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OCTOBER/NOVEMBER 2010

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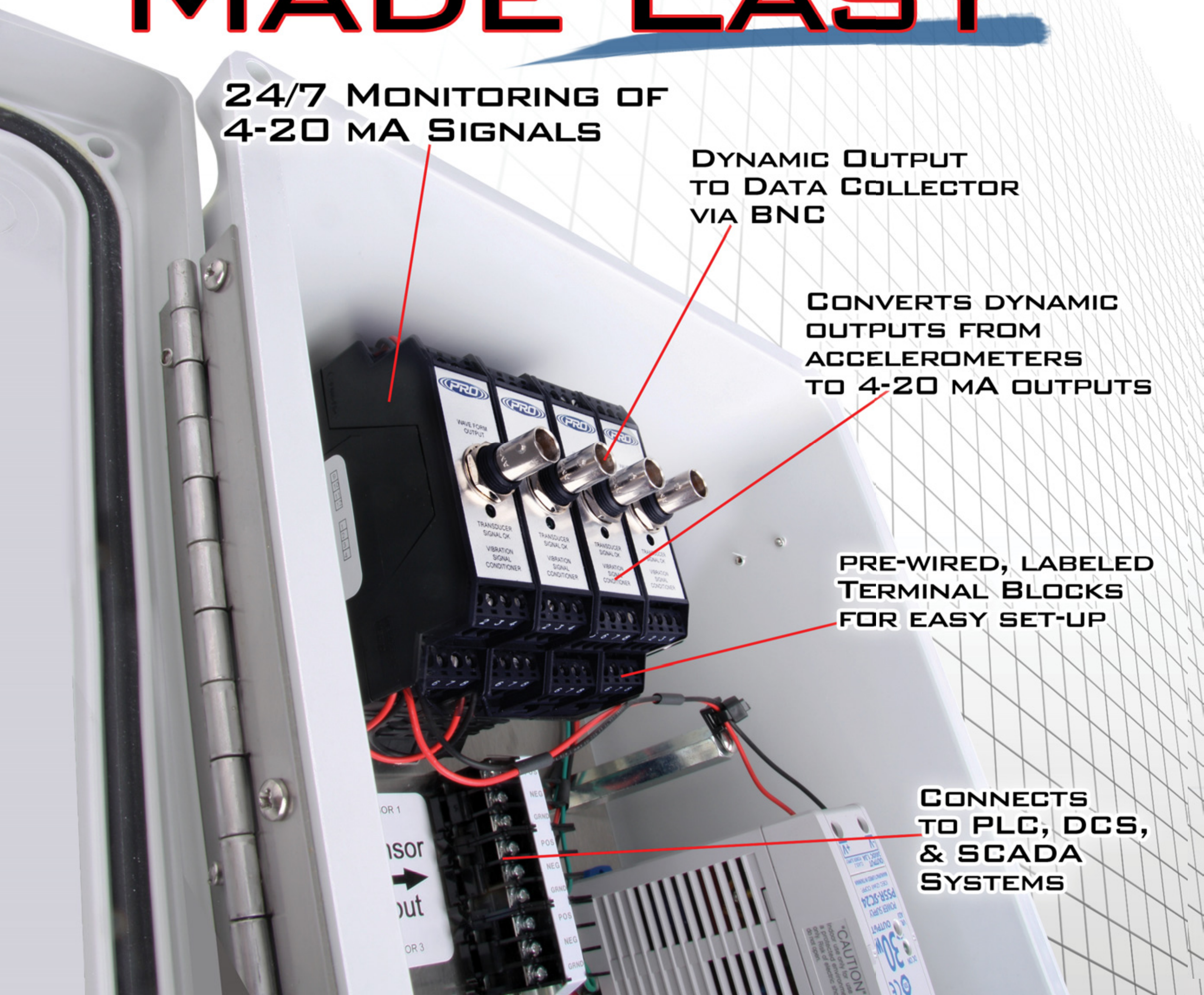

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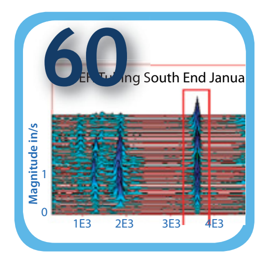

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Making RCM Work

Reliability Centered Maintenance (RCM) is an important topic in our industry. It is a process full of potential — potential for increasing reliability, increasing productivity, increasing throughput and increasing bottom line profits for any company that can successfully implement it.

Yet RCM is certainly not without controversy. There are several branches of RCM: Classical, RCM2, Streamlined, Blitz and many would include PM optimization too. There are those who say you have to go all in, Classical RCM or nothing at all. There are those who say any kind of RCM is better than no RCM at all.

I fall into the latter category, with one caveat. Whatever form of RCM you choose, it must be implemented well to be worth anything at all. So in this issue, we have chosen (for the first time since Uptime's start) to run two feature articles, both on RCM. We hope that they will give you a better understanding of RCM implementation, and that they help both organizations that haven't thought about implementing RCM and organizations that have thought about it, but haven't yet made the plunge.

There is a lot to know to get RCM right, and we hope these articles will help you on your way to reaping the massive benefits that RCM can provide.

We also want to congratulate the 2010 PdM Program of the Year award winners. Please see page 29 for a list of the winners. Their hard work to put together top performing PdM programs is truly an inspiration. My favorite time of the year is when we get to pour through the applications for the awards and see how many fantastic programs are out there and the positive results they are providing to their companies.

The competition is always stiff and there are many companies that applied and didn't win, yet deserve a big tip of our hats for the work they are performing. Thank you to all who entered the awards contest for sharing your journey to excellence with us.

The award ceremony will be held at Solutions 2.0 in Bonita Springs, FL on Nov 8th, and the winners will be presenting their stories throughout the conference (Nov 8th-11th). We hope you will join us at Solutions 2.0 for the ultimate maintenance and reliability conference of the year and perhaps to hear about the journeys that some PdM programs have made to become PdM Program of the Year winners.

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

EDITORIAL ADVISORS/
CONTRIBUTING EDITORS

Ron Eshleman
Terry Wiireman
Winston Ledet
Jack Nicholas, Jr.
Joel Levitt
James Hall
Heinz Bloch
Jay Lee, PhD
John Mitchell
Jason Tranter

ADVERTISING SALES
Bill Partipilo
888-575-1245 x 125
Intl 239-333-2500 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
Intl - 239-333-2500 x116
jshuler@uptimemagazine.com

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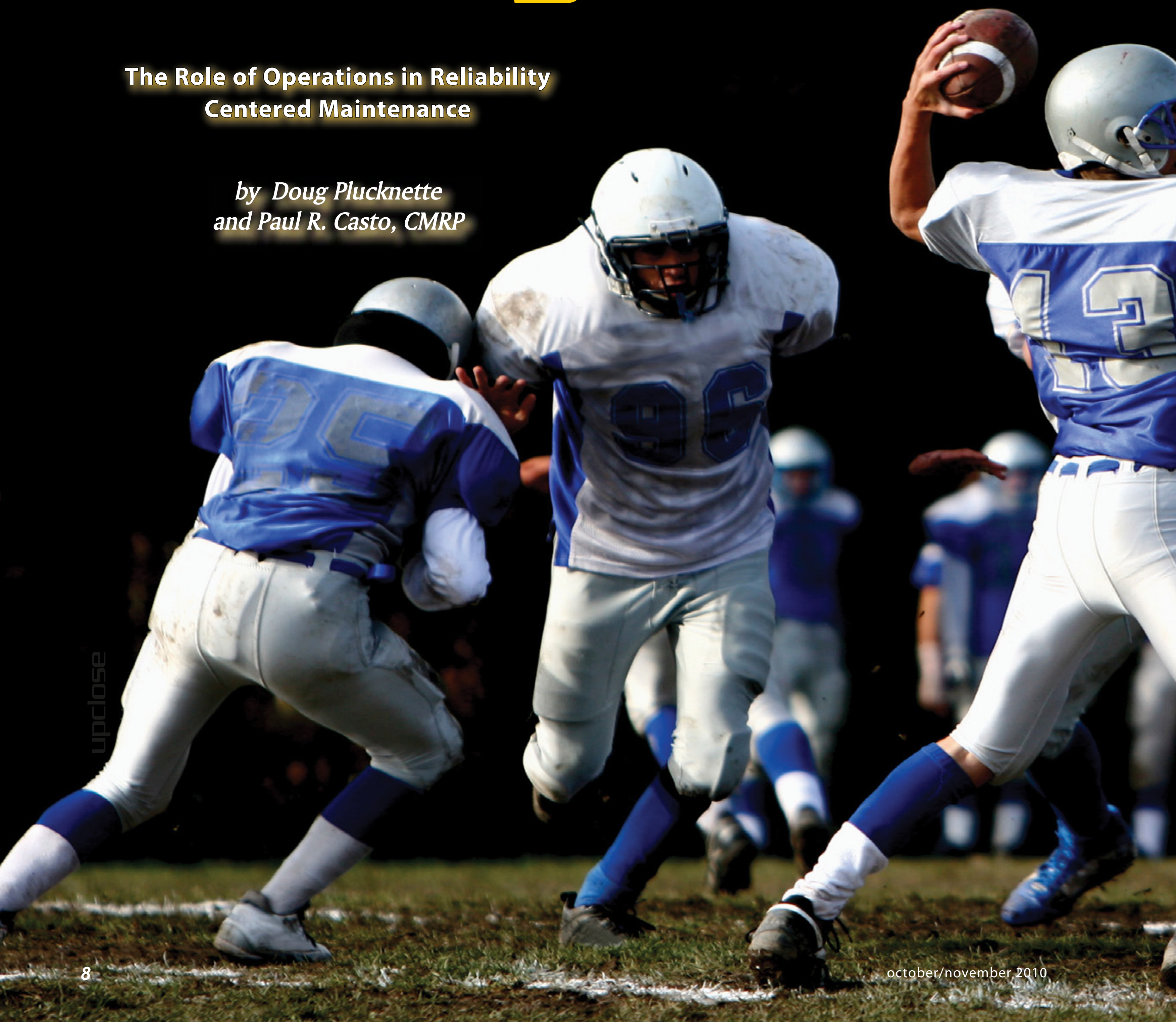
Missing a Key Player?

The Role of Operations in Reliability Centered Maintenance

by Doug Plucknette and Paul R. Casto, CMRP



In today's economic environment, where companies around the world are tightening their financial belts to decrease costs while assuring plant safety and environmental protection, the key performance indicators of equipment and process reliability have become an important area in which to focus initiatives. While some companies got an early start in building reliability programs, the vast majority are just now getting educated about the benefits that equipment and process reliability can bring to their business. Those who have worked in the field for years understand that the word "reliability" means more than just having equipment and processes that run when needed. Reliability has a direct effect on nearly every aspect of your business. Reliable equipment costs less to maintain, produces higher product quality, is more energy efficient, and most importantly, reliable equipment and processes suffer less health, safety, and environmental incidents.

One of the time-proven ways to improve equipment and process reliability is to perform a Reliability Centered Maintenance analysis (RCM) on your critical assets. Developed in the 1970s as a tool to build a complete equipment maintenance strategy for commercial aircraft, the RCM process has transformed how companies view and perform maintenance around the world. From food and beverage, to oil and gas, to pharmaceuticals, customers are learning the value that a thorough RCM analysis can bring to their business with results that have improved productivity by 27% while at the same time reduced maintenance costs by a similar amount.[1] The key results of an RCM analysis are failure mitigation tasks from which maintenance plans can be developed. RCM is a powerful tool that effectively integrates maintenance and reliability by focusing maintenance activities on four aspects of failure mitigation:

1. Elimination
2. Prevention
3. Prediction
4. Control (Plan to recover when an unexpected failure occurs)

One of the keys to getting the most from your RCM effort is having a cross-functional team that includes operations, maintenance, and reliability. It is imperative that these three groups work together closely, and develop a joint vision and strategy to address reliability issues. This strategy will include a holistic approach to failure mitigation and there will be spillover into improving work processes and communication channels. The team members representing these groups include: the tradespeople, process engineers, PdM (Predictive Maintenance) technicians, reliability engineers and the often overlooked equipment operators. Working together, this integrated team will provide a multifaceted perspective on the problem. By expanding the identification of failure modes and the corresponding failure mitigating tasks, a cross-functional team will develop a more robust solution than would a group that consists of only one specific work group. The integration of the operators into the RCM team will provide additional methods and expand the number of tasks available to address potential failures.

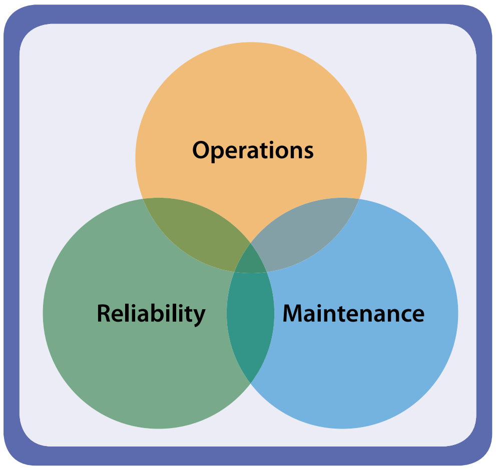


Figure 1 - Operations, Maintenance and Reliability must work together for any RCM effort to be successful.

The Role of Equipment Operator in RCM Analysis

Allied Reliability and Meridium have over 30 years of combined experience teaching and facilitating Reliability Centered Maintenance, and during these sessions the question instructors are most often asked is this: "The RCM process uses the word 'maintenance' and I'm an equipment operator. Why am I here?"

This question opens a critical discussion around Reliability Centered Maintenance: the importance in having operations deeply involved in the RCM process from start to finish. Simply stated, RCM does not achieve its full benefit without involving key operations people in the process. Completing an RCM analysis without having an experienced and respected equipment operator involved will always result in an incomplete listing of failure modes and poorly detailed failure effect statements that, if done correctly, could help determine the actual cause and mitigate the failure.

So, how important is the operator when it comes to performing an RCM analysis?

Well, our experience has proven that it's not a best practice to conduct an RCM analysis without an experienced equipment operator. If you're thinking your operations people are not important in helping to develop your equipment maintenance strategy, think again. They are not only important in helping to develop the strategy; your strategy is incomplete if the operator is not a part of your equipment maintenance plan!

Let's think of an introductory RCM meeting as a train. This is the point where we can metaphorically see the engineer/operator of our train reach over and apply the hand brake. Just as things were beginning to roll along quite smoothly, we are about to come to a complete and abrupt stop. While the question regarding why an equipment operator should be involved in the RCM process is the most popular, the question that is most feared comes next: "You don't really expect the operator to actually perform maintenance tasks, do you?"

The room falls silent, and while it is now clear that we all understand why we need to have operators involved in the RCM analysis, it is not clear at all why operators need to perform maintenance tasks. In fact, what is clear at this moment is that the operator is not keen on performing any maintenance. He/she is, after all, an equipment operator, not a maintenance technician. And, the maintenance people don't want the operator taking away any of their tasks because of the fear that giving up certain tasks could cost someone their job. Our train has now screeched to a halt, and it is at this point we begin to discuss some real-life examples of equipment operators who are involved in, and perform regular maintenance tasks.

The relevance of the operator in maintenance tasks can be illustrated by asking questions that the attendees can relate to: "Do you watch NASCAR? Who is the operator of the race car? Is he or she in any way involved in the maintenance of that car?"

These questions are usually answered with "the driver drives the car and the mechanics and pit crew maintain the car" but within a minute or two someone brings up the fact that the driver actually communicates several things to the race team throughout a race in regard to how the car is performing, and how it holds the track in and out of the turns. Could this information that is being passed from the operator to the race team be considered maintenance?

Here is another relevant example: "Have you ever flown on a jet for vacation or business? Who is the equipment operator of that jet? Does the pilot perform any maintenance tasks for his aircraft?"

This conversation is easy, as most everyone has seen the pilot walk around the aircraft and perform visual inspections of the equipment before the passengers board. Once the visual inspection is complete, the pilot and copilot work to complete the preflight procedures or checklists. Safety and reliability are extremely important to this industry, and as a result there are several items that need to be checked each time to ensure the aircraft is fit for operation. While the pilots are indeed the equipment operators, it is quite clear that they perform several important maintenance tasks each and every time they operate the equipment. The airline pilots also receive some very intensive training on how to start, operate, and shut down the aircraft along with detailed instructions and training on how to handle and address critical component failures.

Types of Failure Modes Often Overlooked When Operators Are Not Included on the RCM Team

The reality of why equipment operators need to be part of your RCM effort comes down to the identification of failure modes. While your maintenance mechanics and engineers can typically do a thorough job at identifying the mechanical and electrical failure modes associated with the components within your system, they will fall short in identifying the process-related failure modes that the operators deal with and experience in the day-to-day operation of your equipment. While we would like to believe that most of our equipment is automated and controlled through a PLC, the reality is that we often rely on the operator's training and experience in starting, operating, and shutting down the equipment and performing equipment and product changes. In reviewing failure modes identified through the typical RCM analysis, 28% of the failure modes identified address failures resulting from how we operate our assets. Equally important, these failures are often the most frequent in occurrence. Without the participation of the operator, these important failure modes would surely be overlooked and continue to impact the reliability of your assets.

The Value Operators Bring in Writing Good Failure Effect Statements

An important aspect of every analysis is identifying and recording the failure effects that result from each failure mode. It is through the failure effects that we determine the consequence to our business should the failure occur. While our maintenance and engineering team members are well suited to identify the effects the failure will have on the component or part being analyzed, they often struggle to identify the effect each failure has on our overall process. Each failure-effect statement should include the following information:

- Events that lead up to the failure for wear-based components/parts and components/parts that have a useful P-F interval.
- First sign of evidence that the failure has occurred. This is where in most cases, the operator will be able to identify the alarm that results from the failure or the indication they receive that failure has occurred.
- The secondary effects or damage that results from the failure mode. While, again, our maintenance people will do an outstanding job of identifying the mechanical and electrical collateral damage, we will need to rely on the operator's experience to identify how the process is affected.
- Events required to bring the process back to normal operating condition. While in most cases, some may consider this to be a simple statement about shutting down, troubleshooting, and replacing or repairing a part, we will again rely on the operator to identify critical effects regarding how to best avoid secondary damage that could result from improper shut down following the failure.

With a well-written failure-effect statement, we look for one more piece of critical information to help determine the consequence of the failure mode: the downtime that results from the failure mode. This data is best determined by the operator's input with regard to how long it takes from the time the failure occurs and the equipment is shut down to the time the process is restored to normal operating condition again.

The Role of Operators in Sound RCM Task Decisions

As the team moves forward to identify mitigating tasks, the operator will again play a key role in helping to identify operator-care tasks, as well as tasks that can be performed by the operators during equipment start-up and shutdown, product changes, and daily rounds. Experienced operators are also valuable in the development of tasks associated with process monitoring or process verification, including control logic changes and process data trending, as well as warning and shutdown alarms. Process verification is one of the most cost-effective and reliable forms of PdM. By using the PLC to monitor, trend, and alarm key process variables such as pressure, temperature, flow, amp draw, and vibration, the system essentially becomes a condition-based monitoring tool—while your equipment is running. Our statistics show that nearly 50% of process verification tasks are identified by the operators participating on the RCM team.

As time moves forward and technologies improve, the role and involvement of operators in the effort to continuously improve equipment reliability will surely increase. Innovations in handheld data loggers over the last 10 years have made it simple to develop precise operator rounds where critical pressures, temperatures, and conditions can be entered for trending as well as immediate feedback.

The Role of Operators in Implementing RCM Mitigation Tasks

Operators provide a unique opportunity to add significant amounts of content to the proactive maintenance work process. Operators know the operating parameters of their processes and equipment and recognize when it isn't running correctly. As mentioned earlier, using this knowledge in building failure-based maintenance plans will result in sound RCM tasks. Many of these tasks will be proactive inspections which can be integrated into operator rounds (inspections). These inspection tasks utilize the operator's senses and knowledge base to detect process disturbances and equipment problems that are much harder to capture using sensor technology. Due to the

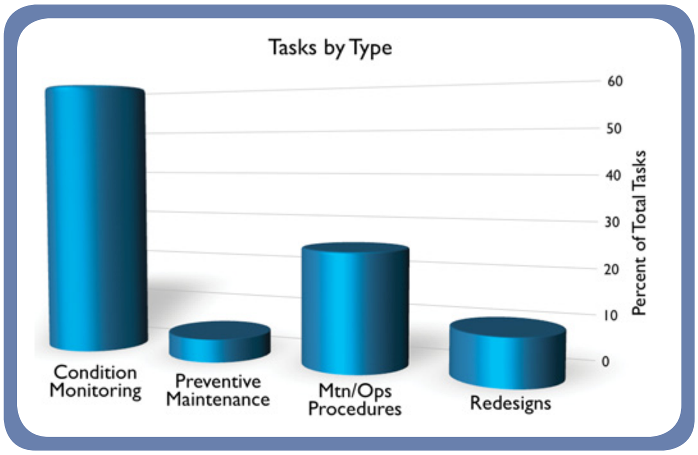


Figure 2 - Tasks by Type

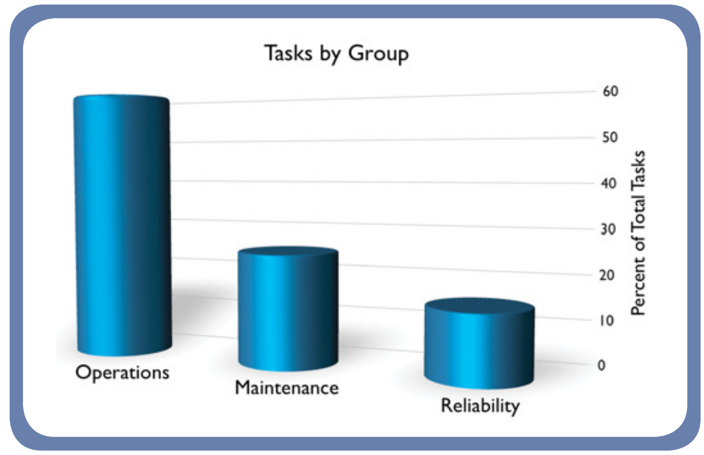


Figure 3 - Tasks by Group

capture using sensor technology. 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.

A key to the effective use of this mitigation strategy is the use of handheld technology to enable the inspection work process. Using this technology the operator can efficiently perform the inspections identified in the RCM analysis. Where abnormalities are seen, he/she can input information to create alarms, which provide the basis for actions to be taken prior to the onset of performance degradation and equipment damage. The effectiveness of this strategy is leveraged by seamlessly linking the operator findings (alarms) into the maintenance work management systems. The work process may create work requests directly through an Asset Performance Management (APM) system, or there may be an intermediate step where the alarm is reviewed before a work request is processed. This enablement technology, linking the output of the RCM analysis to the work management system, is a distinguishing feature of advanced RCM systems.

Results of Operator Development of RCM Tasks

The inclusion of the operators into the development of the failure mitigating tasks can have a dramatic effect on the makeup of the proactive maintenance plan. A breakdown of proactive tasks by task type is shown in Figure 2.[2] This plot suggests that 60% of the tasks resulting from failure modes analysis (the heart of RCM) are proactive in nature. Figure 3[3] indicates that 60% of the resulting tasks belong to operations, indicating if operations were not included in the failure mode analysis and development of RCM task decisions that 60% of the proactive maintenance tasks may not have been included in the maintenance plan. Further, much of the content is specifically focused on proactive tasks—a significant upgrade to the overall quality of the maintenance plan which will be manifested in the results realized from execution of the plan.

Importance of Integrated Information Flow in RCM

The ability to obtain key information concerning operations, failures, failure modes, PMs, etc. is important in the RCM process. This ability to get information directly impacts the productivity of the RCM team. By way of example, consider that each piece of critical equipment will have a work history, failure information, maintenance tasks, etc.—helpful information in the RCM analysis. In addition, there is condition monitoring data, preventive maintenance data, process data and operator inspection data, which can provide insight into identifying effective failure mitigation tasks.

