uptime®

july 2007

the magazine for PdM & CBM professionals

Correctly Covering the Spectrum of Criticality

Effective In-Storage Maintenance

A Primer on DC Motors

Trial Weights - Where & How Much?

Condition Monitoring Works

www.uptimemagazine.com

Once you get reliability, you can get off the crazy ride!

IVARA
WORK SMART

You arrive at work & fight fires. One day you're a hero and the next, you're taking the heat for unexpected failures. Sounds like you're on a crazy roller coaster ride! Want to get off? Ivara can help.

As a leader in Asset Reliability Solutions, Ivara offers a proven, multi-faceted solution to move your organization from repair-based equipment maintenance to proactive asset care.

Our reliability experts are well-known and -respected. They provide insight into the processes and practices you need to improve and sustain equipment reliability.

And our unique WorkSmart implementation methodology and unparalleled reliability software Ivara EXP, have helped many capital intensive companies to:

- increase production throughput by 14%
- increase machine efficiency by 5%
- extend asset life by more than 60%
- capture the knowledge of their aging workforce
- reduce environmental & safety risk

Attend Ivara's Reliability Leadership Summit, Sept. 17 - 20, 2007, Las Vegas

Whether you're new to reliability or well on your way to operational excellence, Ivara's Summit will provide you with the tools you need to accelerate your journey.

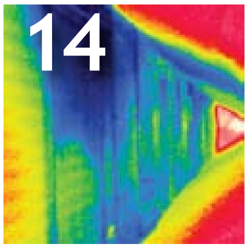
Attend the Summit to meet reliability experts and leaders, hear dynamic keynote speakers and listen to exciting case studies that prove reliability delivers breakthrough performance and measurable results.

This year's Summit offers:

- Dynamic keynote speakers including Terry O'Hanlon, publisher of reliabilityweb.com and Stephen Thomas, author of Improving Maintenance & Reliability through Cultural Change.
- Unique plant simulation tours that offer all the great value of a plant tour without the long drive to the plant.
- Reliability workshops delivered by renowned experts including Ricky Smith, Stephen Thomas, Al Weber and others.

Register Today! Call 1-877-746-3787 ext. 312

Complete details at http://summit.ivara.com

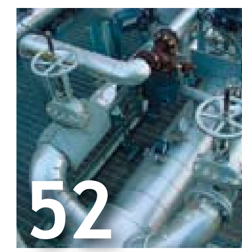

14

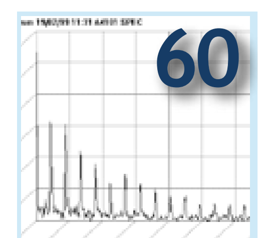

18


22


42


4


52


60

upfront

Don't Miss It

It's time.

Time to mark your calendars, and to set aside the dates of September 11th-13th. Why? Because those are the dates when the only independent conference focused exclusively on Predictive Maintenance and Condition Monitoring is taking place. PdM-2007 in Las Vegas is the place to be in mid September.

If you are involved in planning, implementing or using a PdM or CBM program, PdM-2007 promises to be an event well worth your while.

Best practices show that up to 50% of your maintenance activity should be performed, not according to an ineffective time-based schedule, but according to the condition of your machinery. The challenge is in finding and implementing the right combination of predictive maintenance and condition monitoring technologies. By doing so, you will actually lower your maintenance costs. That's right, effective condition based maintenance programs are less costly overall than inefficient reactive maintenance programs.

A plethora of informative sessions, workshops, the 2007 Uptime PdM Program of the Year winners, and a true community of PdM experts and practitioners will all come together to create a truly unique learning atmosphere.

PdM-2007 provides an excellent opportunity to broaden your knowledge of PdM and Condition Monitoring. It sold out last year, so registering early is a good idea.

In this issue, the feature article by Rob Bloomquist tackles an issue that everyone who uses PdM, at one time or another, has faced. What level of condition monitoring is appropriate for machinery that is not necessarily critical, but is not inconsequential either? Rob provides a process to determine, in quantifiable numbers, whether the investment in condition monitoring for a specific component or system is worth making or not. It's good stuff and, hopefully, can help you determine where to direct your valuable, and limited, resources.

Thank you for reading. We hope you find something of value within these pages. 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

uptime®
volume 2, issue 21

PUBLISHER
Terrence O'Hanlon

EDITOR IN CHIEF
Jeffrey C Shuler

ADVERTISING SALES
Bill Partipilo
888-575-1245 x 114
sales@uptimemagazine.com

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

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

SUBSCRIPTIONS
to subscribe to Uptime, log on

www.uptimemagazine.com

Uptime® (ISSN 1557-0193) is published monthly by Reliabilityweb.com, PO Box 60075, Ft. Myers, FL 33906, 888-575-1245. In the U.S. Uptime is a registered trademark of Reliabilityweb.com. No part of Uptime may be reproduced in any form by any means without prior written consent from Reliabilityweb.com.
Uptime is an independently produced publication of Reliabilityweb.com. The opinions expressed herein are not necessarily those of Reliabilityweb.com.

