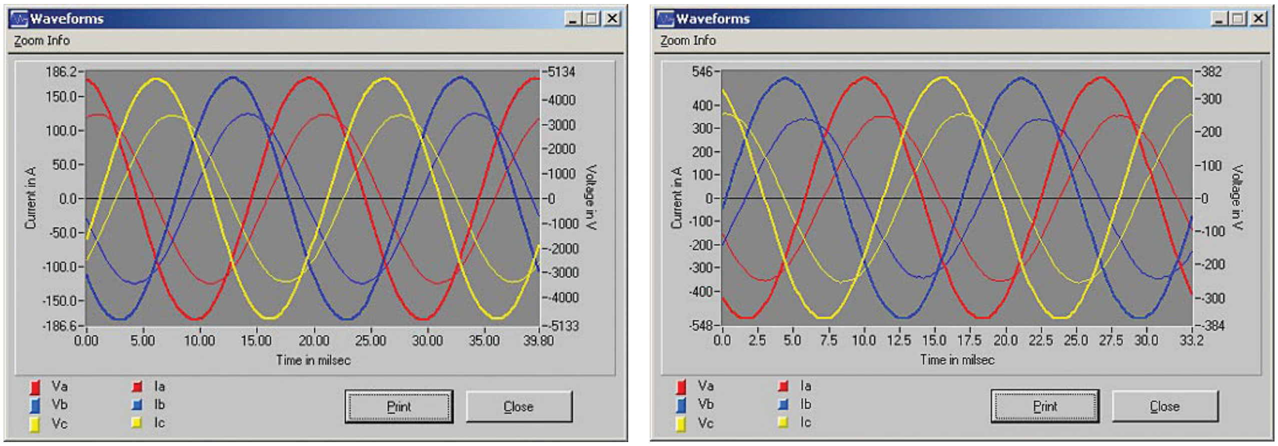


Figure 10- Voltage and current vs. time signatures. At left is an unfaulted, and right is a faulted pump signature.

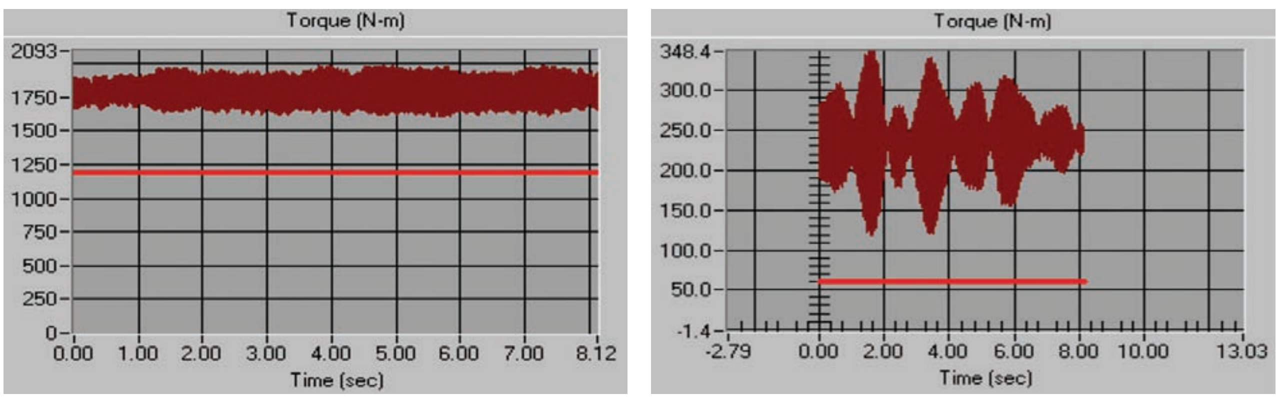


Figure 11 - Torque vs. time signatures. The left figure is unfaulted, and the right is a faulted pump signature.

Demodulation Domain — Evaluation of the demodulation signals quality for current and torque signals is performed by looking at the field example of eccentricity quality control. As discussed previously, the rotor bar pass frequency is not a reliable identification of eccentricity faults for motors. Table 1 compares the signatures obtained using the identical data for the four motors tested. The signatures are investigated at 1x and 2x electrical frequencies.

Table 1 shows that the difference in amplitudes of the demodulated current's signatures is maximized at 31% in the motor showing a fault. This level barely suffices in the field for defining useful thresholds. The torque signature, however, shows an increased signature of almost 600%. This signal would be of reliable quality for setting pass-fail criteria. Here again, the torque signal proves to be a better quality tool for field use than the current signature technology.

	Demodulated Torque		Demodulated Current	
	60Hz	120Hz	60 Hz	120 Hz
Bad Motor #1	3.47E-05	7.94aE-05	0.00324	0.03150
Bad Motor #2	4.26E-05	7.96E-05	0.00398	0.03091
Good Motor #1	2.96E-05	1.35E-05	1.00245	0.03109
Good Motor #2	3.46E-05	1.42E-05	0.00308	0.03057
Difference	**120%**	**590%**	**131%**	**101%**

Table 1 - Demodulated Torque and Demodulated Current signature's amplitudes at 1x and 2x electrical frequencies.

Conclusions

Instantaneous torque was used to identify a variety of field relevant fault modes. Looseness and pumping of sand were successfully diagnosed with the time-domain torque signal. Mechanical unbalance and bearing faults were recognized with the torque vs. frequency representation. Eccentricity was diagnosed with the demodulated frequency representation of the torque signal. Dynamic VFD applications showing cases of regeneration, dynamic overloading and hunting were diagnosed with the time domain signal.

Many of these diagnoses are impossible to make successfully using the current signature analysis technology. The advantages of the modern and proven torque signal were contrasted to the results obtained using the same data.

Ernesto J. Wiedenbrug (S'94 M'00 SM'01) holds a Dipl. Ing. from Aachen, Germany and a Ph.D. in electrical engineering from Oregon State University. He is the project manager for Baker Instrument Company's on-line technology. He has worked as an intern for Siemens SA in Buenos Aires, Argentina and as a power engineer for ISCOR, in VanderBjilpark, Rep. of South Africa. During his doctoral degree he had a one year fellowship with Volkswagen AG Germany, and was subsequently employed as the general manager of the Motor Systems Resource Facility, an EPRI funded center. His main area of interest is predictive and preventive maintenance of electrical motors.

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The 5S Method to Improvement

Enhancing Safety, Productivity and Culture

by Mike Bresko

Let's face it, we all face tough challenges. Competitive pressures continue unabated. Prices are too low, and costs are too high. Companies strive to reduce costs. Some look to improve technology. Some reduce head-count. Too few have become operationally excellent. Costs pile up in the form of defects and waste. Consider these all-too-familiar situations:

- Output does not meet its potential due to crew-to-crew variations.
- Utilization suffers because product changeovers take too long.
- An important part cannot be found, so another is rushed in.

Companies attempt to improve through Lean, Six Sigma, or Total Productive Maintenance initiatives. However, studies since 1998 report that two-thirds of these initiatives fail to meet the expectations of company leaders. Learning about the methods isn't the challenge, putting them into daily practice is, as evident in these situations:

- Process improvements often backslide.
- Continuous improvement is just a phrase.
- The methods of the initiative aren't institutionalized.

The root of these failings is the inability to achieve culture change. An Aberdeen Group survey (2005) re-inforced this conclusion when it found that significant culture change remains the top challenge in over 80% of the companies surveyed.

One Answer is 5S

Some companies beat the odds and foster strong, positive cultures. Danaher and Toyota are two of the better known examples.

The method of 5S is one way to engage people and contribute to culture change. 5S is a visually-oriented system of cleanliness, organization, and arrangement (Figure 1) designed to facilitate greater productivity, safety, and quality (Figure 2). It engages all employees and is a foundation for more self-discipline on the job for better work and better products.

5S is a foundation for more disciplined actions. If workers cannot even put a tool back in its designated location, will they follow standards for production? Its visual nature makes things tat are out of place stick out like a sore thumb. And, when properly supported, it

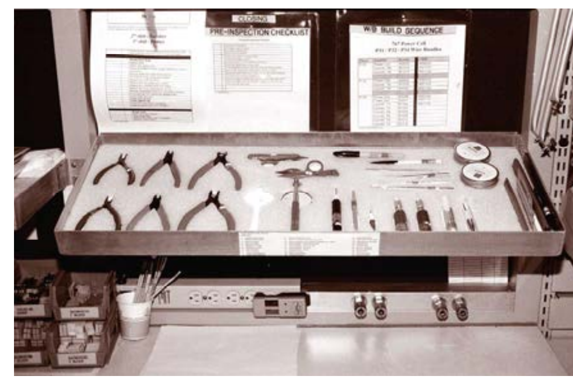

Figure 1 - 5S is visually oriented, so anyone can tell at a glance that everything is right.

builds a culture of continuous improvement. The benefits of 5S are:

- Cleaner and safer work areas — when a work area is clean and organized tripping hazards and other dangers are eliminated.
- Less wasted time through more workplace organization — when tools and materials are accessible and orderly, workers need less time to "go get" and less time to search.
- Less space — when unneeded items are eliminated and the needed ones are organized, required floor space is dramatically reduced.
- Improved self-discipline — the 5S system, especially its visual nature, makes abnormal conditions noticeable and makes ignoring standards more difficult.
- Improved culture — when 5S is applied systematically, it fosters better teamwork and enthusiasm.

People like to work in a well-organized and clean environment. They feel better about themselves and better about their work, and they restore the self-discipline that is found in winning teams.

What are the 5S's?