The overall information flow supporting the RCM process is the centerpiece to improving efficiency. Further, the ability to access this information from a single portal, which also contains the RCM analysis, will improve docu-

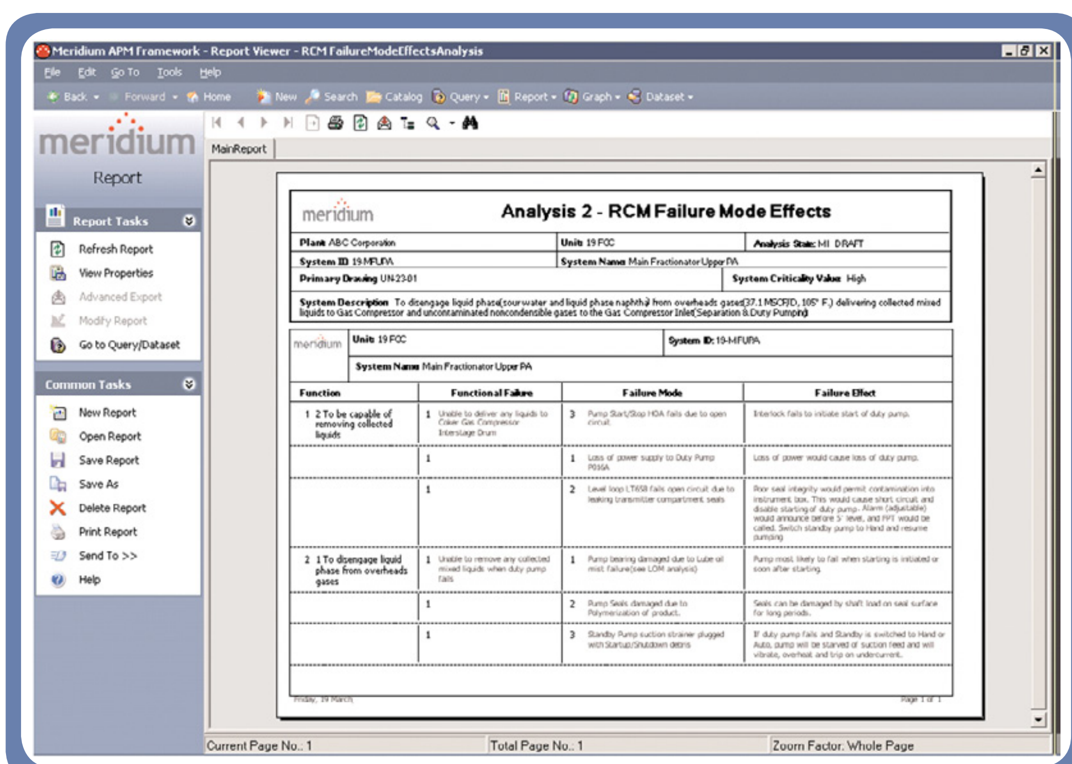


Figure 4 - A single portal integrating RCM information from a number of sources will increase productivity and efficiency.

mentation and the ability to review/upgrade the RCM results in the future. The information of interest to the RCM team comes from a disparate number of sources. As can be seen in Figure 4, an RCM platform which integrates this information provides the RCM team with the tools to improve their productivity significantly.

Expanding the Role of Operations to Leverage the RCM Process

RCM is an elegant and proven process that addresses failure modes by identifying causes and developing mitigation tasks. Earlier it was pointed out that such systems could improve productivity up to 27%. While this return is impressive, consideration should be given to how to leverage these results further. Implementation of the RCM process can be disruptive to the workforce, as it will introduce many changes to their daily work patterns and processes. Therefore an area to consider to further leverage the RCM process is leadership. There is a need for strong leadership to help the workforce manage the disruption introduced by a new and proactive maintenance approach until the new processes become integrated into the fabric of everyday work life.

Operations is uniquely positioned to have a significant impact on the success of a program by leading this change, and a key part of this effort will involve communication. It is generally accepted that, with a significant change in the work processes, communication is critical—there can never be too much communication during change. The operators on the team are in a position to greatly impact the success of the RCM effort through positive influence of their peer group. Through communication of team activities, ensuring stakeholder involvement and improving work processes, the powerful RCM solution can be leveraged to deliver much more value.

The operator(s) chosen for the RCM team should not only be knowledgeable of equipment failures, but also have the ability to influence their peer group. This ability is important to the communication process, vetting operator routes, creating short-term wins, and making the changes sustainable. The operators will be the interface point between the crews and the RCM team to:

1. Communicate activities, strategies, and progress of the RCM team.
2. Manage all crew interface such as meetings, presentations, and demonstrations.
3. Demonstrate operator routes and duties, get feedback on them, and optimize the proactive tasks based on peer feedback.
4. Report progress, performance (measures) and status to crews.
5. Manage the stakeholders' acceptance, involvement and support of the RCM change through interaction with the operators, coordinators, and maintenance.
6. Provide an important link to the long-term sustainability of the program.

All of these activities are, in one way or another, related to communication. Of these steps, one of the most important is stakeholder management. The operator will know the personnel, culture, and needs of their peer group. He/she will also be uniquely positioned to support sustainability. The sustainability of the program must be addressed as a first step in the project and will require a focus on the work processes between groups, especially the interface points between maintenance and operations. Ineffi-

cient work processes cause communications problems between groups which result in ineffective actions, wasted resources, and interpersonal problems, as well as further degradation of communications and a downward spiral in the ability to sustain the process. Operators can play a key role in overcoming these roadblocks to sustainability.

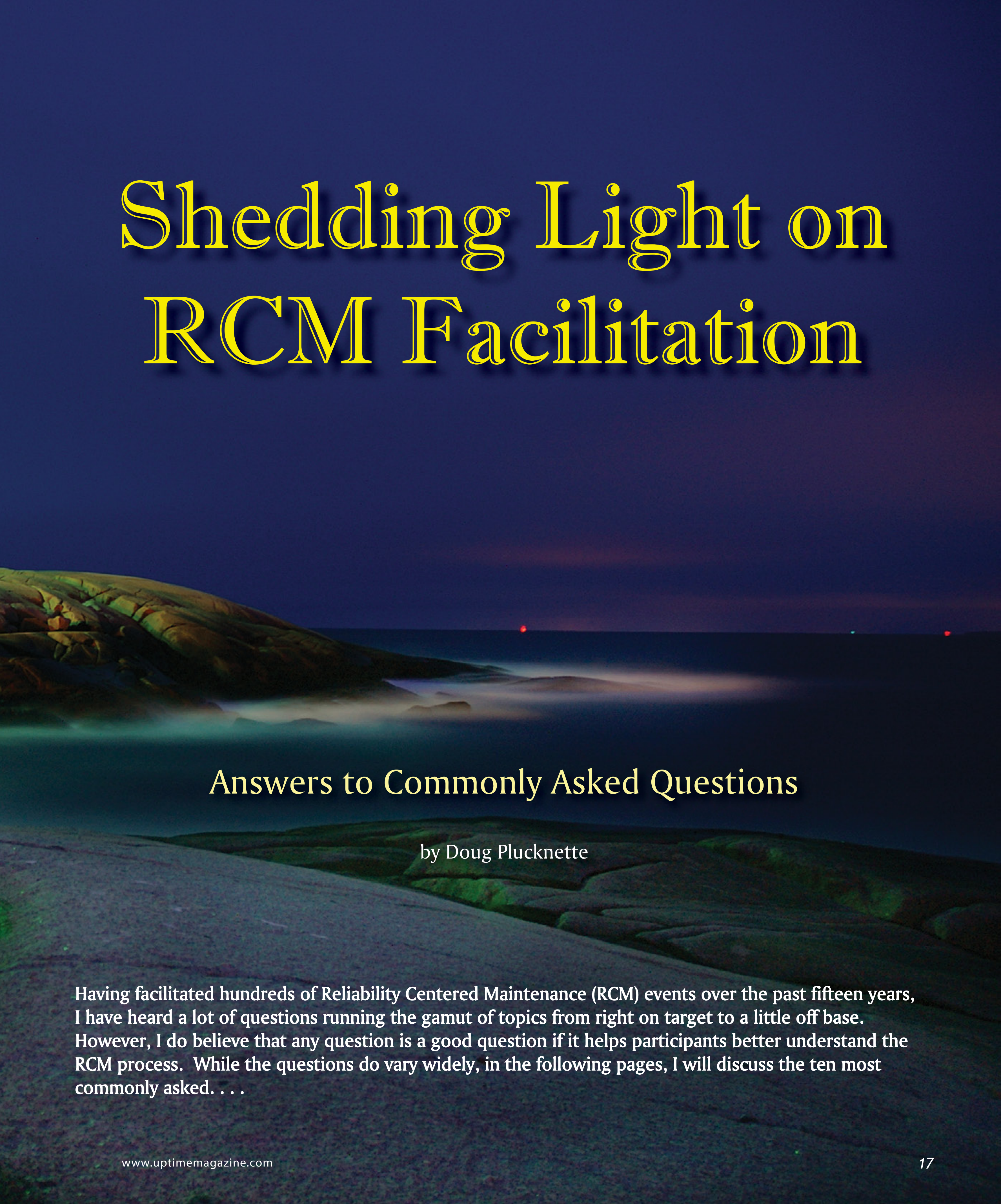
Conclusions

Many reliability and maintenance solutions have been implemented in manufacturing plants in recent years with varied success. The RCM process is a robust technical solution that has proven it delivers significant value in many applications. Technology and information flow must be viewed as a work process enabler, and as a necessary step to execute failure-driven maintenance strategies efficiently. Through improved information management, integration of work processes, and leadership in the change process, the technical solution can be leveraged to deliver significantly more value than a stand-alone technical implementation. The results of this approach have proven to far exceed those that are seen from many traditional R&M programs. In addition, the ability to leverage the technical solution through communication and management of key stakeholders has been discussed. This approach will provide higher returns, faster implementation and is key in the sustainability of the RCM program.

Douglas Plucknette is the creator of the RCM Blitz™ method, author of the book Reliability Centered Maintenance – Using RCM Blitz™ and RCM Discipline Leader for GPAllied. Well-known on the conference and lecture circuit, Doug has over 30 years experience in the field of maintenance and reliability. Over the past 15 years, Doug has facilitated hundreds of RCM analyses and trained certified RCM Blitz™ Facilitators for companies around the world.

Paul Casto is Vice President of Value Implementation at Meridium, Inc. Paul is a leading practitioner in reliability and maintenance improvement methodologies with a focus on helping Meridium clients with value creation and realization. He gained hands-on manufacturing plant experience in reliability, maintenance, operations, engineering, and construction in a variety of industries including chemical, steel, aluminum, automotive, mining, aerospace, and consumer goods. Before joining Meridium, Paul served as the Manager of Reliability Technology for Eastman Chemical. Paul holds a BS in Electrical Engineering from West Virginia University, a Masters in Engineering Management from Marshall University Graduate College, an MBA from Clemson University, and a Masters in Maintenance Management and Reliability Engineering from the Monash University in Gippsland, Australia. He is currently pursuing an MS in Applied Statistics and a PhD in Industrial Engineering at the University of Tennessee. Paul is an ASQ certified Six Sigma Black Belt, holds ASQ certifications in Reliability Engineering and Quality Engineering and is a SMRP Certified Maintenance and Reliability Professional. He has served on the University of Tennessee's Maintenance and Reliability Center's advisory board and is an active member of ASQ and IEEE.

1. Paul Arnold RCM Blitz™ at Whirlpool http://www.maintenanceworld.com/Articles/arnoldp/whirledclass.html
2. Kathy Light and Steve Powers, "Managing Change in a Major Reliability Improvement Effort", MARCON 2010 Proceedings (2010) Presentation slide 15.
3. Ibid



Shedding Light on RCM Facilitation

Answers to Commonly Asked Questions

by Doug Plucknette

Having facilitated hundreds of Reliability Centered Maintenance (RCM) events over the past fifteen years, I have heard a lot of questions running the gamut of topics from right on target to a little off base. However, I do believe that any question is a good question if it helps participants better understand the RCM process. While the questions do vary widely, in the following pages, I will discuss the ten most commonly asked. . . .

1. What criteria should we use to select an asset or piece of equipment for RCM analysis?

Selecting the right assets to perform RCM analysis is critical in building and sustaining a first-class effort. While some would argue that Reliability Centered Maintenance should be performed on every asset at your facility, I have always believed that the application of RCM is no different than any other project or improvement effort in that it should deliver a return on investment in a short period of time. Selecting the best assets on which to perform RCM begins with understanding the criticality of the assets at your facility. This requires a quick but formal equipment criticality ranking process. In performing this criticality ranking, you will not only find out where to begin looking for good RCM candidates, but the end product will be a tool with which you can now begin to prioritize and schedule all types of maintenance work.

Once your criticality analysis has been completed, I recommend the use of reliability measures such as Overall Equipment Effectiveness (OEE), Total Effective Equipment Performance (TEEP) or Mean Time Between Failures (MTBF) to then identify the best candidates for RCM analysis. In measuring OEE/TEEP on our critical assets, we can now identify the assets that are suffering equipment-based operational, speed, and quality losses. Equipment that fits these criteria should be considered the best candidates for analysis. For more detailed information on how to measure OEE/TEEP, I would recommend that you read *Overall Equipment Effectiveness* by Robert Hansen.

The use of MTBF to identify assets for analysis is a formal way to identify and quantify the bad actors at your site at a more detailed level. While OEE and TEEP are ideal ways to measure the reliability of a system or process, MTBF gets down to the equipment level and is good for identifying problem pumps, compressors, motors, or drives that would benefit from the complete maintenance strategy developed through the application of RCM. The key in using MTBF is to measure and record where you started prior to performing the analysis and what you accomplished upon implementing the new strategy.

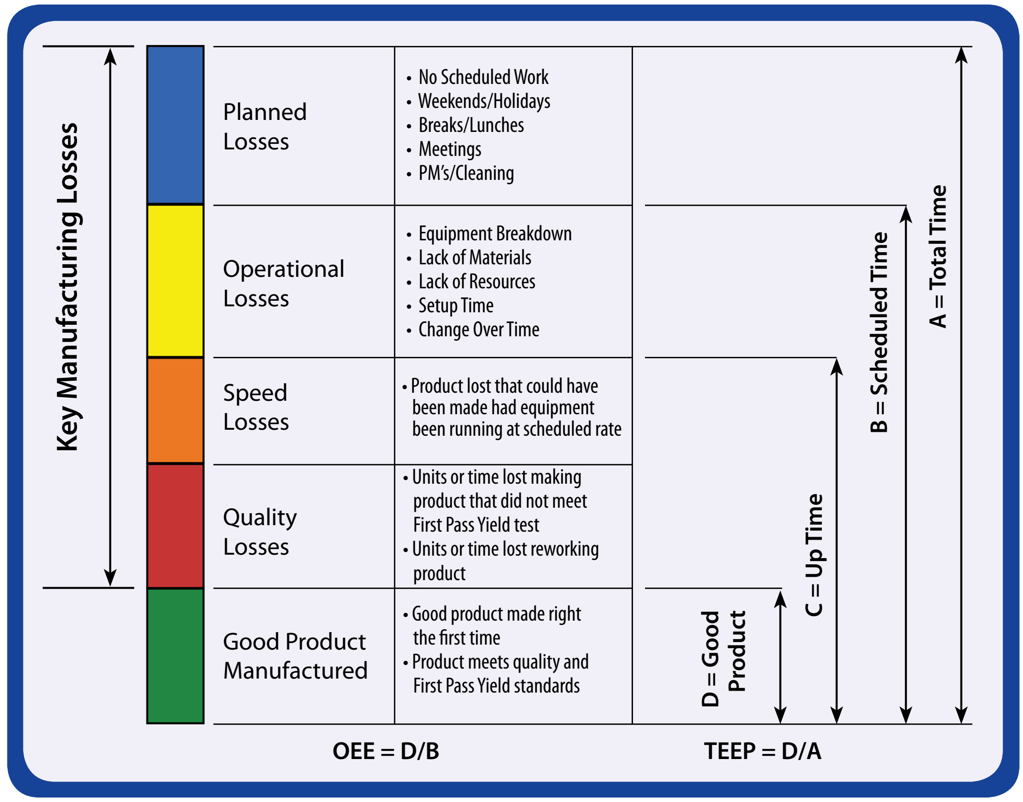


Figure 1 - OEE/TEEP Chart

2. How do you know how long it will take to complete an RCM analysis?

This can be a very difficult question to answer if the person asking the question has no past experience with RCM. My standard answer is a good facilitator with a new RCM team can complete an RCM analysis of 85 to 100 components that covers 120 to 140 failure modes in 5 eight-hour sessions. (Using the RCM Blitz™ format, this would be performed over one week.)

The problem with this answer is that we all have different ideas of what a component is. Therefore, we need to share drawings and parts lists to clarify exactly what the boundaries of the analysis will be and the components that will be covered as part of the analysis. As an example, I recently worked with a client that wanted me to provide an estimate to perform RCM on a compressor system. In my own mind, I envisioned your typical plant air compressor, but to be safe I asked for drawings and a component list for the system. I was shocked when I came to realize that the compressors are nearly the size of a school bus and are driven by a natural gas engine. There are close to 200 removable/repairable components in these compressor systems.

3. Who should we have on our RCM team and what is the ideal team size?

The ideal RCM team consists of one or two equipment operators, two to three skilled tradespeople (ensuring we cover mechanical, electrical, instrument), a process engineer, a PdM technician, and where applicable, an OEM representative. The ideal team size is five to seven people, understanding that having too few will result in missed failure modes and too many results in a challenge for the facilitator to manage the group and maintain the pace required to finish within the estimated time.

Your RCM team should be a team of people who are considered experts in the process or piece of equipment they are about to analyze. These people should be open to change and highly respected among their peers.

4. What are the biggest problems companies face in getting a successful RCM effort started?

Let me first answer this question with the statement that all successful RCM efforts have three things in common: Leadership, Structure, and Discipline. If you're lacking in any one of the three, you could struggle in kicking off a successful effort. This being said, the three most common problems in starting a successful RCM effort come in managing the implementation of the RCM tasks, selecting a good piece of equipment with which to start the effort, and trying to start the effort with a facilitator who has little or no experience.

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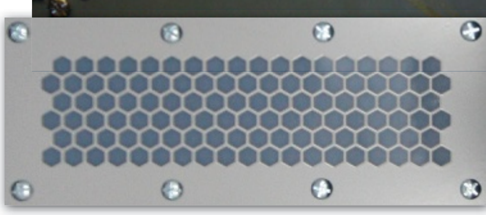

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Figure 2 - An experienced facilitator increases the odds of a successful implementation.

When it comes to Reliability Centered Maintenance, the analysis is the easy part. The challenge comes when we now have to manage and implement the 150 to 200 tasks that were identified in the analysis. RCM implementation is best managed by assigning one individual as the implementation manager for your RCM tasks. This person will then prioritize and manage the implementation by assigning each task to a specific individual along with a due date that corresponds to the task criticality/priority (criticality/priority is determined by the probability the failure will occur and the consequence to your business should it occur). Completing the implementation tasks is no different than completing any other planned work or project at your facility. The manager needs to track the assigned tasks and hold people accountable to completing them prior to the assigned due date.

Selecting a good piece of equipment to start your effort was covered under question one, but I will add here the importance in using reliability measures to identify assets, and more importantly, show the results of the implemented strategy.

Second only to failing to implement the RCM tasks is the problem created by trying to begin your RCM effort with a facilitator who has little or no experience in facilitating the process. From a high-level view, the RCM process looks easy. Follow the 7 steps identified in the SAE standard (see Table 1) and within a couple of weeks you should have completed your first RCM analysis. If you're at all worried, read a book or attend a pubic RCM event and you should be good to go.

I wish I could say it was that simple, but the reality is experienced RCM facilitators deliver results. Inexperienced facilitators most often

Step	Name	Description
1	Functions	The desired capability of the system, how well it is to perform, and under what circumstances.
2	Functional Failures	The failed state of the system (when the system falls outside the desired performance parameters)
3	Failure Modes	The specific condition causing a functional failure.
4	Failure Effects	The description of what happens when each failure mode occurs.
5	Failure Consequences	The description of how the loss of function matters.
6	Maintenance Tasks and Intervals	The description of the applicable and effective tasks, if any, performed to predict, prevent, or find failures.
7	Other Logical Actions	Including but not limited to run-to-failure, engineering redesigns, and changes/additions to operating procedures or technical manuals.

Table 1 - The 7 Steps of RCM

deliver frustration and failure. If you are looking for a successful RCM effort you need to hire an experienced and proven facilitator or spend the time and money required to train a certified facilitator.

5. How long should it take us to implement the tasks from our RCM Analysis?

The time required to implement the resulting tasks is dependent on the resources or people you have available and the number of tasks assigned to each person. The first analysis you complete always sets the benchmark for implementation. In the past I have had two companies take the better part of a year to implement their first RCM (I thought this was excessive, but I'm always happy when a company completes an implementation), and I have had several companies complete their first implementation in three months. The best companies are completing the implementation in three weeks and do this by following our detailed plan for implementation. This plan dedicates individuals to write/implement operator checklists, maintenance PM/PdM procedures, job plans, and an engineer that is assigned to implement any redesigns that require MOC (Management of Change) or small capital.

The key to successful implementation is to set realistic goals, communicate the progress on a regular basis, and remain focused on moving forward to complete the implementation phase. The companies who have been the most successful at implementing results each focused on ways to improve the implementation cycle. Creating standard format documents for checklists, job plans, and procedures improved both the quality and cycle of implementation.

6. What should the return on investment be for a good RCM Analysis?

In my opinion, Return-on-Investment should be the primary focus of your RCM effort. In the minds of some, however, the key driver of any RCM effort should be a reduction in Health, Safety, and Environmental incidents and accidents. I see them as common goals provided we can measure and place a dollar figure on the improvement realized by implementing and performing our new maintenance strategy.

The most important thing to remember in regard to the question is the fact that you must first implement the tasks identified by the


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RCM team to recognize any Return-on-Investment. While identifying and discussing failure modes will certainly improve the knowledge of the RCM team, the benefits of the process end there if we fail to implement. Having stated this, I would offer that, for companies who follow our prescribed methodology of selecting assets and implementing tasks, it is not uncommon to see a Return-on-Investment of 5 to 15 times the cost of training the team, conducting the analysis, and implementing the tasks within a year of completion. Just as important as implementing the tasks is having an agreed plan in place on how we plan to measure the success of the analysis or Return-on-Investment. Typically, I again recommend using OEE/TEEP (Figure 1) along with maintenance savings to quantify the ROI.

7. Should we train our own RCM facilitators or use a consultant?

This might be one of the most difficult questions to answer because depending on the situation and the company, the answer could be different. Keeping this in mind, I have a few general rules on how to make the best decision as well as the risks or downside of each.

If you're planning on training your own facilitator, do your company a big favor and ask the company you have selected to provide the training for some assistance in helping you select the right people. The companies who have a proven record of training successful facilitators should have documented selection criteria. Start by following this criteria and even involving the training company in the interview process. I know for a fact that the chances of a company having a successful effort increase dramatically if I can help them select facilitators.

Insist that your facilitators achieve facilitator certification through mentoring. While the 7-step process may seem simple, facilitation of the process is an art that takes time and experience and this can only be accelerated through a structured mentoring program. Training a facilitator takes both time and money invested wisely by selecting a proven methodology and an instructor with a successful reputation in the business. Always ask to see a resume and a list of references when making this decision.

The biggest risk or downside to training and using your own internal RCM facilitators is that they quite often are given a fair amount of credit for the success of your program and business, and as a result, they are often promoted out of the position or hired away by other companies who are looking to bring on an experienced RCM facilitator. Second to losing your facilitator, the other downside of internal facilitators is the bias they bring to the table in regard to your equipment and culture.

Using a consultant to conduct your analyses is the quickest way to get results. You don't have to wait for he/she to be trained, mentored, and certified; you simply contact a proven facilitator and you are ready to get started. The proven and experienced RCM facilitator brings no bias to the room; they follow the RCM process to the letter, they ask the team questions and lead the process to the best result. The challenge here is that all RCM facilitators are not created equal. If you want your effort to be successful, take some time to research and contact some companies who have had a successful effort or contact providers and ask for references. Some key things to remember in selecting a consultant:

- Experience in facilitating successful RCMs across varied industries is critical – This indicates the facilitator is an expert in the process, not a specific equipment type
- Ask for a resume – An experienced RCM consultant should have a resume that states his experience and successes. I would look for a minimum of two years experience or 12 completed analyses
- Always contact references – This is the best way to ensure you are getting a proven leader

The downside of hiring a consultant to facilitate your effort is cost and availability. In the world of RCM, the most successful facilitators cost money and are often scheduled out months in advance. I would advise anyone who is starting an effort to let patience be your guide. The best facilitators deliver results and are worth waiting for.

8. Why can't we use a library of known failure modes to develop our maintenance strategy?

Those of us in the business hear this question all the time. If it's not this question, then it's a similar statement: "A pump is a pump and a motor is a motor. They all have the same failure modes and once you have completed one you can apply that same strategy to every pump in the plant." I used to say good luck, give it a try and call me a year from now and we can discuss why that won't work.

Let me say it again, I used to say that. Time and experience have changed my stance on this, and I now reply there are places where the strategy of common failure modes can be of value. First, however, I want to explain why we need to perform Reliability Centered Maintenance on our critical assets and why each analysis will deliver unique failure modes and unique tasks.