Finding the Right Fit

Across the

Cost/Benefit Analysis of Condition Monitoring Solutions Using FMEA-based Methods

by Rob Bloomquist, P.E., CMRP

One key challenge faced by reliability and maintenance managers is determining the appropriate level of condition monitoring technology for plant equipment assets which are in the middle of the spectrum from an overall criticality standpoint. The majority of plant assets, typically low horsepower and less critical machinery, are commonly monitored with portable, predictive technologies. Similarly, it is an easy decision to select on-line condition monitoring solutions for large horsepower equipment that are highly critical to plant operations. The quandary, often, is determining the appropriate level of condition monitoring for assets that lie somewhere in between these two classifications.

Typically, criticality ranking is used as one criteria in the development and implementation of preventive and predictive programs over a large population of assets. Safety and environmental factors alone often provide the justification needed to make the case for a particular condition-monitoring solution. However, when safety and environmental considerations are not an overwhelming concern, a true cost/benefit analysis may be helpful to support the business case for the right condition monitoring technology for assets that fall in the middle of the criticality spectrum. This article will demonstrate Failure Mode and Effects Analysis (FMEA) based methods for cost/benefit analysis of condition monitoring solutions for specific assets and groups of similar equipment that fall into this category. These methods, especially when performed in conjunction with RCM analysis, help answer key questions about whether or not a proposed condition monitoring solution is both technically feasible and worth doing.

The Criticality Spectrum

Virtually every industrial operation relies on equipment assets considered critical to their process. Some of these operations involve large horsepower machinery and fixed assets that have significant impact on plant output, and represent high repair costs or safety considerations, in the event of a failure. For these assets, continu-

e Spectrum

of Machine Criticality

ous monitoring of equipment behavior and condition indicators with fixed transducers and on-line protection systems have been considered best practice for decades. With a dedicated channel of monitoring for each transducer, continuous systems not only provide protective functions but enable in-depth analysis of measured parameters and diagnostics capabilities. Original equipment manufacturer (OEM) recommendations, end-user best practices, industrial insurer guidelines, and standards such as API 670 have all served to reinforce these applications as standard practice for critical assets. In addition to on-line continuous monitoring, best practices for critical assets also incorporate periodic off-line techniques such as lube oil analysis, infrared thermography, motor current analysis, and others.

Toward the other end of the criticality spectrum, but still above the threshold at which a "run to failure" strategy might be considered, collective groups of smaller horsepower general purpose machinery and fixed assets are commonly managed with programs that apply these "portable" predictive technologies as the primary strategy. On a periodic basis, data is collected and analyzed with the aid of portable vibration data collectors, infrared thermography cameras, lube oil sampling and testing, ultrasonic detection equipment, and other techniques that provide indications of asset condition at relatively low cost per point when applied across a fair sized asset base. Benchmark data from a variety of industries offer proof that predictive maintenance programs, when properly designed and integrated with operations and maintenance activities, pay out significant and recurring dividends.[1] One main reason for this is that maintenance performed as directed by machine condition is generally more effective and efficient than maintenance that relies exclusively on time-based and reactive strategies.

The Need for FMEA-Based Cost Justification Methods

For equipment assets that fall in between these two classifications, the appropriate level of condition monitoring may not be as clear a choice. A good question to ask when evaluating a potential solution is "what is the expected return-on-investment and payback period?" The following discussion on FMEA-based cost justification methods is offered to help answer this question.

ASSET ID	Date Out of Service	Downtime (Hours)	TBR (Hours)	Cumulative TBR (Hrs)	Event	Maintenance Cost of Repair	Operations Cost of Repair	TOTAL COST	What was Repaired?
C101	09/08/2001	38	634	634	21	$4,388	$33,250	$37,638	Packing Gland
C101	10/06/2001	85	251	885	22	$9,816	$74,375	$84,191	Cylinder & Valves
C101	10/20/2001	146	694	1579	23	$16,860	$127,750	$144,610	Cylinder & Piston Rings
C101	11/24/2001	36	900	2479	24	$4,157	$31,500	$35,657	Valves
C101	01/02/2002	34	1502	3981	25	$3,926	$29,750	$33,676	Valves
C101	03/07/2002	18	534	4515	26	$2,079	$15,750	$17,829	Valves
C101	03/30/2002	26	22	4537	27	$3,002	$22,750	$25,752	Valves
C101	04/01/2002	10	1406	5943	28	$1,155	$8,750	$9,905	Head Gasket leak
C101	05/30/2002	24	72	6015	29	$2,772	$21,000	$23,772	Valves
C101	06/03/2002	10	2990	9005	30	$1,155	$8,750	$9,905	Valves
C101	10/06/2002	6	522	9527	31	$3,389	$5,250	$8,639	Valves
C101	10/28/2002	6	978	10505	32	$3,389	$5,250	$8,639	Valves
C101	12/08/2002	66	246	10751	33	$37,279	$57,750	$95,029	Valves
C101	12/21/2002	34	1142	11893	34	$19,204	$29,750	$48,954	Valves

Figure 1 - CMMS Data Showing Failure Cost History

Most successful maintenance and reliability programs have developed comprehensive criticality rankings for all the assets in their facility. Typical factors used in criticality determination are potential impact given a failure on:

- Safety
- Environment
- Production
- Costs
- Product quality

What usually results from this exercise is a list of assets ranked in terms of relative criticality using an arbitrary scale such as 0 to 10, A/B/C, or other alphanumeric scheme. These rankings are typically used to prioritize direction of limited asset management resources (both people and technology) to where they will have the most impact. Though these rankings may incorporate numerical scoring and can be roughly linked to actual quantities such as cost, they are for the most part qualitative, meaning the numbers are determined based on subjective interpretation of characteristics relative to established ranking criteria. This is entirely appropriate when the task at hand is to determine relative criticality of several thousand individual pieces of equipment as efficiently as possible.

Criticality scores developed this way, however, typically lack accurate and reliable detail that can support a quantitative or "absolute" determination of risk in terms of true event probability and severity expressed in financial terms. A more scientific analysis that determines annualized financial risk or probabilistic cost is therefore helpful for those cases where cost/benefit analysis is needed to evaluate feasibility of potential solutions.

The need for cost/benefit analysis is also an important part of the Reliability Centered Maintenance analysis decision making process. Proactive measures, including application of condition monitoring, must be both "technically feasible" and "worth doing"[2]. A solution must be effective at reducing risk and costs to an adequate degree, and capable of yielding benefits that will outweigh the costs to implement it. By applying concepts from FMEA to help us gauge the degree of risk mitigation that can be achieved by a potential solution, and employing those results in the cost/benefit analysis equation, we can answer these questions with much more certainty.

Quantifying Costs and Risk

The remainder of this article will examine how to express risk as probabilistic cost, determining the level of risk mitigation that can be achieved by applying condition monitoring solutions, and weighing these benefits against solution implementation costs in a true Net Present Value cost/benefit analysis.

Costs and risks that an asset poses to a business, in financial terms, can be derived with several different methods:

Method A – Historical Data

If historical data is available in a Computerized Maintenance Management System (CMMS) that has enough granularity to link lost production and maintenance costs to specific failure modes, then probabilistic cost determination can simply be an extrapolation of the actual cost history of a specific asset from a data set such as the one shown in Figure 1.

Costs from the table can be easily sorted by failure type and converted into equivalent annual cost values that can be used in a Net Present Value cost/benefit analysis of potential solutions.

Method B – Published Reliability Statistics

When cost history is not available because accurate records have not been kept or perhaps the plant is not yet in operation, annualized risk, in financial terms, can still be estimated using reliability statistics compiled by a variety of industry user groups and available in a number of published sources.

Risk is defined as follows:

$$\text{Risk} = \text{Probability} \times \text{Severity}$$

Where:
Probability = the statistical likelihood of the event occurring
Severity = consequences of the event should it occur

Probability is a percentage value which represents the statistical likelihood that an event will occur within a defined mission time. This can be calculated from the formula:

$$\text{Probability} = 1 - e^{-(t/MTBF)}$$

Where:
MTBF = Mean Time Between Failure
t = mission time

For simplification, in the above formula we are assuming a random failure distribution i.e. failures are not run-time dependent. However for failure modes that are strongly time-dependent, such as infant mortality or wear-out, Weibull parameters Eta and Beta should be used in the exponential function as shown below to provide more accurate failure probability calculation for a given

Failure Mode	# of Assets	Annual Operation (Hours)	Lost Production	Repair Cost - Parts	Repair Cost - Labor	MTTR (Hours)	MTBF (Hours)	Annual Failure Probability (Single Asset)	Annual Exposure
Motor - Stator Winding Failure	4	7,500	$15,000	$3,000	$2,500	75	60,000	12%	$9,635
Motor - Bearing Failure	4	7,500	$4,800	$400	$600	24	45,000	15%	$3,562
Pump - Seal Failure	4	7,500	$6,400	$1,200	$1,250	32	15,000	39%	$13,929
Pump - Bearing Failure	4	7,500	$5,200	$500	$800	26	35,000	19%	$5,015

Figure 2 - Calculating Annual Risk

mission time:

$$\text{Probability} = 1 - e^{-(t/\eta)^{\beta}}$$

Where η = characteristic life
β = shape parameter

Because values for reliability metrics can vary widely, some published reliability databases present MTBF and Weibull parameters as upper and lower percentile values as well as mean values. The upper and lower percentile values typically represent the 5% and 95% percentile points within the range of database values. Since 90% of the database values fall between these two limits, reliability calculations that use both the upper and lower limits will yield a range of probability corresponding to a 90% confidence interval or 90% certainty.

The Severity factor as used in the Risk definition above, can be expressed in financial units. This is the severity or expected cost to the business in lost production, labor, repair costs, fines/penalties, and lost product quality that will result if a failure occurs undetected. If mission time used in the probability calculation is one year, then multiplying Severity x Probability yields the annualized risk or probabilistic annual cost posed to the business by that asset or group of assets.

When quantifying costs and risks associated with an asset or group of assets, it is best to look at dominant failure modes independently. This is because each failure mode will have its own associated probability and severity. The example in Figure 2 was derived from analysis of four motor-driven pump sets that have an intermediate level of impact on plant production. Probability of failure in any given year (mission time = operating hours required in 1 year) were calculated independently for a short list of dominant failure modes using MTBF statistics compiled from several sources. Mean Time to Repair (MTTR) statistics were used to estimate lost production and labor repair hours. Multiplying the probability values by the sum of expected costs for lost production, labor, and parts associated with a potential failure yields the probabilistic cost, or annual exposure, these assets pose to the business.

Please note several assumptions were used in this example to keep the calculations relatively simple. First, random failure distributions (Weibull parameter Beta = 1) were assumed, meaning probability of failure is not time dependent and is basically the same from year to year. This will not be the case given failure modes that exhibit strong infant mortality or wear-out characteristics. Also, mean values for MTBF were used; upper and lower limit values representing the 5% and 95% percentiles could also have been used, if available, yielding a range of annualized risk

Occurrence Factor		Failure Rate per 1 x 10^6 Hours
1	Low	<50
2		50-100
3		101-150
4		151-200
5	Moderate	201-250
6		251-300
7		301-350
8		351-400
9	High	401-450
10		>450

Figure 3 - Occurrence Ranking Scale

System or Asset:	Pump Set		Customer:				
Asset or Component:	Motor and Pump		OWM:				
Level:	Dominant Failure Modes		FMEA Date/Rev:				
Description	Function	Failure Mode(s)	Effect(s) of Failure	SEV	OCC	DET	Initial RPN
Motor	Convert Electric Power to xxx HP of Rotational Energy	Stator Winding Failure	Short to Ground, Motor Trips, out of service for ~ 3 days	8	2	9	144
Motor	Convert Electric Power to xxx HP of Rotational Energy	Bearing Failure	Bearing Seizure, Motor Trip on over-amps, out of service for 24 hours	3	3	8	72
Pump	Pump Fluid at xxx GPM	Seal Failure	Fluid Leakage, EHS Riskout of service ~ 1.5 days	5	8	7	280
Pump	Pump Fluid at xxx GPM	Bearing Failure	Bearing Seizure, possible motor trip, pump & impellor damage, out of service ~ 1 day	4	4	8	128

Figure 4 - Abbreviated FMEA for Dominant Failure Modes on Pump Set

representing the 90% confidence interval. Financial considerations due to safety/environment ramifications could have been included, but did not apply to this example.

Method C – Team Input

When cost history or reliability statistics are not available, another method can be employed which uses the collective input from team members based on their experience to identify dominant failure modes and determine expected costs associated with them. Cost ranges are determined for three classifications of failure such as "minor", "moderate", and "severe" in terms of lost production, parts, and labor. Failure modes are ranked by the team in terms of occurrence, then the three cost classifications are assigned to each failure mode with weightings determined by the team. Completing the math exercise by multiplying out the values and weighting factors yields an annualized cost for each of the identified failure modes which reflects the collective team input.[3]

A variation of this method which also relies on the collective experience and input of team members can be used to estimate repair times. Three time ranges are determined by the team, and probabilities are assigned to each time range for each failure mode.[4]

Developing Improvement Factors

Now that costs and risks from dominant failure modes have been determined and expressed in annualized values, the next step is to estimate as accurately as possible the level of improvement that can be expected based on the ability of recommended solutions to mitigate risk. The Risk Priority Number (RPN) concept commonly used in FMEA can be employed in a before/after analysis to determine an Improvement Factor for each failure mode analyzed.

RPN = Occurrence factor x Severity factor x Detectability factor

Where:
- Occurrence factor describes the relative frequency or likelihood of an event, essentially related to MTBF
- Severity factor describes the relative severity of the event
- