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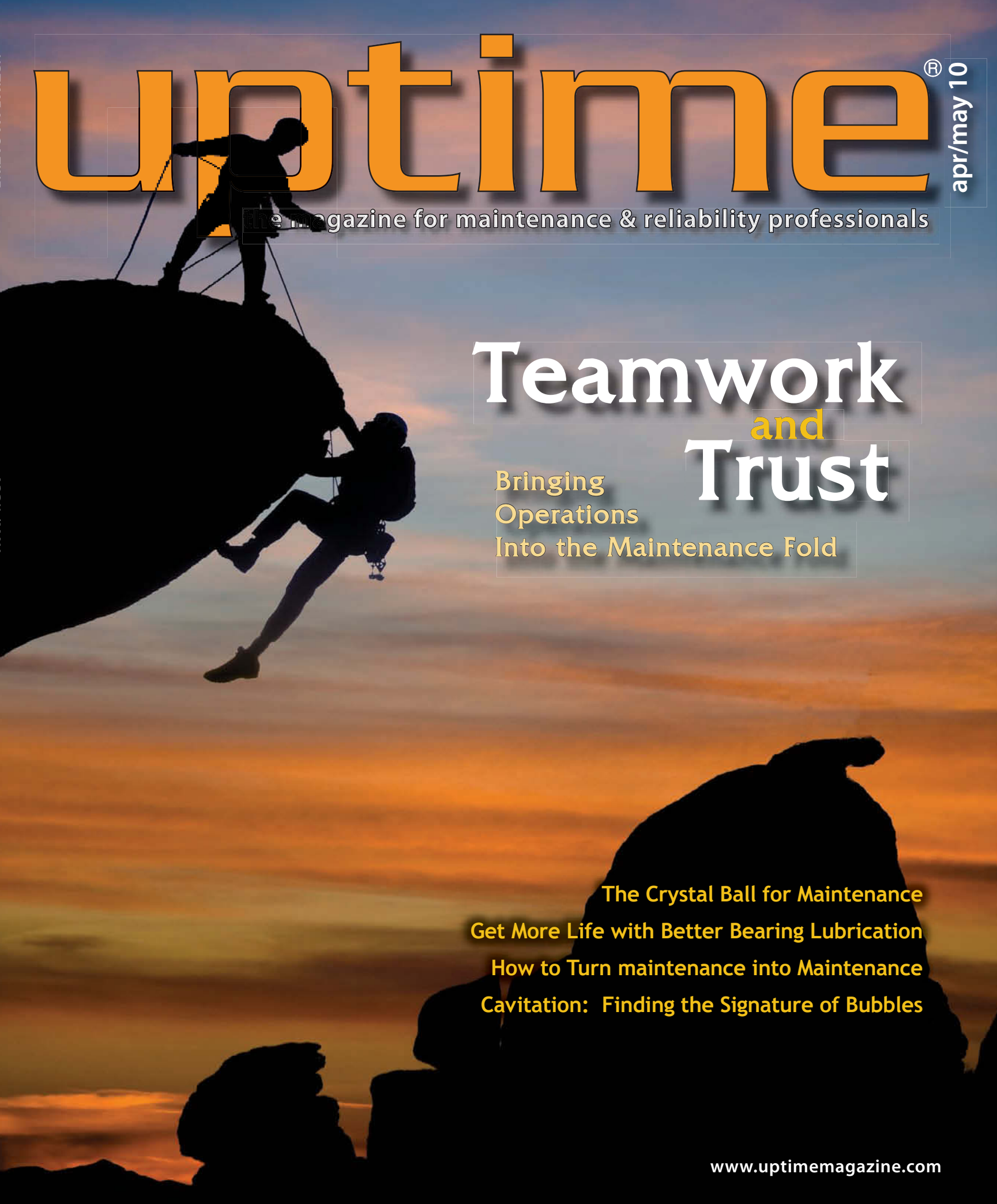

Teamwork and Trust

Bringing Operations Into the Maintenance Fold

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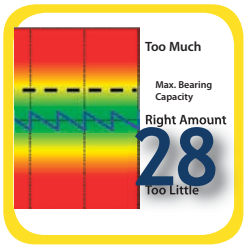

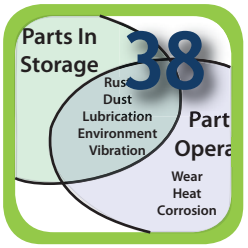

It Takes A Team to Succeed

In this issue's feature article "Reaching for the Top", author Paul Casto discusses the importance of teamwork in developing an effective maintenance program. He outlines a process of developing a maintenance strategy based on failure analysis, and, while this can be accomplished solely by the reliability and maintenance staff, its power is exponentially greater when operations is included as part of the team.

The importance of breaking down barriers between departments, and supporting cooperation among the various players in an organization, in our case maintenance and operations, should not be underestimated. Operators know the machines they run, and they know the consequences of that equipment's failure. Therefore, involving operators in the discussions and decision-making processes regarding how to best maintain the equipment they run empowers them to take part in ownership for the equipment's reliability. They will care more about the machines they run, and, perhaps to some's surprise, can help immensely in their maintenance.

I think this is an issue worth talking about in a more general sense. I am sure that most of us, at one time or another, have worked in dysfunctional situations, where work efforts were vertical, or generally made in silos. If so, you may know first hand that this set up intrinsically lacks cooperation, and many times, also lacks the checks and balances and varied perspectives needed to make good decisions for the overall health of the company. After all, many times a decision can be in the best interest of a department, but not in the best interest of the company.

With this in mind, bridging the gap between maintenance and operations, and other departments where it makes sense (purchasing and accounting immediately come to mind), begins by adjusting goals to make sure the two different departments are genuinely aligned. Once they see that they are on the same team, with interconnected goals, they will become empowered with mutual and vested interest in seeing that each other's departments run smoothly. This redirection will inevitably support higher morale, inspire corporate excellence and create a stronger overall organization.

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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PUBLISHER
Terrence O'Hanlon

EDITOR IN CHIEF
Jeffrey C Shuler

ADVERTISING SALES
Bill Partipilo
888-575-1245 x 125
sales@uptimemagazine.com

EDITORIAL INFORMATION
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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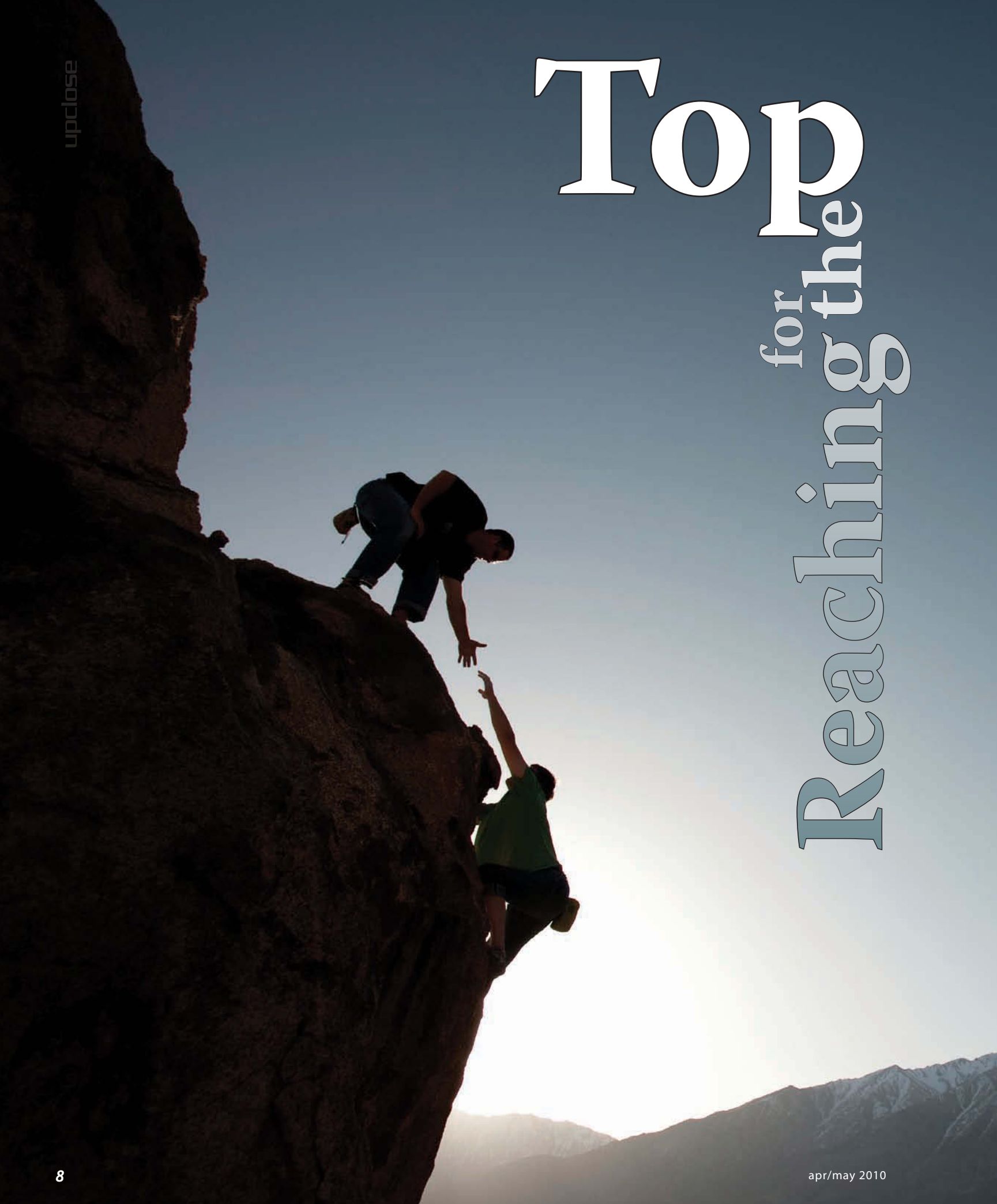

Creating a New Partner with Reliability Centered Operations

by Paul R. Casto, CMRP

To optimize both maintenance risk and cost, the interrelationships between reliability, maintenance and operations must be considered and leveraged to capitalize on the strengths of each. Reliability Centered Operations (RCO) is an approach that optimizes these relationships through the application of a maintenance strategy built from failure analysis that will yield more expansive and cost-effective risk reduction tasks. A high percentage of the results from traditional RCM/FMEA analyses are conditioning monitoring tasks, and the majority of these are tied to operator rounds. This approach links the operators into the development and execution of this strategy. Two key elements are required to effectively break down the walls between operations and maintenance: empowering operators with technology and handheld devices to execute reliability-focused operator rounds, and utilizing asset performance enterprise systems to manage data flow, thus tying operators into the work management system already utilized by maintenance. This article discusses the technical solution for a systematic, technology-based approach to develop a strategy and results for typical projects using this RCO approach.

Introduction

The goal of Asset Performance Management (APM) is to safely maximize predictable production at the lowest sustainable cost while addressing the risk profile of the business. This is primarily achieved by implementing APM best practices, which use data-driven reliability methods and sustainable maintenance practices. The objective of a reliability and maintenance strategy is to provide the minimum amount of maintenance work required to meet the business needs of the operation. To achieve this, reliability and maintenance must be focused on and be structured to support and understand the changing goals and requirements of the business units.

Reliability is about failure elimination, and maintenance is about work processes. These functions are inextricably woven together with the fate of one being dependent on the success of the other. While there are many tools and techniques available for the plant maintenance manager in the quest to improve APM performance, none is more powerful than the effective and efficient use of the maintenance workforce. This workforce is the primary means to execute repair and improvement tasks. Further, the workforce labor and material usage make up the majority of the plant maintenance cost. Optimization of this group's work plan is paramount to lowering cost, improving reliability and meeting the risk profile of the business.

Changing Risk Profiles

Current economic conditions have changed the risk profile that most businesses must manage. These new profiles include lower levels of production, greater variability in production schedules, and shorter windows for product delivery. These conditions result in risk profiles where lower costs are needed and slower repairs can be tolerated, but the need to respond to orders dependably is required. These changing risk profiles are manifested in maintenance as "cost cutting" while still requiring critical equipment to be operational at the right time, further emphasizing the need for a cohesive approach to managing the relationship, information flow and interdependence between reliability and maintenance.

The Symbiotic Nature of Reliability and Maintenance

The interdependence between reliability and maintenance is best illustrated when considering that they intersect at the failure mode level. That is, maintenance is either repairing a failure that has occurred or performing work to predict and prevent failures that have not yet occurred. Thus, all maintenance activity should be focused on the failure mitigation principals of:

1. Elimination
2. Prevention
3. Prediction
4. Control

Developing a maintenance strategy based on these four failure mitigation principles requires that equipment failure modes are analyzed in detail. This analysis is central to creating actionable maintenance plans that contain optimized risk mitigating tasks, which can then be applied based on the risk vs. cost profile the business units can support. The optimized integration of reliability and maintenance at the failure mode level is a strong tool and is one aspect of maximizing APM results.

Leveraging the R&M Strategy by Including Operations

These failure mitigation strategies can be leveraged for improved results by expanding the ownership of equipment reliability to include operations. Operators are knowledgeable about the equipment operating characteristics and circumstances surrounding many of the failure modes, and have an acute understanding of the failure consequences. This experience equips operations to play a key role in the development, execution and sustainability of maintenance and reliability strategies.

Linking operator knowledge into a maintenance strategy based on failure analysis will yield more effective risk reduction tasks. In addition, by participating in task creation, operators will feel "ownership" of the solution, which is a pivotal factor in program sustainability.

This cross-functional failure mitigation strategy requires the identification of conditions, processes and upsets which can lead to equipment damage before the damage occurs and the failure mechanism has begun to deteriorate the equipment's performance. This is illustrated on the Installation, Potential Failure,

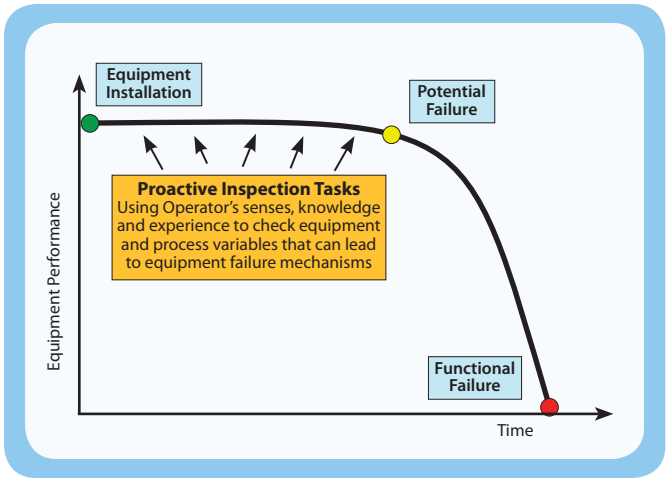

Figure 1 - The Installation, Potential Failure, Functional Failure (IPF) Curve.

Functional Failure (IPF) curve shown in Figure 1. The objective of this strategy is to extend the IPF curve over time (to the right) to realize longer equipment life.

By linking operator knowledge into a maintenance strategy....operators will feel "ownership" of the solution, which is a pivotal factor in program sustainability.

Building Maintenance Plans Based on Failure Analysis

Creating maintenance plans based on failure analysis is a basic element of improving asset performance. Properly designed maintenance plans integrate reliability principles with actionable maintenance tasks, and through the application of these tasks maintenance can impact asset performance. Developing these maintenance plans is best done using a systematic approach implemented by a cross-functional team. The steps of this approach can be summarized as follows:

1. Forming the Failure Analysis Team – The formation of the analysis team is an important part of the overall strategy development. This team should provide the technical and operational expertise, the interface to their maintenance, operations and supervisory peers, and development and debugging of the plans. The team is typically comprised of a Reliability Engineer/Facilitator, an Operator, a Mechanic, and a Team Leader (Foreman). Other resources can be brought into the team on an ad hoc basis.

These teams can sometimes be reduced to three members: operator, mechanic and team leader. This approach reduces the resource requirements to perform the analysis. In this case, the team leader will have extensive hands-on plant experience, demonstrated experience applying reliability tools and strategies, and is skilled in failure analysis facilitation.

2. Mapping the Equipment and the Process – The next step in the process is to map the process flow and the layout of the supporting manufacturing equipment. The mapping process is similar to the Six Sigma and lean mapping process. This is a powerful tool and the resulting map will help the team visualize the process and understand the equipment. The map is also useful in identifying system constraints as well as production bottlenecks, and it will facilitate equipment criticality analysis. It is also helpful in getting the team members to learn aspects of the equipment and processes that they may not already be familiar with.

3. Analyzing Criticality – Criticality ranking is an important step in identifying what type of maintenance strategy should be applied to individual equipment. Criticality is determined by integrating the probability and consequence of failure. Factors such as safety, environmental impact, risk to production loss, replacement cost and maintenance cost are typically included as part of failure consequence. The consequences of failure can also be weighted by the factors mentioned above and used to determine overall risk ranking.

There are known and accepted processes to perform criticality ranking, which is usually done by a cross-functional team operating with clear ranking guidelines. The criticality analysis is typically done at the equipment level, and the output will rank the equipment from most to least critical. This may be represented as high, medium and low, or with a numbering system such as 1-5. The highest criticality should contain no more than 5 to 10% of the equipment, the important (medium level) equipment 30% to 60%, and lower levels should cover 30% to 50% of the equipment.

Using these guidelines, the bulk of the analysis work will be done on 40%-60% of the plant equipment and the amount of equipment using a run to failure strategy is driven by the criticality analysis. A problem occurs when organizations want to rank the vast majority of their equipment at the highest level, which hinders the development of effective R&M plans and will lead to excessive (non-value added) maintenance work. Discipline must be exercised to adhere to criticality guidelines.

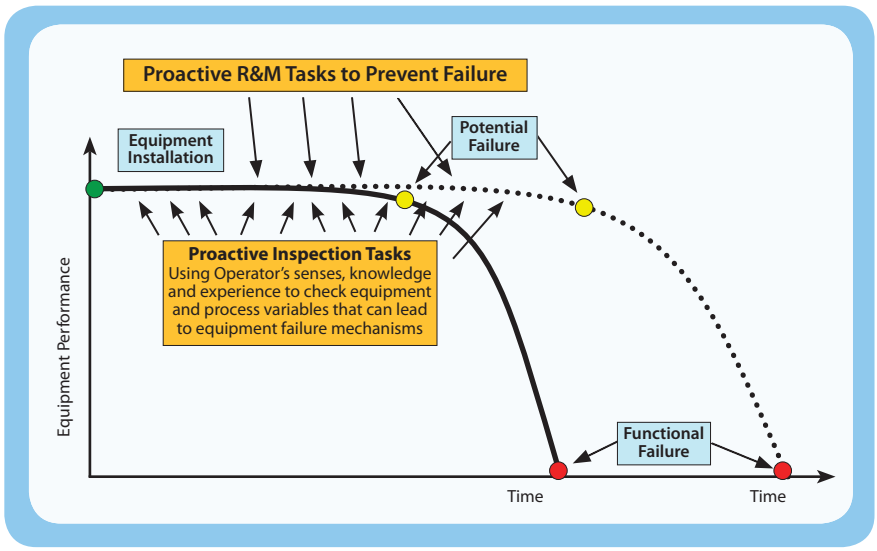

Figure 2 - Extending the IPF Curve with Operator Inspection Tasks.

Using these rankings, a comprehensive asset maintenance strategy can be applied. These strategies will contain a mix of tasks that are optimized to mitigate failure based on the criticality of the equipment. The strategies applied to equipment with higher criticality rankings require more analysis and often result in more complex maintenance strategies. Some maintenance strategies which could be associated with criticality ratings are:

1. Reliability Centered Maintenance (RCM) methodologies
2. Equipment-centric failure mode and effects analyses (FMEAs)
3. Analysis of existing maintenance plans (often called PM optimization)
4. Application of predefined maintenance plans (based on equipment class and service)
5. Basic equipment care

4. Analyzing Failure – To build maintenance plans based on failure analysis, a systematic work process should be followed. For the critical and important ranked equipment this may be done using classical RCM, RCM Blitz® or basic equipment-centric FMEAs. These processes are well known and accepted and can be applied directly to the equipment to evaluate failure modes, causes and effects. For any of these methodologies, FMEA is at the heart of failure analysis and development of the associated mitigating tasks. FMEA focuses on failure modes and causes that lead directly or indirectly to equipment failures. Some of these are:

- Gradual equipment deterioration
- Process upsets that damage equipment
- Human error
- Variation in operational parameters
- Variation from standard operating procedures
- Improper equipment installation, repair and maintenance

The resulting tasks are designed to mitigate the causes of the failures in a proactive manner. That is, many of the tasks will address issues on the IPF curve (Figure 1) prior to the potential failure point (P) being reached. The resulting actions prevent equipment damage and lengthen the operating life of the equipment by extending the IPF curve to the right as shown in Figure 2.

5. Analyzing Risk – One of the outputs of the initial FMEA process is an unmitigated risk index, which can be modified for user preference but, at a minimum, it accounts for the likelihood and consequence of the failure. This index may be used to filter those failure modes from the analyses that have low risk. The output of this filtering process will focus the plan on the highest risk failures. Typically, a cut-off value for the risk index is established, and, for those items which exceed this value, risk reduction tasks are developed.

These tasks are then evaluated and a new risk index (mitigated risk index) is developed to measure the impact of the tasks on risk reduc-

tion. The effectiveness of the tasks can be evaluated vs. implementation cost, and, based on the risk reduction value, a further filtering process can be applied. This process will focus the results of the analysis to create the highest value maintenance plan.

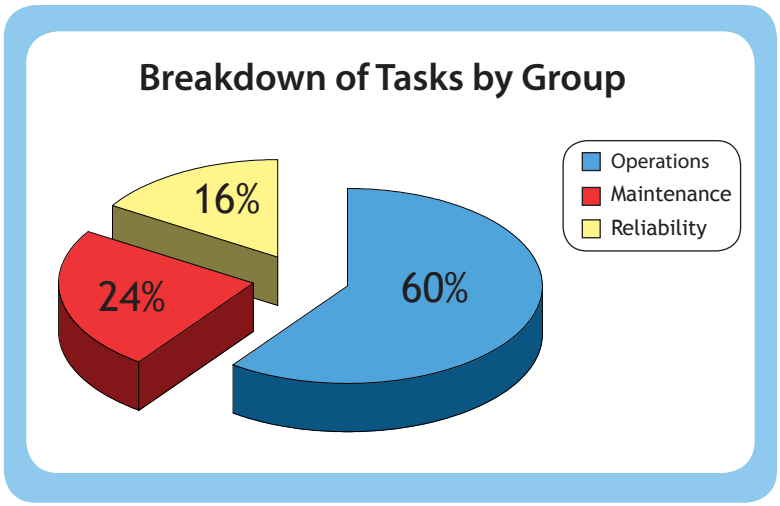

Figure 3 - Breakdown by group of the mitigating tasks designed to proactively eliminate process, operating and maintenance problems that lead to equipment damage.

6. Developing the Mitigating Tasks – The mitigating tasks are developed as part of the FMEA process and they are filtered based on the risk and cost profile for the business. The goal of these mitigating tasks is to proactively eliminate process, operating and maintenance problems that lead to equipment damage. Typical mitigating tasks resulting from the analysis include:

1. Development of standardized work procedures
   a. Operations
   b. Maintenance
   c. Contractors
   d. Rebuilds
2. Time-based maintenance actions
   a. Preventive maintenance
   b. Lubrication
   c. Cleaning
   d. Minor repairs
3. Condition monitoring
   a. Predictive technologies
   b. Inspections
      i. Operator
      ii. Maintenance
   c. Diagnostic systems
   d. Process monitoring
4. Equipment design
   a. Poor equipment design requiring upgrades
   b. Redesigns to improve reliability
   c. Redesign to improve maintainability

Typical project results indicate that task breakdown by group may be as seen in Figure 3.[1] This chart indicates that 60% of the tasks (by number of tasks) belong to the operations group, due to the number of operator inspections that come from the FMEA. It is worthy to note that, if operations weren't included on the failure analysis team, and subsequently participating in the design of the maintenance strategy, almost 60% of the mitigating tasks (risk reduction tasks) would not have been included in the final plan. This aspect of building maintenance plans using a cross functional failure-analysis team is not seen in traditional maintenance approaches and is often overlooked. Clearly, this method offers a significant advantage over traditional plan development.

A breakdown of mitigating tasks by type is shown in Figure 4[2], indicating that the proactive condition monitoring tasks make up 60% of the total tasks by type. This is in alignment with the proactive strategy illustrated in Figure 1.

7. Integrating Proactive Operator Inspection Tasks – Operators know the operating parameters of their processes and equipment and recognize when it isn't running correctly. Using this knowledge in building failure-based maintenance plans will identify mitigation tasks which are typically included in the operator rounds(inspections). These inspections tasks utilize the operator's senses and knowledge base to detect process disturbances and equipmentproblems that are much harder to capture using sensor technology. These inspections can comprise up to 50% of the R&M program's proactive tasks. Further, due to the proactive nature of these inspections, critical data is obtained either prior to equipment damage occurring or very early in the failure process. Using handheld technology (Figure 5) as an enabler, the operator can easily and efficiently input conditions to create alarms. These alarms provide the basis for actions to be taken prior to the onset of performance degradation and equipment damage.

Figure 5 - Handheld technology enables quick and efficient data input, which increases ability to proactively maintain equipment.

The proactive operator inspections are a direct result of the FMEA process. Some examples of these are, but certainly not limited to:

1. Visual inspection such as looking for leaks
2. Inspections dependent on the operators senses (for example, "it sounds different")
3. Quantitative reading of values, such as the level of lubricant
4. Use of basic tools, such as vibration pen, heat tape, etc.
5. Equipment settings

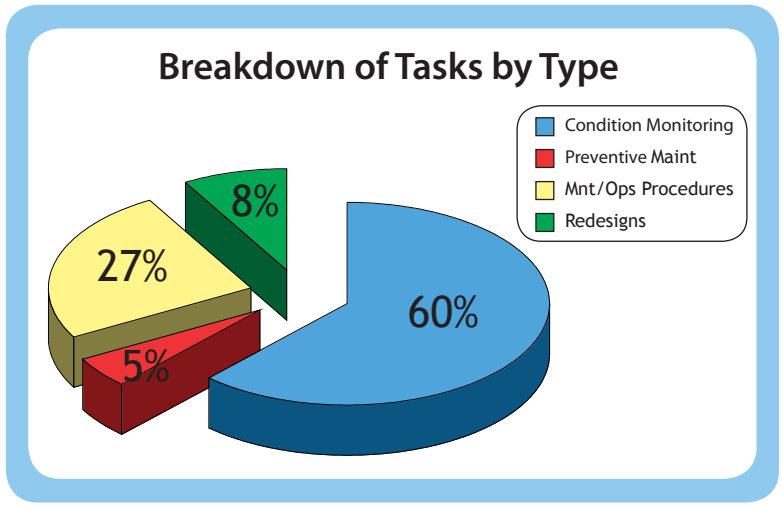

Figure 4 - Breakdown by type of mitigating tasks.