The problem with failure modes lists is two-fold; first, the list is basic, covering only the common engineered failure modes for the component. The problem here is the failure modes do not address the most common failures that result from the context and environment in which we operate this equipment. The resulting output from a common engineered failure modes strategy will deliver a partial strategy that will deliver some improvement but fall far short of what would be delivered by addressing the failure modes that result from the context and environment. The second type of failure modes list is all inclusive and covers engineered failure modes as well as failure modes that are highly unlikely to occur, resulting in an overblown and costly maintenance strategy.

Putting this in the most simple of terms, would you expect the same failure modes for a pump that operates in the hot, dry, dusty environment of Southern California as compared to an identical pump in size and manufacture operating in Northern Alaska? The changes in temperature alone could result in very different failure modes. Now consider the fact that not all equipment designs are created equal; a pump with a sound foundation base and supports has an entirely different list of failure modes than one that is bolted to the floor, aligned with a mash hammer, and uses the pump itself as the piping supports.

Critical assets have unique failure modes and result in a unique maintenance strategy. If you want to use a failure modes list that maps tasks to failure modes, these are perfectly acceptable for non-critical assets where we look to quickly upgrade a PM-focused strategy to include applicable and effective PdM tasks.

9. What can we do to make sure we have a successful RCM effort?

The best way to ensure you have a successful effort is to learn all you can about successful RCM efforts prior to starting your own. The more you understand the RCM process (Figure 2), what it takes to select the best assets, perform each analysis and implement the tasks, the better prepared you will be to manage your own effort. I recommend attending a conference where several companies (practitioners, not providers) will present information in regard to how they have applied RCM at their facility. Make a point to sit and talk with these companies and take detailed notes on the things they believe helped make their effort a successful one as well as the obstacles they may have encountered along the way.

Read everything you can get your hands on in regard to RCM, I would (of course!) recommend my book Reliability Centered Maintenance – Using the RCM Blitz™ as well as Gateway to RCM by Mac Smith. ReliabilityWeb.com and Uptime magazine also have an abundance of articles that can help you to better understand and manage a successful effort.

Along with this I would be remiss if I did not say the best way to a successful RCM effort is to follow the proven process. Much has been written through the years and still today about how RCM works, and why the process has been so successful for so many companies around the world, yet I can still find articles and examples from those who believe the process is excessive or over done. The 7-step RCM process has been proven to provide the most effective maintenance strategy to ensure the inherent designed reliability of your equipment. If you're looking for something less, simply save yourself some time and eliminate a few of the 7 steps. I also tell people who are considering skipping some steps to give me a call and ask what the potential consequences are. I will be happy to tell you because in the past 15 years I have had several facilitators in training make these same foolish mistakes.

10. What should we expect from an experienced RCM facilitator?

I recently had two separate customers share with me stories about hiring people/consultants who claimed to be "RCM Experts." In both cases their "expert" turned out to have very little experience actually facilitating an RCM analysis. One had attended an RCM public offering, recorded their analysis in MS Excel, and worked with their RCM team 1 day a week for 14 weeks. In the end, the team delivered a PM-focused maintenance strategy because their facilitator told them that they were "not ready for PdM and it would cost too much for them to get started.

There were a lot of red flags within the 14 weeks that they worked on this project, but the pressing questions were not asked until after the team presented their new maintenance strategy. Following this disappointment they did a little homework and found out their experienced facilitator could not provide a single reference in regard to his RCM experience other than his 3-day course certificate.

Company number two was slightly more aggressive in making the discovery that their newly hired RCM expert had little to no experience facilitating the RCM process. It turns out that company number two has a few certified CMRPs and one happened to attend the RCM team training that was being put on by their newly hired consultant. After a few pressing questions it turned out that Mr. RCM Expert was a new hire and had yet to attend formal RCM training and had never even sat in on a single RCM analysis!

My expectations of an experienced RCM facilitator is the person should at a minimum have proof that they attended RCM facilitator training and achieved certification as a facilitator through a formal mentoring process. They should be able to show proof of this certification including contact information and a reference from the practitioner who mentored them through certification. If you're hiring a facilitator, they should have the capabilities to not only facilitate the RCM analysis, but also be able to train your RCM team, provide managers with overview training, and offer assistance in managing each step of the RCM process, from selecting assets to completing implementation.

The only problem associated with selecting an experienced RCM facilitator is that the world has no set standard for what qualifies one as an experienced facilitator. In today's world you can read a book, develop a simple spreadsheet in Excel use your brother-in-law Joe as a reference and call yourself a world-class experienced RCM facilitator. It's up to you to do yourself and your company a big favor by carefully researching and verifying the credentials of your facilitator/consultant.

Douglas Plucknette is the creator of the RCM Blitz™ method, author of the book Reliability Centered Maintenance – Using RCM Blitz™ and the RCM Discipline Leader for GPAllied. Well-known on the conference and lecture circuit Doug has over 30 years experience in the field of maintenance and reliability. Over the past 15 years, Doug has facilitated hundreds of RCM analyses and trained and certified many companies around the world in RCM Blitz™.

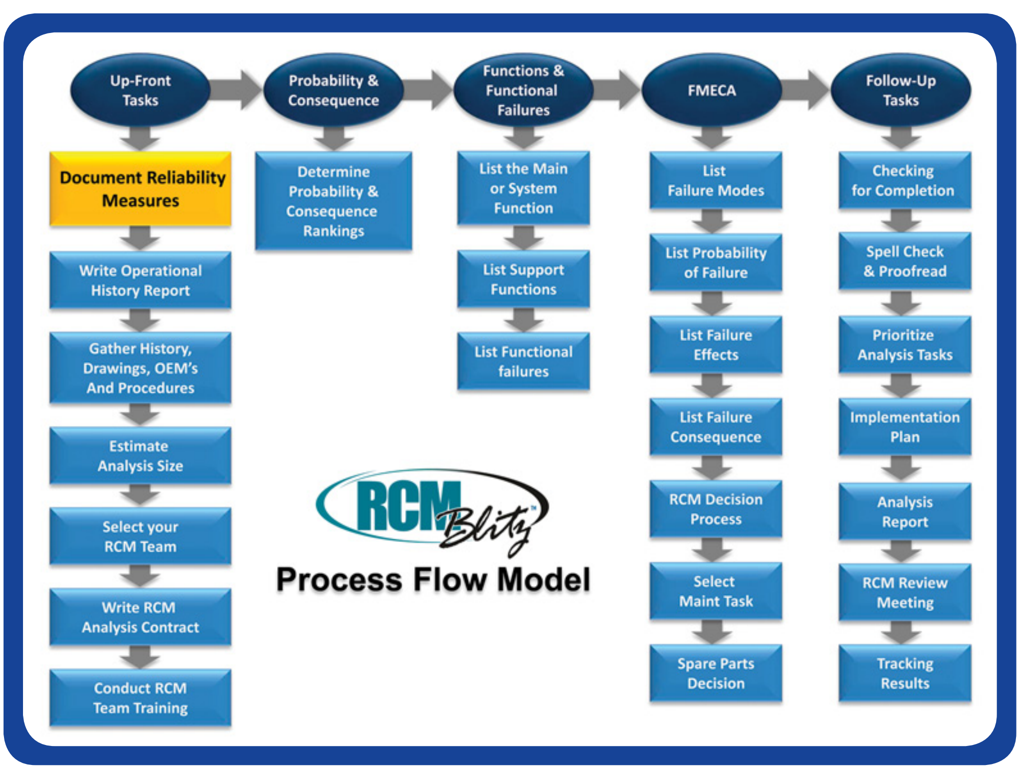

Figure 2 – The RCM Blitz™ Process Flow Chart


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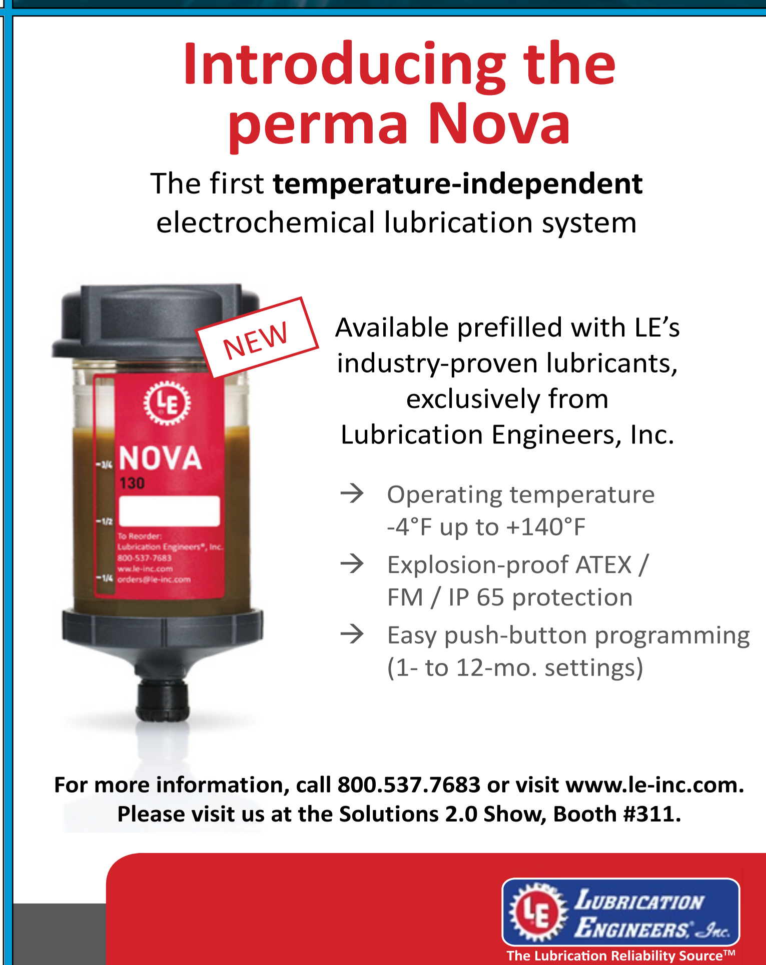

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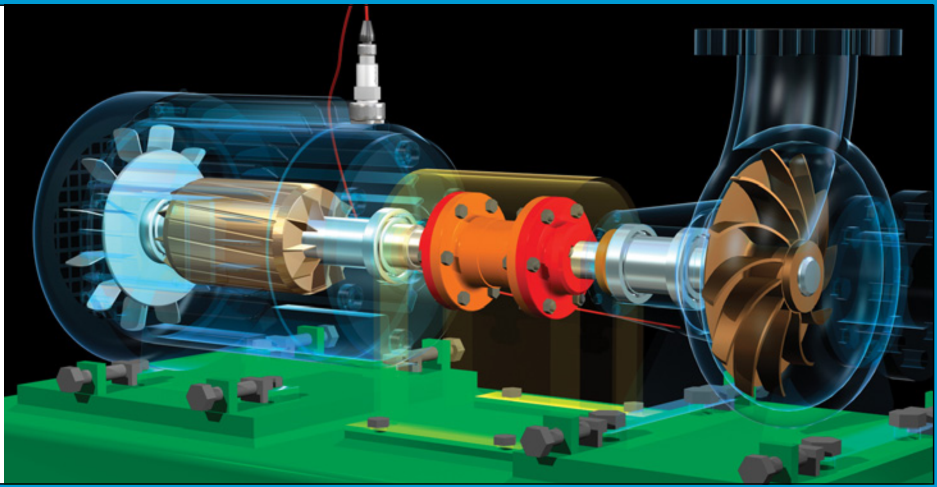

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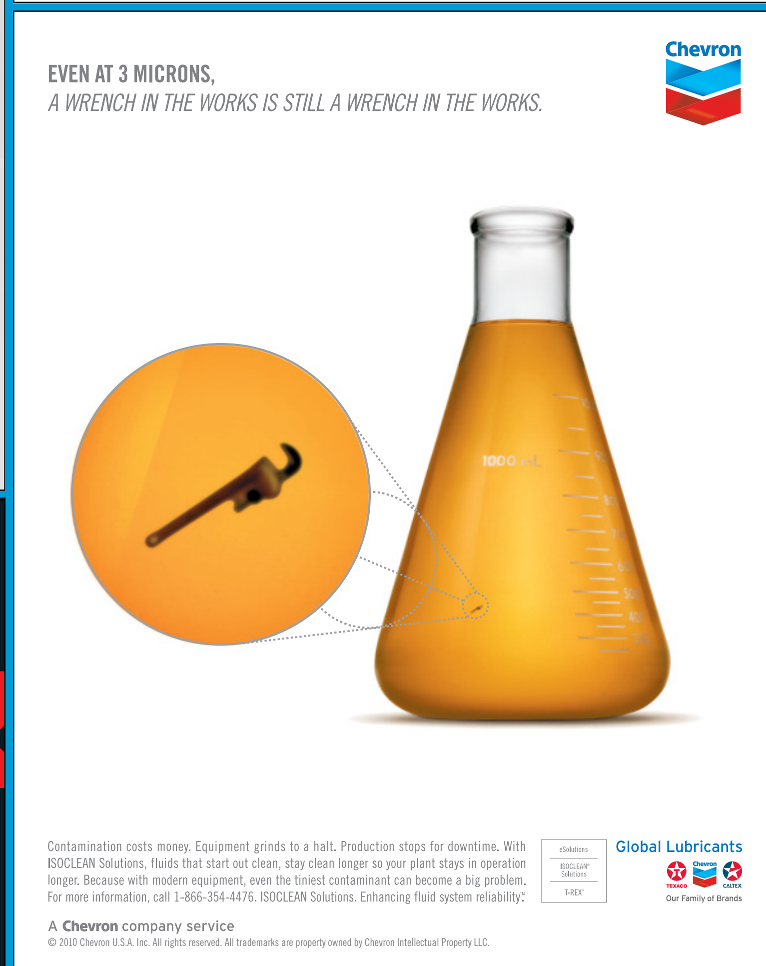
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Audit, Develop and Implement

Completing an Audit and Implementing Changes to Boost Lubrication Program Performance

by Paul Dufresne, CLS, CMRP

In 2009, Trico Services was contracted to complete an equipment lubrication audit of a large mill in the southeast that produces liner and corrugated material for containers. This audit was for roughly 2500 pieces of rotating equipment. Upon completion of the audit, Trico was to take the lubrication recommendations and input this data into the MAINTelligence software platform that the facility uses using to manage their plant lubrication programs.

Outline Scope of Service

The Scope of Service for this project was be broken into four phases. Phase I of this project would begin in the Pulp Mill area of this facility. The Pulp Mill area is comprised of the following sub-areas: Caustic Area, Tall Oil, Digesters and Pulp Mill general. Phase II was the Power House. Phase III was Paper Manufacturing consisting of three paper machines and Phase IV was the Chip Yard. Under our arrangement the following services were provided:

- Verify lubrication requirements for all equipment in their specific area.
- Verify that correct lubricants are being used for each point identified.
- Establish the correct frequency for re-lubrication.
- Create an electronic database that would be used to house the lubrication audit and will facilitate the development of a "living" lubrication database.
- Tag equipment with a bar code used for accessing hand held lubrication routes manage by the MAINTelligence software.

Upon completion of the lubrication audit in each area, the data was transferred into the MAINTelligence software. Under our agreement the following services were provided:

1. Create appropriate reading type (inspections) for equipment that would be inspected.
2. Build lubrication points into the MAINTelligence database; create detailed outage and non-outage lubrication routes for the designated areas.
3. Mentor the local system administrator on the following:
    - Setting up the inspection routes (see Figure 1).
    - Creating inspection specifications in the database.
    - Scheduling the inspections for a specific time period.
    - Scheduling and conducting any remedial action needed to eliminate the exceptions.
    - General operation of the MAINTelligence software.
4. Mentor the area lubrication technicians in lubrication best practices along with MAINTelligence operations.

Lubrication Audit Overview

Purpose - The equipment audit was performed to obtain knowledge of the equipment, its internal design, the system design, and the current operating and environmental conditions. Failure to gain full understanding of the equipment operating needs and conditions undermines the technology. This information was used as a reference to set equipment targets and limits while supplying direction for future maintenance activities. The information was placed in an automated lube list that is accessible to all plant personnel via the local intranet. There were approximately 2,500 lubrication assets audited during this process. Below is a list of other criteria that were evaluated per asset.

Equipment Mission Criticality - Safety, environmental concerns, historical problems, reliability, downtime costs and repairs must all be considered when determining the equipment included in the program, the frequency and the selections of all health monitoring tests.

Equipment Component and System Identification - Collecting, categorizing and evaluating all design and operating manuals including schematics are required to understand the complexity of modern equipment. OEM's assistance in identifying the original bearings, wear surfaces and component metallurgy will take the guesswork out of setting targets and limits and also aid in future troubleshooting. Equipment nameplate data with accurate model and serial numbers allow for easy identification by the manufacturer to aid in obtaining this information.

Operating Parameters - Equipment designers and operating manuals reflect the minimum requirements for operating the equipment. These include operating tem-

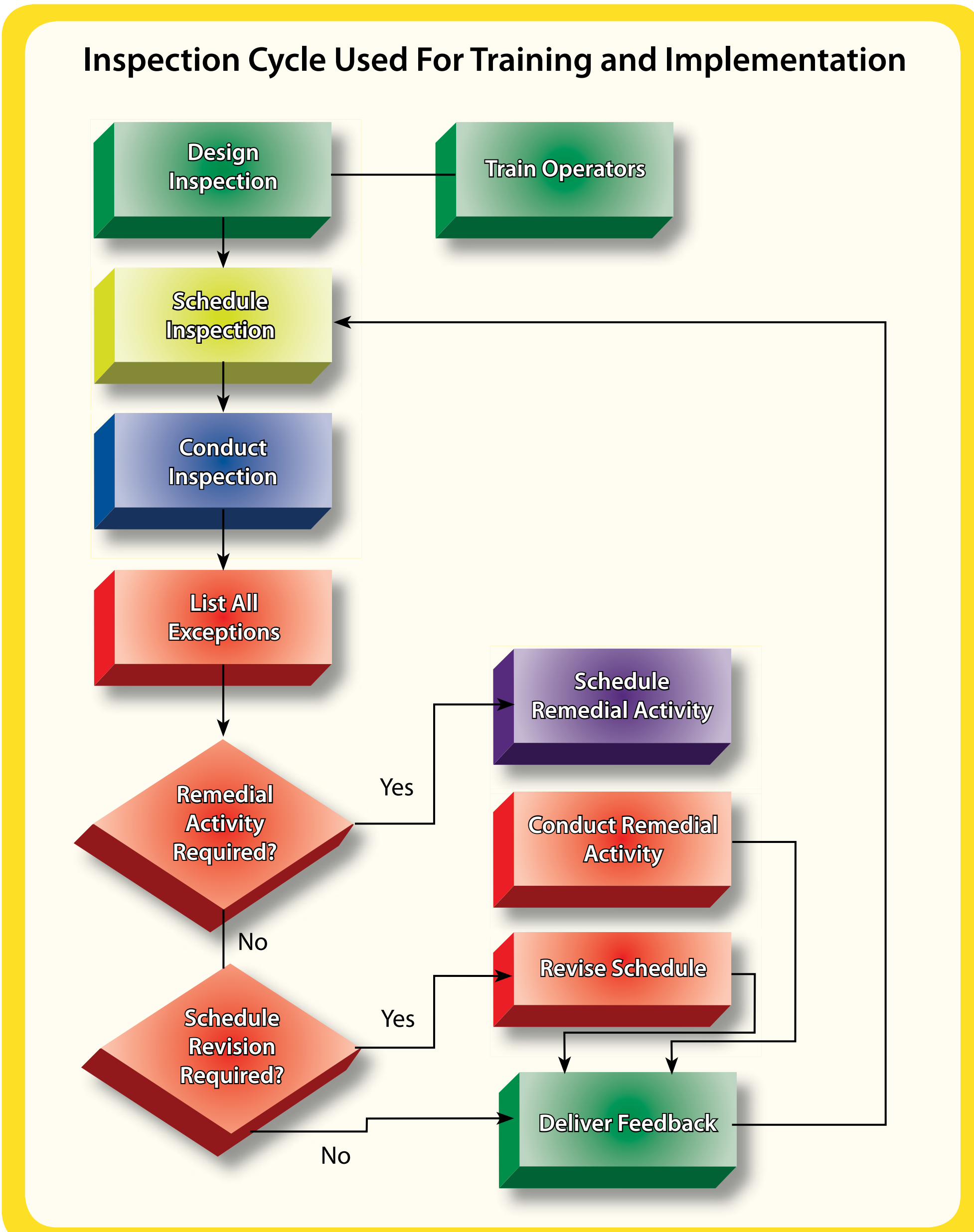

Figure 1 - Inspection Cycle Workflow

perature, required lubricant needs, pressures, duty cycles and filtration to name a few. Operating outside the recommended values could require modifications and/or additions to the system to allow the component to run within an acceptable range.

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

Operating Environment - Hostile environments or environmental contamination in most cases is not taken into consideration when OEMs establish operating parameters. These conditions can influence lubricant degradation, eventually resulting in damaged equipment. All environmental conditions such as mean temperature, humidity and all possible contaminants must be recorded.

Installing Tags and Barcoding Assets

The decision was made to scan barcodes at each inspection point. Scanning the barcode automatically records the identification of the maintenance technician, and the time and date stamp of when the inspection is completed. This is helpful for regulatory compliance. When a maintenance technician walks up and scans the barcode, the corresponding inspection is brought up on the data collector. We were furnished with an equipment list that we scrubbed for accuracy during our lubrication audit. Once the list was verified, the data was provided to our production personnel in Pewaukee, Wisconsin where the labels were printed and the tags put together (see Figure 2).

Figure 2 - Example of Tag with Bar Code

How Lubrication Audit Augmented Hand Held Technology (MAINTelligence)

At the time, the plant was using paper based lubrication inspections. These inspections were usually completed on schedule. However, using the information from these inspections as a tool for work identification and triggering corrective work orders was fairly difficult. The paper forms were hard to sort through. Often, the needed form would be stacked deep on the inspection clipboard, so finding the noted exceptions either took a considerable amount of time or just couldn't be done. By completing the lubrication audit on the rotating equipment assets in the plant, the initial verification and leg work had been completed for a successful implementation. There is no question that lubrication inspection procedures can be carried out using paper check-sheets. However, it was felt that implementing the lubrication rounds using an automated approach would resolve the problem of incomplete work identification.

The benefits of automated lubrication inspection rounds are:

- Implementing automated lubrication programs are easier and more efficient.
- Increases the accuracy and consistency of collected data.
- Immediate feedback is available to the operators when assessing the asset.
- Exceptions are indicated immediately to maintenance and reliability staff.

The primary goal of collecting the data electronically is to capture this data into a searchable database automatically, without having the need for data entry from the paper inspection forms. This allows the information collected from inspections to be sorted and flagged as exceptions, and used to immediately generate corrective work orders.

Implementation Costs

Many first time purchasers of software encounter severe sticker shock regarding the cost of implementing maintenance software systems. The reality is that the cost of implementation will typically range from 1:1 to 2:1 compared to the cost of the software. In this case the cost of implementing the software was far less since the software was already loaded on the network CITRIX server. Trico was able to take the data from the equipment lubrication audit, immediately input that data into the MAINTelligence software and then create the lubrication routes for the plant.

Implementation for this project came in on budget as planned, and at the customer's request, an additional week of work was added to the end of the project. This work was scheduled as a four phase project completed in about 70 days.

Maintenance Cost Reductions

Maintenance costs are the second highest component of operating expenses (after utilities), and nearly every industry is working to control these expenses for at least a couple of reasons. First, the rising costs of electricity, gas, and even water and sewer charges are pulling funding away from maintenance activities. Second, economic times are difficult right now, and most companies have been requested to make budget reductions. Everyone understands that you have to keep paying the electric bill, but there is a perception that you can cut the maintenance costs... at least for a while.

Many companies are doing the same types of maintenance with lower funding levels. With lower maintenance funding, the facility conditions deteriorate and the productivity of the workforce suffers. Also, poorly maintained equipment will use more energy and overall expenses will rise even faster. This can be a difficult cost spiral from which it is very difficult to recover.

A better strategy in these difficult budget times is to increase the productivity of your maintenance workforce. Nearly every organization with which we have worked either supplements its staff with contracted resources or utilizes overtime by its regular staff to complete their maintenance activities. By getting more work done with your own staff, you will be able to reduce the need for contractors, reduce the need for overtime, or both.

How can one increase the productivity of a maintenance workforce with a very short return-on-investment? Consider implementing handheld devices for the maintenance workforce. It is one of the maintenance "Best Practices" identified by many industry experts. Fortunately, the company's management recognizes this and is implementing this across their entire organization. They realize that the devices can increase efficiency and productivity of their staff. By doing this they can reduce their costs and operate more efficiently.

Currently the facility is in the infancy stage of operating their handheld units and metrics are in place to track work efficiency and other related maintenance metrics directly relating to the use of handhelds. The following is a simplified list of potential key indicators that could be used as the lubrication program matures:

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

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

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

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

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

Tracking and Trending Lubricant Disposal Costs – Understanding the total consumption, leaks, top-ups, and oil changes, will allow a company's efforts and behaviors to be better focused toward the effective implementation of the lubrication program.