5S consists of:

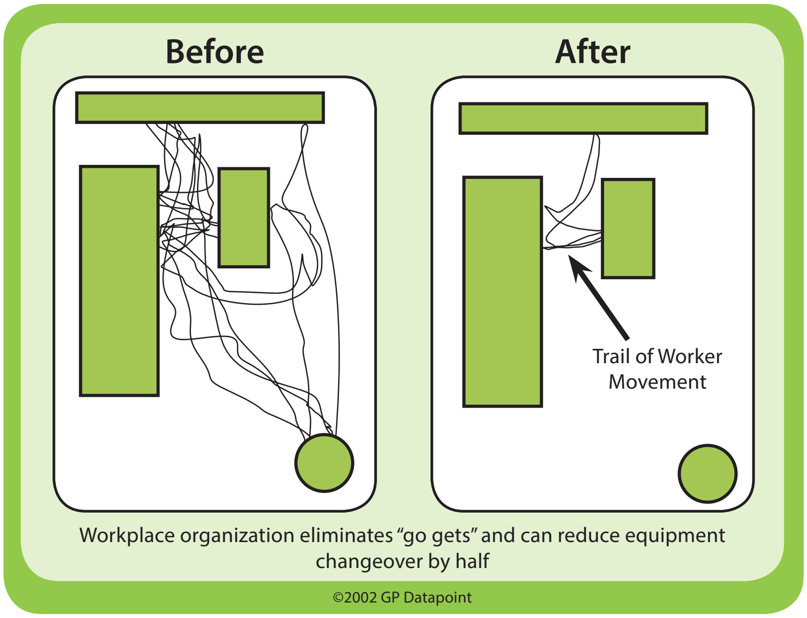

Figure 2 - 5S Facilitates Greater Productivity, Safety and Quality.

- Sorting — separating the needed from the unneeded. Sorting activities aim to eliminate unneeded items from the work area and to perform an initial cleaning.
- Simplifying — a place for everything and everything in its place, clean and ready for use. Simplifying arranges the workplace to ensure safety and efficiency.
- Systematic Cleaning — cleaning for inspection. Systematic daily cleaning and inspection of work areas and equipment help you understand current conditions and determine if corrective action is required.
- Standardizing — developing common methods for consistency. Standardizing aims to make abnormal conditions noticeable and to document agreements to ensure consistency and sustainability.
- Sustaining — holding the gains and improving. Sustaining is aimed at maintaining the improvements from the other 5S activities and improving further.

Implementing 5S

Often, companies mistakenly view 5S as a housekeeping activity. Housekeeping is housekeeping, not 5S. 5S is a visual system and a system for engaging employees. 5S must be a team effort and the results must enable anyone to "tell at a glance" what is right and what is out of place. It also must make doing the work easier. Implementing 5S occurs in two phases: initial implementation and later refinement.

Since organizing is a key to 5S, eliminating unneeded items comes first. It is wasteful to find a home for something that is not needed.

Sorting — Sorting clears the deck for the remaining activities. It can often take weeks to accomplish in any given area or department. The steps of sorting are:

- Establish criteria for what is not needed. For example, if something hasn't been used for a year, it may be a candidate for disposal.
- Identify the unneeded items and move to a holding area.
- Dispose of the not needed items, either by transferring to a department that needs them, selling them, or discarding them.
- Conduct an initial cleaning.

Once the initial sorting is completed, the natural sequence is to get the work area organized. Simplifying, systematic cleaning, and standardizing go hand-in hand. Simply simplifying – organizing the work – area will deteriorate if the standards are not set. The next paragraphs cover each "S" separately, but they work as a system, and must be performed at the same time, or nearly so.

Simplifying — Simplifying finds a home for everything. The home should be where the item will most efficiently be stored. Frequently-used items must be as close to where they are used as possible. The steps of simplifying are:

- Determine a location for each item based on frequency of use and proper safety zone (decreasing the likelihood of strain injuries, for example).
- Develop shadowboards and label items – a home for everything.
- Determine how to replenish supplies.
- Document layout, equipment, supplies, and agreements for returning items to their homes.

Systematic Cleaning — Systematic cleaning provides a way to inspect, by doing a clean sweep around a work area. This means visually as well as with a broom or rags. The idea is make the job of doing daily cleaning and inspections easier. The steps of systematic cleaning are:

- Identify points to check for performance.
- Determine acceptable performance.
- Mark equipment and controls with visual indicators (e.g., gauges show the correct range).
- Conduct daily cleaning and visual checks.

Standardizing — Standardizing assures that everyone knows what is expected. Since the workplace team establishes the standards, everyone should have had some involvement in establishing the 5S in their work area. Still, it is important to make these standards very clear. The steps in standardizing are:

- Establish a routine check sheet for each work area. The check sheet is like a pilot's pre-flight check list. It shows what the team should check during self-audits.
- Establish a multi-level audit system where each level in the organization has a role to play in ensuring that 5S is sustained in the work areas and that the 5S system evolves and strengthens.
- Establish and document standard methods across similar work areas.
- Document any new standard methods for doing the work.

Sustaining — Sustaining is usually thought of as the toughest "S." However, it doesn't need to be. The trick is to let the 5S system work for you. When you get to this point, you should have engaged everyone in the work area during 5S activities and have a "tell at a glance" visual workplace. If this is so, then sustaining is much easier. That is important, but not sufficient. A more systematic way to prevent backsliding and to foster continuous improvement is needed. The steps of sustaining are:

- Determine the 5S level of achievement – the overall grade.
- Perform worker-led routine 5S checks using the 5S check list.
- Address backsliding and new opportunities found during routine checks.
- Conduct scheduled, routine checks by team leads or supervisors or by people from outside of the workgroup.
- Perform higher-level audits to evaluate how well the 5S system is working overall. For example, are there systemic issues with sustaining 5S? Often, the company's safety committee is an excellent body for conducting these audits.

It is through sustaining activities that the practice of 5S is refined. When items aren't returned to their homes, the cause is most likely to be that the home was inconvenient. When the work team addresses these problems, they improve the sustainability of 5S and, more importantly, they improve safety, morale, and productivity.

Measuring the 5S Level of Achievement

Applying the adage, "what gets measured gets done", 5S uses a five-level maturity matrix to grade the 5S level (illustrated in Figure 3). To illustrate the use of the matrix, look at the levels from I to V for Simplifying. Level I is a typical starting level where the work area is an unorganized mess. Achieving Level II for Simplifying requires that needed items are safely stored according to frequency of use. Frequently-used items should be close to the point of use. Achieving Level III requires that the correct quantities of those items have a clearly marked home. Often work areas can achieve this level relatively quickly by installing shadowboards (outlines showing visually where items belong). Levels IV and V require additional refinement. Level IV requires that the number of items in an area are minimized. That means fewer consumables, fewer files or paperwork, and fewer tools. Level V requires that anyone, even people unfamiliar with the area, can retrieve any needed item within 30 seconds and with minimal movement. The overall 5S Level of Achievement is the lowest level attained for any of the S's. 5S is only as good as its weakest link. If a work area has not addressed Standardizing and Sustaining, no matter how high the level achieved for the other S's, the area will eventually revert to a non-5S state.

Conclusion

Although 5S will not solve today's competitive challenges, it does provide a solid foundation for achieving operational excellence. In fact, some world-class companies claim that there can be no improvement without 5S.

The teamwork and discipline built through 5S improve worker-to-worker and worker-to-manager relationships. When people see that what they do makes a difference, and when they see that they have eliminated wasteful practices, their pride grows. This is perhaps the greatest benefit of 5S.

Mike Bresko is a Lean Six Sigma Master who coaches and instructs practitioners, front-line associates, and executives; and guides clients to accomplishing and sustaining operational excellence. He has performed both Lean Six Sigma as well as Maintenance and Reliability conversion projects; and is an experience senior-level executive who is also a hands-on

5S Levels of Achievement					
Level V: Continuously Improve	Cleanliness problems are identified and mess prevention actions are in place.	Needed items can be retrieved within 30 seconds and require a minimum number of steps.	Potential problems are identified and counter measures are documented.	Reliable methods and standards for housekeeping, daily inspections and workspace arrangement are shared and are used throughout similar work areas.	Root causes are eliminated and improvement actions focus on developing preventive methods.
Level IV: Focus on Reliability	Work area has documented housekeeping responsibilities & schedules and the assignments are consistently followed.	Needed items in work area are minimized in number and are properly arranged for retrieval and use.	Inspection occurs during daily cleaning of work areas and equipment and supplies	Reliable methods and standards for housekeeping, daily inspections and workplace arrangement are documented and followed by all members of the work group.	Sources and frequency of problems are documented as part of routine work, root causes are identified, and corrective action plans are developed.
Level III: Make It Visual	Initial cleaning has been performed and sources of spills and messes are identified and corrected.	Needed items are outlined, dedicated locations are properly labeled and required quantities are determined.	Visual controls and identifiers are established and marked for the work area, equipment, files and supplies.	Work group has documented agreements on visual controls, labeling of items, and required quantities of needed items.	Work group is routinely checking area to maintain 5S agreements.
Level II: Focus on Basics	Needed and not-needed items are identified. Those not needed are removed from work area.	Needed items are safely stored and organized according to frequency of use.	Key work area items to be checked are identified and acceptable performance levels documented.	Work group has documented agreements for needed items, organization and work area controls.	Initial 5S level has been determined, and performance is documented and posted in work area.
Level I: Just Beginning	Needed and not-needed items are mixed throughout the work area.	Items are placed randomly throughout the workplace.	Key work area items checked are not identified and are unmarked.	Work area methods are not consistently followed and are undocumented.	Work area checks are randomly performed and there is no visual measurement of 5S.
Place yellow box where each area is on the 5S Levels of Achievement.	**Sorting**	**Simplifying**	**Systematic Cleaning**	**Standardizing**	**Sustaining**

Figure 3 - 5S Levels of Achievement Matrix

practitioner of process excellence. Mike has 30 years of industrial experience 15 being at Alcoa and the last 13 being with GPAllied or its parent. While at Alcoa, Mike held positions in product engineering, strategic planning, internal consulting, and as President, Alcoa-Zepf and Global Manager, Packaging Equipment where he took a hand-on approach to slash product lead times 60% and product development times 40-60%, and improve the reliability of Alcoa's packaging equipment. While a consultant, Mike has worked with a wide variety of industries from automotive to smelting, insurance, and high tech. Mike has benchmarked world-class companies and published papers or books on 5S, Goal Deployment, Lean Transformations, Lean Reliability Culture, Daily Management, and Reliability Excellence. He holds B.S. and M.S. degrees in Civil Engineering from Carnegie-Mellon University and an M.B.A. from the University of Pittsburgh. Mike is currently Principal Advisor at GPAllied, and can be reached at 206-484-0816 or mbresko@gpallied.com

Speed Up Low RPM Data Collection

Using Ultrasound for Effective Inspection of Slow Speed Bearings

by Thomas J Murphy, C.Eng

Measuring the condition of bearings rotating at speeds below 60rpm using vibration is fraught with difficulty. This article describes using a portable ultrasound system as an "intelligent sensor" in association with a normal vibration data collector to overcome this problem. It includes results of measurements taken on a group of rotary crushing machines where this combined approach reduced the measurement time from 21 minutes per measurement to less than a minute per reading.