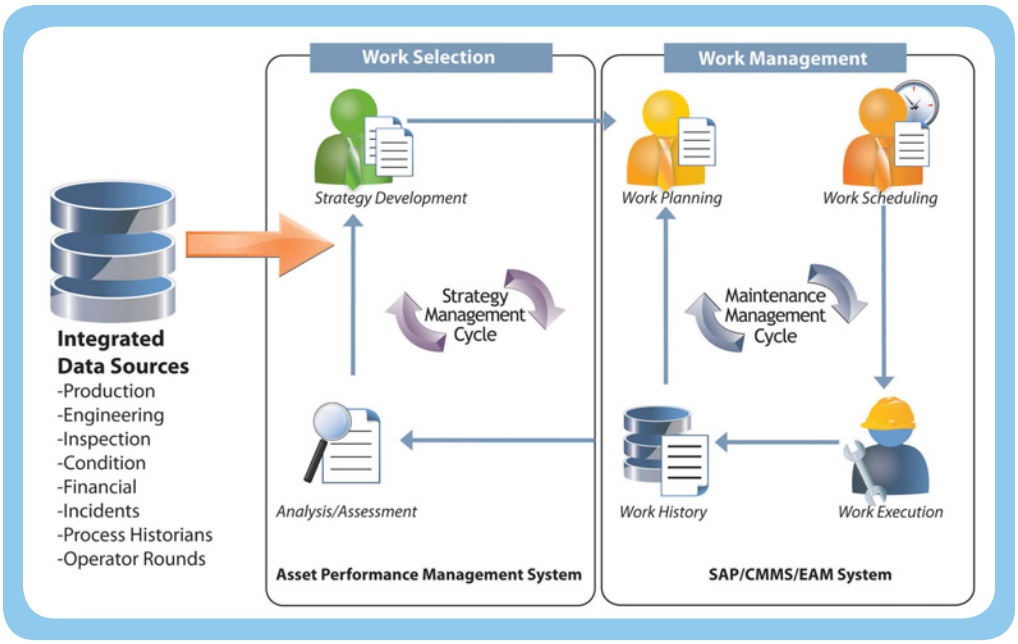

Figure 6 - Integrating multiple data sources into the work selection and work management process.

The execution of these tasks will also vary by time periods, which may include every shift, once a day (or multiple days), once a week (or multiple weeks), once a month, etc. Taken together, these tasks must be integrated into an executable operator round. This is a major responsibility of the operator as a member of the analysis team. The operator will organize the routes, do the initial runs and testing of the routes, review and test the routes with the other operators, lead the rollout of the routes, and provide the necessary training for the users.

Also it is worthy to note that using handhelds as an enabling technology provides the opportunity to set up routes and gather data on functions that are not related to reliability or operations, such as safety inspections, housekeeping, environmental inspections and maintenance PM inspections.

8. Linking Proactive Alarms with the Work Management System – Operators have been performing inspections for years, often recording their findings on paper and most recently using handhelds to perform standard process checks. And, the integration of operator inspections into the maintenance strategy is not new. However, the process as described in this article is innovative in two areas:

1. The operator inspections were developed based on failure analysis. This results in proactive tasks which utilize the operator's senses and knowledge to identify process and equipment variations that can lead to equipment damage and, thereby, extend the life of the equipment.
2. Properly designed, the handhelds provide a portal to link the operators work identification efforts into the work management system. This allows the efficient identification and dispatch of failure-causing disturbances. This is illustrated in Figure 7.

Proactive work identification is driven by (1) allowing the operator to create alarms on out-of-limit conditions at the point of detection and (2) processing these alarms into the work management system (an EAM such SAP or a CMMS). The operator normally runs his/her route, creating alarms on the handheld screens. At the conclusion of the route, the handheld devices can be connected to the operator's computer, the alarms reviewed, and any other relevant information is added. The alarms are then processed to the work management system for work order creation, planning and scheduling. Wireless technology could also be applied and the alarms sent directly to the work management system from the field if desired. It should be noted that, if during the inspection, the operator finds a condition that requires immediate attention, this is handled by the normal emergency work notification process.

This process links the operator rounds input into the work selection process. This overall maintenance strategy and work selection process is normally managed by an Asset Performance Management (APM) system, which manages the data, creates alarms and passes the information to the work management system. Work management is typically done in the CMMS or EAM system. This process is shown in Figure 6.

Recently, one major U.S. chemical producer implemented an integrated approach between reliability and maintenance focused on operator rounds that included the right mix of people, education, goals and technology. At this company, more than 70 operators embraced the use of a technology-supported initiative that yielded a 40% reduction in reactive maintenance within one year - clearly a fulfillment of the RCO approach's driving principle to positively impact the bottom-line.[3]

9. Developing Metrics for Evaluating Strategy Performance – This work process should be monitored closely in order to measure (1) progress of strategy development, (2) completeness of mitigating tasks, and (3) bottom line results. These measures should focus in three areas:

1. Completion of FMEA Tasks - There will be many tasks resulting from the analysis that will not be completed immediately and, depending on the nature of the tasks, these can take months to complete. It is critical that the leadership team monitor the progress against the task completion schedule in order to provide needed resources and support. The measures which should be considered are:

a. Percent FMEA tasks complete in total
b. Percent FMEA tasks complete by task category
c. Percent FMEA tasks complete by group responsible for completion

2. Effectiveness of the Proactive Strategy - The different elements of the proactive strategy developed by this work process should be measured to understand the strengths, weaknesses and effectiveness of the strategy. Some measures which should be considered are:

a. Percent of maintenance work identified proactively
b. Percent of work from condition monitoring tasks
c. Percent of maintenance work identified through handhelds
d. Percent of inspection routes completed

3. Bottom Line Results - The results of the strategy must be measured in order to understand the enterprise-wide, bottom-line value that has been created, both short term and long term. Some measures for consideration are:

a. Percent reactive work

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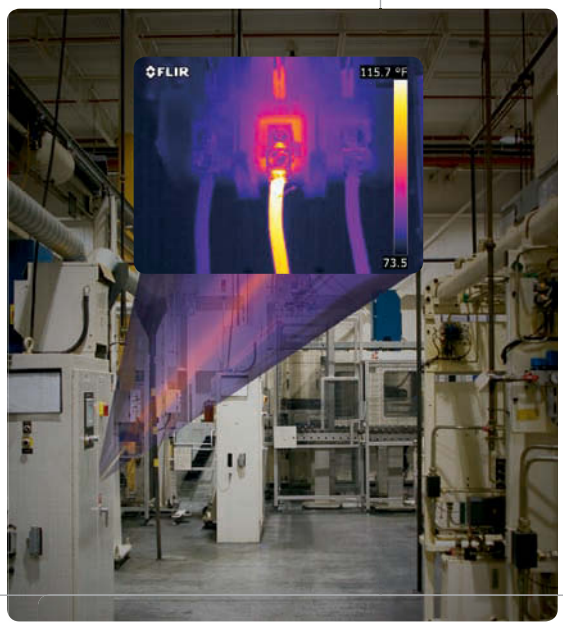

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b. Percent downtime
c. Increased availability
d. Additional revenue
e. Maintenance cost

One of the most telling of all the measures is the percentage of reactive work. There are various ways to define "reactive work" but generally it is work that must be done immediately, is unplanned, and breaks into the weekly schedule. It is normally the result of a breakdown, safety, or environmental issue. As the failure based maintenance plans are implemented, changes in the levels of reactive work should be seen quickly. The first step in any improvement program is to stabilize maintenance in the targeted area by lowering reactive work. This is done by addressing failures and responding to the proactive work that is identified from the maintenance plans and especially operator rounds. These actions will lower reactive work because the work is being identified in order to correct defects before the failure has occurred, and, in some cases, before equipment degradation has begun. As these proactively identified items are addressed, the level of reactive work will drop, and maintenance resources can be utilized more effectively.

It should be noted that once the plan is implemented, and proactive work is being identified, the single most important element of success is performing the proactive work and addressing the failure before it occurs. If the operations and maintenance organizations fail to take advantage of the prior knowledge of impending failures, the program will not achieve the desired results.

Information Flow

Centerpiece to the approach described in this paper is the ability to obtain condition monitoring data, process this data, and efficiently convert this information into proactive maintenance actions. A critical part of this is the management of the overall information flow. As can be seen from Figure 4, the majority of mitigation tasks can be categorized as condition monitoring. Figure 3 indicates that, due to the large number of operator inspection tasks that are identified in the FMEA process, the majority of the tasks (by number) are implemented by operations. This complete set of data must be integrated and communicated to the users via asset health indicators. This information, when properly structured and displayed, can be reviewed by users to quickly understand the alarms and assess the overall health of the assets.

The ideal information-flow system should integrate all data from predictive technology, process historians, diagnostic systems, and engineering analysis. The data flow should be bi-directional where applicable and linked to the asset performance management system where it can be reviewed, converted to a work request, and sent to the work management system or otherwise be dispositioned. The objective of this data structure is to maximize information effectiveness with as little manual intervention as possible. This optimal information flow is illustrated in Figure 7.

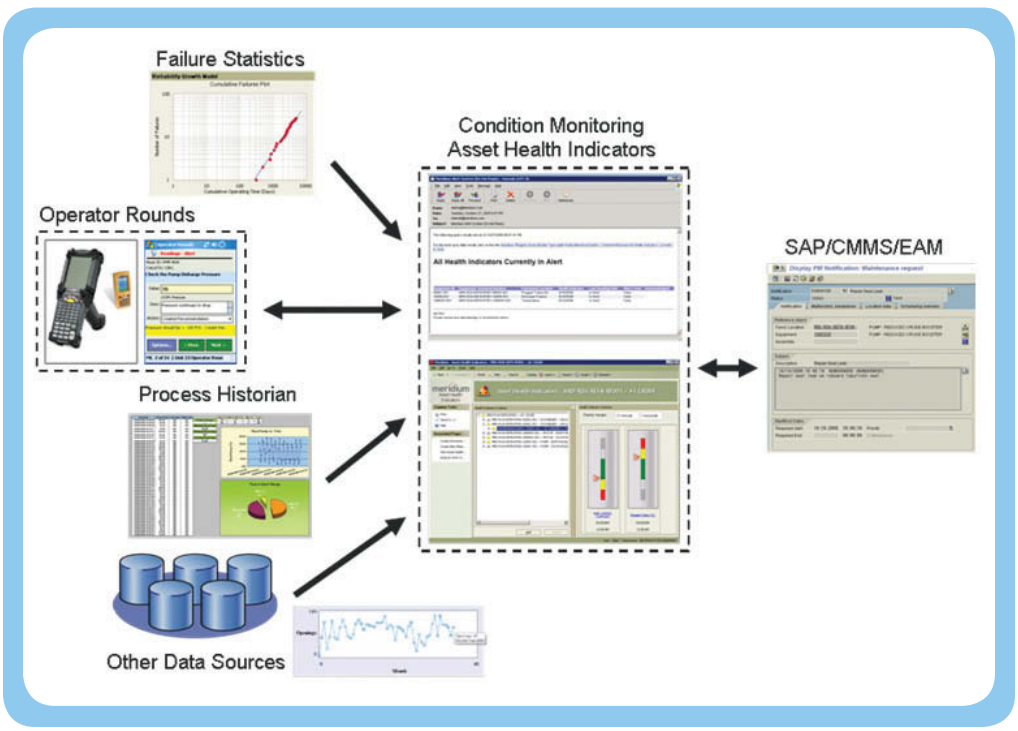

Figure 7 - Information flow constructed for maximun effectiveness.

Results

One of the primary tools in the manufacturing plant to improve equipment reliability and improve asset performance is the maintenance strategy. Maintenance and reliability intersect at the failure mode and this interrelationship is exemplified in the creation of improved maintenance plans using failure analysis. A key result of these improved maintenance plans will be a reduction of reactive work. A secondary effect of this reduction will be observed in work planning and scheduling. As the reactive work is reduced, this will free up resources to focus on planning and executing proactive work, which will lead to a further reduction in reactive work. The impact of this cycle can be dramatic.

Another area that is substantially impacted by cross-functional failure analysis is safety. Ten to twenty percent of recommendations resulting from this process will be focused on correcting unsafe conditions.[4] Further, it has been shown that there is a positive correlation between the amount of immediate corrective and reactive work to total injuries.[5] This positive correlation means that lowering the amount of reactive work will also lower the total injuries incurred. This is a very important benefit that should not be overlooked by the plant leadership team.

Overall results from implementation of this strategy include the following:

- Significant increase in utilization and availability
- Reduction in reactive work by up to 50%[6]
- Increase in operators' knowledge of their equipment
- Substantial improvement in management of backlog as more work is ready to schedule[7]
- Significant increase in planned maintenance work
- Reduction in maintenance cost[8] (The largest impact in this reduction will be seen after all of the mitigating tasks are complete.)
- Improvement in MTBF and MTTR

Conclusions

Many reliability and maintenance solutions have

been implemented in manufacturing plants in recent years, and these have seen varied success. Leveraging the interactive relationship between maintenance and reliability in order to improve overall asset performance can be a key differentiator and force multiplier in developing a successful APM initiative. To increase the probability of achieving the desired results, the potential success of mitigating tasks can be increased by integrating operations into the development and execution of the technical solution. Capitalizing on the knowledge and sensory capability of the operators will increase the options available to address failure causes, thereby multiplying the improvements of this approach versus a traditional maintenance program. Technology and information flow must be viewed as a work process enabler, and as a necessary step to execute failure-driven maintenance strategies efficiently.

The results of this approach have proven to be impressive and far exceed those that are seen from many traditional R&M programs. However, this approach does require discipline and strong leadership to be successful. Further, it must be emphasized that after implementation has begun and proactive work is being identified, the single most important element of success is completing the proactive work before equipment degradation begins or the failure occurs. When the operations and maintenance organizations take advantage of the prior knowledge of an impending failure, the program results can be outstanding.

Paul Casto, CRE, CQE, CSSBB, CMRP, VP Value Implementation, Meridium, is a leading practitioner in reliability and maintenance improvement methodologies. He has hands-on experience in reliability, maintenance, operations and engineering in the chemical, steel, aluminum, automotive, aerospace, consumer goods and construction industries. Paul holds a Bachelors degree in Electrical Engineering from West Virginia University, a Masters degree in Engineering Management from Marshall University Graduate College, an MBA from Clemson University, and a Masters in Maintenance Management and Reliability Engineering from the UT/Monash University program. He is currently doing additional graduate work related to R&M improvement methodologies at the University of Tennessee. Paul is an ASQ certified Six Sigma Black Belt, holds ASQ certification in Reliability Engineering and Quality Engineering and is a SMRP Certified Maintenance and Reliability Professional. He is a member of the University of Tennessee's Maintenance and Reliability Center's advisory board, serves on the SMRP Best Practices committee, the SMRPCO Advisory Council and is an active member of ASQ and IEEE.

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A Vision of Enterprise Reliability

Looking Into the Future of the Industry

by Dennis Belanger

What is the ultimate vision for enterprise reliability? If you're like me, occasionally you find yourself drifting off into a day dream. One of the recurring day dreams I've been having for the last 10 years involves this question. I often lapse into deep thought, pondering, "How is all of this reliability and maintenance stuff supposed to work? And what does an organization have to do to really make it hum?"

This article will explore the questions above as well as others in an attempt to illustrate what it takes to create the ultimate reliable enterprise. My objective is to stimulate your thinking and generate some discussion. I probably won't cover all of the bases, but hopefully I'll get your creative juices flowing.

To gain a broader prospective, I asked MRG's consultants to give me their ideas and thoughts on what the future might look like. I received some interesting responses, and, as you might expect, they run the gamut from strategic to cultural to technical. I have incorporated their ideas into this article, so without further delay, let's start the discussion.

What would a high performance, highly reliable organization look like?

The consensus of our group is that the organization of the future will be structured to optimize the reliability of the enterprise in a manner that eliminates plant-driven initiatives and fully leverages data and technical decision making across the company. Today, most organizations take shipping costs, plant efficiency, capacity constraints, etc. into account when leveraging the portfolio/fleet, but they do not consider the impact of reliability (or unreliability). Truly managing assets across the enterprise will create game-changing results.

We will see the role of a chief reliability officer (CRO) established on equal footing with the CFO and COO. The CRO will be responsible for maximizing shareholder value through the optimization of assets across the enterprise. Additionally, the CRO will be the corporate steward of enterprise assets and master data. This person will lead the development of the enterprise reliability standards and drive the implementation of corporate standards across the enterprise and down to the sites.

The CRO will also be responsible for enabling enterprise-level investment decisions across the portfolio based on life-cycle asset value. Currently, operating assets in a portfolio often receive disproportionate levels of investment due to plant autonomy, serial acquisitions without integration, strength of plant manager, etc. If this is done too often, then it stands to reason that shareholder value will be jeopardized or end up as sub-optimal.

Corporations of the future will have a reliability team, as opposed to steering committees and ad-hoc groups that are continually bouncing new people in and out. The team will include financial, technical, and administrative personnel, as well as experts in organizational behavior, and it will have a budget that can be used to ensure the balanced funding of initiatives across the enterprise. This team will be directly responsible for the performance of all enterprise assets including budgets.

The future organization will also leverage technology, automation, and engineering information to make solid data-based decisions. Consistency, standardization, and common practices will be the rule, and the corporate team will be staffed with experts who understand the assets and can create the best technical solutions.

How would it behave?

Long-term, sustainable financial performance would be valued over short-term or quarterly gains, and performance incentives would be properly balanced to encourage the right behaviors and ensure long-term success. A mind set of total cost or life-cycle cost would be prevalent, encouraging long-term thinking about issues such as new construction, acquisition, divestiture, or expansion.

The organization would build and execute long-term (10+ year) reliability improvement plans and goals, replacing the short-term incremental approach to performance improvement that exists today (Figure 1). Additionally, the organization would have clear long-range targets and would work backwards to figure out what has to be done to achieve those targets. Longer-range thinking will greatly increase reliability and shareholder value.

From a cultural perspective, companies will stop reinforcing negative behavior with the wrong type of incentives. Situations with conflicting objectives, such as corporate maintenance inventory value reduction efforts that are not tied into reliability improvement efforts, will disappear.

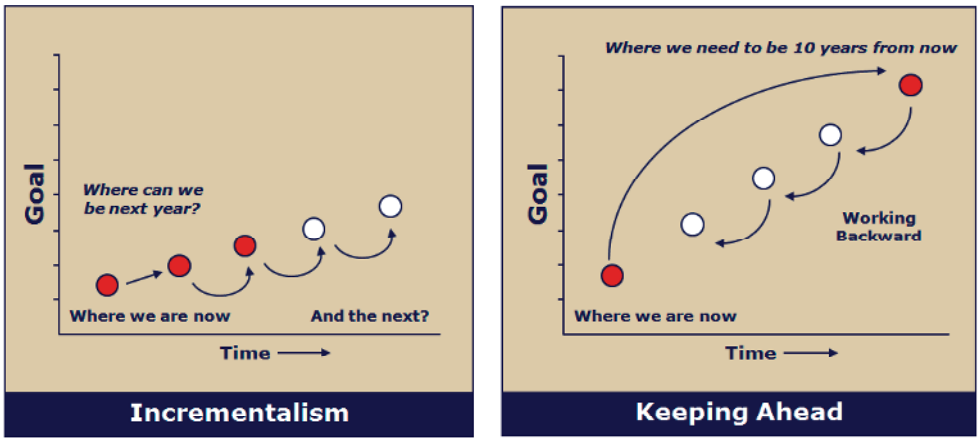

Figure 1 - Visual representation of Incrementalism vs. Keeping Ahead.

Companies will stop the practice of pitting plants against one another, which results in wasted effort, time, money, and resources. All efforts will be focused externally on things that provide value to the shareholders, improve the company performance, support the sustainability of performance, and minimize risks.

Organizations will move toward ego-less communications as employees become less territorial and more willing to share information with people in other areas.

Communication has to flow constantly so the changes one party makes are immediately understood and taken into account by everybody else in the system. The ideal company operates as a single unit, but this cannot be achieved as long as individuals feel the need to protect their territory. A major change in culture must occur within the companies of today before effective integration can be achieved. This change is usually thought of as something that has to happen on the production floor, but in reality, this change has to occur through every level of the company.

Changes cannot be limited to just shifting patterns of communications; they must address the motivators that drive people to act the way they do. Companies cannot look at individual achievements as the primary measure of a person's effectiveness within a collective, nor can they pit one division against another in an attempt to build a culture of competition. This behavior promotes silos and shuts down communications.

Such changes within an organization will result in a unique workplace—one with a well thought out reward/benefit system and a communication process that bridges the natural silos that exist in most companies.

What skills would it require?

At the corporate level and throughout the organization a balanced mix of business/financial knowledge and technical knowledge will be required. Leaders will have to do their homework to create this balance. Business personnel will have to understand much more of the technical aspect of maintenance and reliability to ensure that they are making sound decisions, and technical people will have to understand the world of ROI, ROA, business cases, balance sheets, etc.

What would the systems look like?

All systems will be aimed at enabling enterprise-level investment decisions amongst the enterprise portfolio based on life-cycle asset value. Integration, standardization, and flexibility will be the name of the game. A paradigm shift will be required for corporate organizations, and most maintenance and reliability departments will focus on data management. High quality, usable asset-performance data, enabled by integrated systems will be highly valued, and considered a competitive advantage. In fact, considerable resources will be focused on leveraging that data. Contrast that to the current situation where very little integrated information exists, and if it does, it doesn't exist across the enterprise because no one is tasked with using the information. Collecting accurate information will be considered a key part of the job for all people in the organization.

Information that can be rolled up across the enterprise will be required. Live dashboards that provide instantaneous status on the true health of the assets will be the norm, and all decision making will be based on highly accurate real-time information

There will be a lot of automation. Organizations will trust technology and not need to shut down equipment for manual inspections and time-based parts replacements. All work will be driven by the actual condition of the asset. Technology will enable the control of most systems to be primarily handled at the plant or operations manager level through automation. Any operator function that can be automated will be, and process shutdowns due to operator error, mistakes and inconsistencies, and non-conformity to standards will become virtually non-existent.

In the future, companies will automate the simple things that are still being done by hand today. For example, when new assets arrive on-site a "smart tag" provided by the manufacturer will automatically link the asset to the asset management and operations management systems. The "smart tag" will insert the equipment into the hierarchy and populate all of the information such as class/sub, BOM data, specifications, spare parts, drawings, etc. The addition of a new asset will trigger a validation and finalization of the RCM/FMEA-driven maintenance strategy to ensure it complies with corporate reliability standards. All appropriate procedures and monitoring points would then be set up in the integrated system.

In addition, the "smart tags" will contain the tools and sensors required to monitor the equipment from all aspects, including operational performance, vibration, heat signature, amp load, oil analysis, etc. All of this information will travel wirelessly to the maintenance application where an expert system will determine up-to-the-minute asset health, tie in with the business systems, and generate corrective work based on the condition of the asset in real time. The typical time-based overhaul/PM will be non-existent.

The CMMS system will be a 3D graphical representation of the entire company's asset complement. Speaking the asset name will pull up a graphical interface that provides all the business and technical information on the asset and all related assets throughout the organization. Based on the type and the location of the asset, the CMMS will forecast the life of the equipment in real time, continually changing based on failures, scheduled maintenance, industry historical data, time in service, etc. This information will feed inventory stock levels, revenue forecast models, supply chain, scheduling, and all other applicable areas of the EAM.

In essence, the asset will use tools to determine when it is time to repair or replace. Based on the rate of repair and other factors, the system

will also re-engineer itself for optimal performance. It will look at the failures and how they relate to normal wear and tear, asset physical location, and application. If the equipment is wearing prematurely, the system will offer suggestions to correct the oversight in engineering.

All of this automation will generate savings in every aspect of the EAM. With the maintenance cost at a minimum and the revenue flow tightly forecasted, companies will benefit tremendously from a higher profit margin. Data and information will be integrated across the organization:

- Production capabilities will be understood by sales.
- Impacts on production due to asset health issues will be fully communicated by maintenance.
- Difficulties holding quality tolerances should be shared immediately with maintenance and with sales.
- Changes in the operational characteristics of a machine that will result in an increase or decrease in the repair parts required will be transmitted to procurement, so stores can adjust their min/maxes or purchasing practices as necessary.

What type of results would be achieved?

Based on the ineffectiveness, laziness, and negligence that I have witnessed over my 25+ years in this business, I can confidently say that there is more opportunity for improvement than most people realize. Businesses are often comfortable if they are making money, and in many cases the organization spends a lot of time patting itself on the back for doing a good job, and then sitting back as if it is finished, as opposed to asking, "How good can it be?". What can be done to get even better? In order to correct this, the current pay structures need to be torn out and incentive-based compensation structures rolled out as far into the organization as possible. These structures need to clearly allow people to see a significant share on the upside of the business. When people make the same amount of money no matter how they perform, there's not much incentive to really "go above and beyond."

If companies start taking advantage of 80% of the opportunity available, they will see groundbreaking results! Organizations will stop making the same mistakes over and over at each plant, and operational efficiencies and manufacturing reliability will go through the roof. Cost structures will be half (or less) of what they are today. True supply chain integration with customers will be achievable and unnecessary waste and scrap will be eliminated. Overnight shipping costs will all but disappear for maintenance parts (FedEx may need to find another source of revenue!). On-hand maintenance parts inventories will be cut by 2/3rds, and capital expenditure to prematurely replace existing capacity due to failed, or worn out, assets will be significantly reduced.

How would it measure performance?

Performance will be measured through a balanced set of metrics, again, across the enterprise, as opposed to at the tactical plant level. Measurement processes that enable an organization to focus on optimizing the overall fleet performance through the standardization of practices, processes, and equipment, thereby getting more of the plants to perform at the top levels, will be prevalent.

While overall performance is driven by individual plant performance, the difference will be that corporate will be measured on their ability to tighten the performance distribution curve and shift it in a favorable direction.

Of course, the information required to measure this performance will be available and properly configured to achieve the desired results. Foundational data will be consistently applied and set up in accordance with corporate standards. Maintenance and reliability systems will be operated and maintained the same way at all plants, so accurate enterprise performance measurements can be easily pulled.

Personal rewards will be tightly linked to enterprise performance. Locally, at individual plants, the management team will be rewarded for overall business results as well as their level of compliance with corporate standards and their contribution toward continually improving the overall enterprise performance.
Maintenance performance will be measured in a way that evaluates the economic value an enterprise is able to extract from the profit in return for the higher availability, higher reliability, and increased quality.

KPIs will need to take into consideration things such as the ability to work with other departments or joint successes with another department. This will force upper management to go beyond the methods they have used in the past and create new ways to measure performance. The old performance metrics will have to be abandoned.

The plant performance will also be instantaneously available to the marketing and corporate management teams. This information will be combined with the enterprise's entire fleet and will allow the corporation to make well informed enterprise-level business decisions, based upon current profitability and market demand. The output from online monitoring will enable profitability to be determined relatively accurately at any time it is requested. This will also be supported by input from the sales and marketing organization, so both sides of the business are in synch.

How would they get there from where they are?

A significant change in focus must occur. Primarily, companies must start to manage their assets as a portfolio. This will require a change in the organizational structures of companies. Can anyone say, Chief Reliability Officer? Organizations will need to develop the ability to share expertise across the enterprise as opposed to holding it close to the vest. They will need to leverage their commonality and minimize things that unnecessarily don't fit the mold of standardization.

It all starts with the develop-

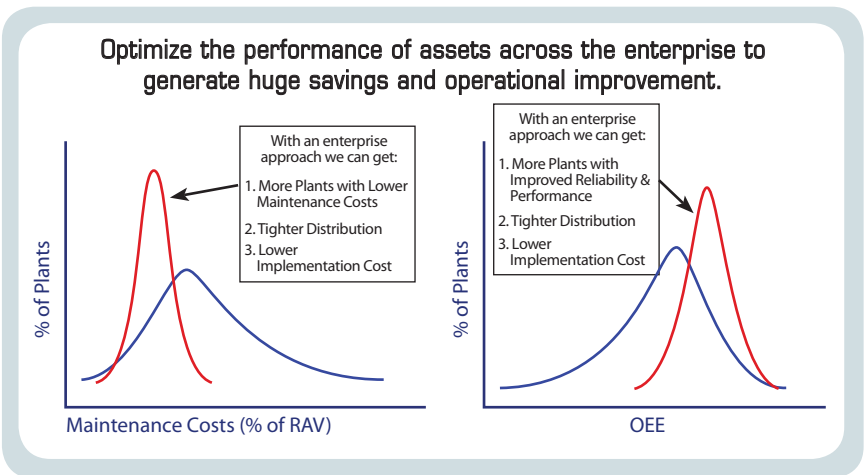

Figure 2 - Enterprise-wide metrics will optimize asset performance.

ment of a long-term roadmap that is the framework for the future state of the enterprise. This roadmap will outline the concepts, models, and requirements for the organization for:

- Organization Structure
- Technology
- Funding
- Equipment and Engineering Standards
- Reliability Principles
- Data Standardization
- Maintenance and Reliability Best Practices
- Measurements
- Training
- Skill Requirements
- Roles and Responsibilities

This is not necessarily a comprehensive list, but it should give you an idea of what we're talking about. The roadmap will also outline the steps required to achieve the plan and the funding plan to support the plan. Without a clear vision, it will be very difficult for everyone to understand what they need to do.