Other Key Performance Indicators to Consider

Breakdown, Availability interruptions, Failures

- O.E.E. (Overall Equipment Effectiveness)
- TTPM: Time To Preventive Maintainance, as a % of total time

Preventive, Corrective, Scheduled Maintenance

- % of work scheduled
- % of work type backlog

Maintenance Costs

- Maintenance cost as % of asset value
- Ratio of unplanned to total maintenance cost

Effectiveness

- Number of jobs planned but not yet performed
- Number of jobs not started at planned time/date

Efficiency

- MTBF: Mean-Time-Between-Failures
- MTTR: Mean-Time-To-Repair
- Production losses due to unplanned downtime
- Production losses due to planned/ preventive maintenance

Regardless of the indicators that are used, the purpose should be to help quantify the maintenance effectiveness and impact on the company's bottom line through equipment and facility availability, defined in terms that are meaningful to their organization.

Next Steps

Operator Basic Care Program – Currently there is a vision within the organization to establish a comprehensive program to ensure that operators, as the owners of equipment, understand equipment condition at all times by cleaning, lubricating, adjusting, inspecting, and making simple repairs to maximize uptime and reduce unplanned events to zero. The company wants to use the MAINTelligence platform to house all of these inspections for their operators. We have been asked to provide a proposal that would outline all the scope of work and associated cost in developing the Operator Basic Care program at the facility.

Lubrication Program follow-up – As the lubrication program (MAINTelligence) matures at the facility we are currently focusing our direction on other opportunities within their lubrication program. We are currently working on installing turnkey lubrication storage & handling unit in the Pulp Mill and have a plan to install lubrication storage & handling units in the other areas of the mill. We have also focused our efforts in addressing lubrication best practices when it comes to installing and using desiccant breathers. We have also identified and addressed the need for proper lubricant filtration, proper sampling ports for an effective oil analysis program along with establishing the proper cleanliness codes and test slates that should be performed per family type of equipment.

Our plan is to review the current lubrication routes after a 12-month cycle to ensure we have the correct frequency based on the operating and environmental conditions within the facility and adjust as needed. Our goal is to help the facility follow all of the best practices when it comes to lubrication excellence.

Paul Dufresne is an industry leading expert in the area of plant lubrication and equipment reliability. Paul is a Distinguished Military Graduate from the University of Central Florida and holds a Certified Lubrication Specialist (CLS) rating from the Society of Tribologists and Lubrication Engineers; Certified Maintenance Reliability Professional (CMRP) rating from the Society of Maintenance and Reliability Professionals. The article was written by Paul while he was employed with Trico. Paul is now the Operations Excellence Specialist with Georgia Pacific. Paul can be reached at paul.dufresne@hotmail.com

Back to the Basics

Developing and Delivering a Maintenance Plan

by Malcolm Hide

So how do you go about setting up all of the maintenance requirements for several thousand discretely maintainable assets? This was the challenge facing us when we needed to set up the maintenance requirements package for a baggage handling system in a new airport terminal in a major international airport. From previous experience, and the airport requirements, we had a good idea of what needed to be done. The challenge was in the sheer size of the system—with a total asset base of over 28,000 discretely maintainable assets, we needed to find a more efficient way of doing things. As a result, we developed a three-step process (see Figure 1) that delivers a robust maintenance plan, based on a clearly defined strategy, which is easy to review and enables the implementation of changes when necessary. We have found that the principles hold well, regardless of the size of the system.

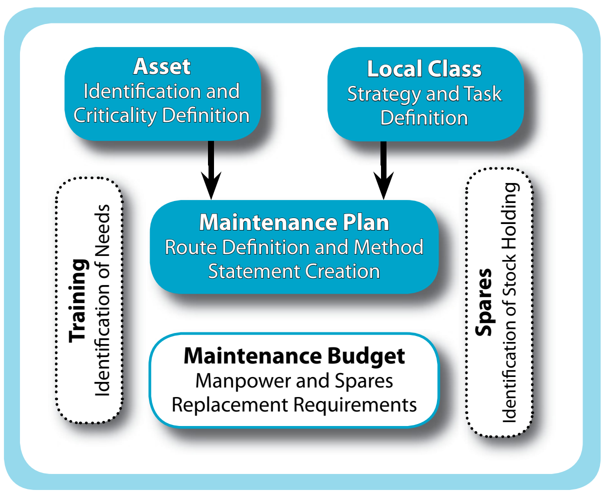

Figure 1 - Showing the three-step process and additional knock-on information.

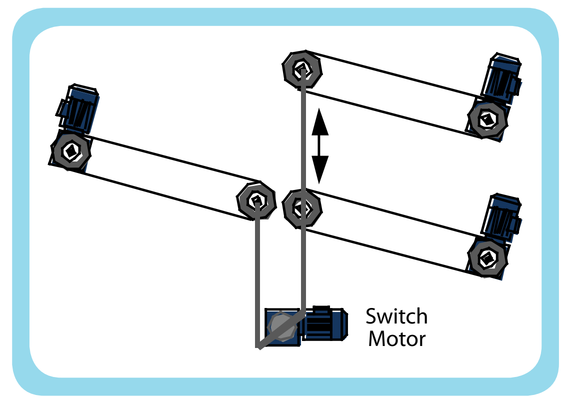

Figure 2 - Illustration of a vertical switch conveyor.

Methodology

Phase 1 – Identify all Assets

Assets are assets. What can be difficult about identifying them? Well, that depends entirely on how far you might want to go down the asset tree. Take a conveyor for example. Do we take the asset structure down to the component level, such as the drive motor, or do we leave the asset at the conveyor level and take a motor as a component? We defined a maintainable asset as an item we could isolate individually, and as a result, we opted for the latter. In some instances, this did create some exceptions. For example, a vertical sorter unit (see Figure 2) was taken as a single asset, even though it clearly contains three individual conveyors. In another instance, a pneumatic conveyor extender at fire breaks was taken as a discrete subasset of a conveyor in order to simplify the development of the maintenance strategies.

Ultimately, asset identification becomes a fine balance between the identification of local classes (similar equipment) and discrete equipment. This may sound simple, but there is an art to doing it in a way that helps to simplify the development of your overall maintenance strategy. We will try to clarify what local classes mean in Phase 2.

Once you have identified all of the discrete assets in your system, you will need to define how critical they are to the performance of your business. To do this you might want to take a process layout of your system, and mark off large areas, such as “Check-In Island A” or “Picking Floor C,” which have a measurable impact on your business. Now define a series of business-related questions with five possible realistic answers for your business, such as:

1. What would happen to our business if the identified section was out of operation for 24 hours?
   a. Production loss of over €1 million ($1.285M)
   b. Production loss of over €500k ($642.5K)
   c. Production loss of over €100k ($128.5K)
   d. Significant production loss which could be supplemented by another site.
   e. Minor production losses which could

be supplemented by another area on our site.

2. How would our customers react to the identified section being out of operation for 24 hours?
   a. Losses in sales in excess of €1 million ($1.285M)
   b. Losses in sales in excess of €500k ($642.5K)
   c. Losses in sales in excess of €100k ($128.5K)
   d. Significant losses in sales which could be supplemented by another site.
   e. Minor losses in sales which could be supplemented by another area on our site.

You need to make sure that you address the several aspects of your business that have a direct impact on your business and its ability to function and operate in the future: environmental impact, media coverage, customer perception, reputation, and any other issues you can identify. You need to be aware that both the questions and their relevance might change over time as the business and its environment changes.

Once the business criticality for an area has been determined, you will need to consider the failures that could take place on the equipment in that area, and the frequency at which these failures might occur. These should not be operational issues such as bag jams, but rather equipment failure issues that would require component replacement or adjustment, such as motor failure or belt adjustment. At this stage you should ignore the length of time it takes to repair the failure—we are more concerned at this stage with the frequency of maintenance-related disturbances.

The two values—Business Risk and Frequency—are mapped onto the grid (see Figure 3) to define the resulting criticality for the area. This process needs to be repeated for all of the areas you have defined on your process layout. Two items you will need to be aware of when performing this activity:

- If the business risk incorporates a question related to health and safety in relation to people performing maintenance on the equipment, these risks need to be carefully considered. While the resulting injury could be extremely serious, this risk of injury needs to be mitigated in the risk assessments and resulting method statements or redesign, not in increasing the business risk. The reason for this is if the business risk is too high, then you might consider doubling up on the equipment to reduce the risk, but this adds to an injury risk when maintaining the equipment.
- All of the equipment and process routes in an area do not necessarily fall into the same criticality as the main routes for the area. You will need to identify the main process routes, secondary and tertiary process routes through the area, and assign lower priorities based on their potential impact on the area.

Business Risk \ Frequency	Low				High
High	1	2	3	4	5
	2	2	3	4	5
	3	3	4	5	5
	4	4	5	5	5
Low	5	5	5	5	5

Figure 3 - The Criticality Matrix.

This process needs to be kept as simple and flexible as possible, and you should ensure all decisions are well documented in order to both eliminate the possibility of misinterpretation and to support any decisions made. Remember that the business needs and market forces will change over time, and this criticality review will need to be re-evaluated fairly frequently (usually annually or in major shifts of the economy) to ensure you are still applying the correct strategies. Changes to your environment could quite possibly change the maintenance plan you have adopted for the equipment on site over time.

Phase 2 – Identifying Local Classes and Strategies

When looking through all of the equipment on your site, you will notice that there are several pieces of equipment that are very similar. The probability is high that the maintenance strategy applied to them can be the same, while making allowances for various criticality levels. We identify these equipment groups by giving them a Local Class designation, and develop the maintenance strategies for each of these local classes, defining different frequencies (and strategies if necessary) for all five criticality levels at the same time. This process allows us to reduce the baggage system from 28,000 items to 122 local classes for which we need to define maintenance strategies.

Based on your list of local classes, you will need to:

1. Draw up a list of every activity that you will possibly perform on this equipment/local class, including:
   a. Component Replacements, where you need to consider the level at which you want to carry out your maintenance. For example, in Western Europe, if a bearing on a motor reducer unit failed, and a replacement unit cost less than Ð150 ($193), then, due to the time and effort required to manage the repair, you might opt to replace and not carry out a repair. Conversely to this, in Central Africa, component availability and/or lower labor rates might mean a repair is the most cost-effective solution based on the resources at your disposal.
   b. Component Adjustments, covering activities such as belt tensioning, oil replacement and defragmenting hard drives.
   c. Cleaning Activities, covering any equipment and the immediate surroundings that are in a restricted-entry area. In many instances cleaning could fall to a lower skill level. However it should not be ignored in the maintenance plan as it forms part of a holistic approach to maintenance. At a food processing plant, we reduced downtime by 20% by reducing dirt in the system and from staff noticing future problems while cleaning – problems which could then be averted.
   d. nspections, covering visual inspections, stoppage inspections, and statutory inspections.
   e. All condition-based inspections such as Vibration, Thermography, and Ultrasound. If there is no in-house expert to perform these activities, you could contract them out to specialist companies to perform the work. In our experience, contracting out can be set up and managed well, or poorly, so consider

the options carefully. A well-managed process of “contracting-to-inhousing” can be most beneficial.

2. Estimate the following:
   a. How long each of the identified tasks will take to complete (Mean Time to Repair [MTTR]), and how many people will be needed to complete the work.
   b. Predict the Mean Time Between Failures (MTBF) for replacements and adjustments. To define the MTBF, you might want to look at the design or predicted life of a component that you intend to replace or adjust.
   c. Decide if the work will require the equipment to be isolated in order to complete the work.
3. Define one of the following strategies for each of the criticalities you are using (see Figure 4 – Strategy Sheet):
   a. Time Based, where you define a set frequency to perform the maintenance activity. Some of the tasks are in themselves a strategy, such as a thermal inspection (Thermography) or vibration inspection (Vibration Monitoring), in which case you need to define a frequency based on an anticipated PF failure curve.
   b. Operational Based, which sets out the flow or operations required between maintenance activities.
   c. Condition Based, using an inspection or other strategy which will identify the onset of failure and allow for reaction time to address the failure.
   d. Run to Fail, which allows the component to fail before replacements or adjustments are made.

As part of the creation of the maintenance strategies you can also develop safe working practice method statements and generic risk assessments for all of the maintenance tasks that you have identified. These method statements and risk assessments are an ideal way of helping to develop a training plan for new employees.

By developing these individual strategies, we found it relatively easy to adopt a cohesive maintenance strategy across the entire baggage system.

It’s important to remember that all of the condition-based inspections, such as Vibration, Thermography, and Ultrasound, are

Strategy Sheet: DL - Dock Leveler

Key	Task(Name)	Duration(mins) MTTR	Interruptable	Downtime	Labour Qty	Skill	Criticality A	Criticality B	Criticality C	Criticality D	Criticality E	Life(hours) MTBF	Workshop Task	Start Date	Obsolete
Replace															
REP - DL01	Replace - Lift-mechanism bearing-block / bus	30	N	Y	1	0	COND	COND	COND	COND	RTF	32000	N		
REP - DL02	Replace - Connectors or terminal blocks	10	N	Y	1	0	COND	COND	COND	COND	RTF	96000	N		
REP - DL03	Replace - Contactor / Relay	30	N	Y	1	0	COND	COND	COND	COND	RTF	96000	N		
REP DL04	Replace Damaged cables or wiring	30	N	Y	1	0	COND	COND	COND	COND	RTF	96000	N		
REP - DL06	Replace - Fuses	10	N	Y	1	0	RTF	RTF	RTF	RTF	RTF	24000	N		
REP - DL07	Replace - Indicator lamp	10	Y	Y	1	0	RTF	RTF	RTF	RTF	RTF	48000	N		
REP - DL08	Replace - MCB	15	N	Y	1	0	RTF	RTF	RTF	RTF	RTF	96000	N		
REP - DL09	Replace - Isolator	30	N	Y	1	0	COND	COND	COND	RTF	RTF	96000	N		
REP - DL10	Replace - Push-buttons	10	N	Y	1	0	COND	RTF	RTF	RTF	RTF	48000	N		
REP - DL10	Replace - Hydraulic cylinder	30	N	Y	1	0	COND	COND	COND	COND	RTF	96000	N		
REP - DL11	Replace - Hydraulic filter unit	20	N	Y	1	0	COND	COND	COND	COND	RTF	96000	N		
REP - DL12	Replace - Hydraulic relief valve	30	N	Y	1	0	COND	COND	COND	COND	RTF	28000	N		
REP - DL13	Replace - Hydraulic pressure regulator	20	N	Y	1	0	COND	COND	COND	COND	RTF	48000	N		
REP - DL14	Replace - Hydraulic hoses / connector	30	N	Y	1	0	COND	COND	COND	COND	RTF	32000	N		
REP - DL15	Replace - Hydraulic valve	30	N	Y	1	0	COND	COND	COND	COND	RTF	72000	N		
REP - DL16	Replace - Hydraulic pressure switch	20	N	Y	1	0	COND	COND	COND	COND	RTF	48000	N		
REP - DL17	Replace - Hydraulic oil	30	N	Y	1	0	COND	COND	COND	COND	RTF	24000	N		
Adjust															
ADJ - DL01	Adjust - Fall rate of hydraulic cylinder	10	N	Y	1	0	COND	COND	COND	COND	RTF	48000	N		
ADJ - DL02	Adjust - Rise rate of hydraulic cylinder	10	N	Y	1	0	COND	COND	COND	COND	RTF	48000	N		
ADJ - DL03	Adjust - Hydraulic pressure	20	Y	N	1	0	COND	COND	COND	COND	RTF	20000	N		
ADJ - DL04	Adjust - Hydraylic pressure switch	5	Y	N	1	0	COND	COND	COND	COND	RTF	20000	N		
ADJ - DL05	Adjust - Top up hydraulic reservoir	15	Y	N	1	0	COND	COND	COND	COND	RTF	32000	N		
Inspection - Stop															
IINS - DL01	Intrusive Inspection - Dock Leveler (DL)	20	N	Y	1	0	0	13	10	26	RTF		N		
	Structure	5													
	- Check structure for any wear / damage / deformation / cracks														
	- Check bolts and fixings for tightness														
	- Check pivot bearing for wear / damage / correct operation														
	- Check local motor starter for damage														
	Control	7													
	- Check Isolator for damage / correct operation														
	- Check cables and wiring for damage / secure routing														
	- Check terminals / connectors for damage / looseness / signs of overheating														
	- Check limit switches for damage / correct activation														
	Check operator panel for damage / correct operation														
	- Check push-buttons for wear / damage / correct operation														
	- Check relays/contactors for damage / correct operation														
	Hydraulic System	0													

Figure 4 - An example of a strategy sheet for a dock leveler.

supportive of a sound maintenance strategy, and should not be performed in isolation.

Phase 3 – Extract the Maintenance Plan

Phases 1 and 2 can be performed in tandem; however, they need to be complete before continuing with Phase 3 of the work. At this point we know all of the equipment we aim to maintain, how critical it is to your business, what strategies we will be using and what maintenance we will be performing. We now need to extract this as a maintenance plan for each piece of equipment and insert it into our Computerized Maintenance Management System (CMMS).

This is where things started getting a little tricky! While for many situations this is a manageable task, in the baggage system discussed above, we had around four time-based activities per piece of equipment, which amounted to 112,000 planned maintenance activities to enter onto the CMMS. These tasks ranged from weekly visual inspections through to oil replacements every three years on the motor reducers. Downloading this many planned maintenance tasks is clearly a significant task, not to mention the work involved in planning and managing a weekly paper trail of around 31,000 work orders. Clearly we needed a way of grouping these activities into more manageable groups, while still keeping the maintenance information at equipment level. To achieve this we created a software program to reduce the work involved. This then fed the CMMS system we were using which managed this level of complexity in the form of maintenance routes.

In order to develop a manageable maintenance plan, you will need to identify and group these PM tasks together, based on frequency, strategy, skill, and on a physical line of equipment to restrict the impact on the system during a stop inspection (an inspection requiring the equipment to be turned off). Our experience has also shown us that these maintenance routes need to be limited to one person for a maximum of 4 hours per route, otherwise the impact on the system will be too great and the likelihood of completion during a shift will be low. In the baggage system, this resulted in around 1200 planned maintenance routes, which was far easier to manage than individual job cards on every piece of equipment, and could be managed by one planner.

At this point there are a few key items to consider:

- The maintenance plan needs to be flexible:
  - It should allow you to review and enhance the strategy, adding/modifying /deleting tasks or checklist items.
  - It should allow you to review criticality (impacting on the frequency and strategy applied).
- Every time these change, the maintenance routes and any checklists need to be updated to reflect this change in strategy.

Once all of the maintenance routes are entered into the CMMS, you will need to ensure that the risks associated with performing the maintenance are correctly addressed. The generic risk assessments developed during Phase 1 of this process need to be refined given the actual environment in which individual pieces of equipment are installed. This ensures that all risks are identified and people are trained accordingly.

Conclusion

The development of this process allowed us to produce a cohesive maintenance strategy and a comprehensive maintenance plan for a very large system, but the process also holds well for smaller systems. More than enabling the creation of the strategy and plan, it also helped to:

- Determine the manpower needed to support and maintain the system.
- Anticipate the spares consumption for the site for the first 10 years of operation.
- Create the training material used to train the engineers on the maintenance of the equipment.

Overall, the process helped to minimize the operating cost of the maintenance operation from the outset, where we found the maintenance personnel level required was 15% lower compared to similar asset numbers elsewhere in the airport. In addition, since everything was well documented, we were able to perform a review of the applied strategies and the maintenance routes, and refine them as a result of the lessons learned over the first 18 months of operation. We believe that without this process and the tools we developed to support the overall delivery of the maintenance plan, the initial maintenance plans would still be in development, rather than having gone through the first major review and refinement.

Malcolm Hide is an independent maintenance consultant, with over 30 years of experience in maintenance practices and setting up maintenance systems. He started his career in the Steel Industry, where he was ultimately responsible for the redesign of the water cooling system on a blast furnace. He then went on to further his experience in the Oil and Gas Industry where he ran the condition monitoring department, performing Vibration analysis, Oil analysis and Laser alignment on hundreds of pumps, motors, turbines and generators. From there he moved into an abattoir and processed meat factory as the maintenance manager, where he was also responsible for a rebuild of around 50% of the factory while still maintaining the production environment inside the rebuild areas. He then moved on to the BOC group of companies, where he became responsible for monitoring and delivering maintenance best operating practices to their air separation plants worldwide.

Following this, Malcolm joined the team delivering the baggage system for Heathrow Terminal 5, which is made up of over 17km of conveyor systems, over 100 PLCs and in excess of 24,000 individually maintainable items. He was responsible for defining the maintenance strategy, developing the maintenance plan, defining the maintenance team size, setting up all system-related training requirements, and setting up their CMMS. This experience has lead him to developing this process of setting up a basic maintenance plan, which he has now been able to successfully apply on several other sites. The process has reduced the time to implement a comprehensive maintenance plan covering all maintenance strategies significantly. He can be contacted at +44(0)7894 744863 or at malcolm.hide@stratmaint.co.uk and his Web site is www.strategicmaintenance.co.uk.

Power Quality Surges in Importance

PQ is a Major Factor as Facilities Go Green

by Ross Ignall

The demand for productivity improvements in the 24/7 global economy, rising energy costs, and increasingly stringent Federal energy conservation initiatives impacting all areas of business and industry are only a few of the reasons why power quality considerations are seeing a renewed surge (no pun intended) of interest among operators of industrial, commercial and institutional facilities. The simple fact is that variable-speed drives, high-efficiency lighting ballasts, and other "green" improvements are themselves the frequent cause of serious power quality issues that can dramatically impact facility operations in terms of equipment service life, bottom-line profitability, and even safety. This article briefly overviews the fundamental power quality concerns facing today's industrial facility, with an eye to providing a few pointers that facility professionals can use to safeguard their operations while optimizing operational efficiency.

Putting Power Quality in Perspective

Anyone who's experienced a brownout or a mysterious series of control system trips should appreciate how power quality, or PQ as it is commonly known, impacts facility operations. As power travels through the wires and energizes downstream equipment, the quality of the power can be altered, making it less suitable for the next device. These changes in power quality, which can include increases and decreases in voltage and other troublesome manifestations, are especially common in systems-intensive industrial and commercial facilities.

It has been estimated that large industrial customers in the U.S. lose up to $114 billion every year due to under-voltage events and sags, and another $39 billion from power interruptions. The fact that the U.S. electric power system, according to the Galvin Electricity Initiative, is designed to operate at a reliability level of three nines—at least 99.9 percent—still equates to supply interruptions in the electricity supply that cost American consumers more than $150 billion every year.

It may come as a surprise to some, but a significant percentage of the cost and effort of maintaining a company's power supply involves identifying and defeating the problems caused by PQ phenomena interacting (Figure 1) with the building's electrical infrastructure and loads. According to industry sources, half of all computer problems and one third of all data losses can be traced back to the power line. Furthermore, some 30-40 percent of all business downtime is power-quality related. A few of the ways that power quality problems impact businesses include:

- Lost productivity, idle people and equipment
- Scrap
- Lost orders, good will, customers and profits
- Lost transactions and orders not being processed
- Revenue and accounting problems such as invoices not prepared, payments held up, early payment discounts missed
- Customer and/or management dissatisfaction
- Overtime required to make up for lost work time.

Traditionally considered "job one" by every electric utility, simply keeping the lights on is no longer enough for today's automated "high-tech" industrial facility. The fact that most utilities only log outages that last longer than 1-5 minutes tends to gloss over the many momentary interruptions that every facility experiences, and which annually result in millions of dollars in lost productivity for American businesses. Given the breadth and depth of these conditions, it is easy to see how understanding what power quality problems are, how to find them

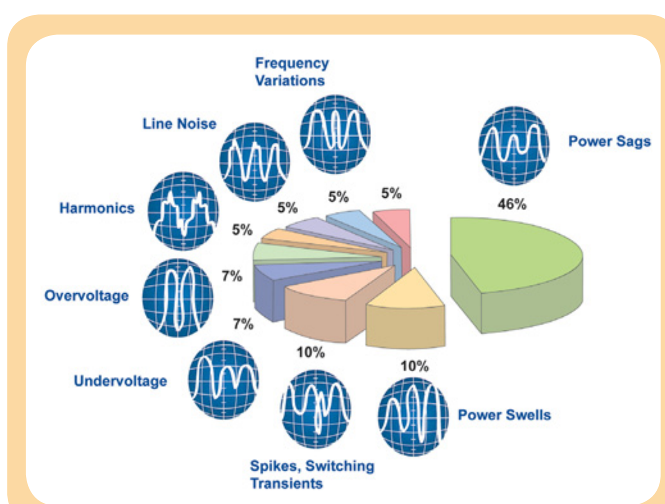

Figure 1 - 2001 EPRI 2001 Study of typical PQ phenomena

and how to solve or mitigate them will continue to gain importance for facility operators, electrical contractors and utility personnel. In general, power quality phenomena fall within the following categories:

- Steady-state events
- Long-duration events
- Short-duration events
- Transient events
- Frequency events

My Friend Flicker and Other Typical PQ Disturbances

Over the years, power monitoring studies have clearly demonstrated that most industrial plants around the country experience up to two dozen power quality disturbances every year that significantly impact plant operations. About 92-98% are voltage sags due to lighting strikes, accidents, animals or equipment failure on the transmission and distribution grid feeding the plant. Also, most are short-duration events of 1-6 cycles corresponding to the clearing time of upstream breakers, fuses and other utility protective equipment.