Background

One of the more difficult areas to apply vibration successfully is to slowly rotating bearings. A misunderstanding of the basics such as sensor selection, measurement procedure and the FFT process itself has often led people to proclaim that measurements on machinery rotating below 60rpm is not possible. This is untrue, it is perfectly possible – as long as you understand how.

The first mistake most people make is that they use the wrong accelerometer. Consider this: at 3,000rpm, a velocity of 1mm/s corresponds to an acceleration of 0.03g, whereas at 30rpm that same velocity is now 0.0003g. If I were using my normal 100mV/g accelerometer, that would give me a voltage of just 30µV of signal in the presence of typically 20µV of noise. That is clearly not going to be easy to deal with.

The answer, of course, is to increase the sensitivity of the accelerometer to say 500mV/g. Some care is required here, and it is highly recommended that you test it before you but it because some of these accelerometers might actually be 100mV/g accelerometers with built-in 5x gain amplifiers. This is also not desirable since, in all probability, the net result of amplifying the signal and the noise is likely to be a reduced signal-to-noise instead of the increase we need.

There are also considerations in terms of electronic noise as well as the noise created by the FFT process itself. With such low frequencies, electronic noise such as Schott or 1/f (one-over-f) becomes critical. As the name suggests, this is a noise source which increases with decreasing frequency. But this noise source, which will be in my measurement chain, is in acceleration. If I integrate this signal to velocity, my 1/f becomes 1/f2 . An increase by a factor of 10 in my acceleration, for example, now becomes an increase by a factor of 100 in velocity. So integration is not a good idea.

The FFT process itself is also a source of noise at these frequencies. To overcome that noise, I must spread out the overall amount of noise present in my system across as many lines of resolution as I can, so that the noise/line is minimized.

At this stage, there is also a temptation to add averaging in order to "smooth out" even more of the noise sources. However, always remember that averaging not only reduces the effects of random noise, but it also acts as a filter for any short duration events which may result in valuable data being lost.

Increasing the resolution means increasing the amount of time it takes per reading. A 10Hz frequency range with 3,200 lines of resolution represents a block of time data 320 seconds long. If you were to take 4 averages, that is over 21 minutes per measurement!

The Ultrasound Alternative

Ultrasound is recognized as being a much quicker way of "listening" to bearing condition. Because it is working at much higher frequencies than vibration, there is no need for an ultrasound system to take the slow rotational speed into such a critical account.

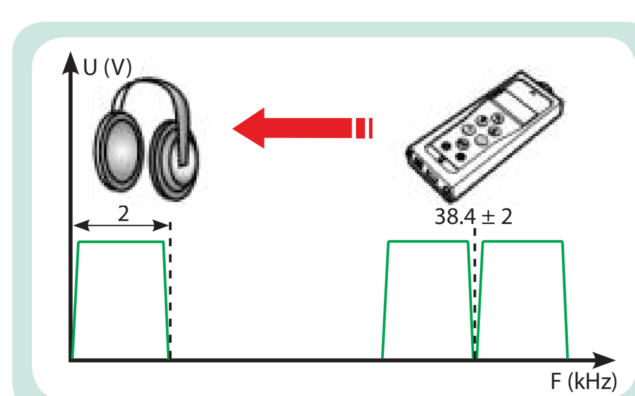

Figure 1 - The SDT170 captures the ultrasonic frequencies and converts them into an audible range.

The SDT170 ultrasound system used for this work measures at 38.4kHz and processes the signal to provide an audio output 2kHz wide which contains data from roughly 36-38kHz and 39-41kHz (Figure 1).

Therefore, this audio signal contains all the activity which is occurring at that much higher, inaudible, frequency. When dealing with bearing defects, what is actually going on up there is normally the broadband noise of friction caused by poor lubrication, and is impulsive or impacting in nature. In the case of bearing defects, this signal is rarely periodic, which makes them all the more difficult to detect when performing long, slow, averages.

Since the ultrasound system is listening to these impacts, the need to work using slow signal processing methods is not required.

By taking the audio output and feeding it into a vibration data collector, the SDT170 can be effectively used as an intelligent sensor. By fixing the amplitude setting of the SDT170, the measurement chain will provide repeatable and comparable data.

In fact, the only consideration is that of how much data should be gathered in order to be considered representative. For a machine rotating at 12 rpm, for example, I would want to have a sample of perhaps 30 seconds in order to be sure that I have representative data.

If I am working with an ultrasound detector in conjunction with a vibration data collector, there is also a limit caused by the selection of frequency range and sample length. Since my ultrasound system produces an output of just 2kHz, there is little point in working with any higher maximum frequency. If I work with the maximum number of lines, say 12,800, then the maximum time sample that I could acquire would be limited to 6.4 seconds.

Clearly, I now have a potential conflict of interest between what I would like to record and what I can record. I can overcome this conflict to some extent by monitoring the signal before I store it to ensure that what I have is representative. Alternatively, I can scrap the idea of using a vibration data collector as my recording device and consider instead using a digital recorder working with a .wav file.

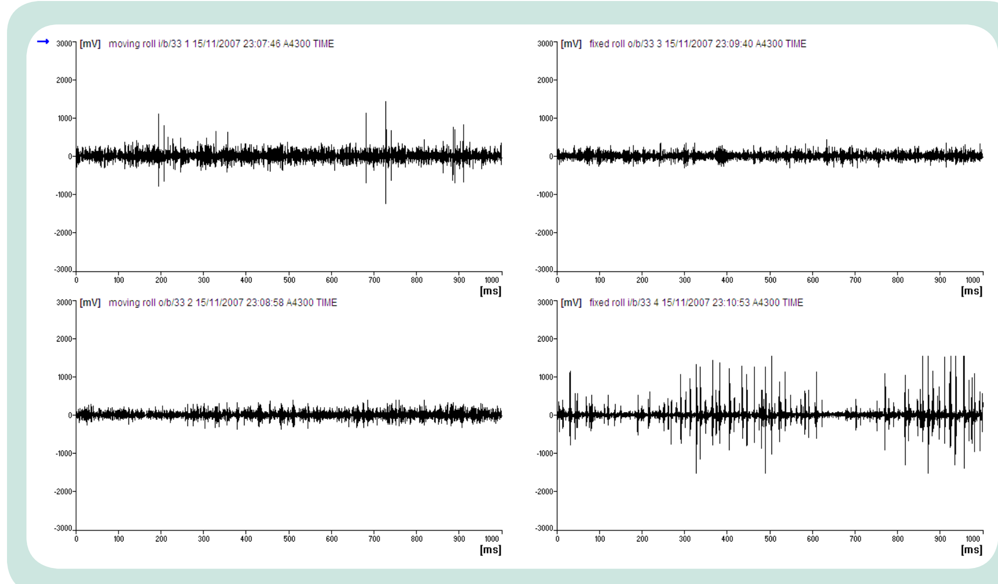

Figure 2 - The top left graph shows a suspect inboard bearing on the moving roll, and the bottom right shows the inboard bearing on the fixed roll as also suspect.

There are devices now available in the professional audio industry which are perfect for this application – small, battery operated, manual gain, .wav file format recording to SD card – which are capable of recording 360 minutes of data onto a 4Gb memory card.

The selection of a suitable device is critical. Because of the transient nature of the signal, auto gain control and MP3 recording are going to cause problems. The automatic gain control will be constantly changing the recording level which makes it very difficult to record comparative signals. MP3 compresses the signal, elevating the level in the quieter parts and compressing the peaks. This will clearly cause corruption of the signal.

The Results

Figures 2, 3 and 4 show results taken on some crushing rolls. This type of machine has two rolls crushing stone down into a powder. This data was taken directly from an SDT170 ultrasound system into an Adash VA3 vibration data collector. The length of the signal was 1 second. These comparison time signals compare the four bearings on one machine.

The two inboard bearings in Figure 2 are

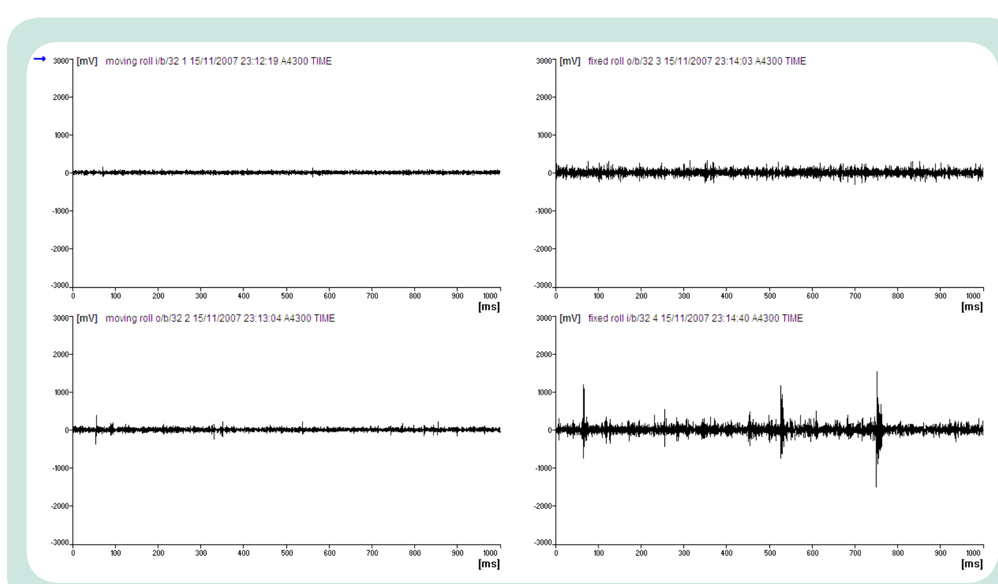

Figure 3 - The bottom right graph shows the impulsive nature of the signal from the inboard bearing on the fixed roll, which is a good indication of a problem.