What are the key enablers?

The key enablers include a vision, an integrated plan to achieve the vision, the right structure to support the plan, the right resources to achieve and sustain the plan, and the right funding to acquire the resources.

There also needs to be a well-communicated transition from old to new, not only for measuring progress, but for the process by which this transition is to happen and how it is going to be measured and maintained. Employees need to be trained, and everyone needs to understand the process before a change is attempted.

Organizations must recognize that creating a reliable asset base across the enterprise is not simply a maintenance or technology project. It must be recognized that it is about engaging the people, integrating the business processes, and utilizing the data and technologies to improve business performance. Key elements include:

- Leadership commitment and involvement
- Incorporation of change management
- Adequate resources and time
- Training and re-training

How would they sustain the results?

All pieces of the puzzle have to be assembled with a long term-focus. Here are a few things to think about:

Create compensation programs that reward executives for building a solid foundation and producing real value, and tie it to profitability and actual business growth. The windfall rewards should only kick in if the business performance is sustained. Stop making executives obscenely rich for running a company into the ground at the shareholders' expense. Create reward systems that value long-term, relentless drive and improvement.

- Build an organization that values learning and sharing information.
- Ensure that systems are installed that enable quick and easy access to the information needed to make good decisions, and make sure that there is an organization in place to aggressively utilize this information.
- Require energetic and aggressive compliance to the standards while also making sure the standards bar is always being raised.
- Train the organization to have the skills needed to succeed, including math, finance engineering, and maintenance. Stop assuming people have these skills or will pick them up. I've run into too many managers and leaders who can't read a balance sheet.

How would they change the culture?

The most difficult part of trying to enact significant change is having the resolve to see the company through the inevitable rocky transition time. People not only fear, but fight change. Some people will be so resistant to change that they will have to be let go. Unfortunately, the ones most resistant to change are the experiential mainstay of the company and the people that have been using the old systems for so long that they can't imagine any other system working. There needs to be a greater and opposite force in place to make change happen. If senior management doesn't have the true resolve to see it through, it will not happen.

Some specific requirements are:

- A STRONG executive sponsor that sees the value and makes everyone aware of the reason for the effort and REQUIRE that it be followed.
- A STRONG in-the-trenches champion that handles the tactical aspects of the effort. Ideally, this is someone who is well respected by others in the organization.
- A STRONG effort to address the cultural aspects of any change required to implement the new/changed business processes.
- A STRONG effort to include all departments/staff that will be affected by the new/changed business process in the definition process of the project goals. Those affected should be made part of the process and not feel they are having something forced down their throats after the fact. I have seen this work, even when related to union issues/pushback.

What needs to be different?

Everything! For some companies, everything needs to be different—from the senior leadership on down. However, for many companies, it really comes down to changing the way they think about enterprise asset management; they need to actually manage the assets across the enterprise. Bring maintenance and reliability into the corporate world with the understanding that it is a key enabler for everything that happens in a company because nothing works out very well if the assets don't run reliably. Other management programs like Lean, Six Sigma, Kan Ban, etc. fall apart if the assets don't run reliability.

Stop playing games to make a quick, short-term buck, and run our companies like we're really in it for the long haul…like a true owner!

I would like to acknowledge the significant contributions by these MRG Team Members: Tim White, Burhan Zafar, Robert Brown, Scott Herrick, Jason Price, Adele Hostettler, John Ferguson, Scott McWilliams, Mike Desabris, Bob Peffen, Brian Maier, and Todd White.

Dennis Belanger, Vice President of Business Development for Management Resources Group, Inc. (MRG), is an a*ccomplished, multi-faceted manager with over 25 years of professional experience supporting various facilities and businesses by acting as a change agent, directing on-going operations, special projects, and budgeting activities. In roles as Maintenance and Reliability Manager he has routinely utilized expertise in devising productivity improvements within both maintenance operations and the manufacturing process. Mr. Belanger has developed and presented Reliability and Maintenance training course in public and private venues throughout the US. He is recognized for his expertise in many fortune 500 companies on the topics of Preventive Maintenance, Planning & Scheduling, Predictive Maintenance and Organizational Change through Reliability initiatives. He can be reached at 203-164-0500 x-121 or at belangerd@mrginc*

The Twelve Step IR Program

Steps To Improving Your Electrical IR

by John Snell and Dave Sirmans

If you are still having any unscheduled electrical outages for any reason, the chances are good you need to look at how to improve your infrared program. Thermography is much less about what kind of camera you use than it is about using the camera you have well. Here are twelve steps, some simple and others less so, that will help improve the results you are getting from this remarkable technology.

1. Safety

Clearly the first step in any successful thermography inspection is to ensure all work is done as safely as possible. While most are familiar with NFPA 70E, we find there are still gaps in both a practical understanding of the document as well as, importantly, the implementation of the guidance it provides.

Among other things, NFPA70E (as well as common sense) suggest thermographers should:

- be working with written work procedures
- be qualified to do the work
- follow the guidance in the new version relating specifically to thermography
- have conducted an arc-flash analysis and kept it updated
- wherever possible, reduce risk by improving the system fault protection and coordination
- wear appropriate personal protective equipment (PPE) and observe required working distances

Realistically, there may be some equipment that cannot be inspected live. The appropriate use of IR windows and viewports should be considered in many instances as a means of improving inspection access and frequency. These devices should not be used, however, without careful planning and forethought. The safety goal is always ZERO accidents and injuries!

Figure 1 - Safety, which includes wearing all proper PPE, should be a program's first priority.

2. Master Your Imaging System

Too often we find otherwise intelligent people using their infrared imaging systems as if they are "answer machines!" They are not! They are tools which, when properly used, will give remarkable data for our interpretation. Simply relying on "auto adjust" or "temperature alarm" functions is not only insufficient, it is dangerous because it means you will miss problems, probably serious ones. A qualified thermographer knows how to use the infrared imaging systems fully—focus, adjust the image manually, capture data with care, use measurement tools appropriately, correct for emissivity, background and transmission, etc—and, importantly, also understands the limitations of the system and technology. If you don't know how to use a tool properly and fully, you will not obtain consistent, high-quality results.

3. Open, Inspect and Close

In the past, thermographers often simply opened a number of enclosures and then came back and "inspected" them. This proved not only unsafe, but also a bad practice as it allowed for significant cooling of the enclosure's interior prior to inspection. Best practices now suggest a preliminary look at the enclosures prior to opening any of them; if one is abnormally warm, additional precautions may be warranted to gain access. Additionally, it may be useful to correlate the thermal signature with airborne ultrasound detection.

Please note, there are still some who insist, for various reasons, that they can fully inspect electrical equipment without opening the enclosures. These cameras aren't x-ray machines, they measure surface temperature only. The notion of being able to "surface scan" is not true, regardless of the type of imaging system or the skill of the thermographer! At best, there may be some indication of internal heating; at worse, there will not be a detectable signature. Gaining safe access to the enclosure is essential, either by opening it while

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- UL 746C: Impact and flammability
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it is under load, de-energizing it and then opening it and inspecting immediately thereafter, or by use of IR windows or viewports (discussed below).

At that point, as is appropriate, enclosures can be opened—again best practices suggests this be done not by the thermographer but by a qualified assistant who can also act as a safety backup and take load readings, and who understand the local system if their thermographer does not.

The inspection should be conducted systematically, using imager settings sufficient to detect any abnormal temperature increases. While the inspection can be conducted quite rapidly, thoroughness should not be sacrificed in the interest of speed.

Many components will have bare metal (low-emissivity) surfaces that can make detection of problems, as well as the measurement of their true temperature, difficult or impossible. Recognize that some may appear normally warm (contactors, overloads) or cool (surge protection). Similarly, some equipment may not be in operation or under full load at the time and this should be noted for later follow-up.

All abnormalities should be noted for later prioritization. Best practices generally suggest documentation only of anomalies but, when access is challenging for any reason, full documentation may be warranted to facilitate possible later analysis. Doing so also assists in trending of anomalies where applicable. Documentation should include thermal images, preferably with two or three of the phases for comparison, as well as a comparable visual image and, as needed, voice or written annotation. Any anomalies judged to be of an emergency nature should be dealt with immediately.

4. Where Appropriate, Consider Using IR Windows or Viewports

More and more often, safety concerns suggest we should minimize the opening of electrical enclosures while they are under load, and yet, not doing so can severely limit our ability to get good data.

Figure 2 - Installing and properly using infrared windows can increase safety and speed inspection time for your program.

One solution that is now being widely used is the installation of IR-transmissive windows or view ports. These devices enable a trained thermographer to look inside the enclosure without opening it. NFPA 70E allows theses devices to be considered as "barriers" thus potentially reducing the level of PPE and the approach distances used.

The use of such devices, however, is not as simple as may be assumed. Care must be given to proper sighting of the device in the enclosure to optimize viewing and to using the device effectively and safely. Because IR windows attenuate the thermal signal, both simple detection of an anomaly as well as measurement of the temperatures involved can be problematic. While a full discussion is beyond the scope of this article, it should be noted that without a carefully developed written procedure for using IR windows and viewports, results can be poor or misleading. Enough of these devices have now been installed, however, that good precedents can be established to ensure good results.

5. What Is The Load?

Basic electrical relationships, $I^2R=P$, clearly tell us heat output (P) increases at the square of the load (I). Heat output will increase exponentially as the load increases. The relationship being between the square of the current and heat, when you double the current, you increase the heat output 4 times. Increase load by 3 times, heat output increases by 9 times. Since heat is the "enemy" thermographers must, therefore, be particularly careful when inspecting equipment while it is under a light load where those loads will increase at some point in the future. The NFPA-70B recommendation for loading is 40% as a minimum, unless loads are normally below that level and not expected to increase.

Likewise, and much less well recognized, is the relationship between the temperature of a material and its electrical resistance. Some will scoff at this notion, and in rebuttal, I would like to offer an experiment to prove this out. If you have access to a low-resistance ohm meter, measure the resistance in a sample of copper bus at room temperature. Then, cold soak the sample in a freezer for 8 hours or so and repeat your measurement. Then, for good measure (pun intended) heat the sample (safely!) to 200°F and measure again. You'll be surprised at what you find. The vicious cycle of increased loads and heating resulting in increased resistance and more heating is one of the reasons anomalies can remain relatively stable for long periods of time before coming rapidly to a point of failure. The near impossibility of predicting exactly when that failure will actually occur has caused many good thermographers a sleepless night or two and

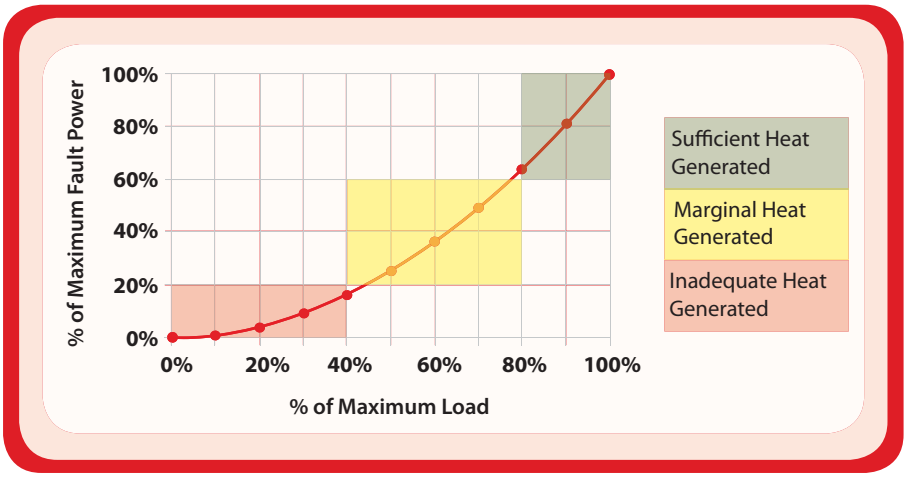

Figure 3 - According to NFPA-70B, a 40% load is the minimum required for accurate thermography readings.

should never be underestimated.

Some suggest that the different loads a thermographer invariably encounters can all, somehow, be miraculously "referenced" back to a 50% norm. While this may be possible in a specific instance with considerable engineering modeling, to think that it can be done wholesale is a mistake no reasonable person should make. Only two things are certain about inspections performed when loads are light and will increase: (1) some anomalies may go undetected and (2) those that are detected may be underestimated because they will generally appear cooler than when loads increase.

6. What Is The Thermal Gradient?

We are limited, for the most part, to seeing radiation coming from a surface. As the surface warms it gives off more radiation that can provide an alarm of a change. The driver of that changing temperature, however, is almost always internal to the surface we see; that is, the point of electrical contact and high resistance heating.

While it is important to view components as directly as possible, for some, such as a bus stab for a fuse block or a transformer bushing, this may be difficult or impossible. Even when viewing components directly, respect that there can be a significant "thermal gradient" between the surface being viewed and the internal source of heating. This can be seen, for example, when a bolted connection becomes welded together at the threads or when a plate connector shows pitting on the contact surfaces. For very large gradients, like an internal fault on a transformer bushing, the indication of a severely degraded problem may be only a few degrees rise in temperature over normal.

If conditions are poor for an inspection, a lightly loaded system or wind, for example, a relatively insignificant indication exhibited by a large gradient component may go undetected. To better understand the significance of findings, it may be useful to categorize gradients as either small (connectors viewed directly), moderate (breakers or large connectors) or large (oil-filled devices and bus ducts).

7. Bare Metals Are Difficult to Understand

One of the most poorly understood issues thermographers must contend with is the low emissivity (and high reflectivity) of bare metals. The result of this inherent physical property is that bare metals not only don't reveal their true temperature easily but they also tend to mask over it with untruths!

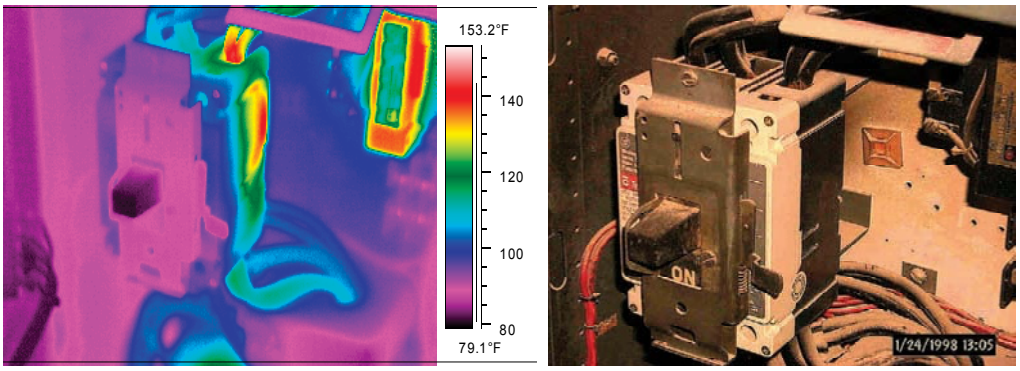

Figure 4 - Understand that there can be a significant "thermal gradient" between the surface being viewed and the internal source of heating.

While it is possible to make corrections for emissivity, the reality is that errors are unacceptably high when doing so for any bare metal. In many cases, the real danger is not just an inaccurate measurement, but a failure to detect the anomaly because the mix of emitted and reflected radiation is so confusing. As a practical guide, and many will find this shocking, it is virtually impossible to accurately and repeatably measure the temperature of a bare metal surface that is as "bright" as any of the coins in your pocket. This is true regardless of your procedure or the brand of infrared system you are using. It is also nearly as difficult to measure phase to phase differences when they are bare metals.

In the end, it is always advisable to increase the emissivity of bare metal surfaces using an appropriate high-emissivity "target" material such as electrical tape or Glyptol paint. If this is not possible, look for a nearby high-emissivity surface, such as the conductor's insulation or a cavity radiator, make your measurement there and acknowledge the probably large size of the resulting thermal gradient.

8. What to Inspect and When?

It is vital to structure inspection routes to optimize the reliability of essential equipment. The process begins by defining what is essential, a task that has often already been done by someone in an organization. While the "high" end of a system (switchgear and transformers, for example) is typically considered vital, downstream equipment must also be considered carefully. The HVAC system for the electrical room, for example, is often critical for reliable operation, and the loss of something as seemingly insignificant as a fuse in a

Mechanical Room											
Scan	Equip ID	Name.	Locator	Preparation	Inspect	Date	Time	Load (A)	Problem	TG #	Photo #
E1	EL360	Electrical Panel	System 01	NO; OP	Y	02/04/20	10:30	20	N		
E2	EL352	Electrical Panel	System 02	NO; OP	Y	02/04/20	10:40	90	N		
E3	EL344	Electrical Panel	System 03	NO; OP	Y	02/04/20	10:50	15	N		
E4	EL333	Electrical Panel	System 12	NO; OP	Y	02/04/20	11:05	15	N		
E5	EL329	Electrical Panel	System 06	NO; OP	Y	02/04/20	11:17	45;40;40	Y	1,2	1
E6	EL321	Electrical Panel	System 10	NO; OP	NIL	02/04/20	11:30	0	U		
E7	EL317	Electrical Panel	System 07	NO; OP	Y	02/04/20	11:35	88	N		
E8	EL325	Electrical Panel	System 08	NO; OP	Y	02/04/20	11:45	23	N		
E9	EL336	Electrical Panel	System 11	NO; OP	Y	02/04/20	11:55	60	N		
E10	EL340	Electrical Panel	System 09	NO; OP	NIL	02/04/20	12:00	2	U		
E11	EL348	Electrical Panel	System 05	NO; OP	Y	02/04/20	12:15	17	N		
E12	EL356	Electrical Panel	System 04	NO; OP	Y	02/04/20	12:30	44	N		
E13	EL367	Pump 1 Disconnect	West Wall	NO; OP	Y	02/04/20	12:46	18;21;18	Y	3	2
E14	EL368	Pump 2 Disconnect	West Wall	NO; OP	NF	02/04/20	12:58		U		
E15	EL369	FirePump 1 Disconnect	East Wall	NNO; LU	Y	02/04/20	12:59		N		
E16	EL370	Fire Pump 2 Disconnect	East Wall	NNO; LU	NR	02/04/20	13:05		U		
E17	AC003	Exhaust Fan Disconnect	East Wall	NO; OP	Y	02/04/20	13:06		N		
E18	TMP01	Enclosed Bus Duct	Ceiling	NA; SE	Y	02/04/20	14:00	U	N		
		NO=Normally Operating			Y=Yes						
		OP=Open Panel			N=No						
		SE=Scan Exterior			NIL=No-Insufficient Load						
		LU=Load Up			NF=Not Found						
		NNO=Not Normally Operating			NR=Not Running						
		NA=No Access			U=Unknown						

Figure 5 - A detailed list of equipment, along with relevant data pertaining to each piece of equipment, is essential to defining the best inspection routes.

control system can have dire consequences. Routes are best designed with input from all relevant stakeholders.

The task of assigning a frequency of inspection is one that is all too often either over simplified ("annually") or made far too complex. Initially the driver for frequency will be based on the resources available for inspection. Those should be distributed in such a way as to provide the greatest returns on the investment after considering such factors as the age of the equipment, its duty cycle, whether or not it is housed in a cooled area, the history of failures, etc.

After several inspection cycles, the feedback provided by the inspection results will serve to help refine the frequency. If for no other reason (and there are many others) it is crucial to note all anomalies, even if they are not all immediately repaired. Anything less than that will only result in a misplacement of resources.

9. Note Everything That is Abnormal, No Matter the Temperature

Too many thermographers make an arbitrary decision to only note "hot ones." This is a mistake for several reasons. First, the only way to accurately gauge asset health is to document everything. Of course, it is not realistic to think that every finding will be addressed immediately but there must be room in the maintenance system to at least note all abnormalities and deal with them appropriately.

Second, serious problems may not appear particularly warm at the time of the inspection for any number of reasons. For instance, if the load is light, not much heat will be generated but, of course, loading can quickly change. As stated before, equipment with a large gradient will rarely show up as very warm and some equipment, such as surge protection, is near failure when it exhibits even a small rise in temperature over normal. So note everything that is not normal and then figure out how much of a problem it is and what to do about it.

10. Measure Temperatures, But Do It Well

While it is often challenging to make accurate measurements of electrical components, every effort should be made to do so while also understanding the degree of confidence

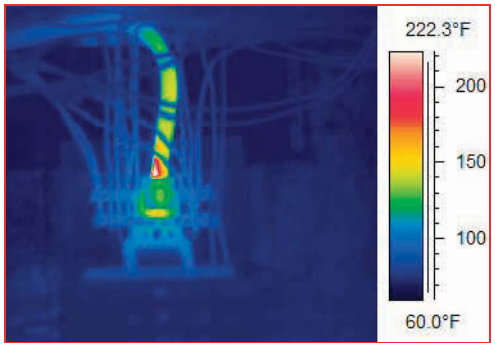

Figure 6 - Many times taking an accurate temperature reading is not as simple as pointing the camera in the right direction.

inherent to a particular measurement. In fact, it is useful to look at not only the component temperature (corrected for emissivity and background if possible), but also the rise over ambient air temperature and the phase-to-phase rise as well. These latter two will help one understand future changes in temperature that may occur and to isolate a rise related to failure.

11. Prioritize Findings Based On All Relevant Factors, Not Just Temperature

Logic suggests that the hotter an abnormal component, the closer it is to failure, and this is often true. However, it is not always true AND there are many instances where we don't have a good indication of either how hot it actually is (or could become), or how eminent that failure is relative to the heat we see. Best practices suggest prioritization of findings be based on all relevant factors, including temperature, but also including the reliability of the data, the criticality of the equipment, the potential for injury, etc. Trending can be

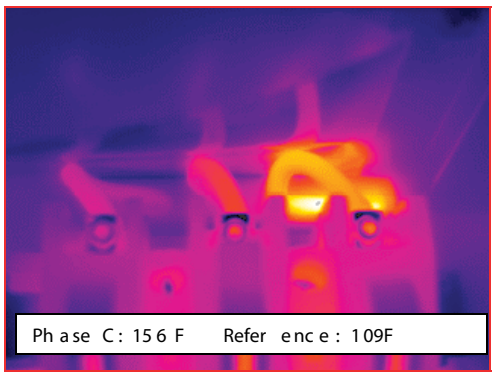

Figure 7 - While temperature is important, basing your prioritization of findings on all relevant factors is a better practice.

performed, but only conservatively and with great care, and with an understanding of the thermal dynamics involved.

Far better to dump all findings into one of three "buckets":

(1) those close to failure or for which the risk is too great
(2) those which can be monitored and managed until appropriate repairs can be made
(3) those which are in good health.

This simple, flexible approach yields remarkable results without being paralyzed by a complicated analysis. A methodology can also be developed and used to provide ever increasingly "smart" results as the system feeds back into itself.

12. Re-inspect After Repairs

In many companies, and for many different reasons, 50% of repairs are not effective the first time. Therefore, it is crucial to re-inspect after repairs have been made. The feedback will help drive improved quality, both on the inspection side as well as the craft side. The payoff for re-qualifying work is immense and should not be ignored or short changed.

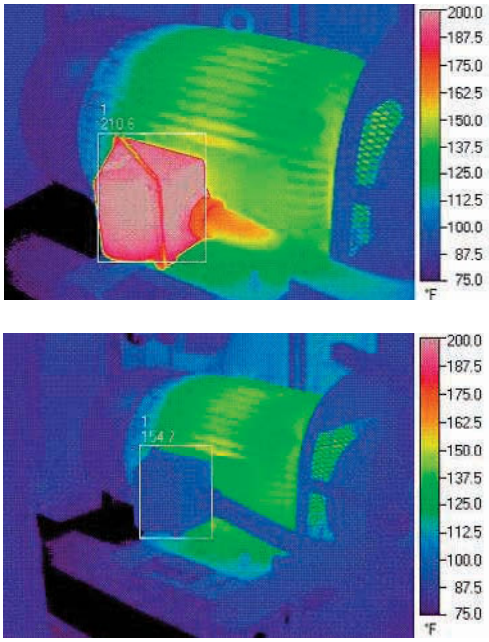

Figure 8 - It is important to reinspect components after the repair has been made. This leads to higher quality repairs and IR inspections.

Summary

There may well be other steps to success or variations of the twelve we've discussed. The bottom line is infrared is a remarkable tool that will provide returns far in excess of nearly any other maintenance investment possible, but it is not magic! To ensure a full return on the investment, thermography must be used intelligently by qualified people.

An infrared imaging system is one of the most powerful tools available to anyone involved in maintaining or testing electrical system. If, however, it is not used properly, this remarkable technology can actually be a dangerous diversion from or mask over what is reality. Modern infrared systems are very reliable and very easy to use; the limiting factor is typically the human being using the infrared system. Qualification is essential to both understanding any problems that are found as well as not missing problems that are there but not obvious. Qualification of thermographers is based on training/education, qualifying experience and proof of qualification (testing). Without that, chances are good there will be quality problems and consequences.

John Snell has been a leader in the thermographic profession for more than 25 years. He established Snell Infrared to serve the needs of the thermographic community. Snell Infrared has constantly expanded their training services and developed extensive on-site offerings for leading companies throughout the world. John continues to be professionally active in his capacity as President of the Snell Group. He was on the Steering Committee for the Thermosense conference from 1990 to 2004 and was Chair of Thermosense XVI and XX. He has worked on the standards development committee of the American Society for Nondestructive Testing (ASNT) and is currently working with three ASTM committees, as well as committees at Electric Power Research Institute (EPRI), ASNT, British Institute of Nondestructive Testing (BINDT), International Standards Organization (ISO), National Fire Protection Association (NFPA) International Electrical Testing Association (NETA) and RESNET. John had the honor of becoming the first thermographer in the world to pass the ASNT Level III exam for the Thermal/infrared method. John can be reached at 802-229-9820.

Dave Sirmans joined The Snell Group in the fall of 2008 as Operations Manager for the company. He is responsible for managing and coordinating The Snell Group's field service operations and overseeing the company's team of technicians that offer infrared thermography, motor circuit analysis and ultrasound testing services at various locations throughout the United States. Prior to joining The Snell Group Dave worked in Reliability as lead engineer in an electrical testing company where he developed and implemented NFPA 70E compliance for their infrared inspections outfit, as well as started an engineering services division within the company. *Additionally Dave founded an arc flash analysis and electrical safety training business that prospered throughout the southeast United States. He originally started his career with the US Navy where he spent eight years as an Avionics Technician and Electronics Instructor. Dave has written a number of articles for industrial publications and conferences. He* enjoys hunting, fishing and coaching little league baseball, and spends most of his leisure time with his wife and children in Georgia. *He can be reached at 706-636-1812 or dsirmans@thesnellgroup.com*

Optimizing Lubrication Practices

Tips for the Modern Manufacturer

by Mike Johnson, CLS, MLT, CMRP

Statistics provided by bearing manufacturers regarding grease lubricated bearing reliability are not flattering for maintenance organizations. As shown in Chart 1, the failures from controllable parameters outnumber the uncontrollable parameters by 9:1. The failure causes attributed to basic care practices equal the other causes (5:5), but the estimated percentage of failures attributed to basic care represents 80% of the reason for failure. From a labor and component replacement perspective, grease use is costly – and not because of the lubricant itself. It would seem that basic care after installation has a significant impact on bearing performance.

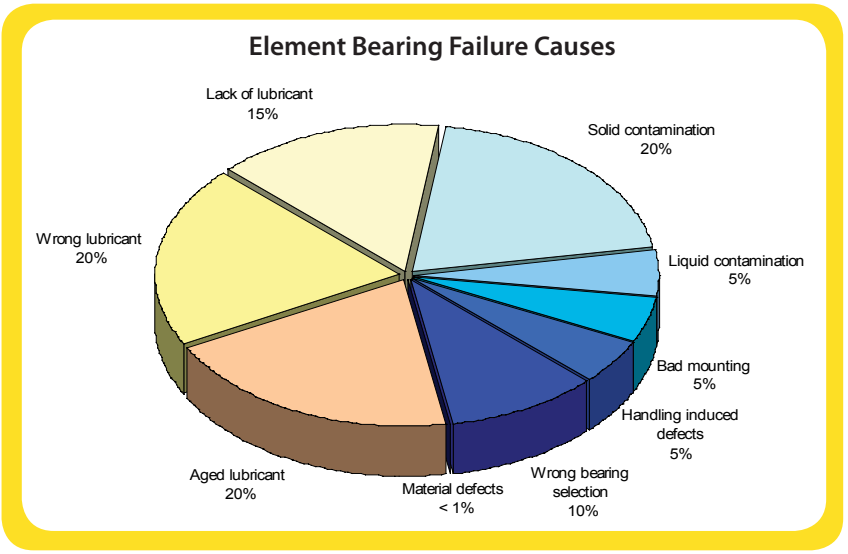

Figure 1 - The element bearing failure causes and their distribution.[1] (Graphic Courtesy of LUBCON, GMBH, Manufacturers of High Performance Lubricants.)

Basic care provided following installation is as much a reflection of attitudes and plant culture as it is individual behavior, perhaps more. The cost to industry for the accepted slovenly practices is high. The good news is that these issues can be corrected without much expense, once management decides that a caveman quality status quo doesn't support modern production demands.

Accordingly, bearing manufacturers have provided detailed advice for estimating lubricant type, volume and frequency requirements. Their intent is to assist the user with placing the optimum volume of a lubricant product with viscometric and surface performance (AW and EP) chemicals that precisely address the operating parameters (heat, load, vibration, moisture, contaminant, process chemical challenges). Once done, the user can expect the grease to feed oil to the race incrementally between the current date and the planned replenishment date so that the replacement practice provides a seamless flow of lubricant to the load zone, as depicted in Figure 2.

Either too much/too little grease, and/or inappropriately high/low oil viscosity causes viscous drag and/or destruction of the bearing surfaces and lubricant within the bearing.

In moderate and high speed bearings (nDm > 150K), even slight variations in consistency of replenishment and fill volume produces effects including dry surfaces and elevated high-frequency vibration (inadequate feed), elevated temperatures and increased energy consumption (overfeed). The faster the shaft speed, the more pronounced the deficiencies. As the shaft speed decreases the negative impact (churning, overheating, and energy losses) declines, but is still evident. The first part of this

The economic benefit associated with precisely defined lubrication practices is strong. The maintenance departments within capital-intensive manufacturing plants spend between $10 and $20 dollars replacing lubricated mechanical components for each one dollar spent on lubricant purchases. Maintenance also spends around three to five dollars in application labor for each dollar spent on lubricant products. The grease-lubricated machines represent a large portion of these (parts and labor) expenses. Plants allocate roughly 5 percent of their budgets for grease purchases (perhaps more for mining and metals processing), but 25% to 40% of the routine lubrication labor is allocated to grease application. Optimizing the grease replenishment frequencies stands to offer a reasonable amount of labor relief for manufacturers operating in a lean state.

multi-part article addresses lubricant viscosity selection. The second part addresses volume and frequency.

Lubricant Selection – Base Oil Viscosity and Additive Type

Viscosity changes with temperature and pressure. As temperature increases, viscosity decreases, and as pressure increases, viscosity increases. These factors are interdependent of one another. The central questions for selecting the correct lubricant grade for a given brand and product are:

1. What is the minimum acceptable viscosity for a given bearing?
2. What is the optimum viscosity for the bearing at operating temperature.
3. What is the viscosity of the current lubricant at the normalized bearing (machine) operating temperature?

Determining the minimum allowable viscosity to sustain element and race separation (EHD film formation) is a simple calculation, as follows:

$$V_{min} = 27{,}878 * RPM^{-0.7114} * Dm^{-0.52}$$

Where:

V_{min} = minimum allowable viscosity
RPM = shaft rotational speed
Dm = bearing mean diameter

For example, assuming the bearings on a 254-frame-size motor are operating at 2400 RPM, and contain single row deep grove ball bearings with a bore diameter (ID) of 45 mm and an outer diameter (OD) of 85 mm, then the pitch diameter is 65 mm, . The minimum allowable oil thickness for EHD film formation would be 12.505 centistokes at operating temperature. The optimum operating viscosity will be three to five times this value, or 36 to 60 centistokes.

Once determined, this should be compared to the viscosity supplied by the select lubricant. Assuming the grease contains a 100 centistoke (ISO VG 100) oil, and the bearing is operating at 50°C, one can use a commonly available viscosity/temperature chart to determine the acceptability of the operating viscosity of the product in use. Figure 3 illustrates this process.

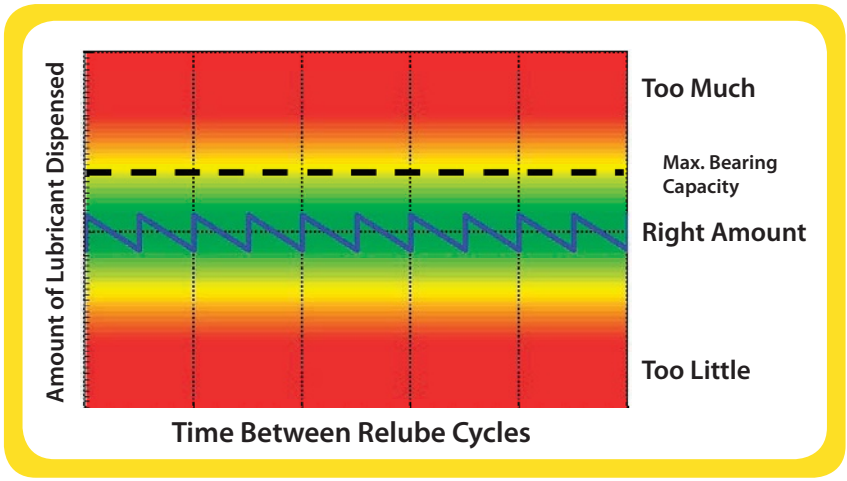

Figure 2 - Timely relubrication with precisely the correct amount provides ideal surface protection for element bearings.
(Diagram Courtesy of Lincoln Corporation)

As can be seen in the example, the suggested product would fulfill the optimum viscosity, delivering 60 centistokes at the stated temperature. The product would function with a margin up to 65°C, and deliver the minimum allowable viscosity to 95°C. As long as the dynamic (operating) viscosity is above the minimum allowable viscosity, the use of EP agents is discouraged. This example reflects why many electric motor lubricants are constructed with wear resistance (AW) rather than seizure resistance (EP) agents and contain ISO 100 viscosity oils.

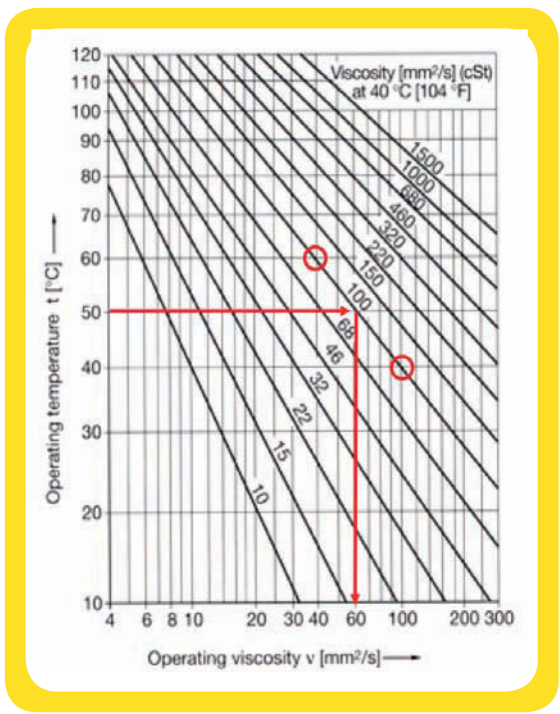

Figure 3 - A Temperature Viscosity chart for VI 95 Mineral Oils.

Viscosity selection for other bearing types and speeds follows this pattern. The bearing's maximum allowable operating speed and the limiting speed for grease lubrication (the point at which any given bearing should be oil lubricated) is determined by the bearing Pitch Line Velocity (PLV = mean bearing diameter times shaft speed = n*dM). Spherical and thrust bearings approaching a PLV of 150K, and ball and roller bearings approaching PVL values of 350K, must be qualified for reliable operation with grease.

Grease Volume Estimates for Initial Fill and Replenishment

Initial Fill – When an element bearing is first placed into service, the initial fill volume should be based on 1/3 to 2/3 of bearing net capacity, depending on expected shaft speed. The higher the speed the lower the initial fill volume.

The bearing net capacity is calculated as follows[2]:

$$V = [(Pi/4) * W * (OD^2 - ID^2) * 10^{-9} - G/7800] * 10^6$$

Where:

V = volume in cubic centimeters,
OD = Bearing Outer Diameter, mm
ID = Bore Diameter, mm
W = Bearing Width, mm
G = Bearing weight, Kg (21.5)

In addition to the grease introduced into the element spaces, enough grease should be placed into the housing to bring the grease level up to the lip of the bottom race of the bearing. When the excess from the initial fill is pushed away from the elements, it accumulates on the grease shelf at the race and becomes a reservoir to continuously serve oil back to the raceway without crowding the elements.

Obviously, the engineer/practitioner making these decisions has to know precisely which bearing, by manufacturer number, is in use in order to provide all the required values. Bearing manufacturer numbers are readily available at the time of initial installation and/or bearing replacement, so enough information is available for a correct initial fill.

Replenishment Fill – The bearing number details get fuzzy as repairs occur, as CMMS systems are upgraded and data is lost, and as the details from the original installation fade from memory. Therefore, it is necessary to have a more user-friendly approach to estimate replacement volumes for 'in-situ' applications. One should consider both feed volume and feed interval since the two are inter-related. The formula shown in Figure 4 gives volumes in both grams (for metric dimensions) and ounces (for English dimensions) for three different interval ranges.

Gq - Annually = D * B * .0912 (.004 for mm)
Gq - Monthly = D * B * .0684 (.003 for mm)
Gq - Weekly = D * B * .0546 (.002 for mm)

Where:
Gq = Ounces (cubic centimeters)
D = Bearing Outer Diameter, inches (mm)
B = Bearing Width, inches (mm)

Figure 4 - The interval-qualified element bearing replenishment volume formula from FAG Bearings Company.[3]

Where actual bearing dimensions are not known, a close proximity to the actual suggested value could be estimated by using housing dimensions and factoring again by one-third{(D * B * .114)*.33}. CAUTION: This provides only a close approximation. For critical applications, the actual bearing make and model should be determined.

Excessive lubricant volume applied to bearings with labyrinth style seals and low pitch line velocity bearings (PLV ≤ 50,000 for ball and cylindrical roller, ≤ 30,000 for spherical and thrust roller) is not considered to be as problematic to the grease or bearing as it would be at higher speeds. Excess grease dissipates readily and any grease remaining in the working area has adequate transport time and space.

High Speed Fill – The replacement volume for high velocity (PLV ≥ 330,000 for radial ball type; ≥ for spherical roller and thrust type) element bearings requires thoughtful consideration due to shearing and heat produced by overfilling. All bearings operating at high speeds benefit more from high frequency and low application doses emulating the continuous replenishment benefit that occurs for oil lubricated elements. For instance, the volume calculated for the short interval, Gq-Weekly, would ideally be uniformly distributed into the number of working hours for the time period and applied accordingly. This technique would require automatic application incorporating the use of timers and low volume injectors or quality single point lubricators.

Replenishment Frequency Requirements for Element Bearings

A relubrication interval is based on theoretical reduced service life (F10 Real) in hours, which is based on known grease degradation performance under test conditions (FAG FE9 Tester, DIN 51821, Part 2; SKF ROF Tester, DIN 51806).

Grease lifecycles can be predicted empirically. Much like a bearing L_{10} lifecycle value that indicates an operating interval for which 10% of a given bearing population would fail under identical operating conditions, the grease F_{10Real} value projects an operating interval for grease lifecycles, and consequently relubrication intervals. The grease F_{10} Theoretical calculation is predicated on work conducted by the German Society of Tribology (GfT, worksheet 3), and requires more space than can be devoted to it's explanation here.[4] Similar to the earlier comment about grease fill volumes, this approach works well when specific greases are being tested for specific applications during design considerations, but is difficult for the plant lubrication technician to apply to in-service components that don't reflect test conditions.

The F_{10Real} calculation is as follows:

$$F_{10Real} = F_1 * F_2 * F_5 * F_6 * F_{10}$$

Where:

F_{10Real} = Adjusted Frequency, Hrs
F_{10} = Calculated Nominal Grease Lifecycle
= (P; T; Kf * n * dm)

and

P = FE9 Load Factor
T = FE9 Temperature Factor
K_f = Factor for Bearing Type
dm = Bearing Pitch Line (mm)
n = Bearing Speed, RPM
F_1 = Op. Environmental Pollution
F_2 = Op. Load Dynamic/Vibration
F_5 = Op. Outer Ring Rotation
F_6 = Op. Mounting Type and Centrifugal Energy

When FE8 and FE9 test data, and F_{10Real} values for specific products are not available, a modified approach can provide the reliability practitioner with a well defined starting point. This empirically derived approach assumes nominal operating conditions for bearings operating at low PLV values (≤ 300K for ball and roller type elements, ≤ 140K for spherical and thrust type elements), and is shown in Figure 5.

The correction factor, K, allows the engineer to adjust frequencies based on machine operating and environmental considerations. The six provided conditions reflect practical issues that degrade bearing life and grease performance. Figure 6 includes the correction factors for a 3.44 inch bore spherical roller bearing operating at 1200 rpm (PLV = 160,800) in direct exposure to rain and in a dusty environment, such as on an unpaved building easement near a roadway, and exposed to the

$$t_f = K * \left[\left(\frac{14 * 10^6}{n * \sqrt{d}} \right) - 4 * d \right]$$

Where:

t_f = Time in hours for replacement
K = Product of environmental correction factors
n = Shaft speed
d = Bearing bore in millimeters

Figure 5 - Generic Grease Replenishment Formula

weather. The calculated interval amounts to 36 hours between relubrication events. For this short of an interval, an automatic application method would be strongly recommended.

Bearing OEM Lubrication Guideline publications provide alternate quantitative approaches that are also valid and could be considered as a strong reference starting point.[5, 6, 7]

Summary

Bearings cannot run reliably without timely and sufficient relubrication. Grease provides an efficiency opportunity that doesn't exist with oil lubricated sumps, and accordingly is a common choice by machine designers.

Without the benefit of thoughtful, purposeful practices, grease relubrication methods have the potential to negatively impact component life and machine health. These common methods for engineering plain and element bearings practice development can be used by the lubrication engineer, planner or reliability leader to greatly enhance the usefulness of grease products and labor utility.

The calculations are central to precise lubrication practices, which is central to plant productivity and economic efficiency. These calculations can be plotted on an excel worksheet or calculator. To assist the guys working with the tools, a device has been developed that incorporates these calculations into a small but representative collection of the most common bearing operating conditions. The device, a circulator calculator, is called the LubeCoach. There is a specific LubeCoach designed for ball bearing applications. Separate tools are required for spherical and cylindrical element bearings. Although it doesn't address every possible scenario, LubeCoach can shorten the estimation exercise from hours to seconds, and bring the power of quality and precision to the planner and craftsman at the plant floor. For more information go to www.precisionlubrication.com, and look for 'Online Tools'.

Bearing Relubrication Frequency Correction Factors				
	Condition	Average Operating Range	Factor	Value
	Bearing Bore (b), mm	3.44		3.44
	Shaft Speed (n), rpm	1200		1200
1	Svc Factor (Ft)	Temperature		1
		Housing below 150 F	1	
		150 to 175 F	0.5	
		175 to 200 F	0.2	
		Above 200 F	0.1	
2	Svc Factor (Fc)	Contamination		0.4
		Light, non-abrasive dust	1	
		Heavy, non-abrasive dust	0.7	
		Light, abrasive dust	0.4	
		Heavy, abrasive dust	0.2	
3	Svc Factor (Fm)	Moisture		0.1
		Humidity mostly below 80%	1	
		Humidity between 80 and 90%	0.7	
		Occasional condensation	0.4	
		Occasional water on housing	0.1	
4	Svc Factor (Fv)	Vibration		1
		Less than 0.2 ips velocity, peak	1	
		0.2 to 0.4 ips	0.6	
		Above 0.4	0.3	
5	Svc Factor (Fp)	Position		1
		Horizontal bore centerline	1	
		45 degree bore centerline	0.5	
		Vertical centerline	0.3	
6	Svc Factor (Fd)	Bearing Design		1
		Ball Bearings	10	
		Cylindrical and needle roller bearings	5	
		Tapered and spherical roller bearings	1	
			Calculated PM cycle (hr)	36
			Calculated PM cycle (day)	1.4977
			Calculated PM cycle (mo.)	0.050

Figure 6 - Practical Lubrication Replenishment Optimization Table.

Mike Johnson, CLS, CMRP, MLT, is the principal consultant for Advanced Machine Reliability Resources, in Franklin, Tenn. You can reach him at mike.johnson@precisionlubrication.com.

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IT TAKES A TEAM TO
WIN A RACE
GASOLINE
uptime
2.0
MRO Zone
PdMCity
VibrationSchool.com
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Is Your Company Running Scared?

Fight or Flight Might Not Be Your Best Strategy

by Chris Colson and Timothy R. Weilbaker

Any time a market (or an entire economy) declines, there are certain behaviors that we can expect to observe in companies. The specific actions we witness should come as no surprise to even the casual observer, especially since the actions taken by companies during tough financial periods are also observable in individual human behavior during times of great fear. And what other emotion would be more fitting than fear when corporate revenue experiences a sustained decline?

Thanks to the work of Walter Cannon, our natural "animal" responses to fear are generally well known.[1] The courageous, strong, fit (or possibly crazy) dig in their heels and fight. Unfortunately, the "dig in" part as we apply it to businesses typically means that a company decides the plan and strategy they have been following for years has led them this far and will, subsequently, lead them through any "muck" the business environment may continue to throw its way. Sometimes extremely large companies succumb to this strategy simply because they lack the agility to react any other way. Alternatively, a company may develop a new plan with a unique strategy to combat the shrinking revenue stream but then commit to it with such ferocity that they become blind to the possibility of any modifications. Of course, this approach carries a requisite ignorance of the fact that a dynamic business environment cannot reasonably be conquered with a static business plan.

The quick-footed, agile, more willing to change, (and cowards, of course) will take flight. A company choosing to fly will generally forego the time and energy required to develop a "freeze plan" and cut straight to the chase. They will announce employee layoffs and plant closings as soon as the fear reaches the decision-makers. This is often the case when a company decides to quickly exit one specific market segment.

Numerous companies see flight as the best (or perhaps even only) strategy to pursue when they realize that expenses must be cut quickly and drastically in order to survive. The authors are not alone in our belief that this is an ineffective strategy. Donald Keough, former president of The Coca-Cola Company and author of a recent book titled "The Ten Commandments for Business Failure" states that in his experience, "in the absence of other strategic changes, the truism is true – you can never cost cut your way to profitability".[2]

And, finally, those who do not fall into either of these two categories will assume a static (or, worst case, permanent) position. In other words, these individuals will freeze and neither fight nor fly – presumably paralyzed by fear. In fact, they may even lie down and 'play possum' to avoid being a target. Is this not what Niccolo Machiavelli warned against when he stated, "For this is the tragedy of man – circumstances change, but he doesn't"?

From an organizational perspective, those who freeze in the presence of fear are easy to identify. These companies institute one or more policies that actually contain the word freeze. Perhaps you are familiar with some of these "strategic actions". Hiring freeze. Training freeze. Travel freeze. Promotion freeze. It is interesting to note that on this last action the only thing that is actually "frozen" is the pay increase. The title and the additional responsibilities will often be exempt from the "promotion freeze". And so it goes with too many companies caught in the throes of an uncertain market.

These reactions to fear are significant as individual human behaviors. Why? In the simplest terms, individual human behavior in an organization becomes organizational behavior. The organizational behavior will then direct the culture of the organization. The culture will then greatly influence the organization's reaction to fear. For example, the fear generated by an economic recession.

What if an approach was employed that was different from "fight, flight or freeze"? In fact, what if a fourth approach existed to confront our fears? Might a fourth approach synthesize the first three? And is it feasible that this synthesized approach would reasonably exhibit one or more of the other three behaviors at any specific point in time? The purpose of this article is to suggest that there is an approach that companies should consider during times of market uncertainty such as what we are currently experiencing in most of the global marketplace. We call this approach being "fluid". Specifically, it is the use of a fluid strategy. But beware, Paul J. H. Schoemaker, research director of the Wharton School's Mack Center for Technological Innovation, warns that this just might be the most difficult choice to make as an organization[3]. In a recent article published on Financial Times.com titled "Destination dustbin", Francesco Guerrera poses a question similar to those we are ask-

ing. Guerrera writes, "In the middle of the worst economic downturn since the Great Depression, companies face a daunting choice. Do they exploit the tough times to lose the ballast accumulated during the boom years and make risky strategic changes in the hope of emerging as lighter but stronger organizations?[4] Or do they adopt a defensive stance, trying to weather the storm without rocking the boat until their markets and the economy rebound?" This sounds like Guerrera is asking, "Which "F" will companies choose to follow". Guerrera later states, "unlike in good times, when corporate inertia and humanity's preference for the status quo heighten resistance to change, crises make it easier to take radical action and sell it to employees, customers and investors." Radical? Maybe. But perhaps it is time for us to break that paradox and begin referring to these strategic behaviors as simply a "fluid" approach. Perhaps, too, it is time for this approach to become standard operating procedure as opposed to a consequential crisis that justifies short-sighted flight or freeze plans.

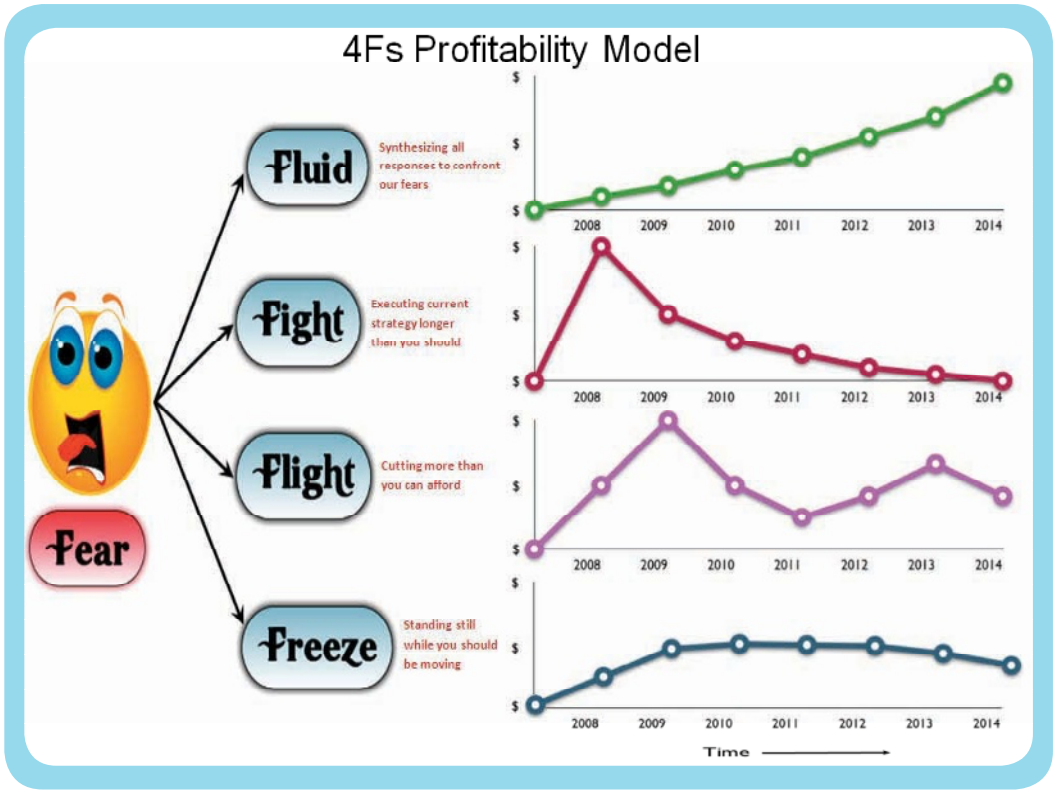

Figure 1 - The Four F's Probablility Model

The best way to understand how these reactions to sources of fear are manifested in a company is to study companies who exhibit one or more of these strategies for dealing with fear. We have selected four extremely large companies with global footprints as a matter of convenience, as we have personal knowledge and experience with all of these companies. Each of them is an international company in every aspect of that label. For this article, we will refer to them as Company A, B, C, and D.

Company A

This large manufacturer has been around for more than 100 years. It has variously been labeled as an innovator and a behemoth too large to keep up with the changing business environment. With thousands of employees and billions of dollars in annual revenue, this organization is a glowing example of the company who is so large (not only physically but organizationally, too) that fight is the most natural strategy during times of uncertainty. However, as is nearly always the case with large (think overweight and out of shape) companies, fight is not the only strategy used by this company. During the most recent economic crisis, the company has alternately utilized freezes on hiring, travel, training, wages, and other variable expenditures as well as divesting itself of employees, factories and even market segments. These behaviors are the archetypes of freeze and flight strategies.

Historically, the company tends to follow a predictable pattern. Initially, they dig in their heels and fight. The logic (strategy) is something like "we know we have a good plan but external forces are making it difficult for us to succeed. We must work harder". When those external forces persist, they concede that some freezing is required in order to "weather the storm". If the environment still does not improve, flight is required and the drastic actions associated with this strategy are enacted. As the organization is pared down, it eventually becomes healthy enough to, once again, fight for survival. This cycle may be repeated depending upon the severity of each market interruption. This cycle does not represent the strategy of fluidity, as posited by the authors, because the company merely alternates among the three lesser-preferred approaches to confronting fearful situations. When the crisis is over, this company always reverts to a fight-only strategy.

Company B

This company is one of the world's largest engineering service providers. Their clients literally span the globe. Their employee population is as diverse as the world's population. With tens of thousands of employees, millions of dollars in high-tech equipment, and numerous facilities worldwide, one could easily predict Company B would be too large for any strategy except fighting. That assumption, however, is not entirely accurate.

During the recent economic recession, Company B did make use of a freeze strategy. The company implemented travel, hiring and wage freezes. It also employed some flight strategy in bowing out of one or two volatile markets. Of course, a company this large would surely be right to employ some level of fight strategy and, indeed, they did. But upon closer examination, something deeper than the natural fight or flight instincts of an organism were at play. Something much closer to what we would term a fluid strategy.

First, the company resisted the temptation to freeze all expenses. Training and hiring were pared back but not frozen completely. As a technology-centered company, suspending training (or hiring) would surely strip the organization of comparative advantage in both the short and longer-terms. Secondly, their flight path would be more accurately described as a retreat path. Though the company ceased

plans for expanding service centers in volatile markets, they chose to leave sales and marketing activity intact to preserve their presence in those volatile markets for the future.

This company clearly represents the implementation of right things at the right times for all the right reasons. Moreover, Company B has exhibited this strategy-setting process even during times of market growth and stability. The authors suspect this company possesses a distinct competitive advantage with this type of strategy. Imagine fighting a competitor whose next move you could not predict, but whose employees knew it and had prepared for it for months. This is the power of a fluid strategy.

Company C

Company C operates primarily (though not completely) in the commodities market. Again, they are a large multinational organization with nearly a hundred thousand employees, dozens of locations and total asset value in the hundreds of millions of dollars. Such a close tie to the commodities market means frequent and often-dramatic market cycles for this company.

Historically, the company has reacted to market peaks by pushing hard (a fight strategy) to produce as much product as could possibly be sold. When the market would fall, the company pushed equally hard to reduce costs (a flight strategy) while generally bypassing any freeze policies. So frequently has the company executed this cycling of strategy that it has long since become culture. In fact, even external stakeholders of the organization expect these predictable reactions to each respective market cycle.

However, this "fight to flight and back again" strategy does not hold sway over every facility within the corporation. One plant, in particular, has recently chosen to break the traditional strategy cycle and pursue something that more closely resembles a fluid strategy. As a result, this plant is reaping benefits not seen in the rest of the corporation.

The plant to which we refer has identified "right practices" for each function of their organization. They have dedicated resources (including money, people and time) to implementing best practice processes throughout the organization even during the current economic recession. These efforts have not been easy, but they have produced benefits not achievable through the old traditional "fight then flight" strategy. This fluid-like strategy has led the facility to be one of only two plants corporate-wide to avoid layoffs, shutdowns, and the other consequences of a flight strategy.

Company D

For over 10 years, this organization has spent an abundance of time, money, and effort improving their overall business effectiveness. They've done this by not only improving their ability to produce at an optimal profit level, but also by understanding the variance that is created by other contributing sources to the overall performance of the company. Recognizing these variances was, in fact, a big step in the overall improvement. Leadership understood that no single department ensured the company's overall success. It would take effort and a desire to improve from all parties and all divisions.

As with many large diversified companies, not all divisions sing from the same sheet of music. This is no less true for Company D. One particular division has never fully embraced

the path to success followed by other divisions. They continue to use the old phrase, "we're different, and that won't work for us".

For example, when given the opportunity and support necessary to improve, they chose to hide their inefficiencies with a capital expenditure rather than to change their internal processes in order to improve performance. The result? After spending more than 20 million dollars, (representing 220% of the amount of their hidden plant – a measure of production inefficiency), they were only able to capture 41% of their pre-capital expenditure losses. They believe that they are different. However, the numbers tell the story differently.

Company D has now acknowledged these "low performing" plants and has recently taken significant strides toward standardizing continuous improvement throughout their entire corporation. Company D understands the current state of the economy and has implemented similar cost saving approaches as Companies A, B, and C using a freeze strategy. They have reduced the amount of training and limited or placed freezes on travel and other variable expenses. However, they have also spent an unprecedented amount (well over one hundred million dollars) on standardization including "best practices". These best practice processes have been mandated for the entire corporation and will be rolled out to every division – no exceptions. Now that is a statement! In fact, perhaps no other example familiar to the authors, displays so well our definition of implementing a fluid strategy during the worst (and the best) of economic times.

Conclusion

So what point are we trying to make? During downturns (including the current recession), the economy only slows – it does not stop. Fear-induced strategies of fight, flight or freezing only prepares a company to be surpassed by its competitors who have elected to utilize a fluid strategy. Think of it this way. How much force does it take to start moving an object at rest? How much force does it take to simply increase the speed of an object that is already moving? Which object would you rather move?

In closing, major shifts in the marketplace cause fear among companies. As humans (and by extension organizations) we tend to execute one of three strategies to combat fear – we fight, we fly or we freeze. Each strategy has its unique strengths and weaknesses. None of the three strategies should ever be used to the exclusion of the others. However, we believe from our experience that employing a fluid strategy is the single best approach to ensure long-term organizational performance. A fluid strategy is one that continually scans the environment looking for best practices and then uses fight, flight or freeze strategies in the right amounts and at the right times to ensure that those practices are successfully implemented. A fluid strategy is simply doing the right things at the right times for all the right reasons.

Remember: to the victor, not the coward, go the spoils. Is your strategy delivering the spoils you truly desire?

Timothy R. Weilbaker is the Founder and President of Process Thinking, a management consulting firm in New Albany, Indiana and an adjunct professor in the School of Engineering Technology at Eastern Michigan University. You may reach Tim at tim@processthinking.com.

Chris Colson is the Director of Strategic Accounts for GPAllied, LLC., an international maintenance and reliability consulting and training firm. You may reach Chris at ccolson@gpallied.com.

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The Missing Link in Reliability

Many Equipment Failures Could Be Linked To Materials Management

by Art Posey and Phillip Slater

Oh no, not again! Is this the perennial cry of the maintenance and reliability professional? We all know this situation: a recent failure was repaired and has now failed again shortly after. This is both annoying and frustrating, after all, why can't we get these things right the first time? Usually we are quick to blame the technician, or the technique, or the design. But none of these may be the fault, the break down could be caused by a poorly maintained spare part.

Empirically we can say that equipment failures result from a combination of poor design, incorrect operation, incorrect installation, inappropriate care activities, and poor cleanliness/environmental management. Therefore, it ought to be no surprise that we can also say that a vast majority of failures are self induced, as we control four of those five factors.

Maintenance and reliability practitioners might consider that reliable operations are achieved through a combination of equipment selection, maintenance program design, the use of tools to enable condition monitoring, and skills development of the team. However, many self induced and premature failures are more likely the result of poor materials handling and storage methods for spare parts. For many maintenance and reliability practitioners, materials management is the missing link in achieving reliability.

Typically most operations, maintenance and reliability professionals associate materials management with having, or not having, spare parts on hand. And despite their focus on optimizing plant performance, too little attention is paid to the maintenance of the spare parts that they hold in stock. The reason for this is that materials management is often thought of as a sideline or support activity, rather than a core function for achieving reliability. For this reason, the influence that materials management actually has on reliability is under estimated. The reality is that many companies could significantly improve their reliability outcomes by improving their materials management.

Why Your Data Doesn't Tell You What You Think It Does

In order to explain this and determine what to do about it let's initially try to understand why this problem isn't obvious, that is, why your data doesn't tell you that you have a materials management problem.

Firstly, downtime is typically recorded as equipment failure rather than materials/spares failure. So your data is often at too high a level to recognize that the part failure is the root cause. In addition, root cause investigations are not performed on most failures, so assumptions are often made about the cause of the failure and usually it is blamed on the installation, not a faulty part. This problem is further exacerbated by the time that may elapse between the installation of a spare part and its subsequent failure. If it is long enough, we tend to disassociate the failure from the installation of the part, even though the spare part has exhibited an extremely shortened life span. Without some form of root cause analysis we are often just too busy getting and keeping the plant going to consider this issue.

Other ways that we can mislead ourselves into not recognizing materials management issues as the cause of our problems include:

- Work orders not being closed off. If we are not disciplined in finalizing work orders then the data isn't available anyway. If we accept too long a delay in finalizing work orders then not only is data timeliness an issue but we also end up relying on memory, which we all know can sometimes be selective!
- Configuration data being out of date. If our records don't reflect our equipment configuration then how will we confidently track any problem, not just spares problems?
- Equipment hierarchies not sufficiently granular. As mentioned above, if your equipment records are set at too high a level then we will not be able to recognize problems.
- The team records their actions, not the equipment needs. That is, records reflect what was done (e.g. replaced fan belt) rather than observing equipment issues and requirements (e.g. broken fan belt seems relatively new, not sure why it was broken.)
- Tracking of assets. Who really tracks their spares as assets? Is there an engineering spares register in the CMMS?

- Multiple failure causes are rarely listed, even if they are known. If an equipment item fails due to a worn part and the repair is delayed due to a lack of availability of the part, is the delay time documented?

- Improper root cause conclusions can skew the data. If a motor is pulled from stores and prematurely fails it may be attributed to a poor rewind, when the true root cause may have been poor storage techniques.

How Proper Spares Storage Can Significantly Improve Your Reliability

If we define maintenance as 'the actions required to preserve equipment in a suitably operational state such that it operates as expected when required' then perhaps we can extend that definition of equipment to our spare parts. After all, aren't they also part of our equipment and don't we want them to operate as expected when required? Many early life failures can and do result from poor preservation of the spare parts and this results from improper storage practices.

The key issues for equipment operating in a plant are exposure to the environment and the effects of being in operation. For both mechanical and electrical elements of equipment, the effects of being in operation includes the kinetic effects of wear, heat, and vibration. Our primary methods of preserving these parts are lubrication and observation.

For parts that we have in storage the issues are similar. We still need to deal with the effect of exposure to the environment but we also need to deal with the effect of not being in operation, that is, the effect of being stationary.

Exposure to the Environment

Two key things to consider are where the spare is kept and how is it stored. For example, is it stored in the same environment as the operating equipment? Sometimes we are very careful to protect the operating equipment with environmental controls such as air-conditioning or dust proofing, but then keep the spares in a storeroom without either of these.

Even items kept in suitable storage or undercover are exposed to the environment and exhibit failure modes from exposure, such as:

- Rust
- Oxidation of rubber components in seals, belts, and other parts
- Build up of dust (especially important in electrical, rotating, and reciprocating equipment)
- Lubrication failure (through contamination, migration and evaporation).
- Vibration from the operating facility – slight vibration over a period of time can degrade many spare parts, from bearings to electronic components.

Effect of Being Stationary

It is easy to assume that because a part is not in operation and is environmentally protected then it will be OK to operate as expected when required. But the main enemy of reliability for items that are stationary is gravity and gravity is always with us!

The two main influences of gravity are:

- Flat spots that result from a constant weight on one section in seals, shafts and bearings.

- Lubricants 'flowing' to the lower areas, leaving upper areas without lubrication.

Exposure can be controlled, gravity must be managed (that is, the effects of gravity). Therefore environmental control is likely to be passive (in that we provide infrastructure which provides control) whereas managing the effect of gravity will need to be active (we need to perform tasks regularly in order to ensure the integrity of the part).

To demonstrate this visually, Figure 1 shows the relationship between parts in operation and parts in storage, and Figure 2 shows the crossover between active and passive issues for parts in storage.

In Figure 1 you can see that whether a part is in storage or in operation, we must still manage the effects of rust, dust, lubrication (lack of) and other environmental impacts. This diagram alone indicates that for reliable plant operation, we must maintain our parts because they are subject to many of the same issues as the items in operation.

In Figure 2 we see that those same core issues of rust, dust, and lubrication require active involvement if we are to ensure that a part will operate as required when needed. This is in addition to actions that must be taken in order to counter the effects of gravity and other environmental protection.

The Real Function of Your Storeroom

By viewing spare parts management in this way we can see that the real function of your storeroom is not just to store and control access to parts, but it is to maintain them in a condition so that they are fit for use when required. This means ensuring an appropriate care and maintenance routine as well as providing environmental protection. Neatness and organization of spare parts only helps ensure storeroom efficiency it does not guar-

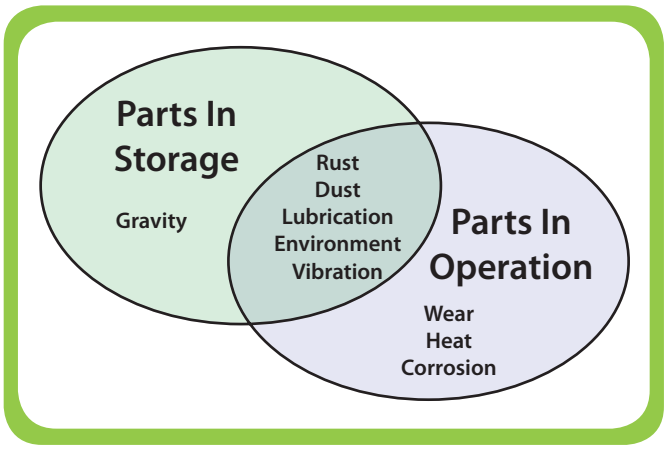

Figure 1 - The Relationship Between Parts in Storage and Parts in Operation

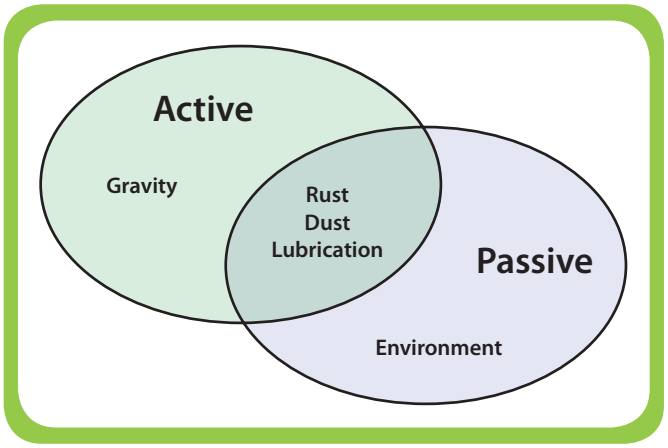

Figure 2 - The Crossover between Active and Passive Issues for Parts in Storage

antee spare part integrity.

Some basic storeroom practices that impact reliability include:

Proper Storage – safe from the environmental effects of dust, water, vibration, and light.

Preservation of Parts – appropriate lubrication and managing the effects of gravity.

Rigorous Rotation of Parts – that is, using the oldest parts first. It seems that human nature is that the newest parts are always pulled first by technicians.

Proper Labeling of Parts – so that the correct part is selected. For example, not selecting a 20 micron filter when a 5 micron filter is required.

Proper Access and Equipment – especially for lifting devices in order to avoid mechanical damage to parts when storing or retrieving them.

Spare Parts 'Ownership' Can Help Drive Reliability Outcomes

One of the main problems with maintaining spare parts is identifying who is actually responsible and are they qualified for the job? With parts in operation it is usually clear who is responsible for their care and maintenance and for achieving reliability outcomes – the maintenance and reliability function. Spare parts in storage are often given over to the storeroom or warehouse, and they are responsible for care and control. But who sees the whole picture? Who really understands how those parts fit in with the overall reliability plans? Surely this is also the responsibility of the maintenance and reliability function.

Are warehouse clerks really clerks? Or should they be warehouse technicians, where the care of the parts is as important as the oversight of receipts, issues, and counts? If so, a warehouse technician cannot perform a job to support plant reliability unless they have access to all manuals that reference storage requirements and have been trained in:

- Lubrication.
- Effects of ozone on rubber components.
- Requirements for storage of code materials (if applicable).
- Motor care and storage.
- How hydraulic cylinders work and how proper storage can extend the life cycle.
- How desiccants work and how they can enhance storage quality.
- Bearing types, components storage and preservation methods.
- Valve types and lubrication requirements.
- Temperature, humidity, cleanliness, and static electricity effects on electrical components.

If you align your spare parts ownership with the need to deliver reliability outcomes, then you can start to see how you can achieve your outcomes with appropriate spare parts maintenance.

Establishing A Spares Maintenance Program

Establishing a spares maintenance program is really just like establishing the rest of your maintenance/reliability program. As we have discussed, the difference is that maintenance/reliability programs typically address kinetic effects, that is, reliability issues that arise through the physical operation of the asset; whereas a spares maintenance program will address static effects, that is, issues that arise because the parts are not operating. Of course, both programs need to address environmental effects.

Therefore, establishing a spares maintenance program only really requires a change in mindset for your failure mode and effects analysis (FMEA). You now need to consider how the item will fail through not operating rather than how it will fail through operating. The rest of the program development is the same as with any other maintenance/reliability program, you need to identify the what, why, when, how, who, and where of your spares maintenance program.

This is an opportunity to expand your maintenance process and procedures to the personnel in the storeroom. A world-class spares maintenance program is likely to not require any more personnel than you currently have. It is an opportunity to transform the perception of your storeroom personnel from a simple receiving, issuing, and counting role to a role integral to the reliability of the facility. A written detailed program could add the structure and professionalism to transform your storeroom and your storeroom personnel.

Conclusion

Maintenance and reliability professionals spend an overwhelming amount of time and energy ensuring that the equipment in their care is preserved in a suitably operational state such that it operates as expected when required. However, in doing this they may over look one of the single greatest causes of equipment failure and subsequent downtime: poor materials management. For many, this is the missing link in their reliability program. Poor materials management results from systemic issues with the way that reliability data is collected, inappropriate techniques for storage, a misalignment of responsibilities, poor training, and a lack of formal policy and procedures in this area.

Empirically we know all this to be true. So, equally, we know from experience that correction of these issues can have a significant impact on the outcomes from any maintenance and reliability program. Materials maintenance is the missing link in most reliability programs and is vital for a reliability program to be a long term success.

Art Posey is the Senior Manager, Maintenance for Wheelabrator Technologies, Inc., a Waste Management company. Wheelabrator owns and/or operates 22 energy facilities in 11 states. Their primary business is burning municipal solid waste and other waste products to generate steam and electricity. Art came to maintenance 13 years ago after 16 years in construction. Art can be reached at aposey@wm.com

Phillip Slater is a Materials and Engineering Spares Management Specialist and the developer of Inventory Process Optimization™. He is the author of a number of management books, including Smart Inventory Solutions, A New Strategy for Continuous Improvement and The Optimization Trap. Phillip utilizes the expertise and experiences built up through nearly 25 years involvement in maintenance and operations management to assist select clients achieve significant improvements in operations management and inventory optimization. Contact Phillip directly at pslater@InitiateAction.com or visit the website www.PhillipSlater.com.

'Big M' and the Performance Culture

Managing Maintenance for Production Reliability

by James Davis, PE, CMRP

About 30 years ago, the Plant Engineer of an ITT Rayonier paper mill in north Florida called me into his office and announced that, as a reward for a job well done, I was being given the position of Plant Maintenance Engineer. This was a bit confusing at first, as I was a mechanical/civil Project Engineer at the time, in a 38 year old facility that had never had a Maintenance Engineer. But the boss had a ready answer. He next handed me a copy of a study done by some "Maintenance Consultant" that outlined the proposed ITT Maintenance Improvement Program (MIP) and said, "All you need to do is read this and then go down to the Maintenance Department and implement the recommendations". When I asked if the Maintenance Manager had been advised of this plan of action, the response was "You can brief him when you get down there".

Needless to say, I was not welcomed with open arms in the Maintenance Department. However, I studied the report and all of the suggestions about doing Preventive Maintenance and Work Order Planning, and proceeded to sign myself up for some courses and seminars on the subjects. This seemed a normal approach for an engineer. We went on to implement a PM/PdM Program with vibration monitoring and periodic inspections and developed a group of planners who learned to plan and schedule most of the repair work. In the end, Digester Utilization went from an average of 83% to well over 95% and the mill became profitable for the first time in several years.

Over the years, I have often pondered the striking success of that first program and others that have been similarly effective, and have come to the conclusion that the first step in any production reliability improvement effort is to become proactive in your approach to the business.

If we define "Maintenance" (Big M) as, 'Everything we do to ensure that our production asset reliably produces quality product", we will then have a broader definition than what is commonly understood in most organizations today. We will have a definition that fits into and supports the concept of a Performance Culture, according to the characteristics and benefits as follows.

The results of operating within a Performance Culture include:

- A Top-down Goals-Driven Paradigm
- A Functionally Integrated Organization and Management Team
- Disciplined, Process Oriented
- Mutually Supportive and Accountable Functions (Operations, Maintenance, Procurement, Engineering, etc.)
- A Learning Organization; Individually and Collectively Seeking Continuous Improvement
- Management Making Data-based Decisions and Focused on Leading Indicators
- A Defined Process for Continuous Defect & Loss Elimination
- A Planned, Scheduled & Measured work environment
- Common and Capable Information Tools Usage Across the Organization

The results of operating within the Performance Culture include:

- Systemically Improved Production, Loss Reduction
- High Equipment Availability
- Reduced Waste and Expense
- High Product Quality
- Predictable Production Levels
- Intimate Knowledge of Process and Equipment Condition
- High Levels of Ownership, Accountability and Cooperation
- Minimized Conflicts Among Competing Interests
- A Safe, Satisfying and Productive Work Environment

Certainly one can make a strong argument that having the operations, engineering, and logistics functions within any organization have a significant impact on Big M and production reliability. When I visit with management of companies and plant sites, I often hear the comment, "Maintenance is responsible for keeping the plant running so we can meet our production targets," or "We need maintenance to repair equipment that fails as quickly as possible, so that we can get production back on line." This approach reflects misunderstanding of the role that all parts of the organization play in the Big M process. In order for Big M to be successful, given the definition above, we must be in control of all aspects of the business that can have an effect on Big M. The general areas that must be included in the Big M management process include Managing Efficiency, Managing Reliability, Managing Materials, Managing Design,

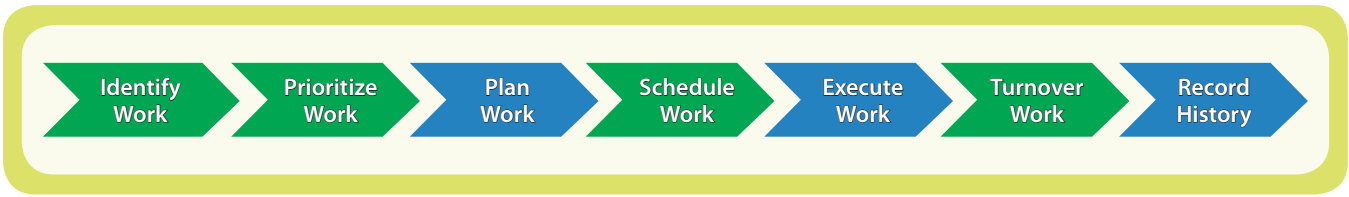

Figure 1 - The Work Management Process Diagram

Managing Information, and Managing Performance.

Managing Efficiency

Everyone knows that the maintenance organization is responsible for planning and executing the various types of repair, preventive, and predictive work that is required to maintain a reliable plant. However, the operations or production organization has responsibility for control of at least 50% of the work management process in most industrial settings. The steps controlled or impacted by operations are shown in green in the Work Management Process diagram in Figure 1.

To properly identify work, it is important that operations personnel are trained in the requirements for preparing a good notification or work request, incorporating a complete description of the problem and information including all that is known about the problem at the time that it was noticed. When prioritizing work, the responsible party must use reasonable judgment in assigning the correct level of priority. In most organizations, priority 1 and 2 notifications are schedule breakers and cause the maintenance organization to respond in an emergency or urgent mode, much less efficient than a planned mode as well as resulting in more accidents and reduced work quality. A planned maintenance organization requires about six to seven weeks lead time (backlog) in order to develop job plans, order materials, and schedule the crews. The Operations Department is always in control of the daily and weekly work schedule through the number of schedule changes and interruptions that they request. They should be a key player in the work turnover process to insure that the work is properly executed, the jobsite cleaned, and the equipment ready to return to full functionality. The bottom line is, "If every job is critical or urgent, then nothing is important."

Around the world, in all industries, maintenance craft efficiency tends to be less than 30%. In world class facilities, maintenance craft efficiency tends to be above 50%. In all my travels and visits to plant sites, I have never met a Maintenance Manager who had too many people! Improving maintenance efficiency has the following effects:

- The maintenance organization will get more work done.
- Material expenditures will be reduced.
- Production reliability will be improved.
- The unit cost of production will be reduced.

Managing Reliability

I am continuously amazed at the number of senior managers who tell me, "We continue to have the same equipment failures and production issues repeatedly". In a Performance Culture, we do not accept unexpected events or unplanned production losses. As a "learning organization" we have people and processes dedicated to identifying the root cause of unexpected events and eliminating those causes to preclude future occurrences of the same event.

In the Big M concept, the most important things we do are focused on preventing repairs, and not on repairing things. It is a basic characteristic of a Performance Culture, "A Defined Process for Continuous Defect & Loss Elimination." One of my friends is fond of saying "Every machine has a reliability strategy; the problem is that we often don't know what the strategy is". Unfortunately, there is a lot of truth in this comment. Once a facility is caught up in the day to day rat race of a reactive approach to maintaining the assets, it is very difficult to change to a Performance Culture and move to a proactive approach to production reliability. There are two key business processes for managing reliability: Root Cause Analysis (RCA) and Reliability Centered Maintenance (RCM).

The RCM approach is a structured decision-making process that makes use of reliable historical failure data, but can also work in the absence of good data. In Figure 2, as in Figure 1, the green activities are those that cannot be performed by maintenance or reliability engineers. They require input from operations, engineering, and logistics personnel.

The RCM analysis will be performed using facilitated workshops as well as individual engineering analyses. The prime objective of RCM workshops is identification and development of maintenance plans to address the dominant equipment failure modes and mechanisms. The most important step in the process is "Implement the Results". Spare part requirements and stocking levels are assessed and will include the review and evaluation of the equipment bills of materials (BOMs) and the identification of the recommended spare parts.

Materials

The impact of the materials management organization on Big M is well known around the planet. It is impossible to Manage Efficiency or Manage Reliability if inventories are inaccurate or parts and maintenance materials are damaged or of poor quality. In many organizations, the materials control function is either missing or carried out part time by one or more groups, often times in addition to their normal work. The materials control function should be responsible for material forecasting, including the identification of critical equipment spare parts. They should perform periodic inventory audits to determine and adjust inventory accuracy. They should monitor shelf life items to insure that expired materials and parts are removed from inventory and

Figure 2 - The RCM Process

replaced as necessary. They should identify special storage and handling requirements for unique items like:

- climate control for bearings to prevent corrosion or damage
- periodic hand rotation of electric motors to avoid bearing damage
- climate control for digital and electrical components to prevent damage

The materials warehouse should provide a work order material staging area, where parts and materials for planned work orders can be staged and kitted prior to delivery to the job-site. Critical spare parts must receive special treatment by the purchasing group. Once an item is identified as "critical", it should only be procured from approved sources such as the original equipment manufacturer.

Managing Design

Perhaps the singular most damaging mistake in industry today is the common practice of overlooking production reliability concepts during the design, construction and start-up of major new facilities. The global cost of this poor management practice is truly astronomical. New facilities experience excessive unplanned downtime resulting in excessive costs and loss of critical production due to quality and quantity issues. These losses can be avoided by implementing proper business processes and good operational planning during project design and construction.

Designing for RAM (reliability, availability, maintainability) will return significant benefit during early operation of the facility. The term "Reliability" is defined as the probability that an asset will function as intended over a specified period of time under a specified set of conditions. Availability, on the other hand, is the percent of time an asset will function as intended. "Maintainability," refers to the effort required to keep or return equipment to the condition needed for it to perform its intended function. Reliability and Maintainability work together to determine Availability, which in turn, provides opportunity to enhance Asset Utilization (AU) production reliability. A Performance Culture is a learning organization; individually and collectively seeking continuous improvement

During the project design we have the opportunity to assess the planning for operation of the new facility and to evaluate any design issues that will have a negative impact on operations and maintenance of the new facility. Conduct a RAM assessment of the design and publish a report highlighting any required action items. Design asset data structures and configure, install and test the ERP or AMS system, load asset and parts data and design reports. Conduct a Reliability Centered Maintenance (RCM) study to establish asset criticalities and maintenance strategies. Develop spare parts and maintenance materials requirements and plan proper receiving documentation and storage. Acquire, document and store spare parts and maintenance and operating materials.

Managing Information

Two key characteristic of the Performance Culture are:

- Management That Makes Data-based Decisions and Focused on Leading Indicators
- Common and Capable Information

Tools Usage Across the Organization

To make intelligent decisions regarding management of Big M, managers need reliable performance data. Raw data itself is meaningless without tools for converting the data into usable knowledge. A properly designed, multi functional tool must be configured to yield useful analysis of the raw data collected. I am constantly amazed at the preponderance of companies who complain that the maintenance history data in their ERP system is useless. Most of our clients are using SAP, implemented at a significant cost. However, many of them have been unable to implement an effective process to accurately capture performance data.

Most analysts agree that a well implemented ERP should trim operating costs, predict demand more accurately, streamline production, and improve customer service, thereby saving a company millions of dollars in the long run. In the short run, the picture is often radically different. Many companies have found that ERP investments resulted in a negative return on investment (ROI). In some cases, the difficulties encountered during implementation led to decreased productivity, loss of personnel time to training and learning new processes, declines in customer service, and a lower bottom line. Companies may find that they don't have either the reports or the information they need, despite the huge amount of data the system produces. Why? Because:

1. There may be inadequate training;
2. They may not have designed the specific reports they required;
3. It may be a cultural issue.

Managing Performance

The key to a Performance Culture is the ability to measure performance at a number of levels (Management Making Data-based Decisions and Focused on Leading Indicators). The key to being able to make good data-based decisions is having reliable, accurate data that is used to develop and trend Key Performance Indicators (KPI's). There are two levels of KPI's that must be used to measure and continuously improve performance:

1. Leading Indicators that measure behaviors and business processes
2. Lagging Indicators that measure the results of the correct behaviors

By trending the leading KPI's, managers can understand whether performance in certain areas is improving, degrading, or maintaining at a constant level. By understanding the relationships between the behavior measures and the results measures, managers can take action before the fact, instead of waiting to see the results and attempting to take remedial action.

Conclusion

It is a widely accepted fact that production reliability based on optimum utilization of production assets is the most effective method for improving profitability, while reducing the unit cost of production. In order to fully achieve this, it is very important to get all parts of the organization focused on improving Big M performance. Companies that have established a Performance Culture within their manufacturing or producing assets understand the importance of Big M. In these organizations, all departments understand their share of the responsibility, and work together with common goals and performance measures to insure optimization of Big M.

James Davis, PE, CMRP is Vice President and Managing Director, SAMI Arabia for Strategic Asset Management, Inc. As Managing Director, SAMI Arabia, James is working with regional companies to develop and implement Asset Management Strategies as a way of achieving Operational Excellence (OpEx) through better Asset Utilization in oil related and non-oil related industries, both in existing brownfield operations and in greenfield projects. James first worked in the region when he joined Saudi Aramco in 1980 and helped to organize and start-up their new facilities in the Yanbu Industrial City. After several successful and rewarding assignments, James left Saudi Aramco in 1995 to enter the field of management consulting, where he has played a significant role in helping a variety of international companies improve operations and profitability.

James is currently working with representatives from Saudi Electricity, SABIC, Saudi Aramco and others to organize a society for maintenance and reliability professionals for regional professionals. He has published numerous papers and articles on subjects ranging from Implementing Effective PM to Enterprise Reliability Database Systems. His most recent article, "Operational Excellence for Greenfield Projects" is being published in regional and global media.

Getting Up Close with Ultrasound

Get Started with Vacuum Leaks

by Jim Hall

Here we are in the 21st Century and some of you are still wondering if ultrasound is the only way to find in-leakage or vacuum leaks. Well, the answer is no, because employing helium is another method widely used to locate leaks throughout a power plant. In fact, Figure 1 shows a technician using helium to find leaks. Still, except for some high-vacuum systems such as autoclaves, or finding leaks on condenser water boxes, ultrasound can definitely get the work done.

Figure 1 - Technician utilizing helium for leak testing in power plant.
Photo courtesy of Rob Earl.

Ultrasound is actually quite useful in locating condenser water box leaks. It may not be as sensitive as helium, but it has its advantages. For instance, there are occasions when helium is used as a trace gas, but it can be either extinguished or just blown away. For instance, I was once observing a technician using helium for leak testing a heat exchanger in Southern California. However, the Santa Anna winds were blowing that day and his trace gas was simply being blown away. Ultrasound would have been a good substitute for him, but some technicians are not familiar with the many applications for ultrasound.

Since ultrasound is sound above the human hearing range, it is a wonderful technology to use in noisy facilities. What is noisy to you and me cannot be heard by the ultrasound receiver. Therefore, the noise that prevents you and me from hearing a compressed air or vacuum leak can be filtered or tuned out of range, allowing the end-user to detect a leak like a vacuum or in-leakage, which is typically heard in the 38-40 kHz range.

Taking The Plunge

What? You say you haven't tried ultrasound yet? When you do take the plunge, you will be amazed at the leaks you find using these instruments. I do encourage you, however, to make sure your instrument, or potential instrument, is well equipped to do what you need it to do. There are some basics to look for, so when purchasing an ultrasound instrument, choose an instrument that has:

- The sensitivity to hear in-leakage
- The ability to reduce or filter out background noise
- Various accessories to aid you in leak detection

I certainly don't want you to feel as though leak detection is a walk in the park. Ultrasound's beauty is that it is a simple technology to get started with and have early success. But it does take time to become familiar with your instrument, develop techniques, learn to filter out background noise, and learn how to use the technology for a wide array of leak detection applications. You need to seek out the necessary training to learn these techniques, and I suggest finding someone with in-field experience. Many of today's sales reps are simply not familiar with many advanced applications, and have little, if any, case histories to share with you.

And Now...Back To The Leaks

Let's consider in-leakage of an expansion joint in a power plant. These leaks can be found by using ultrasound. Within many generating plants an expansion joint leak may go unchecked, again mainly due to the fact that many technicians are unaware of an ultrasonic receiver's sensitivity and potential for this application. These expansion joint leaks are considered by some to be just 'weepers', or defused leaks, and not worth the effort to find. However, ultrasound can be your best friend for expansion joint leaks, so don't hesitate to use it.

Just ask Brian Thorp of Seminole Electric in Palatka, Florida, who recently used his U.E. Systems, Inc., Ultraprobe 2000 pistol and parabolic dish to hear a leak on an expansion joint some 25-30 feet away. I dare say that this leak might have, in fact, sucked the whiskers off his face had he been closer, but it was a good find never the less.

Figure 2 - The precipitator penthouse.

Figure 3 - Cracks and openings around casing walls should be repaired and/or sealed.

Many years ago, I trained Brian in the use of airborne ultrasound, for both his Ultraprobe and his SDT170. Ever since then, Brian has been a strong proponent of ultrasound technology to locate condenser water box leaks as well as steam leaks, compressed air, hydrogen and negative pressure leaks.

The precipitator penthouse (see Figure 2) is an area where ultrasound can pay large dividends. All of the flue gas passes here, and it is also where the electrostatic ash removal occurs. The precipitator penthouse should be tightly sealed and any casing cracks or openings (see Figure 3) that you find with your ultrasound instrument should be closed and/or sealed.

Vacuum Type Leaks

So, what is a vacuum? Theoretically, vacuum is space without matter in it. A perfect vacuum has never been obtained. The most nearly perfect vacuum exists in intergalactic space, where it is estimated that, on average, there is less than one molecule per cubic meter. A common, but incorrect, belief is that a vacuum causes "suction." Actually the apparent suction caused by a vacuum is the pressure of the atmosphere tending to rush in and fill the unoccupied space.

This movement of air or turbulence may be detected with ultrasound. Turbulence is internal, therefore the sound is internal. Technicians typically have to move the ultrasound receiver or microphone closer to the leak to detect the leak. We sometimes describe this leakage as "vacuum" or "in-leakage". In-leakage, is a term used freely in and around a power plant, as air rushes into a closed system due to cracks in casing walls, loose bolts on piping, deteriorated gaskets, or seals. These leaks often greatly reduce the efficiency of the generation plant.

According to Brian Harpster, INTEK Product Specialist, "It's not unusual for condenser air in-leaks to cost a company between $3,000 and $5,000 a day, plus a loss of potential revenues in MW hours of $10,000 to $100,000 daily."

"Most engineers and executives are surprised to discover how expensive air in-leakage can be, particularly when we define the potential losses they may face over the long haul," says Harpster.

"Plus utilities never like to miss the opportunity to sell excess power back to the grid, especially at peak periods. Not only does air in-leakage contribute to back pressure on the turbine, which reduces system efficiency," Harpster explains. "But back pressure may also be caused by vacuum pump partial failure, which may not be easily identified by a search for in-leakage. The 'symptoms' may go unnoticed for several months under conventional industry maintenance programs. With failing exhausters, dissolved oxygen and other noncondensibles quietly build up in the condensate."

Mr. Harpster is referring to the use of the INTEK RheoVac Sentry that monitors in-leakage within the condenser exhaust lines. Whether you are monitoring through a system like this or manually surveying the plant for in-leakage using ultrasound, this fact remains – in-leakage is a serious problem, and knowing how to find, detect and remedy the leaks should be everyone's concern.

Another point that he mentions is the noncondensibles. Dissolved oxygen in the system may require the system to be treated with costly chemicals that may possibly lower the life expectancy of certain components within the generation side. These impurities allowed into the system through leaks can and will cause corrosion throughout the boiler feed water system.

Accessories can help

Do you have an idea where to go look for your in-leakage? Do you understand how to use your instrument? Are you familiar with the accessories offered by the manufacturer of your instrument?

I sold ultrasound instruments at one time and was always amazed at how often technicians didn't know about all of the accessories that were available. For instance, take the UE Systems, Inc., Close Focus Module. This little device allows the end-user to hear a vacuum or in-leakage with a little more amplification. The internal cone design amplifies the detected ultrasound up to 10-11% and has a narrow field-of-view. A great little accessory for examining switchgear or electrical panels, especially when, for safety, you need to stay back and not reach inside a cabinet.

You will notice that the technician in Figure 4 is using an SDT170 with a 31-inch SDT Flexible Wand accessory. This flexible wand accessory (also shown in Figure 5) is particularly valuable tool for this kind of inspection. The universal interconnect pigtail cable allows the technician to stretch some 8 feet away from a holstered or handheld base unit while listening through the headphones for leaks.

Learn how to work in and around competing ultrasound. Learn how to use barriers to block competing sounds. Learn how to use frequency tuning (if your instrument has this feature) to tune out competing sounds, or to tune-in sounds or frequencies that enable you to detect a leak.

Figure 4 - Technician using an SDT170 with an SDT 31" Flexible Wand accessory on a soot blower air line.

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commtest The Revolution

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Implementation Success Training (IST)
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For more information and additional training listings, please log onto www.reliabilityweb.com and then click on the 'Events' menu tab.

Figure 5 - Detecting vacuum leaks on a condenser with SDT270 and flexible wand.
Photo courtesy of SDT North America.

Also, study hard to learn the many applications for ultrasound. Heat exchangers, condenser water boxes, boiler casing leaks, expansion joint leaks, soot blower air supply leaks and vacuum pump leaks are just a small representation of the many applications that await you.

In today's economy, every single technician has to become leaner and more resourceful than ever before. Your job, and many other's jobs, may depend on it.

Equally as important is considering the natural environment. A plant running as efficiently as possible is a clean burning plant. A clean burning plant is a greener plant.

Unless noted otherwise, all photos courtesy of Ultrasound Technologies, Inc.

Jim Hall is the president of Ultra-Sound Technologies (UST), a vendor-neutral company providing on-site predictive maintenance consultation and training. UST provides an Associate Level, Level I & II Airborne Ultrasound Certification. Jim is also a regular provider of on-line presentations at ReliabilityWeb.com and is a contributing editor for Uptime Magazine. Jim has provided airborne ultrasound training for several Fortune 500 Companies in electrical generation, pulp & paper, petro-chemical and transportation (marine, automotive, aerospace). A 17 year civil service veteran, Jim served as an aerospace engineering technician for Naval Aviation Engineering Service Unit (NAESU) and with the Naval Aviation Depot Jacksonville Florida (NADEP). Jim is also president of All Leak Detection, LLC a leak detection company providing air leak audits above and below ground leaks. Jim can be reached at (770) 517-8747 or jim.hall@ultra-soundtech.com

Diagnosing Tiny Bubbles

Vibration Signatures of Cavitation in a Centrifugal Pump

by Dr. Lin Liu & Dr. Suri Ganeriwala

Cavitation is a major source of problems in centrifugal pumps. If it is not detected early enough, it can even destroy a pump. Vibration analysis is often used to determine the cavitation, but its vibration signature is still elusive. In this work, a centrifugal pump was tested for its vibration signatures under different operational conditions. The two abnormal operating conditions studied here are air bubbles and cavitation. A transparent plastic cover was used in the experiments to observe the cavitation. We found that the pump has higher vibration amplitude in the axial direction than in the radial direction. From the experiments, we also determined that a significant amount of air bubbles will significantly increase vibration component associated with impeller vane pass frequency.

Cavitation might excite high frequency structural resonance. It might also reduce the impeller vane pass frequency vibration. Although cavitation is less likely to happen on a slow speed pump, it will develop very fast if it happens.

Introduction

A pump is a mechanical device used to move liquids. Mechanical energy is transformed into hydraulic energy at the pump. Pumps can be classified into two categories: displacement pumps and centrifugal pumps. In this work, a centrifugal pump was tested and studied.

The essential elements of a centrifugal pump are (1) the rotating element, consisting of the shaft and the impeller, and (2) the stationary element, consisting of the casing, stuffing boxes, and bearings. Figure 1 illustrates the single stage bronze centrifugal pump used in this work. This pump has a single rotating metal impeller. Liquid enters at the center and is thrown outward radially by centrifugal force. The five impeller vanes can clearly be identified in Figure 1.

Figure 1 - Centrifugal Pump

One of the important phenomenon in a pump is cavitation. Cavitation occurs when the pressure of the fluid drops below the vapor pressure for the temperature of the fluid. When this pressure drop occurs, whether it is a system pressure drop or a localized pressure drop, voids or cavities (bubbles) will form in the liquid. These bubbles implode or collapse when the fluid moves through the impeller to the high pressure side of the pump, causing the impeller to erode. These implosions tear out tiny pieces of the metallic surface near the implosion. This can be very damaging and eventually the impeller will fail. Figure 2 shows a schematic representation of the cavitation process.

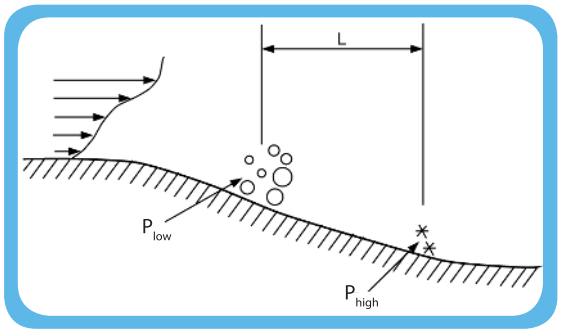


Figure 2 - Cavitation

There are three common causes of vapor formation in a liquid:

1. Flow separation of a viscous fluid from its guiding surface due to a surface discontinuity.
2. The addition of heat to the fluid, raising its vapor pressure (boiling point).
3. Reducing the pressure of the fluid to below its vapor pressure.

One important term in pump theory is net positive suction head (NPSH). NPSH is a measure of the difference between the total suction head and the fluid vapor pressure. The concept of NPSH is closely related with cavitation. For a specific pump, there are both the required NPSH and available NPSH. The required NPSH is the factory suggested value which must be maintained to prevent the occurrence of cavitation. The available NPSH is the real pressure difference between the suction head and the fluid vapor pressure.

Experimental Setup

The pump was installed on the machinery fault simulator (MFS) as shown in Figs. 3 - 5. The suction and discharge sides of the pump are fitted with pressure gauges. The pump discharge is directed through a manual modulating valve and then a flowmeter back into the head tank. Two single axis accelerometers were glued on the pump in the radial and axial directions respectively. The vibration data was collected by using a SpectraQuest software/hardware system.

Figure 3 - Machinery Fault Simulator (MFS)

Experimental Procedure

The experiments are categorized into two groups. In the first group, the original brass pump was tested. In the second group, the original brass pump cover was replaced with a transparent plastic cover to observe the liquid motion inside the pump.

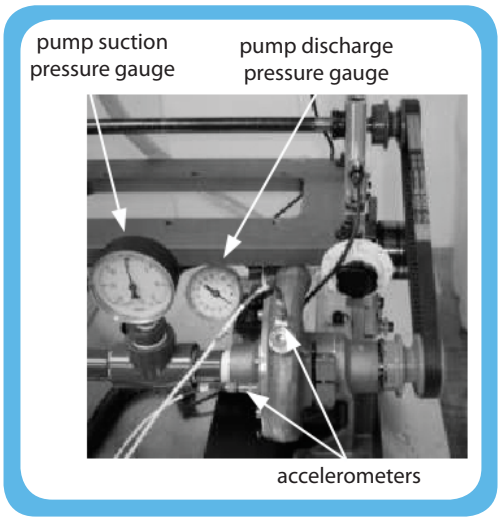


Figure 4 - Pump during test

Brass Cover Pump Experiments

First, the pump was running around 3600 rpm to check the integrity of the system. Through the transparent hose connected to the pump suction end, we noticed that a significant amount of air bubbles were sucked into the pump. The pointer on the pump discharge pressure gauge was vibrating. We found that the air bubbles were created by the returned water hitting the water inside the tank. Before the air bubbles were exploding and disappearing, they were sucked into the pump. The vibration data was collected for both of the cases, with and without air bubbles.

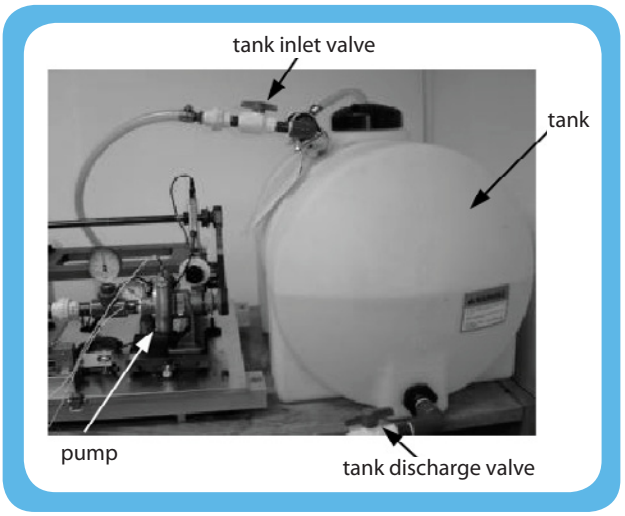


Figure 5 - Tank

Next, the tank discharge valve was turned 45 degrees to restrict the flow rate into the pump. This caused the pressure on the pump suction end to drop. This might cause the water to cavitate as discussed earlier. The water vapor pressure under room temperature is 0.935 inHg. The atmosphere pressure is about 29 inHg. In order to prevent water vaporization, the pressure of the pump suction end has to be higher than $NPSH_{required}$. We did not have the exact $NPSH_{required}$ data for this specific pump. Generally, the $NPSH_{required}$ is decreasing with flow rate or pump speed. On the other hand, the $NPSH_{available}$ is increasing with flow rate and pump speed. As a consequence, it can be argued that the possibility of cavitation is much smaller for low speed pumps than high speed pumps.

As the supply to the pump was restricted, the flow rate dropped. Because of the lower flow rate and smaller impact force as the water returning to the tank, no significant amount of air bubbles appear. Vibration data were collected and used for later comparison.

The speed of pump was then decreased to around 2400 rpm. We found that under this speed, the air bubbles did not appear anymore. The water flow is proportional to the pump speed, that is, the higher the speed, the greater the flow. Therefore, the flow rate under 2400 rpm pump speed is lower than that of under 3600 rpm. The smaller impact force caused by the slower flow rate is not large enough to create the air bubbles. Vibration data for the normal operating status and cavitation status were collected.

Finally, the pump was running at around 1200 rpm. As was the case for the 2400 rpm speed, no significant amount of air bubbles were created. Vibration data for the normal operating status and cavitation status were collected.

Plastic Cover Pump Experiments

The purpose of installing the plastic cover is to visually observe the cavitation phenomenon. With the brass cover, we have no definite answer as to whether there is cavitation or not. We can just give the best estimation we can. However, with the transparent cover, we can determine the cavitation formation with full certainty, and therefore, positively correlate the vibration signatures with the cavitation situation. The procedures for experiments with the plastic cover are similar to those of brass cover.

In the data acquisition process, the frequency limit was set at 20 KHz. Twenty seconds of data were collected for each case.

Experimental Observations and Results

Brass Cover Experiments – The acceleration spectra are presented in Fig. 6 for pump speed of 3588 rpm without air bubbles and cavitation. Figures 6 (a) and (b) display the acceleration spectrum in the pump radial and axial directions respectively. The fundamental 1X component and its harmonics can be identified. The fifth harmonic, which corresponds to the impeller vane pass frequency (because there are five vanes on the impeller), has the highest amplitude. Moreover, two impeller vane

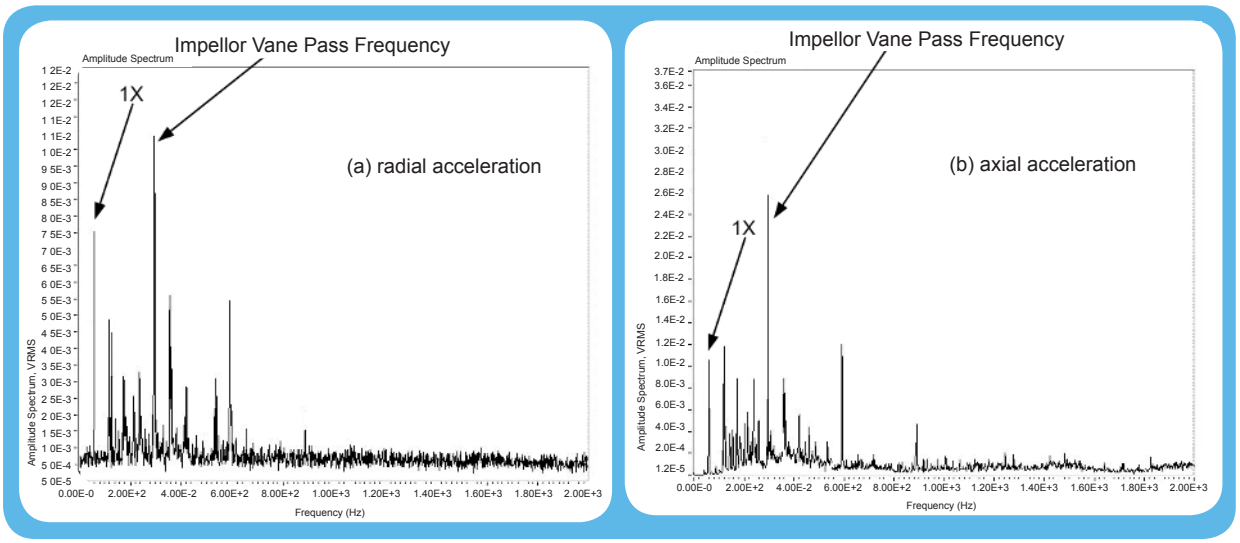


Figure 6 - Vibration Spectrum for Pump Speed 3588 RPM (without air bubble and extreme low suction head pressure).

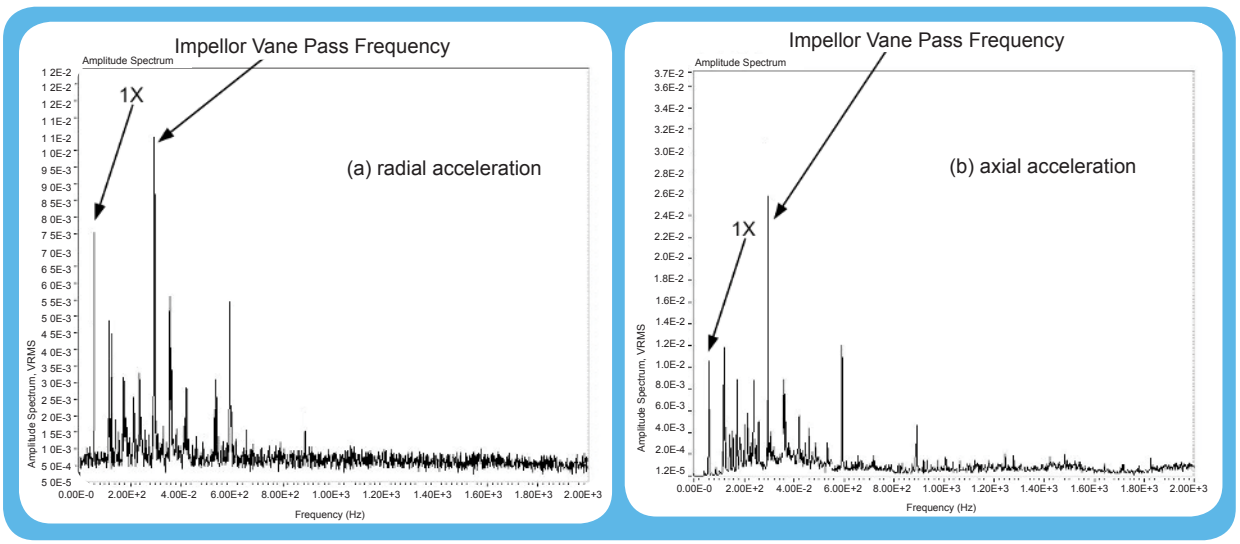


Figure 7 - Vibration Spectrum for Pump Speed 3590 RPM (with air bubble).

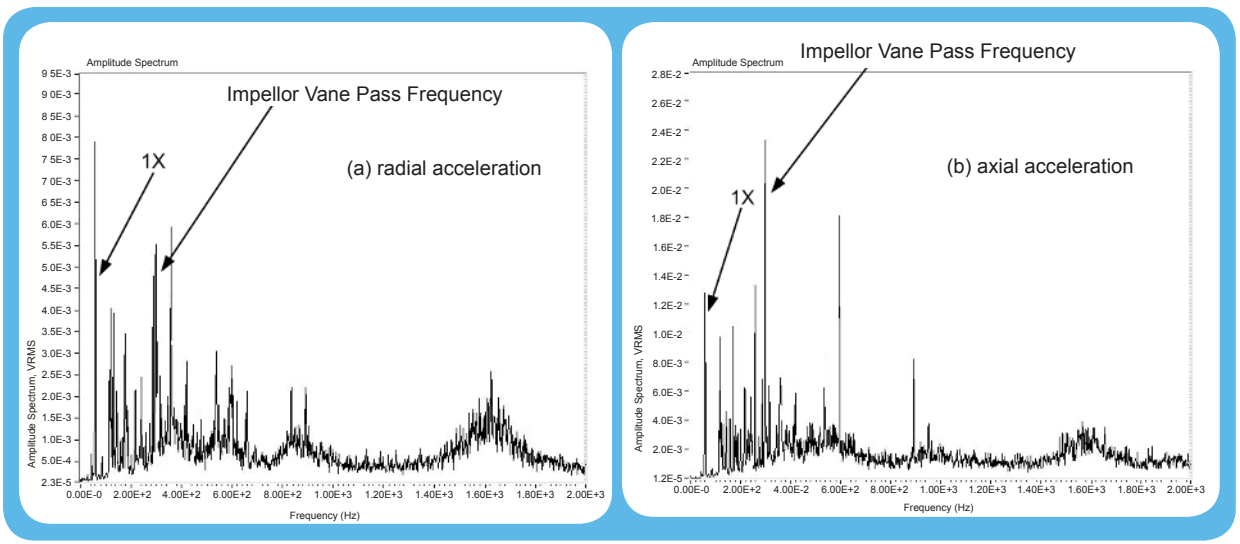


Figure 8 - Vibration Spectrum for Pump Speed 3595 RPM (with cavitation).

pass frequency harmonics also have high amplitude. A comparison of the amplitude of Figures 6(a) and (b) indicates that the pump has higher vibration in the axial direction.

The acceleration in the radial and axial directions is presented in Figure 7 for pump speed of 3590 rpm with a significant amount of air bubbles forming in the tank. A careful inspection of Figure 6(a) and Figure 7(a) indicates that with formation of air bubbles, the vibration component associated with impeller vane pass frequency increases significantly. The vibration amplitudes of 1X and its other harmonics components do not change much. A comparison of Figure 6(b) and Figure 7(b) suggests a similar trend. An examination of Figures 7(a) and (b) indicates a higher vibration level on the pump in the axial direction.

The suction head pressure was dropped below atmosphere pressure by approximately 20 inHg in the cavitation test for pump speed 3595 rpm. There is a great possibility that cavitation will appear under this condition.