The most obvious impact of power quality disturbances is reduced uptime of plant equipment and processes that may run into many hours and many thousands of dollars in scrap, lost production and other costly ramifications. The very equipment at the heart of industrial automation—PLCs, industrial drives, motors, robots, servos, CNC equipment and more—are highly susceptible to power quality variations (Figure 2). There is considerable evidence that industrial plants experience at least 10 to 40 power disturbances every year, mainly from voltage sags. Based on voltage disturbance data from industrial plants, voltage sags occur much more frequently than swells, and it is perhaps surprising that current swells accompanying voltage sag recovery are the root cause of most of the equipment damage.

Power quality anomalies are usually characterized in terms of the effect upon the supply voltage and can be broken down into the following major categories:

- RMS voltage variations, short or long duration, include sags, swells and interruptions. Sags, the most common type of PQ disturbance, usually last from 4-10 cycles and are generated within the facility, not by the utility. Swells, formerly called "surges," occur when nominal rms voltage increases to 110 percent or more. Interruptions occur when the supply voltage decreases to 10 percent or less of nominal.

- Voltage transients, also known as impulses, are rapid, short-term voltage increases that are categorized as either impulsive (large, short-term waveform deviation) or oscillatory (ringing signal following initial transient).

- Waveform distortion – Harmonics, interharmonics, and sub-harmonics are mainly caused by phase angle controlled rectifiers and inverters and other static power conversion equipment found in variable frequency drives, PCs, PLCs and other devices employing switching power supplies. Harmonics are defined as integer multiples of the fundamental frequency, for example, 300Hz is the 5th harmonic in a 60Hz system. Non-integer multiples produce interharmonics, for example, 190Hz in a 60Hz system. Sub-harmonics provide frequency values less than the fundamental frequency and are typically evidenced by flickering lights. Electrical noise, caused by unwanted broadband signals that distort the power frequency sine waves, is often generated by switching power supplies and can be aggravated by improper grounding methods.

- Voltage imbalance – In three-phase systems, voltage imbalance occurs when the amplitude and/or phase angles of the three voltage or current waveforms are unequal. According to the DOE, imbalance is probably the leading power quality problem resulting in motor overheating and premature failure. If imbalanced voltages are detected, a complete investigation should immediately be made to find out why.

- Voltage fluctuation – Sub-harmonics in the range of 1-30Hz result in what is generally called light flicker, an amplitude modulation of the power frequency sine wave. Causes are widespread and include arc furnaces, arc welders, resistance welding machines, lamp dimmers, large electric motors with variable loads, HVAC systems, medical imaging systems and many more. Due to its nature, flicker is difficult to characterize and requires PQ analyzers with considerable processing power to characterize its effects measured as Perceptibility short-term and long-term values, or PST and PLT, respectively, as set forth in IEEE 453.

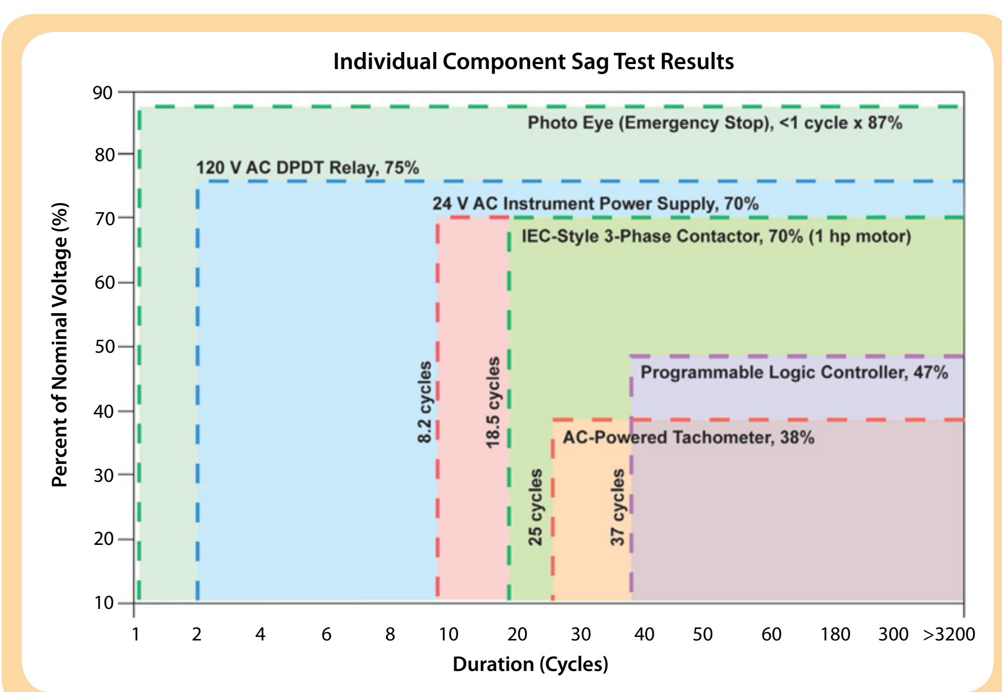

Figure 2. Most equipment is not designed for significant variations in its power supply. This Susceptibility Graph from IEEE Std 1346 shows various types of instruments in terms of their susceptibility to voltage sags based upon magnitude and duration of the sag.

- Power frequency variation – When powered by a back-up generator, UPS, or other alternative power source, maintaining voltage and frequency stability during load changes is of concern, along with making sure the transfer mechanism synchronizes the frequency and phase angle before the switch from back-up to the grid is made.

Wiring and Grounding

Wiring and grounding play a key role in the proper operation of facility equipment and systems. There is much agreement that the majority of PQ-related problems originate within the facility and that the majority of those problems are wiring and grounding related. Grounding systems and equipment are used to limit the voltage imposed by lightning, line swells or unintentional contact with higher voltages. Grounding systems stabilize the voltage to earth under normal operation and establish an effective path for fault current that is capable of safely carrying the maximum fault current with sufficiently low impedance to facilitate the operation of overcurrrent devices under fault conditions. Grounding systems help protect people and equipment from shock and/or damage.

Some of the things to look for in the facility's wiring and grounding are bad or loose connections, missing grounding (safety) conductors, multiple bonds of grounding-to-grounded conductor (neutral-to-ground connections), ungrounded equipment, additional ground rods, ground loops, and insufficient size of the grounded (neutral) conductor. The key components of grounding systems are covered in Article 250 of the National Electrical Code (NFPA 70).

In summary, Table 1 lists six most of the most commonly encountered power quality phenomena, along with their probable causes and typical mitigation solutions.

Domestic and International PQ Standards

One of the most important PQ developments in recent years has been the increasing coordination of standards developed by the IEEE in the U.S. and the International Electrotechnical Committee (IEC). For example, IEEE 1159 Recommended Practice for Monitoring Electric Power Quality complements IEC 61000-4-30 Electromagnetic Compatibility (EMC), which is in force in Europe and most of the rest of the world.

Another important industry standard is IEEE 519 (Recommended Practices and Requirements for Harmonic Control in Electric Power Systems). Early iterations of IEEE 519 established levels of voltage distortion acceptable to typical distribution systems; however, as adjustable speed drives, rectifiers, and other non-linear loads became more common, it became obvious that IEEE 519 needed to be revised and updated to reflect changing industry conditions, especially with regard to the relationship of harmonic voltages to the harmonic currents flowing within industrial plants. The updated standard, IEEE 519-1992, established limits for harmonic voltages on the utility transmission and distribution system as well as for harmonic currents within industrial distribution systems. Other convergences of key elements of IEEE / IEC standards include:

- Voltage Sags and Reliability—IEEE 564 / IEC 61000-2-8
- Flicker—IEEE 1453 / IEC 61000-4-15

Power Quality and Energy Audits

It is not unusual for large industrial and commercial power consumers to see electric bills with demand charges as high as 50% of the facility's actual consumption costs. As an offset, load shedding, peak shaving, installing more

Power Problem	Symptoms (Partial List)	Probable Causes (Partial List)	Representative Solutions
Voltage Sags	Loss of control, data; system shutdown; motor overheating; contact damage; nuisance tripping of ASDs	Weather; fires; trees; animals; people; equipment; large motor startup; undersized distr system	Power conditioning using CVTs; motor generator UPS; stagger motor starts; size infrastructure
Transient Overvoltages	Computer lockups; data loss, errors; component damage; insulation damage; other symptoms similar to above	Lightning; capacitor switching; arching faults; load switching	TVSS; power conditioner with TVSS; UPS with TVSS inductors
Interruptions	All electrical equipment shuts down	Equipment failure; loose or broken power line fittings; safety device tripping	UPS: online, line-interactive or offline; back-up generator
Harmonics	Overheated distr neutrals, xfmrs; voltage distortion-induced timing errors; nuisance-tripping GFRs	Non-linear loads; single-phase computers; electronic power supplies; ASDs	Oversized, dedicated neutrals; K-factor transformers; filters
Electrical Noise (EMI/RFI)	Data errors; monitor noise, wavy screen; process control errors	Motors, welders; improper grounding; electronic devices	Separate loads; isolation xfmrs; proper grounding, shielding; some power conditioners, UPS, TVSS
Wire Grounding	Computer lockups; data loss; component damage; nuisance tripping of GFRs, circuit breakers; failure to operate or misoperation of equipment	Piecemeal work; rapid expansion; obsolete elec dwgs; lack of maintenance; aluminum wiring; high percentage of harmonic loads	Perform wire, grounding survey; use lower-harmonic equipment; regular maint; review entire system

Table 1 - A list of the most commonly encountered power disturbances, along with their probable causes and typical mitigation solutions.
Source: Dranetz

efficient lighting and other energy management strategies go far toward helping facility operators lower their demand penalties. However, before any of these strategies can be implemented, it is necessary to first gain an exact picture of how, when and where their energy is being used. This is the necessary first step to managing it. To that end, handheld power analysis instruments are ideal for facility energy studies and carbon footprint calculations, and for taking forward/reverse energy measurements for grid-tied alternative energy systems.

Energy audits come in many forms and can range from simple applications that monitor a single device or machine, to complex monitoring of an entire campus—and anything between. Regardless of a facility's energy load, most energy audits have much in common. The most important parameters to measure when analyzing electrical energy are typically voltage (V), current (I), watts (W), volt-amperes (VA), volt-amperes reactive (VAR) and power factor (PF). Recorded over time, these basic parameters can provide the necessary information for a complete energy profile.

Voltage and current measurements are used as the basis to compute the other parameters. The parameters can be viewed instantaneous-

Figure 3 - Low-cost energy analyzers like the Dranetz EP1 Energy Platform offer users an un-precedented degree of functionality and flexibility for performing simple to sophisticated energy audits that can be exported into popular software programs.

ly by a variety of instruments, but the key benefit of using an energy analyzer is its ability to record and trend parameters over time. Energy analyzers also compute the demand and energy that utilities use for billing.

What an energy-measuring instrument measures and computes is important, but how it measures can be critical. For example, some inexpensive low-resolution instruments may measure the basic parameters mentioned, but they can miss data and thereby produce false and misleading measurements.

Effective energy-analyzing instruments (Figure 3) should provide a sampling rate that is appropriate for the application while also providing the ability to take continuous readings. Power analyzers typically define sampling rate as the number of measurements taken per AC (60/50Hz) cycle. Because the instrument creates a digital representation of the analog voltage and current being measured, it is generally desirable to use an instrument that provides a higher number of samples per cycle, thus resulting in more accurate measurements of the data being collected.

Users are also encouraged to select an energy analyzer that can measure more than just the basic power parameters, since more advanced parameters may be required to also help understand the quality of the electrical supply, including: voltage and current total harmonic distortion (THD), transformer derating factor (TDF) and crest factor (CF). Additionally, with the advent of alternative-energy applications, parameters such as forward and reverse energy that record the flow of power to and from the grid are often required.

Details of the survey can vary greatly according to the application. The goal of an energy audit is usually to determine the energy profile of the system being monitored. Regardless of application, it helps to know some of the information about what is being monitored, such as the type of load, process or facility. These details are essential for determining the duration of the energy survey.

To obtain a complete picture of the energy profile, it is recommended to monitor several business cycles of the load being audited. For example, an industrial process that cycles (start to finish) every 15 minutes may only need monitoring for approximately an hour to capture multiple cycles and to find out what is usual or typical for that load. An office building cycling on a 24-hour basis may require a much longer survey, such as a week or more, to determine a typical energy profile. A survey replicating a utility bill may require monitoring for multiple utility billing cycles over several months.

PQ Solutions and Strategies

The importance of choosing the right tool to analyze and report the data cannot be overemphasized. But after the data has been analyzed, the next step is to apply the proper equipment or strategy to solve the problems identified by the survey. Solutions for dealing with PQ phenomena can be found under the following general classifications:

- Alternative power sources
- Back-up or standby generators
- Harmonic filters
- K-factor transformers
- Line reactors
- Overvoltage restorers/ stabilizers
- Power factor capacitors
- Power isolation transformers
- Surge-protective devices (SPD)
- UPS systems
- Wiring and grounding

In addition to the above, designing for critical operations is gaining traction in today's digital economy, as well as other high-reliability applications that typically employ several mitigation strategies to maximize uptime to better than "six nines"—or 99.9999 percent—of availability. Although extremely close, this does not guarantee 100 percent uptime, as even highly redundant systems are susceptible to failures or unanticipated problems. In this scenario, permanent PQ monitoring equipment installed in strategic locations will help significantly to determine what happened and what is needed to prevent a recurrence.

For more information on mitigation strategies for mission-critical applications, the National Electrical Code's Article 585 "Critical Operation Power Systems" specifically addresses the additional requirements needed to support vital operations requiring 99.9999 percent availability, including data and communications centers, financial and medical facilities and more.

Benefits of Permanently Installed PQ Monitoring Equipment

Figure 4 - Typical permanently installed power quality monitoring devices.

As opposed to handheld devices, permanently installed power quality monitoring systems (Figure 4) are generally Internet based and allow password-protected access from anywhere in the world. A key advantage of this type of system is the fact that multiple users can simultaneously access the same data, thus allowing the application of valuable input from multiple sources to a given problem. Permanently installed systems can range from a single device up to many hundreds of distributed units, depending on the complexity of the power quality monitoring task. Typical uses include:

- Data acquisition of problematic conditions
- Indication of trends
- Prediction of facility power quality problems

Communications flexibility is an especially useful benefit of the permanently installed system. Not only local and wide area networks (LANs and WANs) are supported, but also land and wireless modems including GSM and GPRS mobile phones. Due to bandwidth issues and other restrictions, however, it is not recommended to employ the latter method when downloading large amounts of data. Most PQ analyzers employ PC-based software programs that provide in-depth analysis of the collected data along with:

- Comparisons of multiple monitoring locations
- Comparisons of current and historical data
- Detailed reportage
- Looking for site trends

Conclusion

Some companies are reluctant to invest in PQ mitigation equipment, either because they lack knowledge about available solutions, or they do not want to allocate funds without a clearly defined return on investment. To help justify the expense, the first step is to determine what the cost of downtime is and how often it occurs. The next step is to determine what is causing the downtime and from that, what solutions are available to solve the problem. The good news for facility operators is that powerful, cost-effective handheld and permanently installed electrical energy monitors and power quality analyzers are now on the market. With the growing emphasis on "green" facilities, instruments from Dranetz and others offer facilities engineers and electrical contractors the ability to monitor, analyze and report on the full spectrum of facility power quality issues impacting the bottom line, as a first step in applying an appropriate, cost-effective PQ mitigation solution.

Ross Ignall is director of product management at Edison, NJ-based Dranetz, the leading provider of intelligent handheld and permanently installed monitoring solutions for electrical demand, energy and power quality analysis. He may be contacted at: (800) 372-6832 or rignall@dranetz.com

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More Than Math

Key Performance Indicators Are Not Just Mathematical Equations

by Tarek Atout

When I decided to write about KPI's, I wanted to see this famous terminology "Key Performance Indicators" from a different prospective. This article will not focus on what KPI's need to be measured in a maintenance organization nor what best practices values are expected, but will discuss how to motivate the principle itself and how to manage the process of developing, measuring, analyzing results and correcting the maintenance process path to achieve the required targets.

Using KPI's is a Management Process

I am sure most of you have heard the famous adage, "what is not measured is not managed." Subsequently, what is not measured will not be controlled, improved or even done. Recognizing this, the objectives of developing the performance indicators should become clear: to be able to manage and only to manage. The intention of KPI's should not be to find someone to blame. If that is the case, then as a manager, you will be the first one to be blamed.

Developing performance indicators for maintenance is a process that starts with the company vision, extends to the objectives of the maintenance division and must be linked to employees' targets in their yearly appraisal. Achieving the best practice benchmark is not an individual effort, but takes contributions from the whole team.

Let's think differently about KPI's. They are not simply mathematical equations or formulas where some numbers are added, multiplied or divided to get the value. Then once the value is calculated, decisions are made on whether this number need to be increased or the numerator and denominator values must be changed. Certainly they can be (and, unfortunately, are) used like that. But that is not where the true value of KPI's lie. The importance is not really the numbers, but what is hidden behind the numbers.

Developing a Key Performance Indicator Process

I have a friend who wanted to reduce his weight. He started reducing the amount of food he ate and doing some random exercises. After few weeks he felt some difference in weight. I asked him how he measured his diet progress. He said, "Now I am able to wear my old pants." After several weeks he was able to wear all of his old clothes, which he thought was great. I advised him to go to a diet specialist to measure his body composition and fitness indicators in a scientific way. The measurements that were taken indicated that he had lost body water and muscles while the percent of body fat remained unchanged. So, after several weeks, he discovered that he was, in fact, measuring his pants and not his body.

It is exactly the same in maintenance, to reduce the fat in the process you have to measure the right things. The purpose is not only to measure but to also know what, how and when to measure.

Let's review two scenarios of developing and implementing the key performance indicators process in a maintenance organization, and how both will impact the work.

1. Shortcut Scenario:

- Management decides to measure the performance of the maintenance department (not the maintenance function).
- Maintenance manager conducts a meeting with his subordinates including maintenance heads for different crafts and the planning head. After a short discussion they select some indicators to be measured starting the next month.
- The planning head is responsible for producing the monthly report that shows poor values for the selected indicators in the first issue.
- Maintenance manager calls for a meeting and invites all the maintenance team, presents the report and starts blaming them for the unexpected values (unexpected from his point of view) and urges them to work hard to achieve the targets in the next month. Meeting is concluded while maintenance team was very surprised, wondering why they were there, what these KPI's are and how to achieve the management goals? Some of them start thinking about KPI's as a ghost or evil spirit that should be feared.
- The following month the report is issued. Some of the indicators improved, some became worst, and no one really knows why the improvement or why the decline.

What Happens In This Scenario?

1. The management team does not communicate the proposed KPI's to the maintenance team; they do not explain or share the objectives, methods and

benefits with the team that is responsible for achieving the targets. Accordingly, the maintenance staff is not aware of what is required and how to achieve it.

2. Management uses the reported values to blame the team, considering them to be the main reason for any shortfalls.
3. The meeting was concluded without any management recommendations or guidelines to help illuminate the road for the team to perform the work.
4. No real analysis was performed to investigate the actual reasons for the poor performance.

In summary, the management enforced the KPI's categories and values without preparing the work environment for such an important practice. Management dealt with the KPI's as mathematical formulas and numbers without taking into consideration the factors that help to improve the results. This process seems to be a show or only for documentation completeness for audit purposes rather than a real desire for success.

This organization may see some random changes in the values due to the efforts of some individuals, but definite and sustainable progress and improvement will not be achieved.

2. Preferred Scenario:

- Management decides to install a process to measure the performance of the maintenance functions in the organization. The maintenance manager conducts a meeting with his subordinates, including maintenance leaders for different crafts and the planning leader. They start by assessing the readiness of the organization for performance measures:
  - ~ Do we have maintenance work processes in place?
  - ~ Do we have a planning / scheduling process in place?
  - ~ Do we have work request / order flow charts in place?
  - ~ Are strategies, policies, procedures and responsibilities published and communicated?

Perhaps the logical conclusion to draw is that if all the above are ready and in place, then all indicators should be at the optimum level. However, that is not necessarily the case.

The documentation may be in place, but it may not necessarily be implemented and/or correctly adhered to. So that begs the questions, "Are there any changes required in the processes or organization?" and "What are the shortfalls in these documents? "

The availability of documents is not enough to assure excellent performance. It is actually the effectiveness of the documents that counts. Of course, the availability of documents is a prerequisite to the measurement process. It is the baseline from where we will move towards our targets. Starting the measurement journey without processes and responsibilities is the same as starting a journey when your vehicle doesn't have a steering wheel.

Back to our scenario:

- The management team selects a set of performance indicators to be tracked; the selected set is a combination of leading indicators that will measure the work process effectiveness, maintenance cost and assets reliability. The selected set is linked to the company business objectives and will work as a catalyst to achieve company vision. Calculations concepts, preliminary target values and data availability have been confirmed before final endorsement. Planning head will be also responsible to issue the report, analyze the results and communicate the output.
- Before start implementing the new process, maintenance manager calls for a meeting where all maintenance staff and representatives from the operations team are invited. The maintenance manager starts presenting the KPI's concept, objectives, targets and the responsibilities of each team member to achieve the required values. Management communicates many important points in this meeting:
  - ~ The objective of the meeting is to share information and communicate the new KPI process
  - ~ The objective of the process is to assess where we are, how to improve and evaluate our success. It is an alert which will allow us to:
    - Evaluate availability and utilization of production facilities
    - Indicate areas for improvement
    - Measure progress after corrective actions
    - Indicate effective use of resources
    - Improve cost effectiveness
    - Eliminate unnecessary work
    - Improve employees training opportunities
    - Add sufficient control to maintenance process
    - Give clear direction to the total organization:
  - ~ The objective is not to blame others and find a victim or guilty party
  - ~ What the impact of implementing KPI's is on both individuals and organization
  - ~ The return on achieving the KPI targets are detailed to attendees
  - ~ The KPI's values, calculation concepts and parameters affecting each indicator are illustrated.
- In the meeting, management listens to concerns, fears and other constraints that may work as barriers in achieving the targets.
- The meeting is concluded to make everyone aware of the process, their role, management expectations and the way forward.
- The following month, the report was issued: management studied the results, analyzed and published the report. A follow up meeting was conducted with all the concerned parties to discuss and agree on recommendations to improve the performance.

What Happens In This Scenario?

1. Management assesses and confirms the readiness for the KPI process implementation before starting. This guarantees a rigid foundation for the process.
2. The selected KPI's are linked to the company vision, business objectives and the individuals' objectives. All constitute a chain and have influence to each other.
3. Calculations logic is well set and understood, so there is no way for different manipulations by different users.
4. Both operations and maintenance teams are invited to the kick off meeting. They are both key players in the process. Maintenance is only one hand, and it can't clap alone.
5. Objectives, methodologies, responsibilities and expectations are clearly communicated to teams; no clouds to block the vision.

6. Analysis, sharing of results and feedback from staff, with management recommendations and actions are well understood to be vital to the process.

The above scenario is an ideal case for a workable KPI's process. This will assure the sustained improvement in the maintenance function.

KPI's Sustained Improvement (Kaizen)

When the process has started, management has to give its full support, ensure control of the process and deploy the proper tools that allow continuous improvement in the KPI's and, subsequently, in the maintenance function to occur. Below are a few quick tips to get the proper output:

– Management holds the main responsibility for process success or failure.

– Management has to promote the concept among the staff. The maintenance team must believe in the value of KPI's. Promoting objectives only related to company vision and business goals is not enough. Staff wants to see individual benefits like how this will reflect on their annual salary increase, bonus or job stability.

– KPI's are developed to measure the success, not to measure the shortfalls. Success is the final destination. Everyone must see KPI's from a positive point of view.

– In the journey to excellence there is no end line, if there is end line. Just like records will be broken in subsequent Olympic Games. If you achieve the preliminary targets, don't stop, there is always something better to do.

– A key element in the process is to assure the data availability, completeness and accuracy. Work process flow and regular data audits must assure the added value of the recorded data.

– Establish a controlled recognition and reward system for best CMMS users and good contributors in the process. Changing the culture of understanding the KPI's is essential, this will create protection against entering false data just to be in good shape.

– Management must be ready with alternative plans to deal with deficient implementation or poor values, the proverbial "what if" scenario. Encouraging and inspiring words are necessary but not enough; you must be ready with practical recommendations.

– Don't be driven by the numbers, but be driven by the analysis results. KPI's again is not just a formula need to balance the numbers. For example;

- Backlog reduction can't be achieved solely by hiring contractors, additional crew or work overtime. These are short term fixes, for a permanent fix think about work process, job estimates, staff organization, performance, utilization and efficiency, training required; otherwise you will be tied with contractors, overtime and illusion of manpower shortage for ever.
- Schedule compliance; think about what interrupts the schedule, you may need to change your maintenance strategies.
- Planning accuracy figure, again review your planning process, planners profile, scope and span.

Finally effective implementation of KPI's is a management process, but output is extremely influenced by staff culture and attitude. You will get the expected deliverable depending on the quality of managing the work process and the staff who work with it. These are leading indicators for the maintenance function indicators. Don't restrict your view to the absolute numbers, they will definitely improve automatically with the proper conditions are in place.

Tarek Atout is currently a maintenance planning engineer with Qatar Gas in their new expansion project. He has 20 years experience in maintenance planning and scheduling in oil and gas industries. Tarek has worked with many international organizations as a consultant in maintenance planning, work management and inventory control, and has worked in many countries in the Middle East e.g. Egypt, Syria, Abu Dhabi and Qatar. He has had planning leadership positions in many industrial organizations where he participated in improving the maintenance planning function by developing the planning process and work management flow and roles and associated performance indicators. His experience also includes CMMS development, implementation and training. Tarek has an excellent record in developing training programs for planning teams in the maintenance organizations to fit with newly introduced best practices. Tarek is a member of the Society of Maintenance and Reliability professionals (SMRP). He can be contacted at tarekatout@gmail.com

Conserve Your Energy

The Benefits of Pump System Optimization

by Roland McKinney

Most process industries depend on rotodynamic pumps to achieve their business goals. Unfortunately in many cases, the approach is to "fit and forget" (at least until a critical repair is needed). There can be severe cost penalties associated with this approach, of which reduced productivity is probably the greatest as well as higher than necessary energy and maintenance cost.

Given that so many processes are dependent on pumps, how can it be that personnel in so many companies spend so little time optimizing their pump systems? The reasons are complex, but amongst the most important is cynicism. In a never ending quest for cost reductions, management may introduce successive new initiatives, such as LEAN, Management by Objectives, Six Sigma, Total Quality Management, Total Productive Maintenance, etc. While each of these can have a valuable impact on a business when well understood and implemented, all too often they are introduced as a "silver bullet" without providing the time and resources to get a proper understanding of the technique. When this happens, the initiative fails and employees view each as the latest management fad, and know that they can wait it out before resuming normal operations. Each poorly implemented initiative boosts cynicism in employees.

Cynicism is the greatest obstacle to the recognition of opportunities. A classic example is the energy consumption bounce following energy saving initiatives. Countless energy efficiency initiatives lose momentum, resulting in an energy consumption bounce, with consumption returning to where it was before the start of the energy efficiency program.

So what can be done to dispel cynicism and to recognize and capture opportunities? First, it is very important to thoroughly understand the system being implemented, whether it is an energy efficiency program or a management technique. Secondly, benefits must be measurable with an implementation schedule developed against quantifiable targets. Third, feedback from implementation must be recognized so that appropriate changes in implementation can be developed. Finally, the costs of implementation must be recognized, and it is this that is probably the most important element in dispelling cynicism. It is pointless for management to implement a new policy and say that no additional funds are available to assure proper implementation – if this happens, it will entrench cynicism not reduce it.

This article illustrates benefits that can be gained from a pump system optimization program. This will help individuals recognize whether or not optimizing pump systems within their process can bring worthwhile benefits.

Generally, optimization leads to reductions in energy use, providing lower operating costs and often it is the anticipated energy cost saving that is used to justify a project to improve a pump system. In fact, benefits extend well beyond energy savings, so savings from optimization programs tend to be underestimated. This can mean that some worthwhile projects are abandoned as they do not appear to meet return on investment hurdles when only cost reductions through energy savings are used.

Energy Management

A comprehensive energy management program should address all significant areas of energy consumption. Pump systems often account for a large part of electrical energy consumption, as shown in Figure 1. In this tissue mill (capacity 25,000 metric tons per year), while most of the installed power was due to tissue machine and rewinder drives, nearly 30% of the installed power was from pump motors.

Although the proportion of electrical power consumption varies according to the process, this example reveals

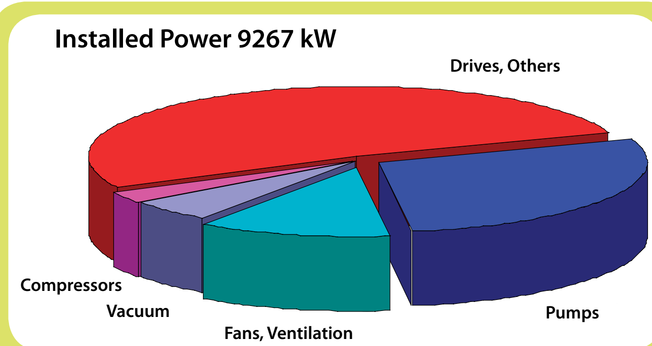

Figure 1 - Pumps as a Proportion of Tissue Mill Total Installed Power

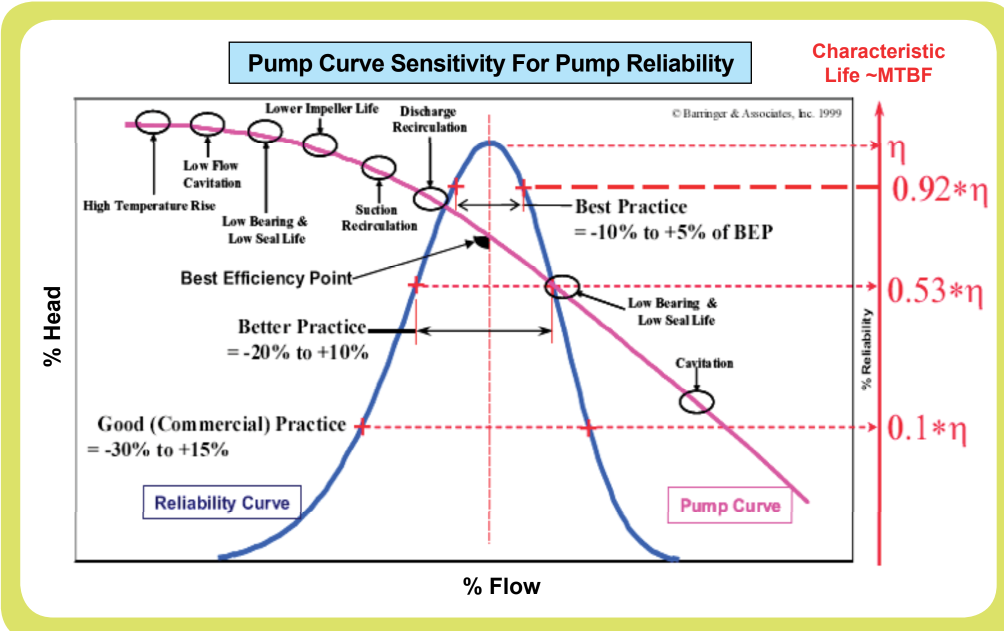

Figure 2 - Mean Time Between Failure as a Function of Flow[1]

the significance of pump electrical power. In this mill, a 10% saving in electrical power consumption in pump systems would have a significant impact on energy costs alone. However, savings would not be limited to energy costs and when promoting pump optimization studies, it is important that all cost savings are recognized.

When a comprehensive energy management program is implemented, some capital must be made available, ideally based on energy reduction targets. For example, if implementation is predicted to reduce energy costs by X dollars in the first year, ideally 50% of X dollars should be made available for energy improvement projects. Assuming that targets are met, a percentage of the savings should then be made available in subsequent years for energy efficiency projects.

Lower energy consumption reduces associated emissions of the greenhouse gas, carbon dioxide. In areas where carbon emissions carry a cost penalty, this ultimately will provide a further cost reduction.

Relationship Between BEP and Reliability

The point at which the highest proportion of energy from the shaft of a pump is transferred to the fluid being pumped is the Best Efficiency Point (BEP) of that pump. At this point, internal forces in the pump are minimized. As the operating point of a pump moves away from the BEP, this energy transfer efficiency falls and axial and radial forces increase. Although some energy loss is inevitable (for instance, friction at wetted surfaces, at seal faces and within bearings) some of the energy that is not being transferred from the shaft to the fluid is wasted. Of this wasted energy, some is lost by internal recirculation within the pump and some as heat or vibration. These are destructive forces, and so the relationship between reliability and energy efficiency is clear – as more energy is wasted, destructive forces increase in intensity, so reliability is reduced.

Research has been carried out into the relationship between the operating point of a pump in terms of its BEP and measures of reliability, such as the Mean Time Between Failure (MTBF). Some results are depicted in Figure 2[1], showing that flow (as a percentage of BEP flow) has a marked influence on MTBF. For instance, if the pump was operating at its BEP, its MTBF is 10 times that expected when the flow is 70% of BEP flow.

The reliability curve shown in Figure 2 is an example of a Weibull probability distribution, and it can be seen that it is skewed in that there is a steeper gradient at flows above BEP, and a longer "tail" at flows below BEP. Weibull analysis is used extensively in reliability engineering to make predictions about a product's life characteristics, such as reliability or probability of failure at a specific time; the mean life, and failure rate. From Figure 2, it is clear that flow rate has a marked impact on pump reliability. When a pump is operating away from its BEP, its efficiency is lower than at BEP so the link between reliability and energy efficiency is simple – an inefficient pump system is an unreliable pump system.

On the basis of anticipated life, maintenance costs at different flow rates can be estimated, and these are shown in Figure 3, based on a typical pump life (η) of 35,000 hours. Maintenance costs at flows equivalent to 70% and 115% of BEP are almost 10 times those when the pump is operated close to its BEP. Maintenance costs are based on those estimated by Dupont[2] from their experience with a chemical transfer pump, a pump rebuild estimated to cost $4,500.

Failure Costs

In addition to higher maintenance costs, the costs of unreliability due to forced shut downs can be high. The cost of unplanned shutdowns vary, and in many cases are difficult to quantify. During a one year survey by International Paper at several of their mills, it was found that in these mills they had 101 pump reliability incidents, at a total of $5 million. Although the value of each of these varied, the average cost per breakdown was almost $50,000[3]. International Paper did not relate reliability with off BEP operation, but this was likely to have been a factor in some of the failures experienced. Assuming this to be the case, and using the MTBF data from Figure 2, allows a value to be placed on failure – where this occurs as a consequence of off BEP operation.

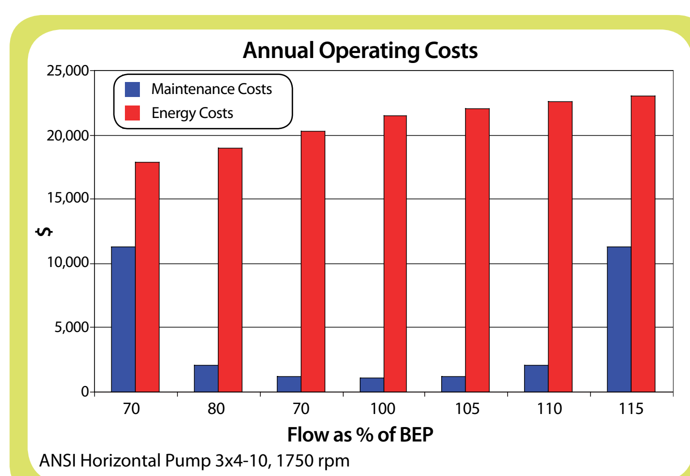

Figure 3 - Annual Maintenance Costs Related to Flow

On this basis, the costs of poor reliability outweigh higher maintenance. And there can be no doubt that an inefficient pump system is a costly pump system.

Relationship Between Energy Efficiency and BEP

Using the same type of pump used to estimate maintenance costs, it is possible to estimate energy costs at different flows, and these are plotted in Figure 3 together with estimated maintenance costs. It can be seen that energy costs are much greater than maintenance costs at all flows, but energy costs fall as flow is reduced, suggesting a better outcome at lower flows. This is simple because lower volumes are being pumped and so even though pump efficiency is low, the energy cost goes down as the volume being pumped declines.

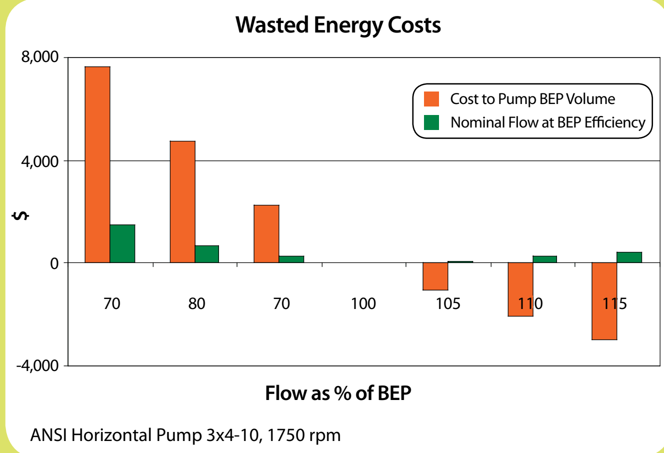

Figure 4 - Additional Energy Costs due to Off BEP Operation

Of course, this lower cost is deceptive and there are several ways to show the energy cost penalty incurred by operating a pump away from its BEP, such as the additional cost to pump the same volume as is pumped over a fixed time period at BEP; or the additional cost incurred through pumping the nominal flow at the appropriate pump efficiency compared with the cost of pumping the same flow at BEP efficiency.

These are both illustrated in Figure 4, expressed as the difference from the energy costs at BEP operation for each option. Due to the lower specific energy (energy needed to pump a specific volume, such as kWh/100000 gals), pumping costs are lower when flows are higher than BEP, which is why the cost of pumping the same volume as that pumped at BEP is negative relative to costs at BEP. However, at flows higher than BEP maintenance costs increase, suggesting it is not possible to take advantage of the lower specific energy at high flows.

Real world situations for each of these conditions are when a discharge valve has been throttled in and is left in this position, so that a pump has to run for extended periods to pump a fixed volume, such as a transfer pump. In the second case, a discharge valve is throttled to reduce flow even though operation at lower speed could deliver the same volume but at higher pump efficiency. This is a very common real world situation.

There are clear differences between these two circumstances, and they reflect the complexity of real world situations and the need for an understanding of the real pump duty before deciding on "efficiency improvements" to a pump system.

Energy use is associated with carbon dioxide emissions, and in many parts of the world there are additional costs due to the emission of this greenhouse gas. This adds to direct energy costs, and so it follows that if energy is being wasted, carbon dioxide emissions and associated charges can be cut by improvements in energy efficiency of the pump system. As this varies so much and is not yet a cost in the USA, this has not been added to the benefits of pump system optimization – but in years to come this will likely become a significant cost associated with energy use.

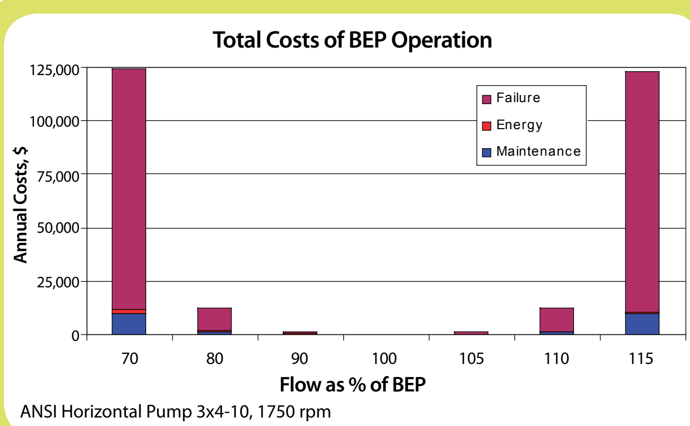

Figure 5 - Total Costs of Off BEP Operation

Total Costs of Off BEP Operation

Having derived costs associated with inefficient energy use, cost of failure and maintenance, it is possible to present an estimate for the total benefits that can accrue from a pump optimization program, excluding the benefit associated from lower carbon dioxide emissions, and this is presented in Figure 5.

Energy costs used in deriving this total were those that would accrue from pumping the nominal flow, but at BEP efficiency. In this specific case, the pump has a relatively flat efficiency curve and so energy costs are low compared with other costs. With other pumps this is frequently not the case, and energy cost savings can be much higher than those shown here.

Although data has been taken from different sources, Figure 6 illustrates the benefits that may accrue from pump system optimization. Each individual case will be different, but it is very important to note that energy savings are only one of a possible range of benefits.

This analysis is largely based on estimates of pump failure rates in Figure 2, and so it is reasonable to ask – what other information is there to support these conclusions?

Reliability Factors

Another way to relate pump reliability to flow rate is through the use of "Reliability Factors". This concept extends beyond flow rate to include other hydraulic factors such as pump speed, suction energy and NPSH margin ratio and these have been discussed elsewhere[4]. The analysis below is limited to flow rate, but this does not imply that these other factors associated with pump reliability are not important.

Reliability factors are non-dimensional numbers used to provide a relative index ranging from 0 – 1 of one attribute as compared to the ideal for that given attribute. A rating of 1.0 indicates this is the

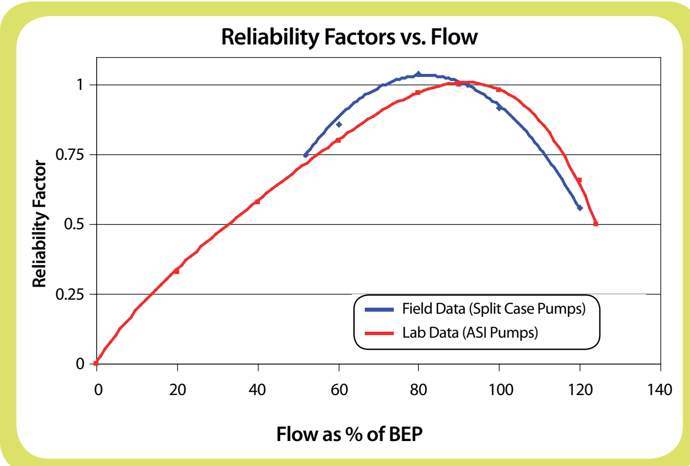

Figure 6 - Reliability Factor as a Function of Flow Rate[4]

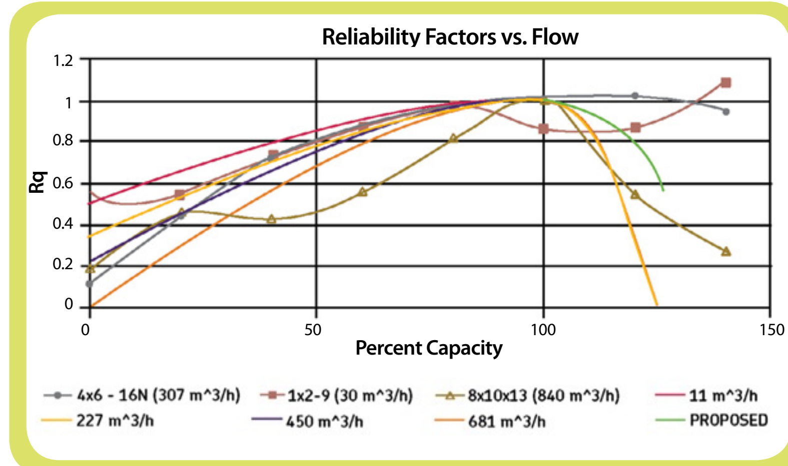

Figure 7 - Reliability Factor as a Function of Flow[5]

best selection possible in terms of that attribute. Similarly, a rating of 0 suggests that this would not be a good selection, but does not indicate zero reliability.

The derivation of reliability factors was determined through both laboratory tests and field analysis of process pumps, and a summary of results is shown in Figure 6. The reliability factors are plotted against flow, as a percentage of BEP.

It can be seen that the shape of the curves are similar to that developed by Barringer and Associates, shown in Figure 2. Note that at low flow rates, the slope of the reliability factor curve is less, suggesting a longer pump life at lower flows. Another difference is that field data suggests an optimum reliability factor at 90% of BEP flow, not at BEP flow, whereas laboratory data suggests the optimum is at BEP. In this case, field data was based on 48 split case pumps in two process plants. It has been shown that reliability factors vary with pump type and capacity, but in general the shape remains similar to that illustrated in Figure 6.

The shape of reliability factors as determined under laboratory conditions is illustrated in Figure 7. The reliability factor was based on impeller vane pass vibration data, with the lowest level of vibration giving the highest reliability factor[5].

During the laboratory studies, 100% pump capacity is at or very close to BEP and the general trend is again clear, with the reliability factor reaching a maximum at capacity (in other words, equal or very close to BEP).

However, there is one interesting inconsistency – for two of the three pumps tested, results showed that at flows above BEP, the reliability factor did not fall sharply. This was suggested by the authors to be due to high NPSHa (Net Positive Suction Head Actual) during the tests. If this finding was confirmed by analysis of field data it could have a profound effect on the selection of a "best operating point", that is, lowest cost operating point. This is because at high flows (above BEP) specific energy is lower, so energy costs can be lower. At the moment, the most economical operating point is assumed to be the BEP. But this data suggests that in fact this may not always be the case, that it may be around 120% of BEP. In other words, it may be cost effective to allow maintenance costs to increase slightly in order to operate with lower energy costs. This finding could also suggest that in order to optimize energy consumption, efforts should be made at the pump design and installation stage to increase NPSHa well beyond NPSHr (Net Positive Suction Head Required).

This approach can also compare the relative costs of maintenance and energy costs, and the additional costs incurred due to off BEP operation. In the case of API pumps, Barringer developed different reliability values, as shown in Figure 8[6], though again this shows a strong relationship between flow and reliability. However, unlike the laboratory data at flows above BEP, the reliability decreases very rapidly with increased flow.

This apparent inconsistency between laboratory-derived reliability factor data and Weibull life derived from field experience may be explained by the fact that few installations provide a situation in which NPSHa>>NPSHr.

After selecting a pump to match the characteristics of one of the laboratory pumps, it is possible to complete the analysis of costs incurred as a function of operating point, as was done previously, and these results are shown in Figure 9. Again, the benefits of optimization are evident: as the operating point moves further away from BEP, the greater the benefits optimization will bring. In this case, the single greatest cost saving is from energy reduction and this increases sharply as the flow decreases. In this chart, the lowest flow is at 70% of BEP but many pump surveys have shown that pumps operate well below 70% of their BEP flow.

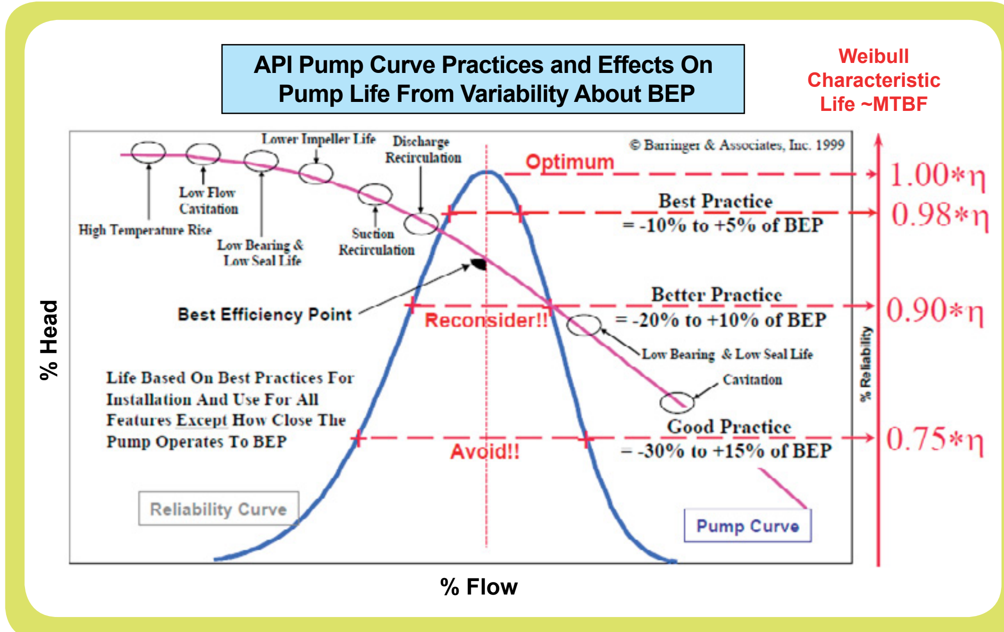

Figure 8 - API Pump Reliability Curve[6]

Although the data suggests that in any optimization program the best operating point should be BEP, this is based on cost savings that can be achieved by moving the operating point closer to BEP and tends to mask other potential benefits. Specific pumping costs (costs to pump 100,000 gal) show a slightly different story, and these are illustrated in Figure 10.