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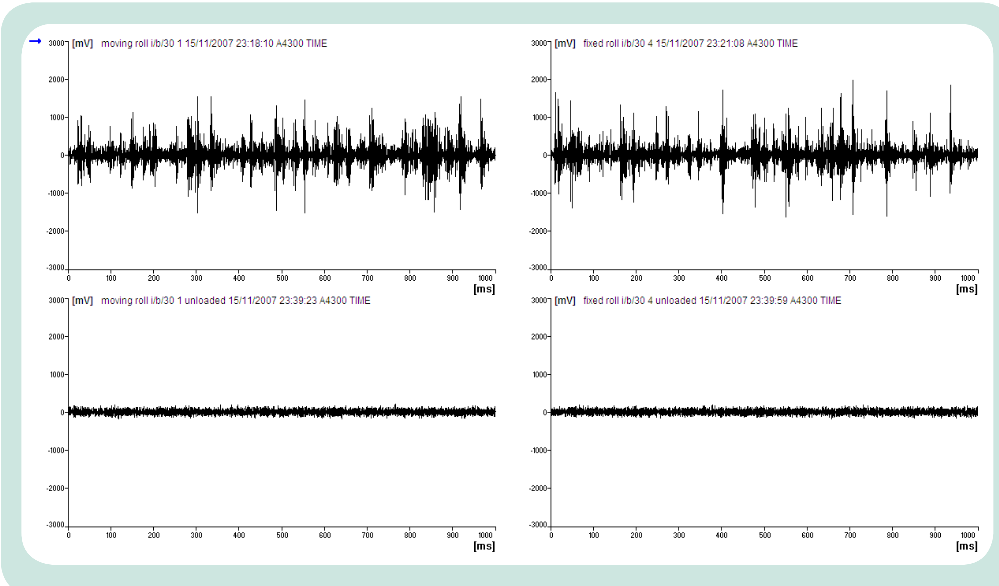


Figure 4 - The difference in measuring bearing in an unloaded state vs. a loaded state could lead to a false sense of security, to problems that are missed and, ultimately, to unwanted downtime.

of particular interest – the inboard bearing on the moving roll (top left) is exhibiting a classical suspect bearing pattern where the bearing on the fixed roll (bottom right) shows a combination of suspect bearing and what was eventually defined as pocket noise – a fairly periodic noise corresponding to 84x rotational speed.

Figure 3 shows a suspect bearing on the inboard bearing on the fixed roll (bottom right) – note the strong impulsive nature of the signal and the lack of any periodic nature.

There is often an interesting, and sometimes heated, debate on the topic of whether measurements should be taken in loaded or unloaded conditions in this application. The argument for unloaded is normally a concern about the random nature of the operating process, which makes it easy to hide a defect in the presence of all the noise.

The counter position, which I support, is that only in real-life operating conditions do we see the true forces being experienced by the machine. The comparison chart in Figure 4 compares the same two bearings with measurements in loaded and unloaded conditions.

This difference is clearly enormous. Measurement in the unloaded condition would never convey the nature of the extremely high forces present in normal operation – surely providing an unfortunate false sense of security.

Conclusions

A portable ultrasound inspection of slowly rotating machinery can be successfully used to inspect bearing condition. The nature of the measurement method means that the time taken to survey such bearings is significantly reduced.

Analyzing the audio output signal for an ultrasound data collector provides diagnostic information in a fraction of the time required to collect and analyze similar information from a vibration measurement.

Tom Murphy is an Acoustics graduate from Salford University and has 25 years experience in the world of industrial ultrasound and vibration measurement – 15 of those years have been involved with the use of Operating Deflection Shape techniques in the paper, printing, petrochemical, power generation, pharmaceutical and food industries. Tom is the Managing Director of Adash 3TP Limited, based in Manchester, England, a Company specializing in the application of vibration, infrared and ultrasonic technologies to improve maintenance. More info can be found at www.reliabilityteam.com and Tom can be contacted at +044 161 788 9927 or at tom@adash3tp.co.uk

From Near or Far

An Overview of Remote Machine Condition Assessment

by John Bernet

Fifty years ago, when labor costs were relatively low compared to operating expenses, managers found that they could simply use more staff to cover the increasing demands of maintaining plant machinery. As labor rates started to increase and competition drove profitability down, technology came to the rescue. Almost every big company was equipped with a team of vibration analysts with small, portable data collectors that paved the way to increased plant production while lowering maintenance costs. Years later, companies were looking for ways to cut costs in an era of sky rocketing labor rates and the highly paid analysts came into the cross-hairs. Many well established reliability programs fell to the wayside. We are now looking at technology again to bridge the gap between labor and maintenance with new Remote Machine Condition Assessment Programs.

A Brief History

1950s – Most industries began by following a maintenance strategy of Run-To-Failure. Labor rates were low and profits were high. They just let machines run until they failed and then fixed them.

1960s – Labor rates rose and profits shrank. Managers looked for ways to manage their maintenance costs. They first looked at Calendar-based Preventative Maintenance which helped reduce costs.

1970s – Industry leaders found Condition-based Predictive Maintenance which revolutionized maintenance planning. Vibration specialists arose to start up the field of vibration analysis. Data collection was labor intensive but still saved maintenance costs over PMs alone. The equipment was heavy, expensive, fragile, slow and complicated to use.

1980s – Portable data collectors became available which drastically reduced data collection labor. Soon, almost every one of the big companies had a team of vibration analysts and they were enjoying the benefits from increased production, decreased maintenance costs, and energy savings.

1990s – CEOs needed to find ways to cut costs because of dwindling profits from increased competition. Reliability programs didn't contribute directly to the bottom line and all the CEO saw was the increasing labor rates of the highly skilled vibration analysts. These CEOs were not around during the 70s and 80s, when the CBM programs turned the maintenance industry around and saved millions of dollars, which went straight to the bottom line. So, they cut the reliability programs because the bad effects would not be seen for years, and the cost savings could be seen instantly.

2000s – A global recession and increased competition continues to shrink profits. Maintenance costs are rising and energy costs are eating away at the bottom line. Companies are looking for a way out of this mess and they are making alliances with some unlikely partners – maintenance with operations; management with IT; customer with vendor. Managers are finding that technology has brought the price of remote monitoring down to the point where the cost is below the rising labor costs needed for portable CBM programs. The Operations manager is willing to provide budget they would have used to hire more labor and give it to the Maintenance manager in order to purchase Remote Machine Condition Assessment programs.

What Does Online Monitoring Mean?

Here are several different examples of online monitoring programs:

Permanent Online Protection – Many large, critical machines are monitored with overall vibration systems that will sound an alarm or flash a light to notify the operator if a threshold is exceeded. Some of these systems are even designed to shut down critical machines to prevent catastrophic failures if the overall vibration level increases dramatically in a very short amount of time.

Continuous Overall Protection – Smaller, vital machines are monitored with less sophisticated vibration systems such as vibration switches and low cost overall vibration systems that will sound an alarm or flash a light to give a warning if a threshold is exceeded. These devices sometimes become a nuisance with spurious warnings that eventually lead to the system being placed in override.

Remote Machinery Monitoring – multi-channel systems that are installed to monitor a sensor or two from each machine. This involves a large number of cable runs and vast amounts of data that no one has time to decipher. Some systems are better and involve a sensor or two per bearing from each machine which is wired to a device that transmits data to the network. A network server then sends the data to a remote analyst who diagnoses the machine condition.

Wireless, Automated Machine Condition Assessment – sorry to get your hopes up, but we are not there yet. Someday, all rotating machinery will have automated self-diagnostic capability that is integrated into the plant's control network. Wireless sensors are on the horizon, but not ready for prime time yet. The current technology does not provide the battery life needed to send complete data often enough when compared to wired sensors. Once wireless sensor technology is better, the machine vibration data can be sent directly to a network server with automated diagnostic software. The data is processed and machine condition information is sent to the manager or planner for repairs to be performed.

Remote Machine Condition Assessment – Taking data away from machinery is expensive; so, we need to move the diagnostics as close as possible to the source of the problems. There are automated diagnostic programs that have over 25 years of proven experience and consistently deliver benefit-to-cost ratios of over 20:1. These programs are now available with state of the art remote monitoring which makes them price conscious in today's high labor markets.

Look Mom, No Hands

If skyrocketing labor rates are the problem, then Remote Machine Condition Assessment is the solution. Over the years, Condition Based Maintenance (CBM) has been documented to save hundreds, thousands, and for some customers millions of dollars a year in maintenance costs. So what can you do to receive the benefits of CBM but reduce or eliminate the high cost of labor? Taking data away from machines and getting machine condition information from the data can be expensive. But now, you can choose the amount of labor you want to take on yourself, and either outsource the rest or implement programs using the latest technology.

Remote machines – you can now wire sensors from your machines in remote or hazardous areas to multiplexers. The traditional method is to use portable data collectors which mean high labor costs.

Remote data collector – you can now install remote data collectors right on the machine floor. You can access them remotely using Remote Desktop Connection (MS Windows XP) and control the data collector from the comfort of your office. The traditional method is to use portable data collectors (high labor costs).

Remote analysis – you can analyze the data yourself, or send the data to an experienced analyst to analyze, or pre-configure the data collector with the machine templates and a diagnostic screening program. This way, the diagnostics are being done down on the machine floor and the machine condition information is sent directly to the maintenance planners to schedule repairs. The traditional method is manual analysis which means high labor rates and high expenses for training your staff.

Remote support – you can contract an experienced analyst or an engineering company to access your database remotely to fine-tune and mature your baselines, set up parameters, and provide a full machine condition report. The traditional method is to pay high rates for annual service and support contracts.

Machine Condition Assessment – not just

overalls for warning or protection, and not just a bunch of data that you don't have time or experience to analyze. This is a proven data screening and machine fault diagnostic program loaded right on the computer of the remote data collector. The traditional method is manual analysis.

What Do You Need to Implement a Successful Program?

Before you rush right out and order your own Remote Machine Condition Assessment program, you should do your homework - look at the four main topics that will ensure you receive the benefits for years to come:

1 Collect complete and accurate data – To get the best results, you need more than overall vibration levels. Overalls are fine for protection systems, but diagnostic systems need more detailed FFT spectral data.

You also need more than one sensor per machine in order to accurately diagnose machine condition. At a minimum, you need one vertical or horizontal reading from each bearing and one axial reading per shaft.

In order to save on cable installation costs, you should use multiplexers that combine sensor wires from multiple locations to a single multi-pair cable. The multi-pair cable is then daisy-chained from multiplexers to a small network device with a data acquisition card. The diagnostic fault templates and individual machine baselines are loaded right onto the mini-computer on the machine floor. Data is screened on the machine floor, and then machine condition fault exceedances are transmitted over the company network.