The acceleration in the radial and axial directions is presented in Figure 8 for pump speed of 3595 rpm with cavitation forming in the pump. Because there is not a significant amount of air bubbles forming during the cavitation test, a comparison of Figures 8 and 6 is appropriate. A careful inspection of Figures 6(a) and 8(a) indicates

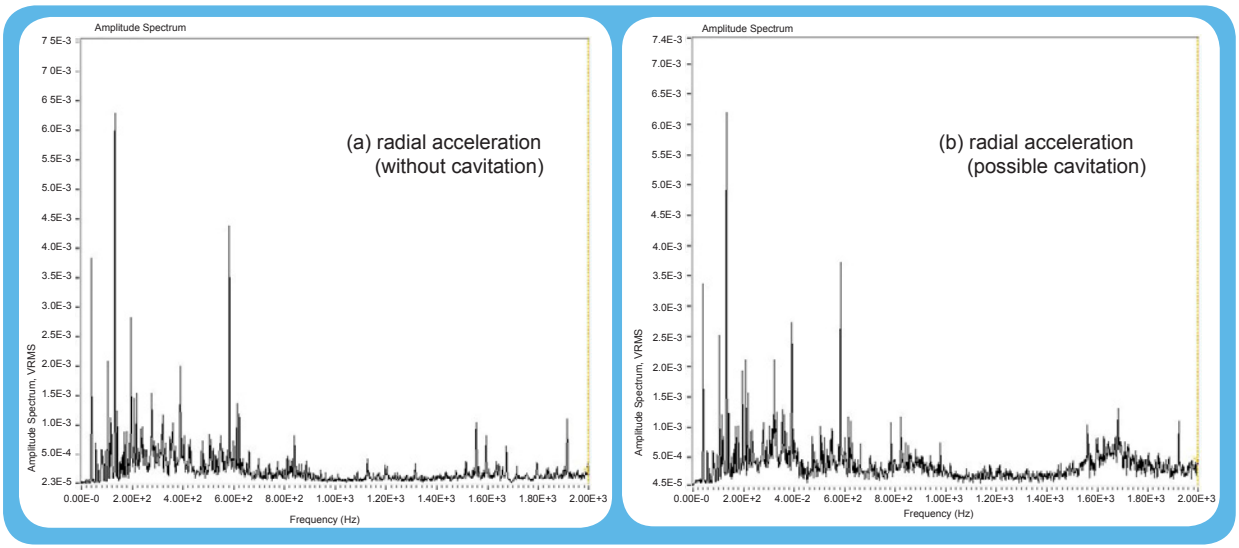


Figure 9 - Vibration Spectrum for Pump Speed around 2400 RPM.

that there is a frequency component around 1600 Hz emerging in the cavitation signal. In Figure 6(a), the background noise has an almost constant level, which does not show in Figure 8(a). The 1X and its harmonics components have similar amplitude levels in Figure 6(a) and Figure 8(a). A comparison of Figure 6(b) and Figure 8(b) has the same conclusions.

The pump speed was reduced to around 2400 rpm. The suction head pressure was dropped below atmosphere pressure by approximately 15 inHg in the cavitation test. Again, there is a possibility that cavitation will appear under this condition.

The acceleration in the radial direction is presented in Figure 9 for pump speed around 2400 rpm. Figure 9(a) presents the data spectrum for pump speed 2355 rpm without cavitation. Figure 9(b) presents the data spectrum for pump speed 2360 rpm with a possibility of cavitation. Similar to the cavitation case with pump speed around 3600 rpm, there is a vibration component around 1700 Hz for the case with cavitation possibilities.

The pump speed was then reduced further to around 1200 rpm. By turning the tank discharge valve to restrict the flow rate, the suction head pressure could be dropped below atmosphere pressure by approximately 5 inHg in the cavitation test. The pressure drop could not be increased further because of the low pump speed. It is not likely that cavitation will happen.

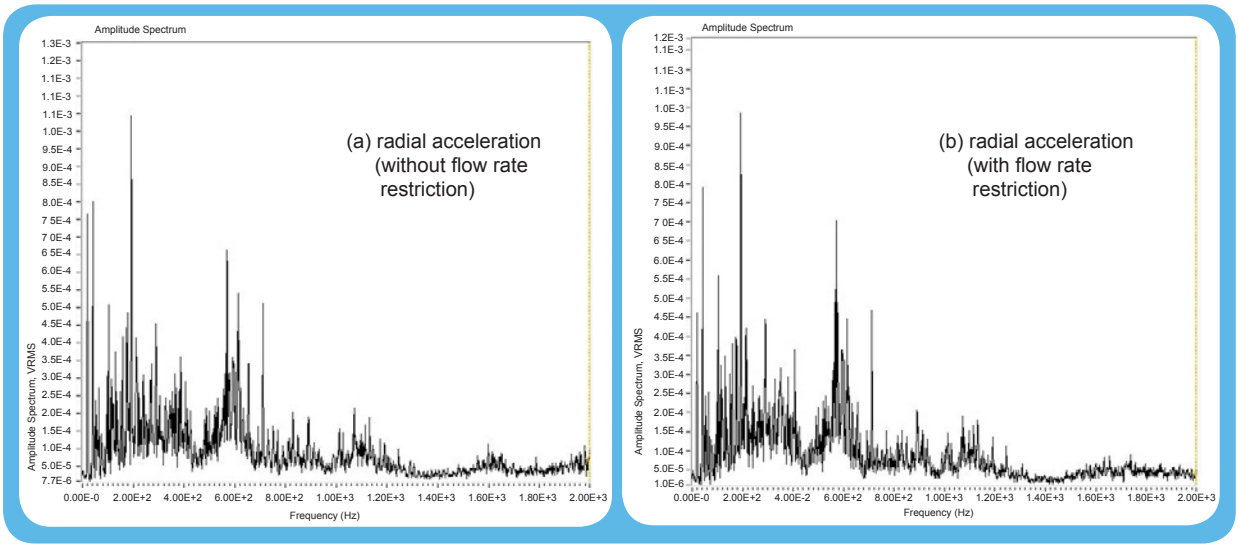


Figure 10 - Vibration Spectrum for Pump Speed around 1200 RPM.

The acceleration in the radial direction is presented in Figure 10 for pump speed around 1200 rpm. Figure 10(a) presents the data spectrum for pump speed 1166 rpm without flow rate restriction. Figure 10(b) presents the data spectrum for the same pump speed with a flow rate restriction. As expected, there is no significant difference between Figures 10(a) and (b).

Brass Cover Experiments

Experiments were performed at different speeds at three tank discharge valve positions. The pump suction head and discharge pressures were read for all operating conditions. The complete pressure data is shown in Table 1.

Pump RPM	Valve position	Pump Head Pressure (inHg)	Pump Discharge Pressure (psi)
3600	Full open	-5	14~15 (depends on air bubble)
	Cavitation appears	-13	13
	Severe cavitation	-20	9
3000	Full open	-4	11
	Cavitation appears	-20	5.5
	Severe cavitation	-21	3.5
2400	Full open	-2.5	8
	Cavitation appears	-18	3
	Further valve closing will cut water off		
1800	Full open	-1.5	5
	No cavitation can be generated		

Table 1 - Pump Pressure

From Table 1, it can be found that the $NPSH_{available}$ and pump discharge pressure are all increasing with pump speed. Another observation from Table 1 and the experiments is that the NPSH range from the appearance of cavitation to fully developed severe cavitation is also increasing with an increase in pump speed. For example, for pump speed 3600 rpm, the NPSH for cavitation appearance is -13 inHg, while the NPSH for severe cavitation is -20 inHg. It has a 7 inHg pressure difference. For pump speed of 3000 rpm, the NPSH for cavitation appearance is -20 inHg, the NPSH for severe cavitation is -21 inHg. The pressure difference is only 1 inHg. Moreover, for pump speed 2400 rpm, the cavitation appears at -18 inHg NPSH, and the cavitation develops into severe cavitation very quickly. This observation indicates that, although it is less likely for a slow speed pump to have the problem of cavitation, if cavitation does start, it will develop quickly into a severe condition.

Figure 11 illustrates the vibration spectra in radial and axial directions, respectively, for pump speed 3619 rpm with the tank dis-

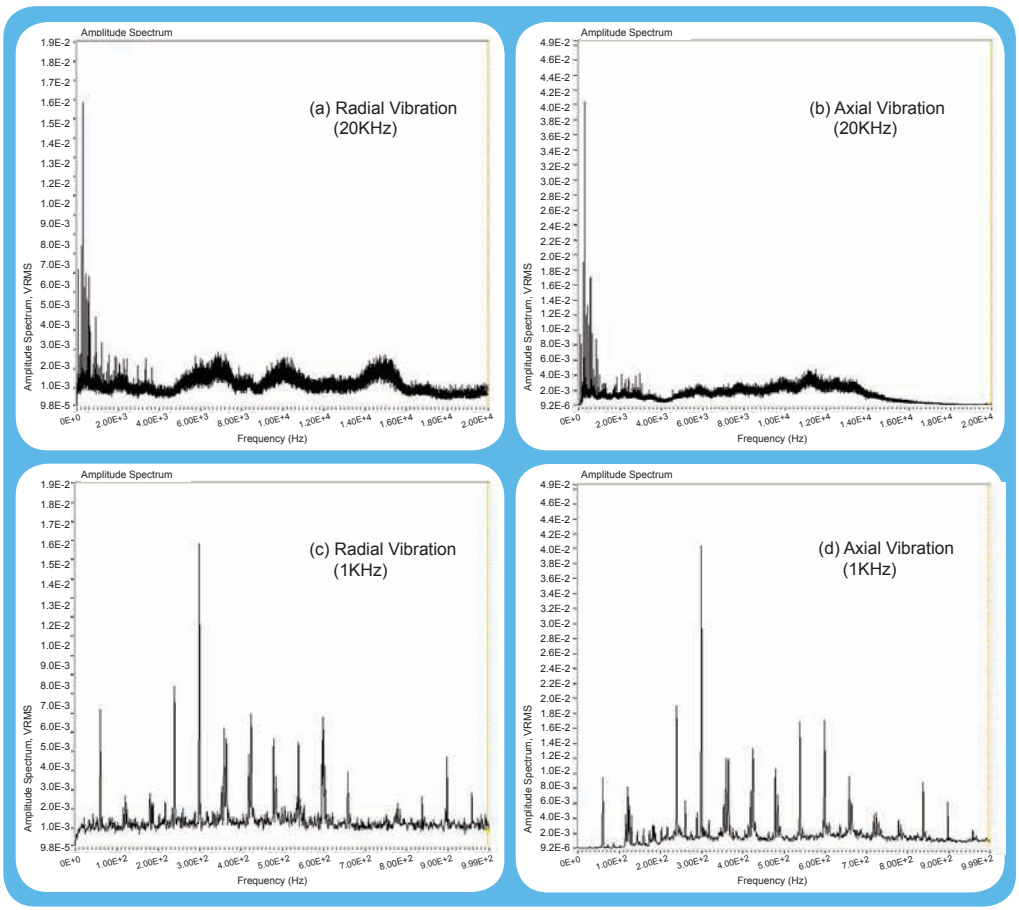
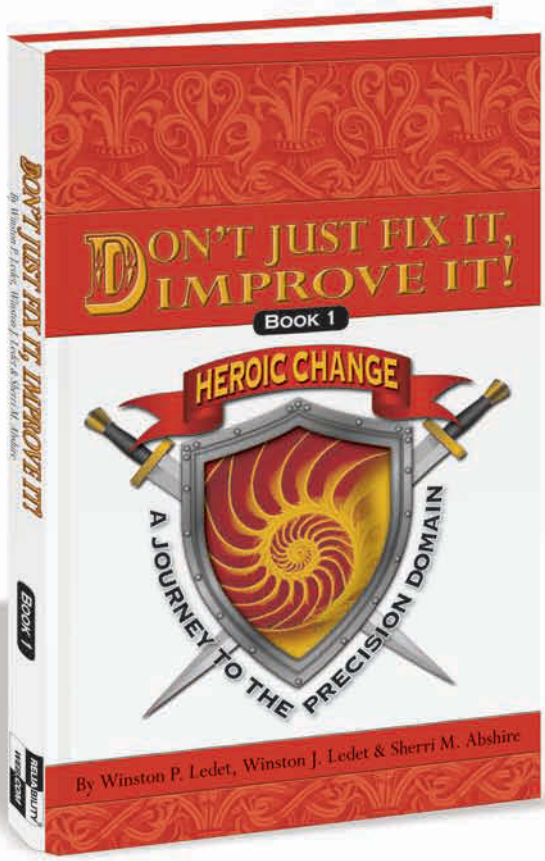


Figure 11 - Pump Vibration with Tank Discharge Valve Fully Open (3619 RPM)



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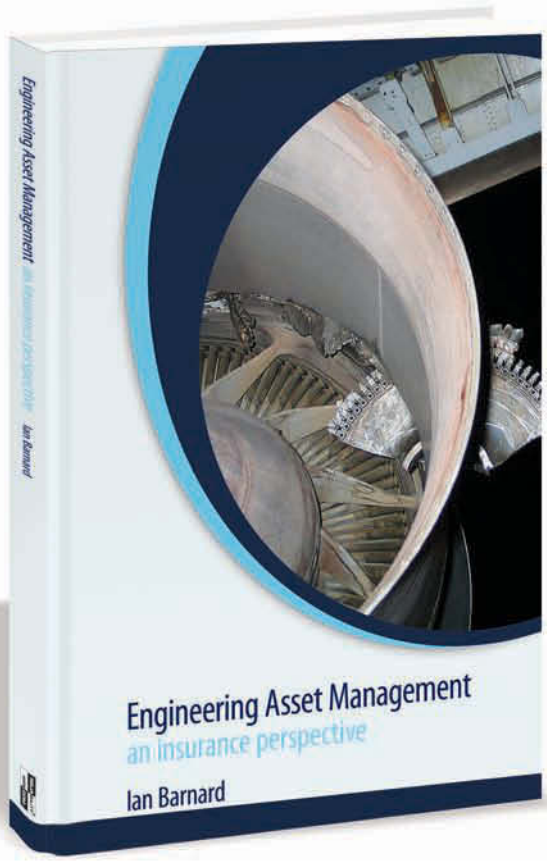

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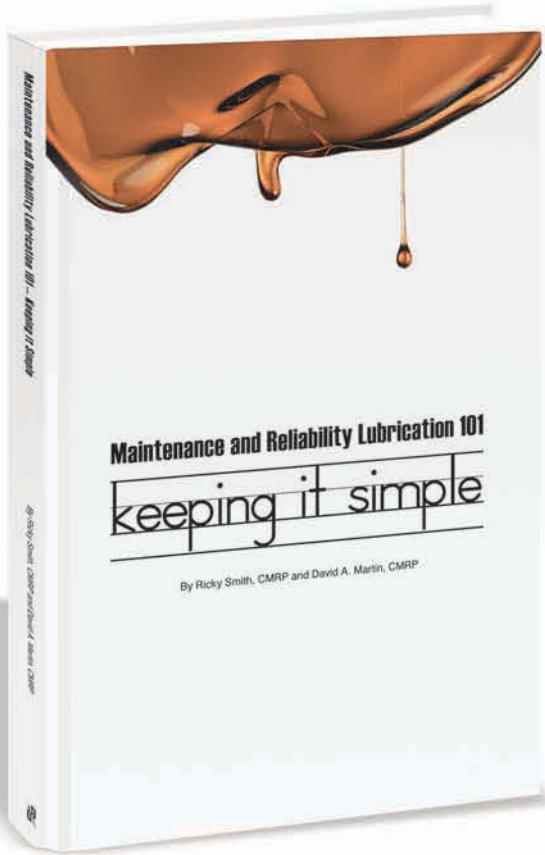

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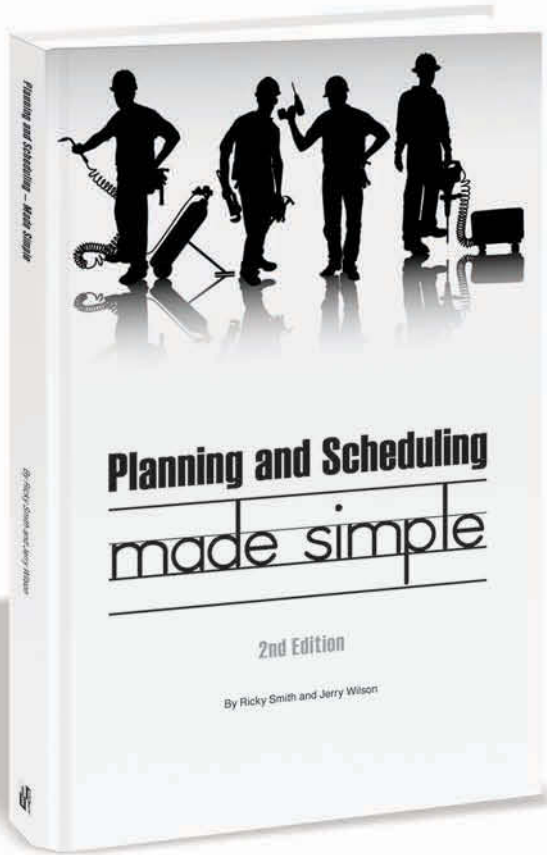

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charge valve fully open and without air bubbles. Figures 11(a) and (b) present the spectrum of pump radial and axial vibration with 20 KHz frequency limit respectively. Figures 11(c) and (d) display the same spectra in the 1 KHz frequency range.

Figure 12 illustrates the vibration spectra in radial and axial directions, respectively, for pump speed 3616 rpm with the appearance of cavitation. Figures 12(a) and (b) present the spectrum of pump radial and axial vibration with 20 KHz frequency limit, respectively. Figures 12(c) and (d) display the same spectra in the 1 KHz frequency range.

Comparing the corresponding subfigures in Figure 12 and Figure 11, Figure 12(a) and Figure 11(a) have the largest difference. In Figure 12(a), there are several peaks emerging around 6 KHz with the characteristics of structural resonance.

Figure 13 illustrates the vibration spectra in radial and axial directions respectively for pump speed 3617 rpm with severe cavitation. Figures 13(a) and (b) present the spectrum of pump radial and axial vibration with 20 KHz frequency limit, respectively. Figures 13(c) and (d) display the same spectra in the 1 KHz frequency range.

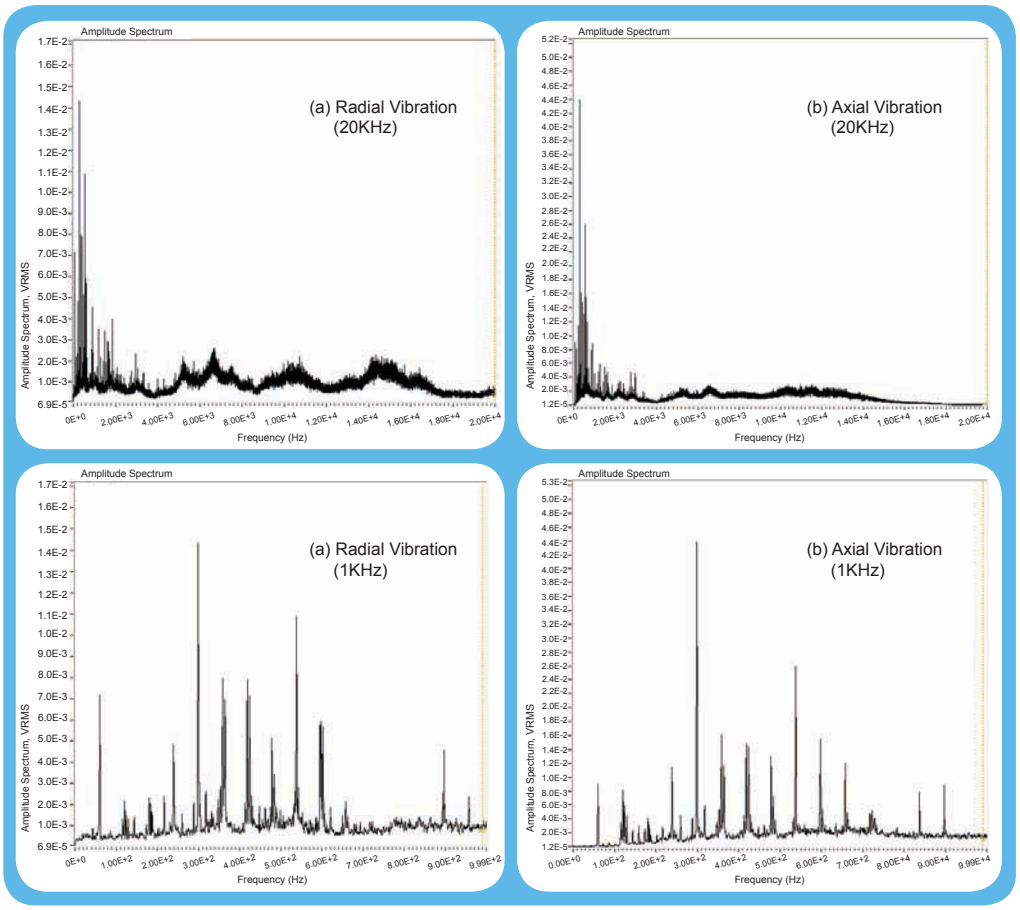

Figure 12 - Pump Vibration with Appearance of Cavitation (3616 RPM)

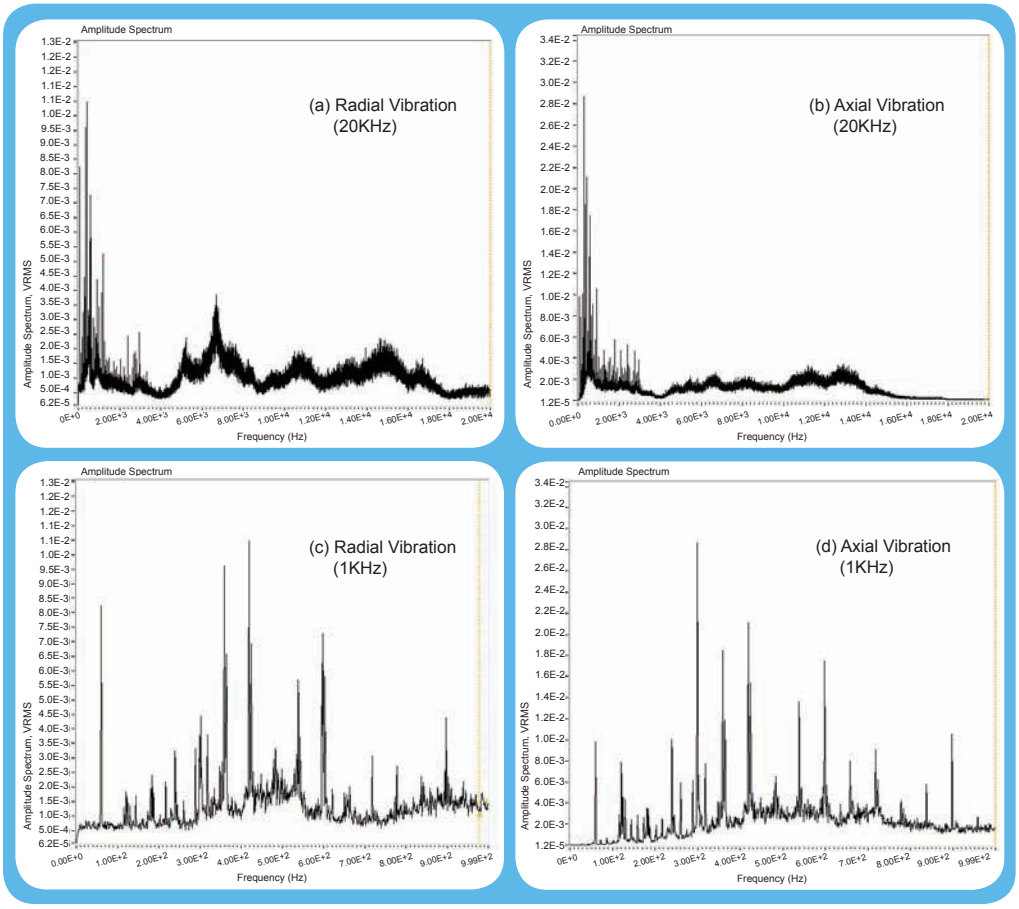

Figure 13 - Pump Vibration with Severe Cavitation (3617 RPM)

In Figure 13(a), the peaks emerging around 6 KHz with the characteristics of structural resonance are clearer. An inspection of Figure 13(c) indicates that the amplitude of the vibration component with impeller vane pass frequency (the fifth harmonic of 1X) has decreased significantly. However, this phenomenon does not appear for the pump axial vibration. The vane pass frequency vibration is still strong, as illustrated in Figure 13(d).

Figure 14, on the following page, illustrates the vibration spectra in radial and axial directions respectively for pump speed 3007 rpm with the tank discharge valve fully open and without air bubble.

Figure 15, on the following page, illustrates the vibration spectra in radial and axial directions respectively for pump speed 3010 rpm with the appearance of cavitation. Figures 15(a) and (b) present the spectrum of

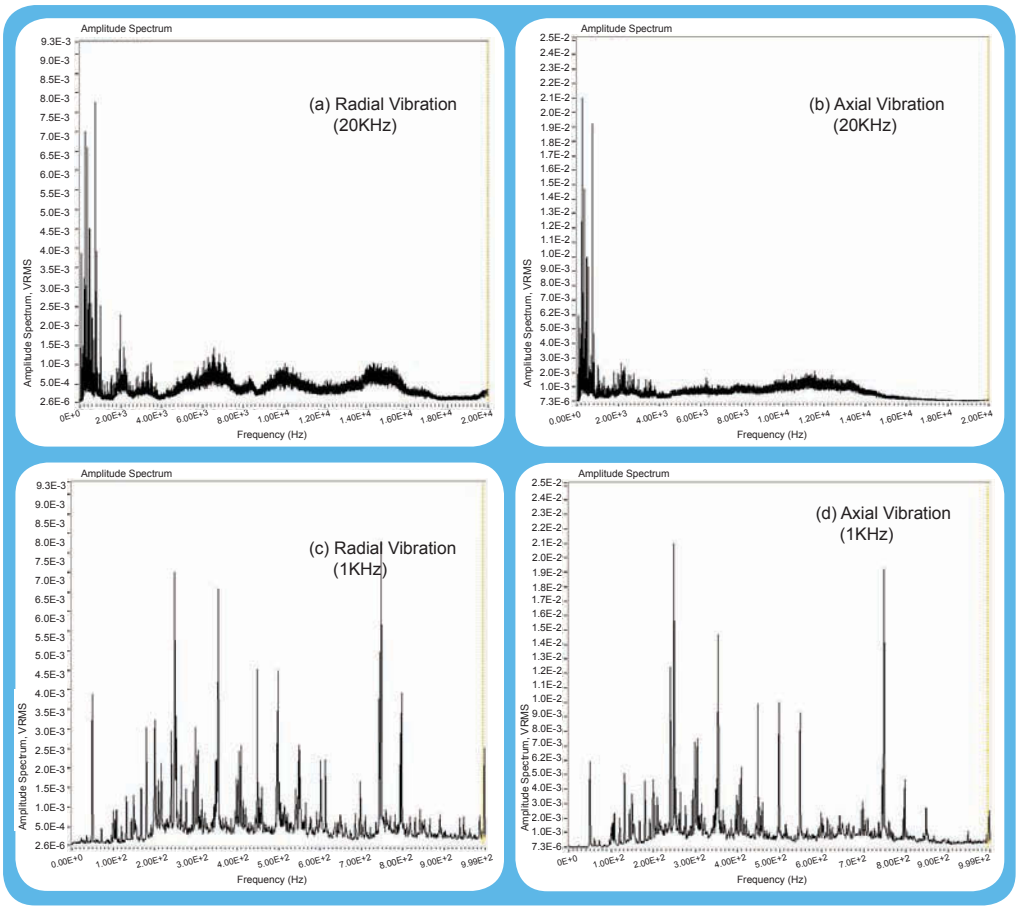

Figure 14 - Pump Vibration with Tank Discharge Valve Full Open (3007 RPM)

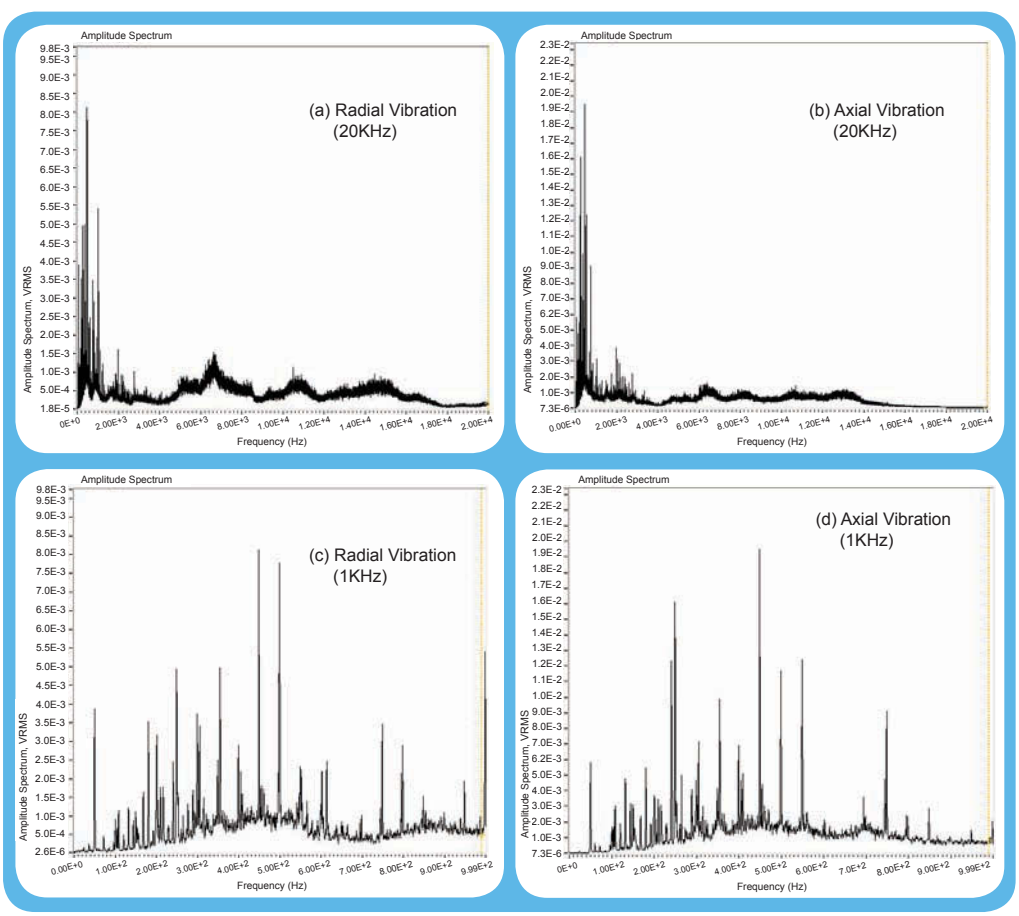

Figure 15 - Pump Vibration with the Appearance of Cavitation (3010 RPM).

pump radial and axial vibration with 20 KHz frequency limit respectively. Figures 15(c) and (d) display the same spectra in the 1 KHz frequency range.

Figure 16, on page 59, illustrates the vibration spectra in radial and axial directions respectively for pump speed 3010 rpm with severe cavitation. Figures 16(a) and (b) present the spectrum of pump radial and axial vibration with 20 KHz frequency limit respectively. Figures 16(c) and (d) display the same spectra in the 1 KHz frequency range.

Summary

In this work, a single stage centrifugal pump was tested for its vibration signatures for different operational conditions. Pump vibration was measured in the radial and axial directions by accelerometers. The pump was running under three different speeds, 3600 rpm, 2400 rpm and 1200 rpm. Air bubbles, caused by the impacting of returning water with the water inside the tank, were observed under pump speed of 3600 rpm. Cavitation was created intentionally by closing the tank discharge valve somewhat to drop the $NPSH_{available}$ below $NPSH_{required}$.

Several observations can be made tentatively based on the experiments.

1. The centrifugal pump has higher vibration amplitude in the axial direction than in the radial direction.

2. A significant amount of air bubbles will greatly increase vibration component associated with impeller vane pass greatly.

3. Cavitation might excite high frequency structural resonances.

4. Cavitation might decrease impeller vane pass frequency vibration.

5. While cavitation is less likely to happen in slow speed pumps, it will develop very fast if it happens.

Dr. Lin Liu has published extensively on machinery health monitoring and prognostics/diagnostics. He is also an expert

in the finite element analysis of aerospace structures, crack propagation simulation and modeling in gearboxes, and helicopter structural analysis. He has authored over twenty technotes at SpectraQuest and numerous research articles in peer reviewed journals and proceedings. Lin obtained a Ph.D. degree in Aerospace Engineering from the University of Maryland at College Station, Maryland.

Dr. Suri Ganeriwala is founder/president of Spectra Quest, Inc. He has over twenty-five years of industrial and academic experience in machinery vibration diagnostics and control, signal processing, and visco-elastic materials characterization. Suri has developed a unique method of instruction using the Spectra Quest Machinery Fault Simulator (MFS), which is his brainchild from concept to completion. He has authored over thirty papers and articles in journals, magazines, and books. He obtained a Ph.D. in Mechanical Engineering from the University of Texas at Austin. Suri can be reached at suri@spectraquest.com or (804) 261-3300.

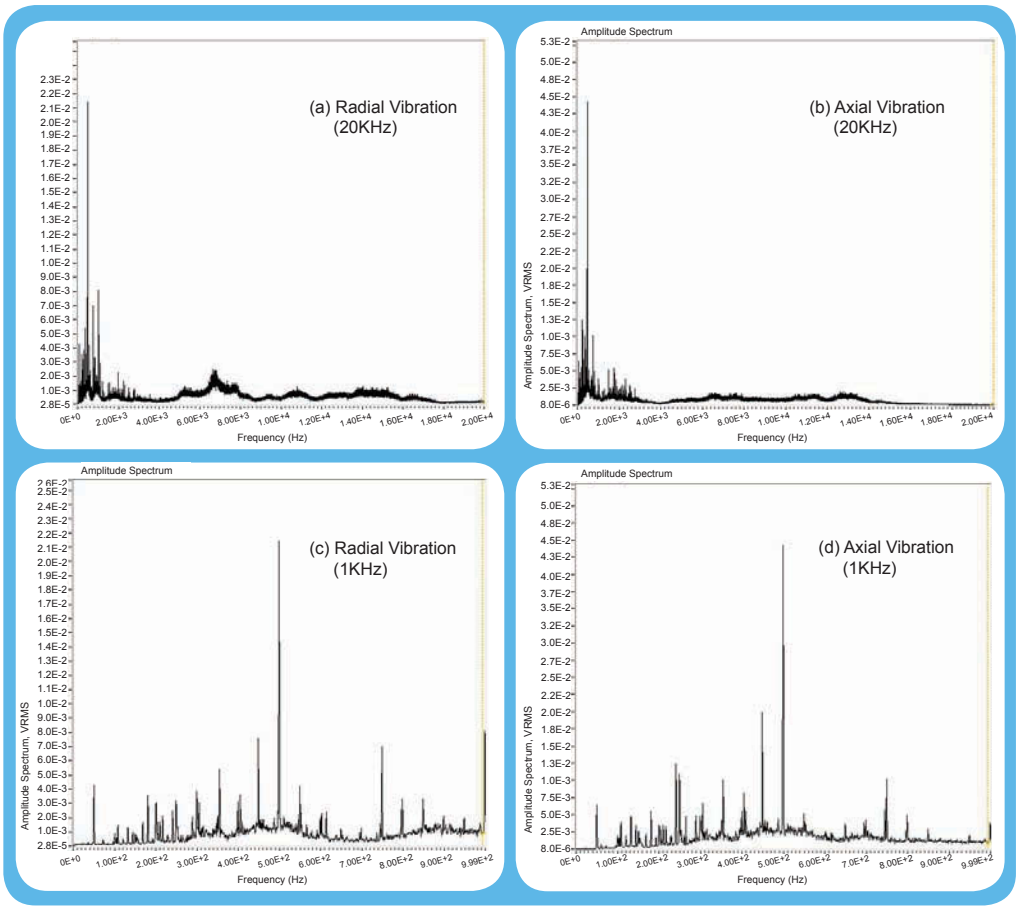

Figure 16 - Pump Vibration with Severe Cavitation (3010 RPM)

Could you benefit from real-time measurement of the condition of your oil? Imagine a product that could report oil's condition continuously to tell you exactly the right time to change it. No more wasted oil, time or money. That would be nice, right? Well let's talk about the...

IntelliStick

Let's face it, you save time and money when you know the condition of your equipment's oil, especially when the info gets to you in real-time. IntelliStick delivers vital oil information quickly, and can be used in both fixed industrial assets and mobile assets. IntelliStick immediately identifies problems in your lubrication, allowing you to move from reactive, crisis-based repairs to proactive, cost-saving condition-based maintenance.

We caught up with Sam Jones, the Business Development Director for IntelliStick at his office in sunny (but unseasonably cool) California, and asked him to give us more detail on this game-changing product. Here is what Sam told us...

Let's start with you giving us an idea of the difference that real time oil condition can make to a company that chooses to use it.

Three words...immediacy, intrusion detection, and productivity. OK, that's four words, but it's also not the end of the list.

IntelliStick is a low cost, single-sensor, multi-function instrument that alarms on intrusion, transmits temperature, and monitors oil condition. Oil sample analysis reports are important, but are often used after-the-fact and/or seen days later. IntelliStick operates in real time.

Immediacy also means you have current condition insight even when the equipment is not easily accessible or is remotely located. The industrial IntelliStick analyzer uses a threaded sensor or a dipstick-style sensor and communicates with plant equipment monitoring systems via RS-232, RS-485 or optional 4-20mA.

IntelliStick makes products that can provide real time oil condition for a variety of assets. Why don't you give us an overview of what types of equipment your products can cover?

IntelliStick operates in-plant or in the field to help protect the lubrication systems of industrial stationary equipment and engines, power generators, turbines, and gearboxes. IntelliStick also works aboard on-road and off-road vehicles, HD trucks, fleets and other crucial operating equipment.

So, tell us what IntelliStick actually is and what is does...

OK, IntelliStick products are based on a patented technology originally developed in university research for the US military to easily and continuously monitor oil wear package depletion, oil oxidation, and detect intrusion.

A typical installation of IntelliStick oil condition monitoring system on a fixed asset.

IntelliStick is a condition-based maintenance tool to avoid catastrophic equipment downtime, reduce repair/replacement costs and extend equipment life. And, depending on the application, other benefits include increased fuel efficiency, environmentally friendly oil drains and disposal (not too soon; not too late), and reduced reliance on outside oil analysis.

Now to how IntelliStick works... The IntelliStick system uses a patented sensor technology that electrically stimulates the oil at a particular low voltage and frequency to obtain the greatest response from both additives and oxidation by-products in the oil. The reading is obtained by measuring the overall conductivity of the oil and compensating for variations in the temperature of the oil.

What does it do? Well, for industrial applications, the instrument continuously samples and monitors the oil while the equipment is operating;

scans for water, coolant or fuel intrusion; expresses oil condition over operating hours; identifies emulsion contamination with an alarm; and reports fluid temperature. Data and immediate alarms are output from the device by way of communications protocol options.

The IntelliStick Industrial Analyzer communicates by RS-232, RS-485, or optionally 4-20 mA.

And what exactly is it capable of measuring?

Well, the IntelliStick makes three primary measurements:

Measurement 1: Contamination / Emulsion. The IntelliStick sensor has two measurement arrays that are used together to detect harmful amounts of water or coolant. The fine array spacing is sensitive to an emulsion of water in concentrations as low as 200ppm, and to certain coolant additives such as glycol in higher concentrations.

Measurement 2: Temperature Compensated Conductance (TCC). A voltametric measurement—measured from the second, coarse array—responds to both oil additives and oxidation by-products. Temperature compensation is applied to this reading.

Measurement 3: Fluid Temperature. IntelliStick operates in a range of 100 to 350 F with an accuracy of +/- 5 F

In the Industrial device, several auxiliary data values can also be returned: Oil Loss Alarm, Emulsion Alarm, Oil Temperature Alarm, and Fault Alarm. These alarms may be set to specific parameters base on the individual installation and client needs.

I can think of many industries that would benefit. What industries have been early adopters of IntelliStick real time oil condition products?

Industries where heavy equipment and large vehicles are mission-critical benefit from IntelliStick. Continuous production or process manufacturing industries are at the top of the list. They want immediate problem detection in order to keep up and running, and to protect and extend the operating integrity of their equipment.

The Recycled Paperboard Technical Association (RPTA), Energy, Engineering and Maintenance Task Force, took an early leadership position and was the first industry group to evaluate the IntelliStick intrusion and oil condition system. The system detected potentially damaging water in oil on a number of occasions, demonstrating IntelliStick is a cost-effective and easily installed tool for paper mill maintenance engineers and supervisors.

What kind of impact do you think the IntelliStick can have on overall machinery reliability?

These days industrial machinery is expected to operate at maximum capacity, efficiency and uptime. The impact of IntelliStick sensor systems has, and continues to be, as a management tool for condition-based practices, in cost-effective planning of predictive and preventive maintenance and labor deployment, and in equipment performance and reliability assessment.

What are the three top reasons a company should consider using the IntelliStick?

The cost-to-value ratio is excellent. The cost of the instrument is significantly less than that of other online oil condition instruments and in-plant analysis equipment. IntelliStick protects, preserves and extends vital equipment where repairs, rebuilds and/or replacements are extremely expensive.

IntelliStick combines several functions into one instrument. Many industrial sensor systems require a separate instrument for individual tasks. The IntelliStick device monitors and reports several conditions concurrently, and at a lower cost than several single-purpose instruments.

The Return-on-Investment is fast. Because IntelliStick delivers a favorable cost-to-value ratio, multiple features set—the investment is low and the payback is quick. The temperature measurement feature alone has significant value for monitoring equipment condition.

What is time frame a company can expect for a return on their investment in IntelliStick equipment?

ROI is typically measured in weeks, but in one instance, an IntelliStick device more than paid for itself on the first day by detecting water in new equipment that was just being brought online.

The Threaded Sensor can be fitted into a threaded port on an oil reservoir or an oil line.

IntelliStick enables increased productivity and uptime, supports efficient maintenance planning, and guards against costly breakdowns, rebuilds and/or equipment replacement. In hard dollars and in savings, it's a rapid ROI.

Would you give us a success story or two from companies that are using IntelliStick now?

The IntelliStick Pilot Program with the recycled paper industry included several companies with mills located in different parts of the country, and with instruments installed in bearing lubrication systems, pulper gearbox, and generator engine oil reservoirs.

In this harsh environment, the IntelliStick system proved to be relatively inexpensive and easy to install. In addition, the evaluation concludes that the system is cost-effective in providing information for condition based maintenance programs, helping protect critical equipment and assure maximum uptime. Since the completion of the trial, all of the participating mills have purchased more units.

Other conclusions from the Pilot Program include:

- The industrial IntelliStick instrument reliably detects water intrusion in a mill environment.
- IntelliStick systems help assure maximum plant up-time, protect equipment investment, and facilitate condition-based maintenance programs.
- IntelliStick real-time data is useful in establishing oil change patterns.
- The device provides immediate information without waiting for lab analysis results. The IntelliStick system is not a replacement for lab analysis, but it may be possible to reduce the frequency of lab testing.
- Its use will facilitate or greatly enhance a real-time condition-based maintenance program.

A complete report about this Pilot Program is available upon request.

How can interested people get more information about the line of IntelliStick products?

IntelliStick product information for industrial and vehicle information—including specifications and Industry Pilot Program Report—is available by calling IntelliStick at 949-955-2721, Extension 221; by e-mail to Sam Jones, sljones@intellistick.com, or online at www.intellistick.com

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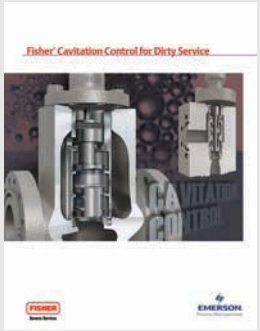
Emerson has published a new brochure that describes Fisher® cavitation control for dirty service applications. The brochure introduces four Fisher technologies that can be used in severe liquid flow conditions. They include the Notch-FloTM DST control valve, Dirty Service Trim (DST), DST-G control valve, and 461 angle valve. Cutaway images and product data are included in the brochure. For a free copy of the brochure contact a local Emerson Process Management sales office and request D351830X012 or go to http://www.documentation.emersonprocess.com/groups/public/documents/brochures/d351830x012.pdf



Meggitt Sensing Systems, the makers of Wilcoxon Research vibration sensors and sensor networks, has added three new accelerometers with M12 connectors to its product line. The M12 connector makes it easy to implement vibration monitoring where the existing infrastructure is already built around the M12 standard, such as the process industries. Several compatible M12 connector-cable assemblies are also now available. Meggitt's new M12-style accelerometers are 100 mV/g general purpose vibration sensors, all with excellent sensitivity tolerance and an acceleration range of 80g.

To learn more about Meggitt Sensing System's Wilcoxon Research M12-connector sensors and cable assemblies, visit http://www.wilcoxon.com/knowdesk/M12%20sensors%20and%20cables%20information.pdf.

800-WILCOXON www.wilcoxon.com
wilcoxon@meggitt.com

Henkel Corporation has introduced two new Loctite® threadlockers formulated to withstand consistent operating temperatures up to 360°F. Curing consistently and thoroughly without cleaning, these new products tolerate the oils and lubricants typically found on "as received" threaded fasteners. These products will also cure on plated, aluminum, stainless and chromated fasteners without primers. Loctite® 243™ and Loctite® 263™ prevent fastener loosening caused by shock, vibration and temperature-induced expansion and contraction. Loctite® 243™ is a blue, medium-strength, thixotropic liquid threadlocker that can be disassembled using standard hand tools. Loctite® 263™ is a red, high-strength, thixotropic threadlocker for applications where permanent assembly is required.

www.useloctite.com For Technical Assistance 1-800-LOCTITE (562-8483)

SKF offers the Multilog On-line System DMx, a multi-featured vibration monitor for both conventional and hazardous environments. Awarded ATEX, IECEx, and cULus certifications, the DMx monitoring system can be directly installed within a hazardous area, removing or reducing cabling, cabinets and isolation barriers, and ultimately saving time and money during installation. The SKF Multilog DMx system combines protection (to help avoid catastrophic failures) and condition monitoring functionality in a single device, making it ideal for monitoring critical machinery such as gas turbines, generator sets, motors, pumps and compressors in the Hydrocarbon Processing Industry (HPI), Power Generation industry and other applications.

For more info, visit www.skf.com/cm

What's Next in Maintenance and Reliability?

We Want to Know... So We Can Let Our Readers Know

Uptime Magazine and Reliabilityweb.com want to know about your new and innovative products and services designed to improve the Reliability and Maintenance community.

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Send information about your product or service to:

upgrade@uptimemagazine.com

We will publicize any and all worthy offerings throughout our information network, where it will reach over 50,000 maintenance professionals worldwide. And who knows? We may highlight your offering with a double page spread in Uptime's Upgrade Section as our Featured Product.

Sherborne Sensors announces their release of the AccuStar® electronic clinometer, designed to provide precision angular measurements within applications where a high degree of accuracy is required. AccuStar's unique design incorporates a capacitance-based sensor without moving parts. When rotated about its sensitive axis, this sensor provides a fundamentally linear variation in capacitance, which is electronically converted into high-precision angular data. Available in choice of analog, ratiometric, digital or serial models, the AccuStar® electric clinometer offers a ±60° measurement range, outputting a signal that corresponds to the direction and magnitude of angular displacement. The compact AccuStar® measures two inches (50 mm) in diameter and weighs just two ounces (60 grams) for easy installation, with units designed to reliably operate in temperatures of -30 to +65°C. For more info, visit www.sherbornesensors.com

US & Canada - 1-877-486-1766 nasales@sherbornesensors.com
Worldwide - +44 (0) 870 444 0728 sales@sherbornesensors.com

UE Systems Ultraprobe® 3,000 Can Now Demonstrate Cost and Carbon Footprint Reduction

The UE Systems Ultraprobe 3,000 ultrasonic detection system is an important tool to help cut energy waste and reduce the plant's carbon footprint. The 3000 has been labeled a "green" instrument for its ability to accurately detect energy waste. UE Systems designed the 3000 to significantly impact energy conservation by locating compressed air and steam trap leaks as well as faulty steam traps, which can lead to millions of dollars in energy waste. Using UE Systems data management software (DMS), plant technicians can download data from a leak survey, and in real-time, generate reports that demonstrate loss and existing carbon footprint, as well as cost reduction and energy savings.

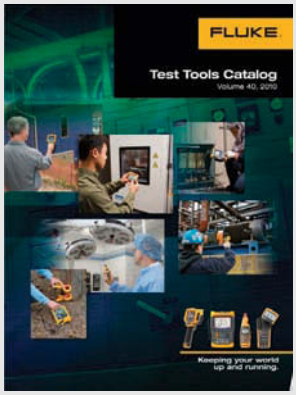
For further info: www.uesystems.com
Alan Bandes 914.592.1220 abandes@att.net

New Fluke test tool catalog now available in print and online
Sixty-four full-color pages cover the full Fluke lineup

EVERETT, Wash. – Fluke Corporation, the global leader in portable electronic test and measurement technology, has published its latest 2010 Fluke Test Tools Catalog. The full-color catalog is available online and in print.

This fully illustrated 64-page catalog opens with overview pages that connect the dots between common industrial and commercial equipment and the measurement tools needed to help maintain it. Focus areas include electrical, HVAC, mechanical, controls, general operations, building diagnostics, and energy management.

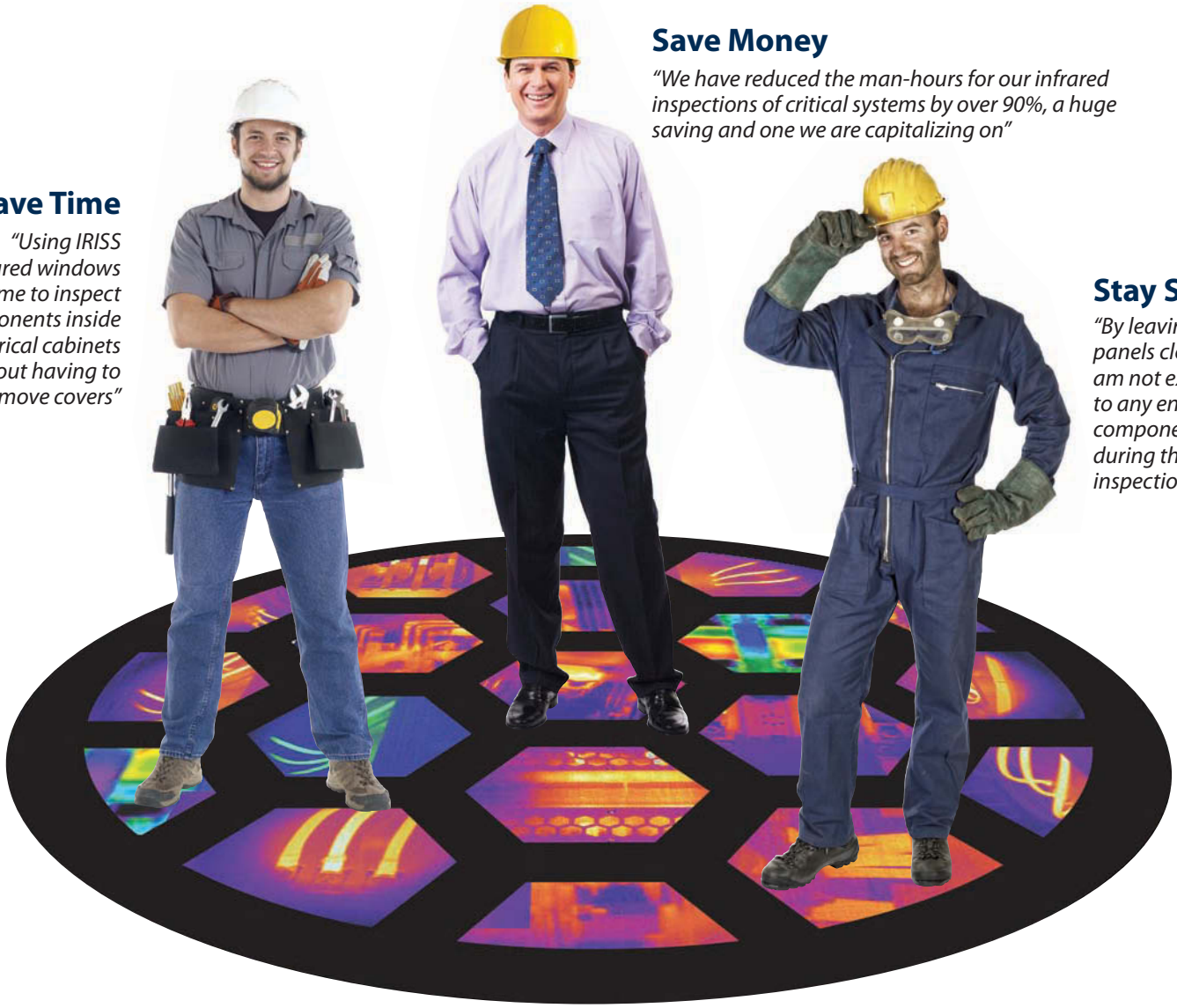
The Fluke catalog also features selection guides to help technicians differentiate by measurement or application area which of the various Fluke digital multimeters, power quality testers and analyzers, process tools and tool accessories will work best in their application.



The new Fluke catalog also includes special mention and full details on four groundbreaking new Fluke test instruments introduced in recent months: the Fluke 773 Milliamp Process Clamp Meter, the high-resolution Fluke Ti32 Thermal Imager, the ultra-durable Fluke 28 II Dustproof/Waterproof Digital Multimeter and the Fluke 233 Remote Display Multimeter.

To view the Fluke catalog online, visit the Fluke catalog home page. To order the printed catalog, just visit the Fluke Web site to register and to fill out the online order form.

IRISS... Your Window of Opportunity



Save Money

"We have reduced the man-hours for our infrared inspections of critical systems by over 90%, a huge saving and one we are capitalizing on"

Save Time

"Using IRISS Infrared windows allows me to inspect components inside electrical cabinets without having to remove covers"

Stay Safe

"By leaving the panels closed I am not exposed to any energized components during the infrared inspection"

Ease of Inspection

As there is no requirement to remove covers to allow access the inspection of critical assets in a matter of minutes "the time it takes to open an IR Window". It really doesn't get any easier than this!

Cost Savings

IRISS Infrared windows and ports are the most affordable products available today… combine these savings with the savings that you will make in man-hours and you will wonder why you waited so long to start your program!

Compliance

Infrared and ultrasound inspections are completed without exposing staff to energized components, thus allowing all inspections to be completed within the guidelines laid down by NFPA 70B and NFPA 70E.

Safety

Protect your staff and equipment. "Prevention is always better than cure" IRISS infrared windows and Ultrasound ports make sure that your staff are never exposed to energized components while completing inspections of critical assets.

Simple Installation

Installation of IRISS infrared windows and ports are simple, installation takes approximately 10 minutes and each one is supplied with cutting templates and fitting instructions.

Visit our website to get your **FREE** copy of our e-book . . .
"10 Things You Need to Know About Infrared Windows"

www.iriss.com

IRISS®

See What You've Been Missing!