Energy costs are the highest, due to the higher reliability rating for this type of pump. As specific costs fall with higher volumes being pumped, even with the lower pump efficiencies due to off BEP operation, energy costs decline with increasing flow within the range illustrated. This again suggests that the best operating point may not always be at the BEP, as lower energy costs outweigh slightly higher maintenance costs and possibly even failure

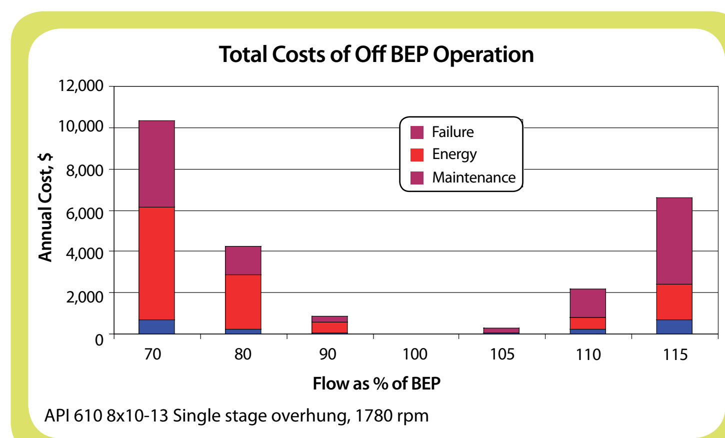

Figure 9 - Total Costs of Off BEP Operation

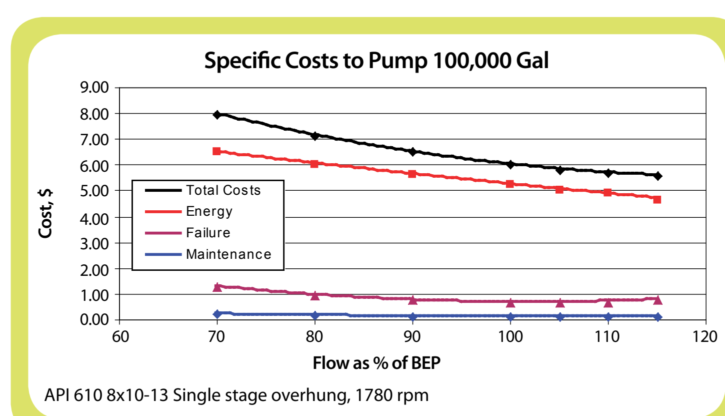

Figure 10 - Specific Pumping Costs to pump 100,000 gal

costs. If it were shown that pumps like this did not suffer from a reduction in reliability at flows higher then BEP when NPSHa>>NPSHr, the trend would be even more evident. In areas where energy costs are high, this trend is also likely to be accentuated. Properly analyzing and selecting a pump requires a confident understanding of the required duty and the cost of failure. The best energy driven business solutions are not always at the point of absolute lowest energy cost.

Internal Wear as a Factor in Reduced Pump Efficiency

Operation away from BEP is not the only reason for reduced efficiency in pump systems, and reasons for this include wear of internal components (through erosion, cavitation, corrosion, etc), increased friction losses in piping (due to partial blockages, corrosion, deposition of calcium carbonate), etc. Many of these changes occur slowly, and so are not easily recognized at a single point in time as having occurred, but they can have a significant impact on pump system efficiency. Opportunities to save energy by replacing or repairing system components are frequently overlooked.

There are many examples of this type of effect in the literature, and one of these is summarized below as an indication of the loss of efficiency that can occur.

In an audit of their pumps, Monroe County Water Authority discovered that many of their pumps were operating below the OEM specifications, often by as much as 20% below the OEM rated efficiencies[7]. One of the pumps had an OEM rated efficiency of 88% at its BEP, but after 6 years in service this had dropped to 77.8%. Mechanical refurbishment plus sand blasting and coating increased the pump efficiency at BEP to 88.5%, equivalent to an annual saving of more than $17,000 at a power cost of $0.085/kWh. The causes of reduced efficiency were mechanical wear and tuberculation on wetted internal surfaces.

Another example is shown by the worn impeller illustrated in Figure 11 – the efficiency of this pump was deteriorated over time and was only detected when the bearing failed. The energy wasted in getting to this stage must have been considerable.

SKF has recently launched a service – "Energy

Figure 11 - A well-worn pump impeller

Monitoring Service - Pump Systems" – that is designed to help pump operators track efficiency, as well as actual operating efficiency relative to BEP. Periodic measurements of pressure, flow and power for each pump being tracked provide the data needed for the analysis, which is completed by SKF @ptitude software. This is based on SKF's Operator Driven Reliability concept and provides plant operators with the information they need to establish the optimization opportunities available within their pump systems. It can be incorporated into any condition monitoring program – and in fact SKF recommend that this should be done, as condition monitoring does not provide all the information needed to assess the health of a pump: energy efficiency is a key component of the information needed.

Conclusions

Pump system optimization provides real opportunities to improve reliability and to reduce costs. There are many tools and training courses available to help provide the knowledge needed to implement a program to realize these opportunities. Where investment is needed to capture the benefit, the full array of cost savings should be estimated to provide a realistic ROI for that investment.

In most cases the best operating point will be at the BEP of the point, but in some specific cases the lowest total operating cost may be at an operating point other than the BEP. Circumstances that may support this include regions with high energy costs or where NPSHa>>NPSHr.

Given that energy costs are by far the largest component of the life cycle costs of owning a pump, more research should be targeted at establishing why some pumps can operate beyond their BEP without an increase in maintenance costs or reduction in reliability and this should include field studies.

Roland McKinney is a Senior Consultant, Environment and Sustainability, with SKF. As a pump system specialist, Roland McKinney specializes in improving the energy efficiency of pumping systems and in training other SKF employees in this and other areas of pump operations. Roland previously spent 30+ years in the Pulp and Paper Industry, working mainly in areas such as the design of paper recycling facilities, tissue production, water and waste water treatment. In many of these roles, Roland was responsible either directly or indirectly for the specification of pumps used in these systems. Roland has wide experience in system start up, having participated in the start up of mills in the UK, USA, Algeria, India and Hungry. He can be reached at roland.mckinney@skf.com

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Out of Sight, Out of Mind

Problems With Dust Extraction

by James Hall

From time to time, I have discussed the process of locating leaks in duct work with ultrasound. I recently had the opportunity to inspect some duct work, so I thought I'd review the basics. All duct work, including that which extracts dust, threads, yarns, coke, coal dust, or any number of other products, must be maintained. Unfortunately, duct work usually receives little to no attention. In many places, duct that is on a roof or outside the plant might as well be invisible. It is simply a case of out of sight, out of mind . . . until there is a problem. Typically the duct we are concerned with is made of heavy gauge steel, so it can rust and become porous, which leads to air and moisture being sucked into the duct.

In the photos that follow, you can see how the duct work appears to be in pretty good shape. You don't see any obvious openings or rusted holes. You do, however, see a number of flanges. With fans blowing the air at high rates of speed, leaking flanges can allow not only air, but moisture into the duct work. In most cases, a good RTV sealant and tightening loose bolts and screws can remedy this problem.

Figure 1 - One of many leaks found around a flange at the Owens-Corning Summit, IL Roofing Plant.

Since Ultrasound is typically capable of hearing a 5 psig leak from .005 opening at 50 ft., it is highly effective in locating these leaks from a distance (Figure 2).

A recent graduate of the Ultrasound Technologies Training Systems (USTTS) Level I Class wrote me regarding his plant's dust extraction system. Mr. Michael McGuire, a PdM Technician with Owens-Corning, Summit, IL, shared his experience regarding water intrusion somewhere in his duct system. I had mentioned in my class about how ultrasound can be highly effective in detecting duct leaks of forced air systems. Michael explained their situation and how they collect dust off the production line (i.e., fiberglass, slate granule dust). The air lock (rotary valve) expels the dust at the bottom of the collector. When moisture enters the system it

Figure 2 - Ultrasound can find leaks at a distance. Note the duct box attaching points, that flange must also be tested for leaks and sealed if necessary.

binds up the dust, and clings to the walls. When this occurs they have to shut down the collector and open access doors to clean out the lower portion. Many hours of labor and downtime were required to perform this fix. After the repairs were made they had some nasty weather. Fortunately, there was no evidence of any more moisture entering the duct work, meaning their fix was a success.

Imagine if your duct work is old and the supporting structure of angle iron is weak. This is especially bad for outside duct work. Duct work out in the elements can collect snow and ice, with the weight of the snow eventually weakening the structure allowing it to bow inward. When this happens, snow, ice, and water sit on the duct. Over time this area rusts and becomes a perfect place for water intrusion.

Inspecting the duct work is as easy as taking an ultrasound instrument and scanning the duct work during operation and listening for air in-leakage. In several of the photos you can see the technicians at Owens-Corning locating their leaks using a UE Systems Ultraprobe 10000 ultrasonic instrument. The Owens-Corning Summit Roofing Plant produces roofing shingles for residential and commercial applications. The plant's products include built-up roofing asphalt, coatings for asphalt shingles, and specialty industrial products.

Figure 3 - Flange after sealant was used to repair leaks found using ultrasound.

Figure 4 - Once leaks are repaired they must be rechecked to assure leaks were repaired properly.

The beauty of the Ultraprobe 10000 instrument is its data-logging capabilities. A route can be made on the fly while scanning the duct work and leak locations given a point ID for follow-up.

Figure 5 - Leaks found at the top of connecting flanges using the Ultraprobe 10000.

This unit can also be frequency tuned to focus in on the in-leakage. Like pressure leaks, the ultrasonic frequency used to scan for vacuum or in-leakage is 38-40 kHz. Figure 6 shows that on Michael's UE Ultraprobe 10000 back panel 38 kHz has been selected to scan for leaks.

Figure 6 - The back screen of the Ultraprobe 10000, which reads 27 db, 38 kHz.

If you are unsure of the frequency, simply hold the ultrasound below your nose. In other words, hold the unit with the scanning module (minus the rubber cone) aimed at your nose. With your hand on the Sensitivity Knob advance the kilohertz setting up or down until you can clearly hear and define the sound of air as you breathe in through your nose. You may be surprised to learn that the frequency selected is between 38-40 kHz. This is also a good practice before walking into a noisy environment to perform an air leak audit using any ultrasound instrument with tunable frequency.

These leaks of course will sound a lot like a pressure leak from an air hose. The reverse of pressure is vacuum or in-leakage. Keep in mind, you are listening for air in-leakage which is going to have the turbulence inside the flange or duct. Therefore, you may want to be close to the duct work or use an accessory such as a long-range horn attachment if your instrument has one available.

Use a rag or glove on your hand when scanning the duct work for leaks around the flanged areas. Use a rubber cone over the receiving end of your unit and your gloved hand, cupping your hand around the front of the cone, moving the instrument slowly while listening for the difference in sound.

Some companies have made a certain module available for close-up work. One manufacturer, UE Systems, Inc., has a Close Focus Module. This attachment gives you a narrow focus of about 25-30 inches, with an increase in amplitude of about 12-14%.

Other companies such as SDT North America has a 31-inch Flexible Wand with an 8-foot pigtail universal cable that allows the end-user to access those hard-to-reach flanges. Great for us guys that barely make the 5'7" mark. No short people jokes allowed.

In some cases using the parabolic dish may be necessary, particularly with duct work over 30 feet away. Be sure when using any of the long-range accessories, these accessories need to be moved slowly and deliberately. Scan as if you are trying to scan every inch of the duct work.

Another option is using the UE Systems, Inc. Warble Tone Generator, or the SDT Bi-Sonic Tone on Tone device. If you have a chance to inspect the duct work during some down-time, you may want to place one of these devices inside the duct work and slowly scan outside, listening for the dedicated sound to penetrate small openings.

These high frequency tone generators emit high frequency sound around 35-40 kHz. Even the smallest of the units can fill approximately 3000 sq. ft. of space. Of course these units are also available in much larger instruments. Some can flood the inside of a Boeing 747 aircraft or the cargo bay of ocean-going vessels.

When using these instruments to flood an area, keep in mind that the sound is carried away from the transducer like a flashlight beam. Let's say you have a main duct that has multiple branches extending off of it. Just as light would only enter the branches a few inches, so would sound. Your sound will not flood those branches, so you would have to put a transmitter inside that branch to leak test it properly.

Another place for water intrusion to occur is around the duct work and flanges close to the ground. As water puddles near a flange that is leaking, water can be sucked from that nearby puddle into the duct. Check your duct for proper clearance between the ground and possible leak points.

Fan assemblies that have service doors or windows which do not shut tightly, have latches that are loose, or a broken or missing door gasket will also pull in air and moisture.

Pay careful attention to long runs of duct (Figure 7). You can see how long this horizontal run is, some 70-75 feet. If not structurally sound, these long horizontal runs can, over a period of time, sag, causing flanges to leak.

Figure 7 - Horizontal runs of duct work must be routinely inspected for structural security as well as for leaks of flanges.

The primary raw materials from which steel is made are iron ore, limestone, and coke. Coke, a by-product of coal, fuels the blast furnace and allows it to reach temperatures ranging from 3400°F to 3600°F, the intense temperatures necessary to make steel. When the raw materials are combined and heated in the blast furnace, iron is "smelted" or separated from the ore, and slag forms from the limestone. The slag floats to the top of the molten iron, where it can be drained, leaving only the molten iron which will be transformed into molten steel. If you happen to be working with an explosive product or a product that is highly combustible such as coke, then you want to use an ultrasound instrument that is Intrinsically Rated (IS). UE Systems, Inc. still makes the Ultraprobe 2000, which is Factory Mutual Rated at Class I, Div I, Groups A, B, C, and D. This is the most comprehensive package of any ultrasound receiver out in the marketplace.

Another reason to scan this type of duct work is the inert gas blown into the system to lower the volatile nature of the coke. Usually, this is a nitrogen charge. Nitrogen can be very expensive. For the plants using nitrogen for this operation, take note of your high cost of nitrogen and think duct work leaks. Again, use an IS-rated instrument for this inspection.

Duct work carrying high temperature air for sterilization or for heating water is very susceptible to rust. I have inspected a number of duct works in plants where the duct work structure was only being held in place with wire or maybe a strap here and there welded to another piece of angle iron. Not exactly the model for efficient duct work.

I was in a food processing plant that transported hot furnace air to manufacture steam and for sterilization. While I was there teaching them how to find leaks in their duct work, I witnessed technicians cutting the fingers from their gloves and stuffing the fingers into holes after globbing RTV sealant onto the fingers before inserting them into the holes to seal them. Not exactly the type of repair I'd recommend.

Duct work carrying tobacco, flour, or the like can be listened to for clogging. I realize that most plants have shakers, or vibrators, that sense a clog and immediately initiate the motor to turn on and shake or vibrate the product loose. However, if your plant is not equipped with a shaker or vibrator, use the ultrasound instrument to take a baseline reading while the product is going through the duct smoothly. The product should sound the same as the baseline reading all the time unless there is a clog.

As you can see by some of the pictures, your duct work can appear to be in great shape. No rust or broken supports. But, air in-leakage can still occur. Find a good sealant approved for the product being blown through the duct and the material out of which the duct work is made, and have it on hand.

Assure your personnel are familiar with how to use the ultrasound receiver. No matter whose ultrasound instrument you use, most will detect an air leak of 5 psig from .005-.050 inch opening at 35-50 feet away in a non-noisy environment. A noisy environment may mean you need to be closer or have an accessory that brings that leak closer to you. You may want to check out what accessories the manufacturer of your instrument has to offer.

All photos courtesy of Owens-Corning Summit, IL Roofing Facility.

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 online presentations at Reliabilityweb.com and is a contributing editor for Uptime magazine. Jim has provided airborne ultrasound training for several Fortune 500 companies in electrical generation, pulp and paper, petrochemical and transportation (marine, automotive, aerospace). A 17-year civil service veteran, Jim served as an aerospace engineering technician for the 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. Jim can be reached at (770) 517-8747 or jim.hall@ultra-soundtech.com

Adventures in Piping Analysis

A Variety of Tools Needed to Locate Problems

by Daniel T. Ambre, P.E.

This article is a vibration case history using Operating Deflection Shape (ODS), Experimental Modal Analysis (EMA) and Finite Element Analysis (FEA) tools and computer animation techniques to solve difficult rotating machinery problems.

Disclaimer

Based on my experience there are very few experts that specialize in vibration analysis of piping and plumbing line applications. At Full Spectrum Diagnostics we get our share of piping problems, but we really can't consider ourselves experts. With piping problems we delve into a world of "rules of thumb," "trial and error," and "tribal knowledge." Now, with that said, let me set the table with some of the complexity associated with this type of analysis.

First of all, piping and plumbing lines will vibrate. They are, for the most part, flexible and under-supported lengths of tube of various diameters. Some lines extend a mere few inches, others can stretch hundreds of feet. It has been my experience that even "identical" pieces of equipment can have drastically different variations in the routing and clamping of their piping. Many piping systems will include routing bends in all three directions, will potentially change diameters and/or thickness, and will include branching somewhere along their paths.

Next, all piping systems will have natural frequencies. Lots of them. All of the design and preliminary analysis in the world cannot eliminate all of these natural frequencies from the most dominant driving sources in the machines to which they are attached.

With all of this complexity, it is rare to come across a system with definitive limits on vibration acceleration, velocity, or displacement. The typical line is only under scrutiny following an unexpected failure. When a failure occurs, the analyst will rarely have a set of baseline vibration readings to compare the repaired line with. The key question becomes, "How much vibration is too much vibration?"

Lacking a set of hard and fast rules for any given piping design, the vibration analyst is left with vibration measurements, and trial and error "Clamping & Damping" to ensure that the repaired system will be trouble-free.

Preliminary Inspections

Before we start redesigning any plumbing line system it's prudent to inspect the system, and if possible compare it to any "sister" units. Some review of maintenance history is a good idea. Any mention of weld repairs, leaky flanges, or offset connections that needed coaxing to come into alignment during assembly (piping strain) can shed light on persistent problems.

A review of the piping clamps to note their locations, tightness, fretting, or damage can be a big help. Keep in mind that most problems develop for a reason. There is likely a root cause in the mix.

This article offers a case history in plumbing line vibration problems to establish a set of guidelines for analysis and maintenance that can assist the vibration analyst in resolving piping problems. The tools at our disposal are vibration analysis, natural frequency testing, and computer finite element modeling. The real key is the ability to "see" the vibrating shape via computer animation and simulation. This is a true case of "If you can't see it, you can't fix it. . . ."

CASE #1 Turbine Generator EH Control Lines

This case history involves critical plumbing lines on a steam turbine generator system in a Midwest power plant. The high pressure steam supply Intercept Valve system on many steam turbines is controlled via Electro-Hydraulic (EH) actuation systems. The plumbing lines contain 1800 psi hydraulic fluid. Any failure of these lines can have the potential to induce a fire and thus are considered very critical.

The line is actually a set of three with similar bends, joints and routing. Two sets of lines are found on each high pressure turbine. The configuration of the lines is similar but different on either side of the unit. An additional note: the line configurations on the "identical" #1 and #2 sister units were NOT the same. The installations appeared to be constructed from a drawing with guideline dimensions and termination points. The actual routing was determined by the original pipefitters.

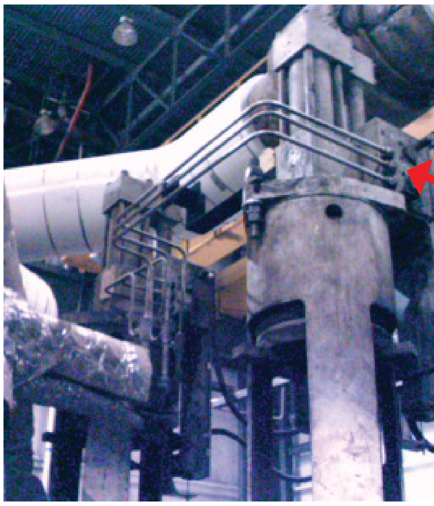

Figure 1 - EH Tubing Lines Unit #1 Steam Turbine

The Unit #1 south side middle tube failure was determined to be caused by High Cycle Fatigue (HCF) issues. The failure location was the termination point on the front of the unit (noted by red arrows in Figures 1 and 2). The line was replaced and put back into service. The on-site vibration analyst was instructed to take some vibration measurements and make an assessment. This was where the problems started. First of all, there was no baseline set of measurements for comparison. Secondly, the line was small (0.500 in) making his standard transducer a bit oversized for the application. The line was also made of stainless steel (non-magnetic). The best assessment formed was that the line was vibrating at very high levels. In fact ALL of the lines were vibrating at high levels.

It was then that Full Spectrum Diagnostics was asked to take a look at the problem. An Operating Deflection Shape (ODS) analysis was recommended due to the fact that the unit could only be tested in an operating condition. The proposed analysis included all three of the lines in the set with the HCF failure, but also included the lines on the back side of the turbine as a comparison point. Note again that the north and south side line configurations were not the same.

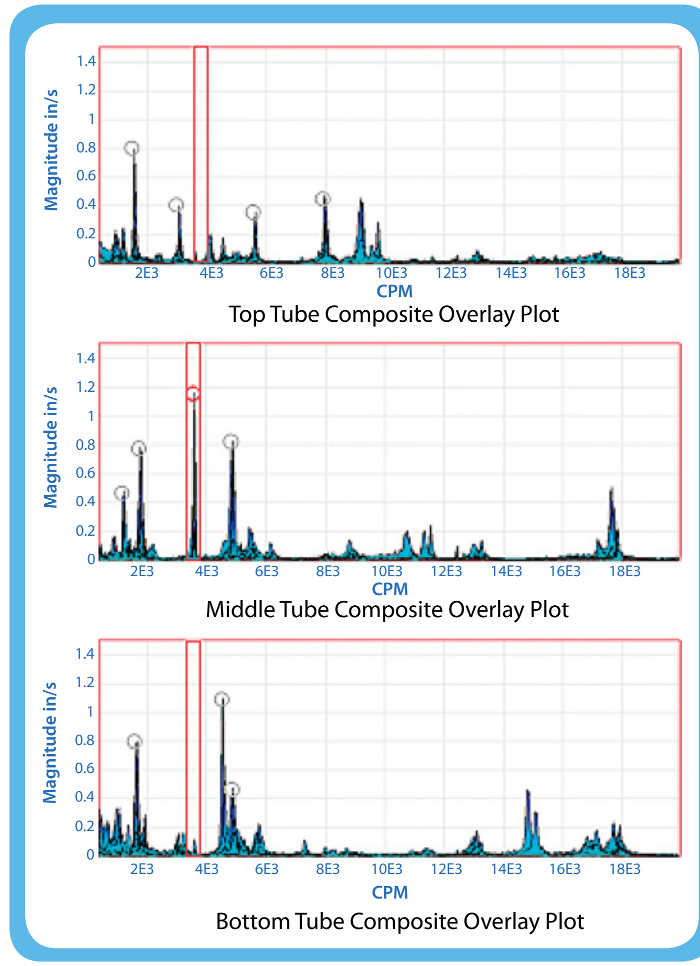

Figure 3 - South Side EH Tubing Spectrum Plots

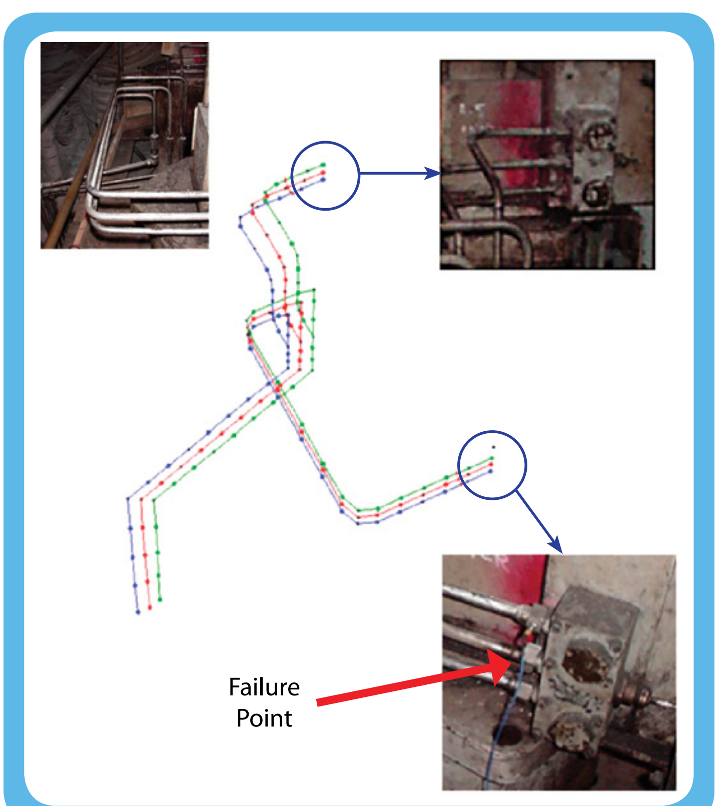

Figure 2 - EH Tubing Animation Model

The vibration signatures showed that the lines were vibrating at levels that would be considered critical if measured on your typical rotating piece of equipment. But remember our first rule: Piping and plumbing lines will vibrate! The vibration signatures included numerous peaks of relatively high amplitudes. Our second rule: All piping systems will have natural frequencies. Lots of them!