2 Turn the data into useful machine condition information – many programs for data screening, analysis and diagnosis are labor intensive. You need to find a program that can analyze more machines in less time.

Figures 1, 2 and 3 show three screening methods (left side of the figures) with their respective report outputs (on the right).

Using an expert system does not replace the human analyst, but provides a powerful, accurate and proven screening tool to reduce

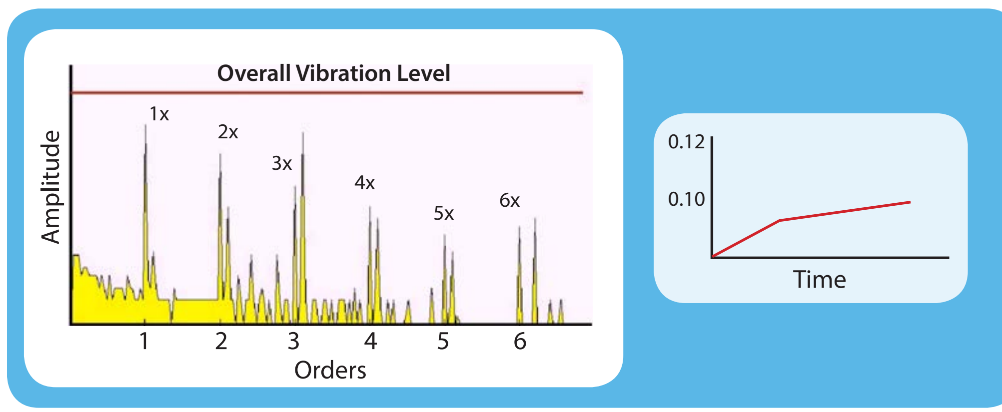
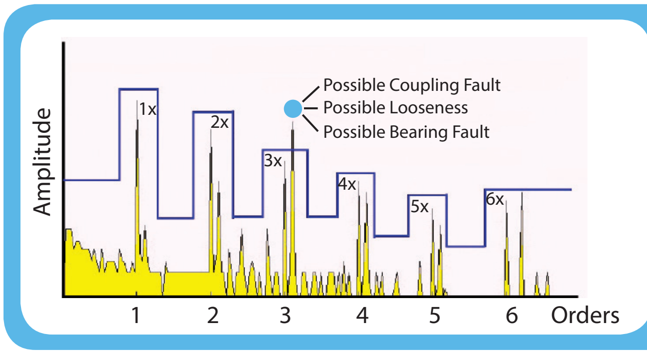
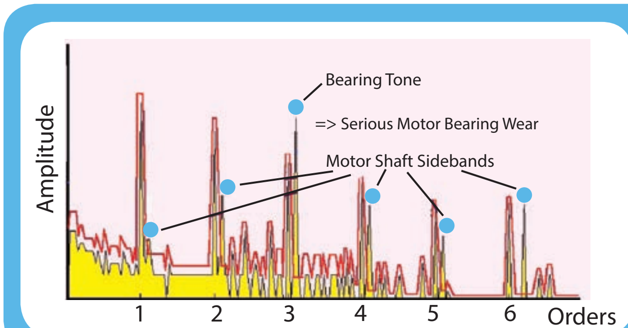


Figure 1 - Overall Vibration (1 Alarm) - based on overall energy on entire machine. No machine condition information - simple trend for protection.



Band	Exceedance
#1	OK
#2	OK
#3	Alarm
#4	OK

Figure 2 - Narrowband Envelope (<12 Alarms) - Bands are labor intensive to mature and require extensive training. One alarm can indicate multiple faults. Manual analysis means more labor costs.



Important: Replace Motor Bearing

Serious Motor Bearing Wear is indicated by:

0.222 (0.194) IPS (3V) at 3.12xM
0.198 (0.166) IPS (3V) at 2.12xM

Figure 3 - Average Baseline (> 500 Alarms) - based on actual machine data; provides highly selective machine condition screening and prioritization. Report includes Severity of Fault & Repair Recommendation

hours required to analyze machine data. Recent studies on a mature program found the expert system was 98% accurate in identifying no-fault machinery and 86% accurate in fault identification compared to a senior engineer. The automated diagnostic program was 8% more accurate than manual data review by analysts with 2-4 years of vibration experience. Most significant was the time saved – the expert system could analyze more than 300 machines and produce a report in 20 minutes versus 3 man-weeks utilizing manual review techniques without producing an equivalent report.

3 Distribute machine condition information to the right people – paper reports get filed away into folders. Use the company network, web pages, email and pagers to get the word out.

Use Remote Desktop Connection (part of MS Windows XP) to remotely access your data acquisition computer down on the machine floor from any computer on your company network. Use MS Excel and Internet Explorer to view your machine condition information from any computer.

Use web-based software (Figure 4) to review reports, vibration data, and machine condition trends from anywhere in the world. Monitor your freezer compressors in Seattle, your wind turbines in North Dakota, your oil rig pumps off the coast of Brazil, your nickel mine crushers in Labrador - all from the comfort of your office.

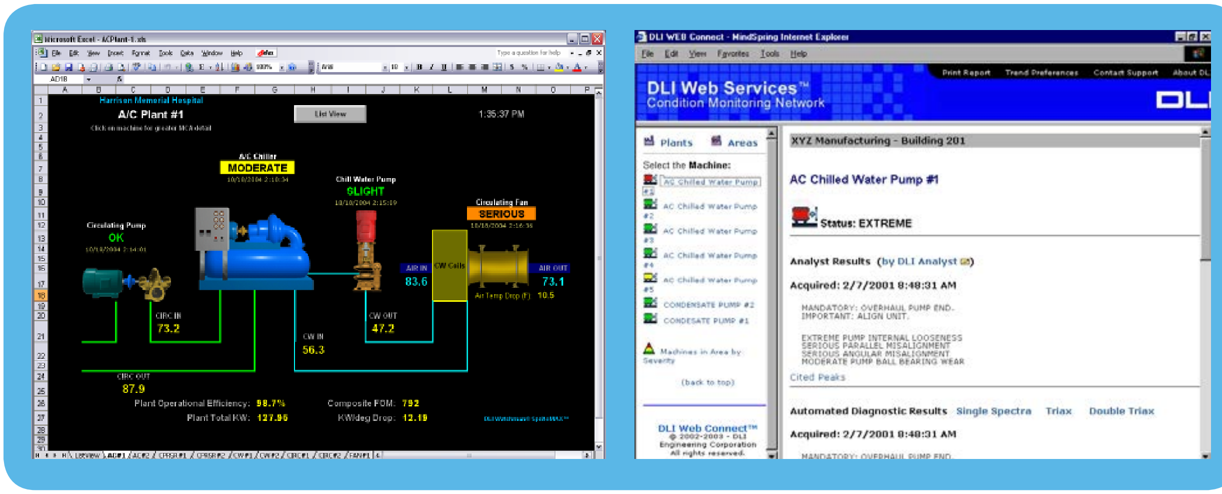


Figure 4 - Web-based software provides access to your maintenance data from anywhere in the world.

Integrate multiple technologies on the same web page from various data collection sensors – vibration, oil, motor current, pressure, speed, temperature, power generated, efficiencies, etc. Information from different sources can give the operator priceless insight when faced with making tough decisions about securing machinery. Multiple indicators supporting a suspected fault can save thousands of dollars in repair costs or lost production.

Today, many companies are combining the results from online and portable systems with the same software program. You can use the same hardware to support diagnostic programs (machine condition) and protection systems (catastrophic failure). You can combine wireless and wired sensors in the same machine condition assessment program. Some examples of combining protection and diagnostic systems are:

a) If you already have sensors on your machines going to a protection system, then you can tie into the connections on the back of the panel and run wires to a multiplexer which can then feed a remote data collector. The results would then be the sent to a diagnostic software program.

b) If you install new sensors on your machines for a diagnostic system, you can use a channel

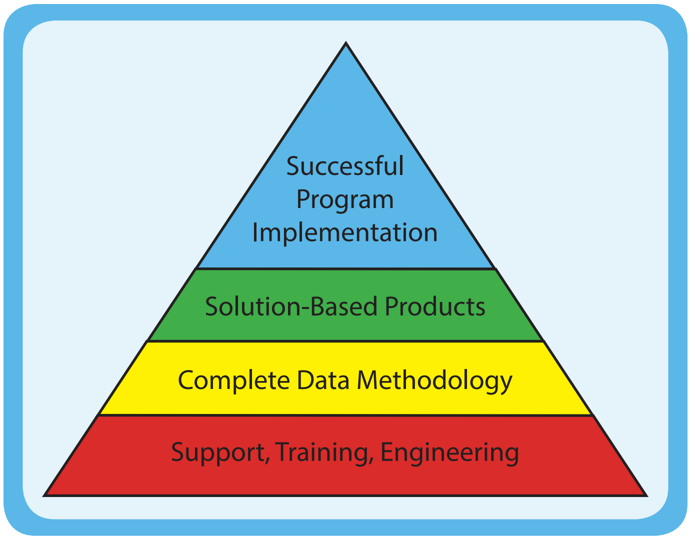


Figure 5 - A successful program implementation needs a solid foundation of support, training and engineering before the next steps can be taken.

of the multiplexer to send a signal to a relay output adapter. This could then flash a light or sound an alarm.

c) If you are implementing a new diagnostic and protection system, you could use dual mode sensors. One part of the sensor would be 4-20mA signal to a PLC for warnings and the other signal would be from an ICP sensor to the multiplexer for the diagnostic software.

4 Get support from inside and outside your company – in order to build a solid program, you will need support from the following groups:

Management – budget to invest in equipment, support and training

Operations – start and stop machines for data collection

IT – company network and server assistance

Maintenance – run program and make repairs

Engineering Vendor – program implementation, training, support.

Many vibration programs in the past failed over the years due mainly to changes in company priorities or lack of support from their vibration vendor. The longest lasting and most successful programs were developed with full engineering support during program implementation, during the first year to fine-tune machine fault templates and develop baselines, and through the years with annual database/program audits. Select machines in small groups as you develop your Remote Machine Condition Assessment program – critical first, vital second and important third. Consider remote and hazardous areas that pose access problems when trying to collect data with portable programs. If you spend a little time and resources ensuring the successful implementation of your program, then it will take less labor and resources to keep it going over the years.

Conclusion

With all of the additional pressures being placed on today's maintenance staff, and the demands for improved financial performance with fewer resources, you need to choose the right partners and the right tools. Technology has shown us ways to bridge the gap between maintenance costs and skyrocketing labor rates in the past, and the latest advances will lead to fewer analysts performing analysis on more machines. Portable data collectors and manual analysis will transition to remote monitoring with proven automated machine condition assessment programs. Someday, wireless sensors will transmit complete data directly to our network programs and detailed machine condition reports will automatically be sent to the worker to make the repair.

In fifteen years at Azima/DLI, John Bernet has worked in technical support, sales, training, and installation of Machine Condition Assessment programs. Prior to Azima/DLI, John served in the US Navy for twelve years where he operated and maintained nuclear power plants. John can be reached at jbernet@azimadli.com or 206-842-7656 x1019.

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Reliability Centered Maintenance

An Intro

by Alberto G Landeaux

W The RCM is one of the most used maintenance tools all around the world, it's being used in a wide variety of industries with excellent success histories. However, on the other hand, there are also many failed projects (over 65%) with a wide variety of reasons for those failures. Most of them blame the methodology, others the consultants or the RCM teams and even the maintenance culture, but one of most seen reasons is the difficulty to link the RCM project with existing maintenance plan, the RCM teams are so focused in determining the maintenance activities required by the equipment, system or plant that is not possible to see how the new maintenance activities impact on the existing maintenance policies or plan, so when they are going to be implemented produce a titanic proportions confusion and incompatibility that the easiest way out is to discharge the RCM project and continuing like the "old days" because it's seems to be at least easier to go through with bare minimum results.

The Reliability Centered Maintenance Management (RCM2) is a methodology that will allow to the RCM teams to have a set of structured steps to manage RCM projects from start to end having all the stages linked from each other and reaching a better project control even after the implementation of the maintenance routines required by the system and avoid the "hit-and-miss" approach that put on risk all the money and time required for a RCM project.

The RCM2 consider that the maintenance budgets are not unlimited and sometimes caused by company policies or financial problems are under the limit to attend the most basics aspects of maintenance, that's why the RCM2 put on the table the maintenance requirements using any of the RCM approaches with the objectives, resources and control mechanisms to run a structured and competitive maintenance policy achieving a balance between the maintenance resources (inputs) and the system or plant outputs in terms of maintenance (reliability, availability, safety, product quality, etc.)

The RCM2 consist of 6 steps or stages:
1. RCM Justification
2. RCM Project Objectives
3. RCM Methodology (RCM2 or any RCM approach)
4. Determining the resources to maintenance activities (manpower, spare parts, tools and information)
5. Maintenance Planning and Scheduling
6. RCM Project monitoring

STAGE 1 - RCM JUSTIFICATION
The are two questions around the RCM projects:

1. In which system is necessary the RCM methodology?
2. When is necessary the RCM in our plant?

Both questions may merge sometimes in a common answer, for example, the RCM may be needed in those systems with a failure rate way over the manufacturer or maintenance department estimations (taking in consideration the operational context or conditions), in that particular case both of the questions asked before (which and when) have the same answer ("In those systems with a failure rate over 0,00045 failures per hour" to answer question 1 or "when the system reaches a failure rate over 0,00045 failures per hour")

Equipment or systems with high levels of corrective maintenance: is necessary to estimate the failure rate and compare with the manufacturer failure rates, maintenance department base rates o with any reliability database (OREDA, NPRD, IEEE). Also is necessary to perform a Root Cause Analysis to see if the operational conditions are not a high level cause of the failure rates levels.

Equipment or systems with high costs of failure: the cost of failure is not only the manpower and spare parts used in the maintenance action, sometime the cost of production lost are way over the maintenance cost, this item should be included as an item in the failure costs. Those equipments or systems with high failure costs are excellent candidates to be included in a RCM project to mitigate the financial risk of failures.

Equipment or systems with unacceptable levels of global risk: there are five basic elements that a maintenance department should consider in the criticality analysis, those are:

1. Operational Impact
2. Operational Flexibility
3. Failure Cost

4. Safety and Environment

With those four elements it's possible to build a risk equation with factor for each one of them to measure the criticality of equipment or systems and select those with the unacceptable levels of risk to be included in a RCM project and mitigate maintenance related risks.

Figure 1

EQUIPMENT OR SYSTEM CRITICALITY LEVEL
Based on Risk Theory
Frequency Factor - FF Failure Cost Factor - FC

STAGE 2 - RCM Project Objectives

A RCM strategy must start from objectives that allow the maintenance department to focus the RCM project on the maintenance requirements, the maintenance requirements are a set of specific items that need to be accomplished to support (from the maintenance point of view) the company strategy. The maintenance department is one of the most influenced ones, if we see it like a system (inputs, process and outputs) is possible to visualize the influencing factors.

Figure 2

As we can see in the figure there are several influencing factors in a maintenance department, that is why defining just one objective may be not enough to communicate goals and the ways of support the maintenance strategy. In a RCM project is also necessary to define objectives that allow to the team to take the project into the existing maintenance strategy or define one in case that this doesn't exist.

Stage 3 - RCM Methodology

At stage 3 the project team apply the RCM methodology to identify the maintenance requirements of the equipments or system under study. There are several RCM variants, any of them may be used if the main objective of the RCM is accomplished "Identify the maintenance tasks required to mitigate the consequences of the failures modes".

Stage 4 - Determining the resources to maintenance activities (manpower, spare parts, tools and information)

The maintenance tasks require resources to be done, the maintenance resources are: manpower, spare parts, tools and information. Building a maintenance resources structure to the RCM project will allow to visualize what is needed to perform the maintenance tasks obtained from the RCM methodology.

Maintenance Resources

Manpower

The RCM2 recommends to classified the manpower according to the technical area (mechanical, electrical, instrumentation, facilities, etc.), then categorize the maintenance work by maintenance lines, that will build a manpower structure that may attend the preventive maintenance and perform the corrective maintenance without neglect the PM plan.

Figure 3

Spare Parts

Achieve a balance between the cost of ordering and holding and the cost of stock out is the core of a Maintenance Inventory Policy. There are several difficulties to reach that balance, the variety of different items is one of the most complex aspects of a spare parts organization because each part requires a inventory policy. A basic classification of spare parts can be: Fast moving parts (>4 parts per year) or Slow moving parts (<4 parts per year), then they should be classified according to the function of the spare part.
For each maintenance task obtained from the FMEA must be build a required spare part list and get information about the inventory policy, in the case of the inventory policy doesn't exists is necessary to calculate the cost of ordering and holding and compare with the cost of stock out and build an inventory policy, an inventory policy may be resumed in: When and How many parts will be ordered?.

The costs of Ordering and Holding includes: ordering, delivery, stocking,: depreciation, interest charges, rental, preservation, taxes (asset). In the other hand the cost of Stock Out include: loss of production due spare part unavailability, ordering (overnight), delivery (overnight).

Tools
The organization of the tools is similar to the spare parts, but it has a control problem because the tools are not consumables, they are assigned to a person or a work group and after the maintenance task it should be returned. Like the spare parts they needed to be categorized, a simple division for tools are:
small tools (usually assigned to a person from artisanal tasks), Large (work groups), lifting and scaffolding, special or electronic tools.
Also, like the spare parts, each maintenance task from the FMEA must have a list of the tools required to execute each task.

Information
Under this heading are: documents, catalogs, manual (maintenance and operation), drawings that might
support the maintenance activities, the categories are:
• Reference: might be consulted before the execution of a maintenance task.
• Instruction: work orders, safety instructions, maintenance manuals.
• Planning & Scheduling: used to plan & record resources, schedule maintenance activities and feedback information about the accuracy of the planning.
• Control: used to store and analyze plant technical history.
There are four questions that needed to be done about the information:
1. How is the information to be held?
2. Where is to be held?
3. Who will use that information?
4. How will the information support the RCM project and the maintenance strategy?

Stage 5 - Maintenance Planning and Scheduling

After determine the maintenance tasks required according to the FMEA recommendations, the RCM project team should estimate the workload of the recommended maintenance tasks, that way they will know how it will impact the maintenance plan (if it exists), also will be useful to map the resource structure, identify the workload demand and resources pattern, the objective of the resource mapping is to take into consideration the RCM project recommendations into the plant maintenance resources availability.

Figure 4

Stage 6 - RCM Project monitoring

The RCM project monitoring is one of the most important stages in the RCM2, because is that way that the project team will compare the before and after of the maintenance situation in the plant. Is necessary to develop maintenance performance indices according to the objectives at RCM2 Stage 2, the objectives are the "What's?", the MPI's are the mechanism to compare those "What's?" with the maintenance situation before the implementation of the RCM.
The MPI's without a objectives statements are usually ignored or not understood because after some time the reasons that take the maintenance department to build those performance indices are overlook or forgotten.

In RCM project monitoring, the key task is to develop maintenance performance indicators according to the objectives and set a checkpoint for each one of the objectives with the performance indices, is possible to build more than one MPI per objective, usually the MPI's need to be contrasted with another MPI or MPI's to see if the maintenance strategy is generating the solution to the problem that justified the RCM project.

Figure 5

Is very important for the Maintenance Department to know that RCM is a tool that helps support the maintenance strategy and reach the department's objectives. It's true that RCM may have performance indicators that will reflect information about the RCM methodology into the maintenance strategy, but each Maintenance Department should have a strategy to incorporate RCM as a tool – not as a project that ends when the maintenance activities are identified. It's perfectly normal to revisit an RCM project, and to make changes, because it didn't completely fit into the maintenance dynamic the first time it was performed. Changes to improve the maintenance function are always welcome – anytime.

Alberto G Landeaux
Reliability and Maintenance Consultant
ISC Gerencia de Activos CA
+ 58 414 6967483
+ 58 412 4809495
alandeaux@iscgerencia.com

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Understanding The Reality of Filter Element Ratings

by Mike Boyd, CLS, CFPS

Our company was the first in our industry to utilize hydraulics to any significant degree. We used hydraulics for propulsion, for auxiliary functions and for steering. With the implementation of an innovative technology, we had to learn all about it. Wally was sent to the training schools of each of our component suppliers. He returned our company expert.

He had learned from George Altland at the Vickers School that dirty oil caused more hydraulic failures than all other causes. So we listened closely as Wally explained how to determine the condition of our hydraulic fluid and our system and components. Wally was thorough and at the time, state of the art. When I attended the Vickers School, George told me pretty much the same thing he had told Wally.