The real insight in this analysis comes not from the single measurement, but rather from a fine mesh of measurements along the length of the line system. Approximately 180 measurements were collected on each tube set (see Figure 2). The measurement sets included a response in each of the x, y and z directions. A small "teardrop" accelerometer was used and was clamped in place with a small lightweight spring clamp. See the measurement data in Figure 3. Note the box at 3,600 RPM turbine speed.

A few of the initial analysis hurdles were resolved, including:

1) The ability to collect numerous measurements, instead of a single point vibration assessment.

2) A transducer that was sized for the job.

3) A method of attachment that was convenient and repeatable.

Now, what do we do with all of this data and what does it mean?

This is where Operating Deflection Shape (ODS) comes into play. Normally, a set of Natural Frequency measurements would be helpful, but this unit was not scheduled for a

Tube Set (North/South)	Tube Position (Top/Mid/Bot)	Frequency (CPM)	Amplitude (IPS)
N	TOP	1875	1.370
N	BOT	5250	1.450
S	TOP	1575	0.800
S	BOT	1650	0.800
S	MID	1800	0.800
S	MID	3600	1.190
S	MID	4912	0.700

Table 1 - Data Table for North and South side tube sets

maintenance shutdown for quite some time. The ODS analysis provides the next best thing. Viewing the operating shapes from each elevated peak in the spectrum provides a glimpse into the response of the tubes and an indication of its driving source.

As noted in Figure 3, each tube (Top, Middle, Bottom) had significant vibration amplitude levels. A preliminary comparison of the North and South side tube sets (See Table 1) revealed that vibration amplitude alone is not good a potential failure indicator. The dominant response on the tube that failed (South side Middle tube) was found at 3,600 CPM, the rotating speed of the turbine. This suggested that a potential resonance amplification may be present. The operating condition of the machine did not permit a direct natural frequency test to verify this suspicion.

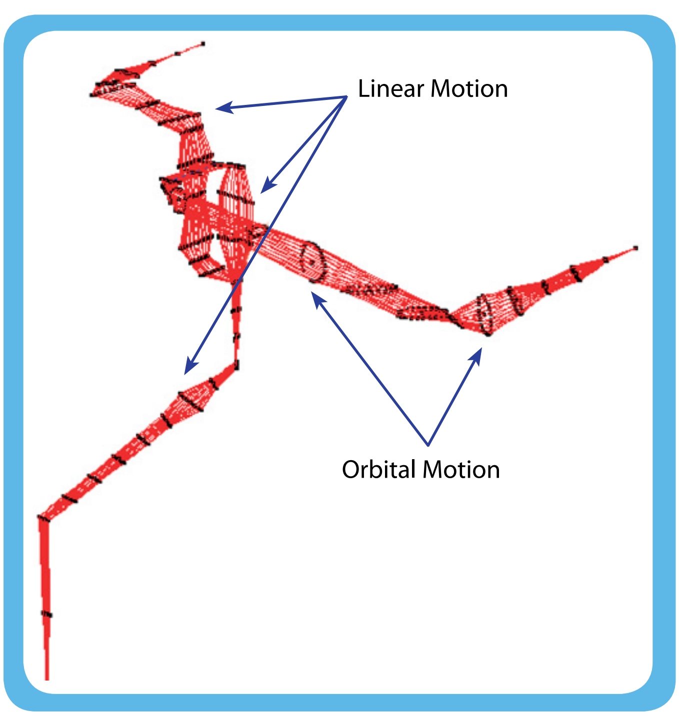

Figure 4 - Persistence ODS Shape @ 3600 CPM

The ODS Shapes of the modes were analyzed next. Remember, piping systems are designed to be flexible. What is of interest is the motions that indicate a classic bending mode shape, or shapes that create a reverse bending motion in the line. This reverse bending motion at a high enough amplitude is a potential HCF driver.

The mode at 3,600 CPM on the South side Middle tube showed an unusual whirling or orbital motion in the longer elbow portion of the line. The image in Figure 4 is constructed in a "persistence" format to show the path of the deflected shape.

The animation suggests two symmetric natural frequency modes are present in the line near 3,600 CPM. These "doublet" type modes share a single natural frequency, but have mode shapes in perpendicular directions about the line of symmetry.

This orbiting motion was suspected to be the root cause of the Middle tube failure at the mount location. When the tube orbits, it produces a multi-axis reverse bending mode at the attachment point(s). Along with an elevated amplitude response, the energy is not dissipated through the flexibility of the line, but rather concentrated at a point where the moment is restricted (in this case at a weld joint).

Even with this analysis, the direct evidence for this line being "resonant" is still elusive. To add credibility to our assumptions, a Finite Element Analysis (FEA) was performed on this line set to better understand the motions. The FEA modes analysis results did show a "doublet" mode near the 3,600 RPM operating point. The two modes at 3,710 CPM (within 3% of operating speed) produced simultaneous perpendicular mode shapes, similar to the operating response.

To resolve the suspected problems near 3,600 RPM, it was recommended that the line be restricted (clamped)

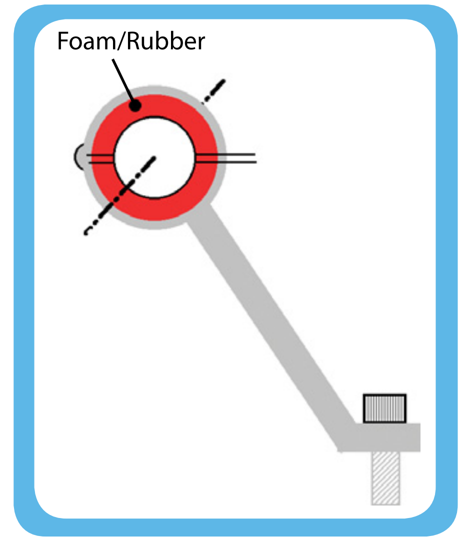

Figure 5 - Potential Damping Clamp Design

at the anti-node location in the center of the tube. The restriction did not need to be a "hard" connection, which might create other problems, but rather, a soft restricting mount constructed to slightly stiffen the tube and at the same time add significant damping to the line (see Figure 5). If the line resonance is moved away from the dominant 3,600 RPM driving frequency (via stiffening) the amplitude of the response should be reduced; and if a softer (foam or rubber) material is used

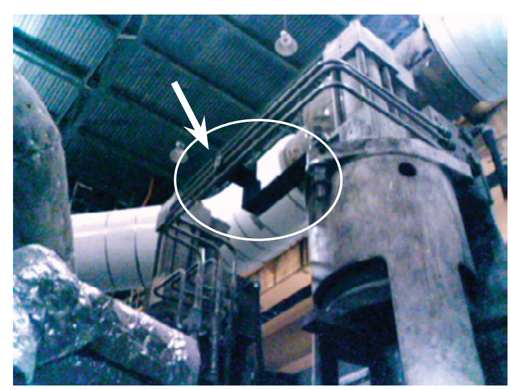

Figure 6 - Tube Clamp Installation

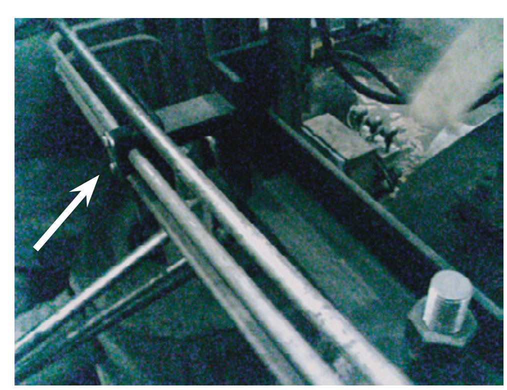

Figure 7 - Tube Clamp with Rubber Insert

within the tube clamp the damping effect should also reduce the amplitude of the response.

The final tube clamp was designed and installed by the customer. The mount arrangement and clamp design is shown in Figures 6 and 7.

The results were dramatic; however, the tubes continued to vibrate at levels that appeared excessive. Again, all piping and plumbing lines will vibrate! Full Spectrum Diagnostics was asked to return to the plant and repeat the original ODS analysis to assess the modifications.

The results were indeed dramatic. Figure 8 shows a waterfall type plot of the piping line data from the original January 2009 measurements and the repeat August 2010 analysis. The overall look of the data is similar with the notable exception to the 3,600 RPM frequency range. The new data shows that the problematic mode was all but eliminated.

Analysis of the other peaks in the data were found to be absent of "reverse-bending" type operating shapes that were suspected to be inducing the HCF problems.

A final note is in order. The hard plumbing lines still produce elevated vibration levels during operation. The goal in this type of analysis is to dissipate the energy of the line via its inherent flexibility rather than concentrate the deflections and moments at a point where those moments are restricted, like a flange or mounting connection.

Some general guidelines can be drawn from this case history.

1) Inspections of the piping system should be performed to determine any deteioration of the existing clamps and mounts.
2) Review maintenance logs for previous failures, leaks, alignment problems, etc.
3) A simple "hand" inspection of vibrating lines can reveal node points (minimal vibration) areas of the line. Existing clamps at node points are not effective.
4) The analyst must have the ability to take the vibration measurements without "mass loading" the test article.
5) The method of transducer attachment must be convenient for taking numerous measurements and reliably repeatable.

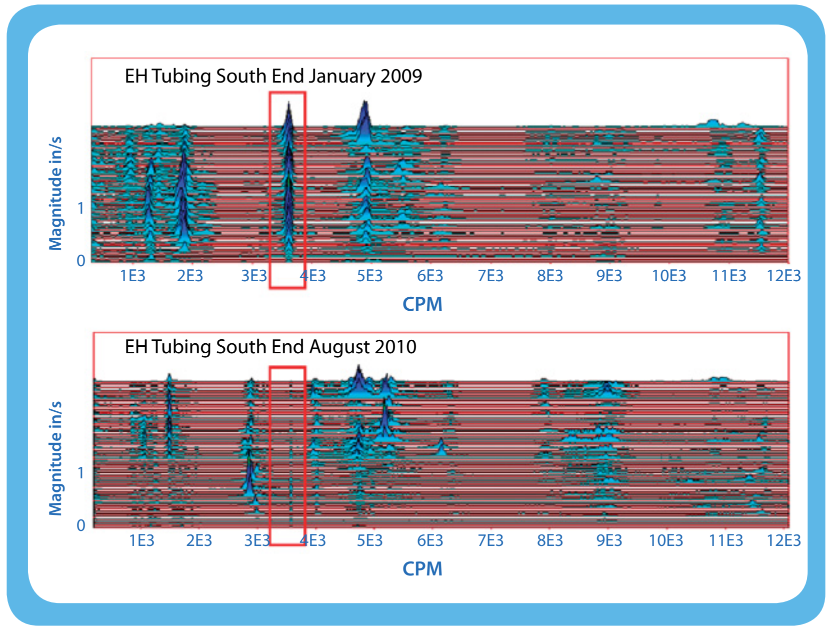

Figure 8 - Before and After Waterfall Plot

6) Vibration measurements must be collected in multiple planes due to the three-dimensional routing configurations of manyline systems.
7) Vibration Amplitude is not the single indicator of plumbing line problems.
8) Amplified peaks near a known driving source should be investigated (rotating speed harmonics).
9) Define potential driving sources: Rotating Speed Harmonics, turbulence, cavitation, water hammer, etc.
10) Plumbing Line Natural Frequencies should be measured directly (impact testing), if possible.
11) Line Resonance should be avoided. Minimal margins should be +/- 10%.
12) ODS animations should not include orbiting or reverse-bending shapes that load fixed points on the line(s).
13) Clamps that add damping as well as stiffness are preferred.
14) Clamps should be used SPARINGLY. Over-clamping lines can eliminate flexibility needed to dissipate energy.
15) The best clamping practice is to collect vibration measurements while installing and adjusting the clamps.
16) Baseline Vibration Analysis surveys on Critical Piping is encouraged. A comparison point is always recommended.
17) Flexible (Braided) Lines can eliminate many hard line problems. Beware of jump rope modes in lengthy flex-line sections.

Finally, the tools required for the computer animation of vibrating systems is currently within the reach of most plant analysts. Even a simple ODS analysis can be performed with a single channel data collector and a sheet of notebook paper. Whatever your method, analysis of plumbing line systems is made easier by making the analysis VISUAL. This format is valuable for the analyst in assessing the problem, and in his explaining the results to a supervisor with little or no vibration analysis background.

Dan Ambre, P.E. is a mechanical engineer and founder of Full Spectrum Diagnostics, PLLC, a full service predictive maintenance consulting company. Dan specializes in resonance detection, experimental modal analysis, and operating deflection shape machinery diagnostics.

Full Spectrum Diagnostics provides a series of vibration analysis level I, II, and III training courses and certification, as well as training in advanced diagnostic techniques. Dan is a certified software representative for Vibrant Technology, Inc., the creators of ME'scope VES software tools. He also provides ME'scope VES software training targeting the field vibration snalyst.

Animations referenced in this article are available via e-mail at modalguy@aol.com. Please visit our Web site at www.fullspec.net.

Simple and effective. That's the way we like our tools. And that is exactly what you get with Trico's newest offering, the....

Opto Laser Level

It's nice when you find a tool that increases efficiency and reduces human error, and does it for quite a reasonable price. The Opto Laser level performs all of the above, and is a nice addition to the family of products from Trico Corp.

With a gazillion Opto-Matic Oilers out there being used in facilities all over the world, it only makes sense to introduce a handy device that simplifies leveling the oilers for better performance. And better performance means higher reliability. We suspect this will be a popular product because companies will see better equipment performance with less time spent leveling the Opto-Matics. Lubrication technicians will also find that the Opto Laser Level just makes their job a little easier.

We tracked down Jay Wilson, Product Services Engineer with Trico Corp, to give us the scoop on Trico's latest new product....

Let's start with you giving us a description of just what the Opto Laser Level is and what is does…

The Opto Laser Level is a quick, convenient and accurate tool used to install Opto-Matic Oilers. It improves installation accuracy, reduces downtime and eliminates confusion. This lightweight, reusable tool fits in your hand. It is made from aluminum die cast and is finished with electro-plated nickel and stainless steel components. The unit is battery powered with a common camera battery that last up to 50 hours of continuous operation, and uses a class IIIA laser beam with a line generator to accurately measure oil level. The unit is calibrated and certified to meet FDA approval of laser devises as well as for accuracy. It is recommended that the unit be recalibrated on a yearly basis.

I'd like you to tell us a story about a piece of equipment. First give us a scenario of what happens without using the Opto Laser Level. Then give us the story when using the Opto Laser Level.

Typical installation of the Opto-Matic Oiler on a centrifugal pump requires a lot of measuring and manual tinkering with the level adjustment assembly to obtain the correct oil level. When using the Opto Laser Level it reduces the installation time of the Opto-Matic Oiler by 2-1/2 to 3 minutes.

What are some of the most common errors and pitfalls you find in oiler installations?

The Opto Laser Level from Trico makes installation of their Opto-Matic Oilers quick and easy.

1. The most common mistakes made are human error, which includes understanding the procedure for measuring and marking the oil level for the Opto-Matic Oiler's lower casting relative to the level within the bearing housing.
2. Incorrectly measuring or not making an adjustment measurement between the upper and lower castings before setting the arms on the level adjustment assembly.
3. Not leveling the lower casting of the Opto-Matic Oiler.
4. Filling the Opto-Matic reservoir to the top with no air gap for oil feed.

During the installation process there are several measurement steps that take place. The first of which is transferring the oil level from bearing/gearbox housing to the Opto-Matic Oiler's lower casting. This is easily accomplished when the Opto-Matic Oiler is in an accessible location, where transferring the marking from the bearing housing to the lower casting is not obstructed and you can actually see how level your straight edge is. However, in more than half the cases you are in a tight space, the piece of equipment that the Opto-Matic Oiler is being installed on is above your head, it is low or has piping and other equipment in the way. These situations make it very difficult for the maintenance technician to accurately transfer measurements and it sometimes comes down to trial by error with the help of a site glass or bulls eye sight (viewport) to help set the Opto-Matic Oiler properly.

When there is no site glass available on the piece of equipment how do you know that all of the steps were done correctly except for going back and repeating the process to double check your work. This is why the laser leveler is a great tool. There is no second guessing, the tool adjusts the level adjusting assembly with the twist of the thumb adjuster, giving the user a visual indication right on the bearing housing where the oiler is set while the adjustment is being made.

All the user has to do after setting the oiler with the tool is remove the level adjusting assembly, lock it in place, and drop the assembly back into the lower casting. As long as you have an accurate oil level mark on the bearing or gearbox housing you can make your adjustments with the laser tool anywhere...high, low or in confined spaces. No measuring or marking is needed.

The two level vials on top of the Opto Laser Level are used for two purposes, to level the casting and to determine how level your projected line is onto the bearing housing.

Also note that after making adjustments, the Opto-Matic Oiler reservoir should be filled and maintained at about 2/3rds full. Many times the maintenance technician fills the reservoir to the top leaving no air gap. This could cause problems in creating an air locked state where oil will not flow.

Please describe some of the impacts on equipment if the oilers are not installed properly…

There are typically two different cases which cause serious impact on lubrication feeding into pieces of equipment. One is during the installation process, the Opto-Matic oiler casting is not leveled properly. Depending on the Opto-Matic Oiler inclination, horizontal or vertical, the oiler may miss-feed, placing excessive lubrication in the housing or starving the equipment bearings. In the field, many of our Service Team Technicians find that the oilers have been improperly installed, or in most cases someone or something has accidently bumped the oiler. This is why PM schedules are critical to follow, not only to check in making sure that oil level is at the correct level but that the equipment supplying the oil is either still serviceable or broken or disturbed.

Improper oil levels are going to reduce the life of your equipment causing early failure and untimely change out of your equipment. This relates to the cost of unscheduled down time.

What kind of impact do you think the Opto Laser Level can have on overall machinery reliability?

There are so many stories that I hear where an Opto-Matic Oiler on a piece of equipment was set incorrectly. Of course, someone thought they adjusted their oiler correctly; but it was actually set incorrectly, resulting in a destroyed pump or bearing causing costly repairs to the company. Many times techs have a 'set it and forget it' attitude to PM or a company's PM SOP's. Techs need to recheck the Opto-Matic Oiler settings on occasion because the settings can easily change due to heat, vibration and good old Mother Nature.

I know it is a time consuming hassle to have to re-inspect your Opto-Matic Oiler periodically. However, instead of taking 5-10 minutes checking measurements, with the Opto Laser Level you can remove the Opto-Matic oil reservoir, drop the Opto Laser Level on and have verification of the oil level in less than 30 seconds. If by chance you need to make an adjustment – within another 30 seconds you are done and on your way. By decreasing the time and making it so easy to inspect your oil levels with this tool, it will increase the frequency of checks and increase reliability of equipment.

Once the maintenance technicians find out how much easier their lives will be with this reliability tool, the Opto Laser Level, everyone and their brother is going to want one.

What is time frame a company can expect for a return on their investment in the Opto Laser Level?

We have been selling Opto-Matic Oilers since they were first patented in 1935 and literally have millions operating in the field today. This project was designed around providing the maintenance technician a very simple, useful and cost effective tool.

The effects of cost savings are dependent on the frequency of installation or oil level rechecks that the maintenance technician performs and the location. I know one location in the nuclear industry where there is an Opto-Matic on every pump and motor within the facility, so about 100-200 units. Given that there is about a 2.5 minute reduction in time savings per installation and given an average worker pay of $15 an hour, ROI would be achieved within 120 installations or rechecks. For the nuclear scenario you have an ROI within one day. This is an explicit cost.

We also have to keep in mind the implicit costs such as time not spent adjusting oilers meaning other PM tasks can be accomplished. It also reduces the chance of injury since there is less need to climb on and around equipment. Accuracy in setting oil levels means less chance of failed equipment by human error.

What are the three top three reasons a company should consider investing in an Opto Laser Level?

This is a very inexpensive tool that helps (1) eliminate human errors and (2) reduces the time in Opto-Matic Oiler setup or readjustment while helping to (3) increase reliability in equipment.

How can interested people get more information about the Opto Laser Level?

Our website has some excellent training videos showing both the manual Opto-Matic Oiler installation and installation with the new Opto Laser Level, explaining in detail the steps for proper Opto-Matic Oiler installation. There is also literature available on the website outlining the benefits of the Opto Laser Leveler.

For more information, please contact Trico Corp at 262-691-9336 or visit www.tricocorp.com

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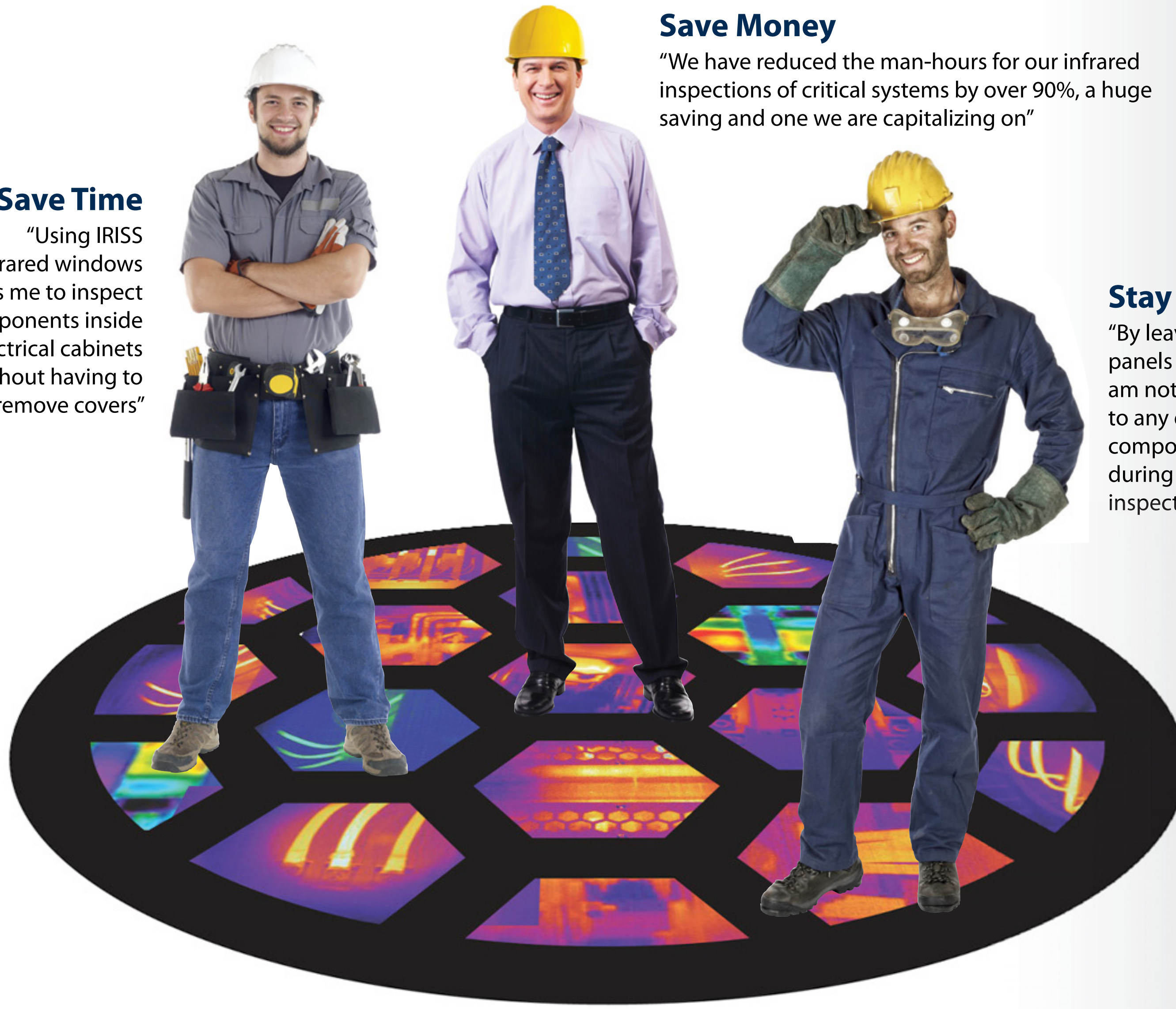

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