You could determine a lot by using then current, state of the art analytical techniques. Wally had explained to us the following protocol. Loosen the drain plug on the reservoir and allow about a pint of fluid to drain into a clear glass jar. Next, hold the jar up to the light to look for chunks in the oil. A few small ones are OK but more than a few or large chunks were a sign that action was required. Next, smell the oil. If it smells badly burnt, change the oil and filter element (spin on). Next, let the jar sit, undisturbed on a shelf for a few days. If water collects at the bottom of the jar immediately or after only a few minutes, drain the water from the bottom of the reservoir after the machine has been idle for several hours. If the water separates out after sitting several hours, don't worry about it, and change the oil at the regular interval. Finally, if there are several chunks in the jar, the first step should be to change the filter element.

Such was the state of the art for hydraulic system maintenance technology in the mid 1960's. I have been continuously involved in Fluid Power since my involvement with Wally and George, and I revel in the changes that have followed and even more so in the currently evolving technology surrounding contamination control and fluid management.

1958-1968

There was very little filtration at all in hydraulic systems with very few exceptions outside of military and aerospace and a few highly sensitive systems. There was practically no fluid condition monitoring beyond that detailed by Wally, and very few studies published. But, as George was warning, since "improper oil condition" caused more failures than any other cause, we needed to look after our oil. But, how?

1968-1978

More equipment manufacturers are including filters on their machinery, but for the most part, the filters were coarse, nominally rated filters. There were few other filter specifications that mattered beyond handling the flow and occasional concern for pressure ratings should the OEM want to place pressure line filters on the machine. Targeted and measured fluid cleanliness is still a concept of interest to only a small number of academics and researchers. Toward the end of this decade the Devil raised his head disguised as the marketing arm of some filter manufacturers.

Filter manufacturers, like all other for profit corporations, are in business to make a profit. That is a necessary goal if they are to stay in business. In a free market the burden of controlling costs is with the consumer. The responsibility for optimizing filter profits resides largely with marketing. So, the most profitable companies will find, and continue to find ways to differentiate their offerings from their competitors at greater profits than their competition.

The superior marketing departments started assembling data from all available sources. They started studies to support their current and developing marketing strategies. They knew that each new strategy had only a short while for them to fully exploit it, before the competition would hitch their strategies to the leader. They also engaged heavily in developing standards (favorable to their strategies) and publishing marketing success stories masquerading as technical papers. During this decade the leading marketers were looking to find ways to move their high tech filters into a relatively stone age commercial hydraulic component market place. ONLY inspired marketing could/would succeed. And, they did.

1978-1988

Led by a growing number of manufacturers of sophisticated machine tools, plastic molders, and other makers of high precision equipment, finer filtration was making large inroads in to the hydraulic industry. With marketing claiming greatly improved cleanliness using fine filtration, the need to verify the results was increasingly important. Microscopic particle counting took too much time and was subject to technician errors. This was all the impetus that was needed to spur on the development of automatic particle counters. Vickers Europe published a paper that has appeared in practically every hydraulic text published since. The document lays out the cleanliness requirements due to system component sensitivity. The filter specifications were limited to the prevailing terms of the day, which were "absolute filter ratings" that were not "absolute".

During this period, there was a great deal of activity in the field of developing test methods and procedures to help the the less knowledgeable better misunderstand filter specifications. I don't believe it was the intent of the researchers and their teams to mislead anyone with their work. I am convinced, however, based on court records and other documents that it was indeed the intent of some marketers and their management to deceive the marketplace with false and misleading test results. During this period the Multipass test gained attention as the best test for evaluating filter efficiency ratings and dirt holding capacity. These are two of the most frequently used specifications used to differentiate filter elements.

A growing number of study results were published and circulated. There followed a growing industry wide awareness of the need for cleanliness. Again the question was how to achieve it.

1988-1998

This decade saw a big increase in the number of different suppliers of "fine filters" both domestically and from abroad. With the increase in sources of filter elements, it became even more important to be able to verify results. Hence a real push in developing fluid condition monitoring equipment resulted in the rapidly increasing availability of affordable, user friendly, accurate instruments. With the readily available instruments, it naturally followed that an entrepreneurial society such as ours would see a prolonged surge in the formation of independent laboratories. This created a dilemma. Which labs were capable of accurate analysis and how to verify it, became a major concern. It also became essential to be able to sort through all the conflicting claims from so many different sources.
This decade also saw the fine tuning of applicable standards for monitoring and reporting fluid cleanliness. Shrewd filter marketers saw the importance of tying these emerging standards to their marketing efforts. They saw the critical nature of differentiating their "filter" from the competitors. Again, Vickers came to the aid of the end user. Vickers published their handbook on Systemic Contamination Control. The publication temporarily refocused the user's attention away from "the filter" to a contamination control system. It also forced the major competitors to talk in terms of systemic control. It wasn't long before the marketers were back to differentiating their elements of the system from competitors. Too few people were seeking to improve the systemic approach.

This was also the period of great growth in information technology, with the introduction and phenomenal growth of the internet.

1998 to the Present

There has been a burst of new fluid condition monitoring equipment as well as in contamination analysis equipment and technologies. Larger users of hydraulic and lubrication equipment are finding it essential to bring expertise and analytical capabilities on board. As a result, whole new information dissemination industries are exploding. There are more conferences and publications dealing with fluid management this decade than in the entire preceding history. Widespread needs for training and certification of areas of expertise are being met by a growing number of independent experts, recently separated from the comfort of corporate life.

The larger users, during periods of acquisition and "right sizing" released their own in house experts to lower costs, thus creating the greater need to hire back their expertise and experience at premium fees. During this decade there has been a return to relying more heavily on filter ratings because of the shift in expertise from the in house decision making practices to the greater reliance on consultants. The marketers returned to focus on the filter.

With the filter element again the main focus on the marketers, "absolute" filter ratings fell out of favor, being replaced by Beta ratios. Beta ratios are one of the key filter "specifications" determined by the multipass test. What the marketers won't volunteer to you is that the odds against your application operating parameters approaching the multipass test parameters are greater than you winning the lottery 4 weeks in a row.

Multipass Test versus Reality
An analysis of the differences between the multipass test and real life is helpful.

Multipass Test	Real Life
Run at constant temperature	Operates at widely varying temperatures
Uses very low viscosity oil	Uses many different fluid viscosities
Constantly adding high contamination load	Cleans system to low contamination levels
Can choose flow rate	Will see many different flow rates
Uses special fixed particle distribution	Particle distribution will vary widely
Can choose in advance when to end test	Element changed on indication
Can select the contamination challenge	The challenge will always be lower after reaching equilibrium
Only a very few elements will be tested	Test results are almost always unique to the element tested and the test parameters

Table 1

Important points to remember include;

1. Dirt particle size distribution varies almost infinitely so no test case applies universally.

2. Test dirt has a relatively high distribution of larger particles, distorting real dirt capacity.

3. Constantly injecting high dirt loaded slurry skews real life Beta ratios.

4. Such a low viscosity is seldom seen in real life and also skews results.

5. Filter element manufacturers typically offer many thousands of combinations of element constructions, media packs and different media. Since multipass tests are expensive and time consuming, it would be prohibitively expensive to test each combination. So, only a few are tested.

The marketers rely on your assumption that the test results are uniformly applicable to all combinations of elements in all applications. Again, they focus on the filter element and NOT the targeted result (See Figures 1 & 2 in the appendix). The published test results, relative to real life applications, are almost never comparable, even within a suppliers own line, and certainly not between competitors. It is the marketer's compulsion to differentiate his product at any cost that keeps these reported test results in front of the general public. Also there is no requirement that all data published on an element be from the same actual test. Test results, most favorable to the vendor, from tests with varying parameters can be published without concern. After all, "caveat emptor".

The Best Place To Put A Filter

Remember the assignment of responsibilities. If you want the most cost effective solution, you must control the process. Marketers will almost always recommend filter placement most profitable for them. Several such recommendations have attained almost legendary status through constant marketing (training and success stories) efforts and pressure. As in so many technical disciplines, the vender says, "The customer is the expert in his industry. We will recommend and then wait for him to counter." The customer says, "The supplier is the expert in filtration. We should not invest time and money seeking a more effective approach."

Who wins? Who Loses? Who is responsible? What is the solution?

Many large customers represent enough business to the suppliers to take control of their own performance and results as well as compelling the vendors to deal honestly with them. Other smaller customers can band together within their industry to achieve the same goals. A major step is to compel the vendors to pay for Multipass testing at the lab of the customer's choice, to the specs the customer has developed (See Fig. 3), on an element configuration and media pack the customer has selected and purchased anonymously. That way all prospective supplier's elements will be tested to the same parameters at the same lab by the same technicians using the same equipment and procedures, without the elements receiving special attention before they leave the manufacturer. Sound fair? Will this separate marketing hype from reality? You bet it will.

Now that we have eliminated the marketing hype from element selection, we can deal effectively with filter placement. The most cost effective placement will be driven by system operating and design parameters. Here it is helpful to examine your supplier's credentials and verify expertise in the particular disciplines. Fortunately, professional societies have undertaken testing and certification of applicable expertise. Using this resource can accelerate and facilitate your search for qualified advisors. Now, following a simple strategy (see Fig. 4) you should successfully achieve your articulated goals.

Mike Boyd, CLS, CFPS

Reachity

Softwag

by Jim Davis

T Each year companies spend "thousands to sometimes millions" of dollars on a new EAM system only to find that one to two years down the road after implementation, they have no better data than what they previously had and find themselves using less than twenty-five percent of the capabilities of the new software.

So what went wrong? Why didn't the investment pan out as anticipated? How then could other companies avoid the same mistakes in the future?

What Went Wrong?

There can be many contributing factors to an unsuccessful EAM implementation. However, the most common ones can be summarized below:

1) IT drove the project, with little to no real user input.

2) The company failed to do a thorough review and update of its business practices, especially in relation to how it could and should fully utilize the new software's capabilities.

3) Little thought and effort was put into developing the right "codes & tables" within the system, especially in alignment with any new business processes that would collect, input and analyze required.

4) User Levels were not well identified and honored.
5) Software training was not aligned with process training. Any association was assumed to eventually occur on its own.

6) Critical KPI's and reports were not well thought through.

7) There was not a software super-user/administrator clearly defined.

Let's take a brief, more in-depth look at these critical elements.

A User-Driven Process

The IT department certainly has an important role to play in the purchase and implementation of company EAM software. Such things as hardware and firmware, supporting software (if any) integration issues regarding other company owned and used software, architecture platforms, hosted/non-hosted solutions, etc., etc. are best coordinated by the IT group. They are not, however, always the best judge of end-use software applications, how they will be fully utilized in the field and what access rights certain individuals should or should not have regarding system usage.

Now, with that said, not all end-users are experts either. In some cases, they are even less educated on the full functional features of EAM than are the IT guys. However, if IT is tasked with the ultimate responsibility of procuring and implementing an EAM, it is their responsibility to ensure that the "end-users" are fully involved in reviewing the software's functionality, understand its relative strengths and weaknesses have the appropriate input for system set-up and configuration.

Business Process Review

In order to further assure that the chosen EAM is

***Editors Note**: We published this article with specific references to Emerson's AMS Suite and Asset Portal software in order to tell more people about potential solutions as maintenance and reliability information management evolves. We did not want to make it generic. There are other unique software products that we will also be presenting to you in Uptime. In order to bring you the full impact of the capabilities of some of these new technologies - we have decided to allow product specificity - not as an endorsement - but to create an enhanced understanding of the rapidly changing landscape of Information Technology. Uptime is comfortable stepping out of the limited and traditional etiquette of magazine publishing and we hope you see the value in our decision. We certainly invite your feedback as we continue to move forward.*

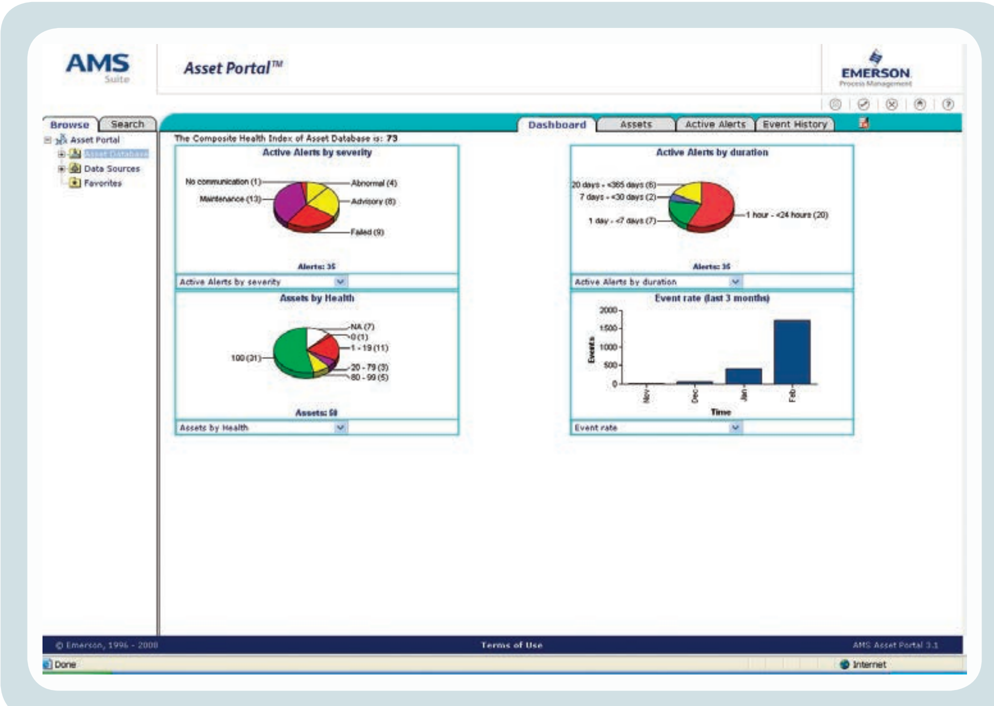

Figure 1 - A screen shot of the dashboard within Emerson's AMS Suite: Asset Portal, which gives you a view of Active Alerts by severity and by duration, a view of Assets by health and a score for the composite health index of you asset database.

the right system for the business processes involved, a complete review of those business processes is necessary. This review also helps IT and the end-user teams define the specific functional and technical requirements needed from the software. This is typically not an IT-driven function, but one that should be driven within the primary end-user department(s). At a minimum, the following should be reviewed:

• What data is needed, and in what form, by the various user groups to better do their jobs and make better fact-based decisions, versus "gut feel" decisions?

• What current processes (e.g., policies, procedures, and flows) need updating to take full advantage of the new EAM's capabilities?

• How will needed data be captured, by whom, and in what format? And, how and when will that data be input into the system for later retrieval?

Basically, a user's "project manager" must be appointed to work with the user group team(s) to determine the above as well as what specific functions of an EAM are required (i.e., absolute musts versus desired). This process alone can take weeks to even months if done correctly and thoroughly.

The Right "Codes & Tables"

As a part of the business process improvement noted above, some portion of that process should begin to identify specific "codes & tables" to be set-up in the EAM.
Specifically with regards to the maintenance work management and MRO storeroom and procurement process. These "codes & tables" when established will provide the framework for easily inputting key data into the EAM that can later be extracted, viewed and analyzed.

Some thought needs to be put into this process. If there are not enough codes, the resultant data may be to general and not provide the details needs to spot recurring problems and trends. Too many codes will often result in guess-work to zero in on what the field user might interpret as the right code and thus filter or dilute a general trend that could be later analyzed by better follow-up means.

One example is work order priority odes. The default, too often, is to have, for example:

1) Within 24-Hours
2) 24-48 Hours
3) 48-72 Hours
4) Greater than 72 hours, etc.

These typical codes don't really help you establish a true priority, rather they pigeon-hole work into often unrealistic timeframes. Most would probably default to Priority-1 or -2 anyway.

Work order type codes, classification codes, cause codes, reason codes, remedy codes, failure codes and delay codes are all important but have to have real purpose, meaning and understanding.

Correct User Levels

Again, configuration data for "user-level" access (i.e., who can do what) in the system should come out of the business process review. These are roughly channeled into four main access types... inquiry only, and/or add/change/delete authority. The less people who have the ability to add/change/delete, the better. This helps to ensure consistent data and minimize constantly changing data that can cause problems in itself.

For instance, with regards to the work order backlog details (i.e., statuses, priorities, WIP, etc.) the Maintenance Planner should typically have more access rights than the Maintenance Supervisor and certainly more than the Maintenance Manager! The MRO Storeroom Supervisor would, likewise, have more add/change/delete access than most storeroom attendants and maybe even the Materials Manager. Obviously you have to have "back-up" personnel with the needed access, but that can typically be accomplished on a "temporary access assignment" basis when required.

In order to maintain consistency in the use of account codes, new part numbers, new equipment numbers, etc., etc. there needs to be a developed standard (set-up format) that those who are authorized have to follow to get new or edited information into the system. Again, the less the better.

Targeted User Training

Once you have defined business processes to adhere to, clear roles and responsibilities on "who does what" and the appropriate user-level access to match, software training should basically be a "no-brainer".

There key here is to link the process training with the software training so that the user understands how and why it is to be done and how the EAM system will be used as his/her tool for future data-mining.

There is more to training than throwing up two-hundred PowerPoint slides that could apply (or not apply) to several different users, and show you fifteen different ways to do the same thing.
User training should be targeted for like user-groups, centered around the exact process they are expected to follow. In addition, the screens that they see during the training should look exactly like the ones that they will see at their own desk, in the same exact sequence they should be expected to follow.
As part of the configuration activities centered around the various user-level access criteria, the screens should be greatly simplified as much as possible. Meaning that if you are only authorized to submit a departmental maintenance work request that only requires that you fill out four fields, then four fields is all you should see and have access to.

KPI's and System Reports

Obviously the main reason for inputting all of this critical data into the EAM (consistently, cleanly and with some semblance of timing and urgency) is to be able to glean useful information out of it at a later date. Information that will be used to make better business decisions.

You put data in, you get information out. Reports and KPI's are like codes, you can have too many (i.e., information overload) or too few (not enough of the right kinds of information). If information is going to be useful it needs to tell you things such as:

- What's not going on that should be
- Deviations from the norm
- Things to do or follow-up on
- Historical information for verifications
- Predictable information for future planning.

The EAM set-up team can and should define some standard reports and KPI's by user level, etc. Custom reports can be developed later either by the IT team and/or the users themselves (properly trained, of course). Most modern era EAM's feature some "dashboard" capability that "pushes" key information to you without you having to always go and look for it.

EAM System Administrator "Super-User"

Ongoing training and system maintenance is a given with the newer, more powerful EAM systems on the market today. There is a need for database maintenance and integrity, associated software interface requirements, hardware issues, etc., etc.
Typically, these activities are handled by the IT department (and, rightfully so).

However, there is also a need for a system "super-user". Somebody who actually uses the system on a regular basis and can provide new training, refresher training, screen layout changes, expose/hide needed or unneeded fields, reports generation, user-level access authority, etc. This person typically would work in one of more of the departments who use the system continuously. This "super-user" would, typically, be the one who controls the input (add/change/delete) of new data entered into the system (e.g., new equipment numbers, new assets in the hierarchy, new item master catalog (stores) items, codes, etc.).

As noted earlier, in order to maintain consistency in the use of account codes, new part numbers, new equipment numbers, etc., etc. there needs to be a developed standard (set-up format) that those who are authorized have to follow to get new or edited information into the system. Again, the less the better.

A Successful EAM Implementation

Obviously there is much more involved in an EAM implementation that could go wrong than the seven pitfalls mentioned throughout this article. There are many more things that can go right and lead to not only a successful implementation, but to a system that is well-liked and well-used.

Some key points to remember might be:

1) Do your due diligence and make sure you buy the right system for your needs.

2) Establish an EAM Project Champion.

3) Involve the end-users extensively through out the entire process.

4) Take the necessary time to review/update all business processes that will be affected by the new EAM.

5) Carefully think through the end-use applications and configure the EAM system to compliment those applications.

6) Develop a sound and thorough implementation plan.

7) Customize the training for the individual end-user groups.

8) Provide ongoing training and support.

These key points in conjunction with an all out effort to avoid the "Top-7 Pitfalls" should lead you to a successful EAM implementation that will provide both staff and management many years of useable equipment history data and enable better, more informed decisions for maintaining company assets.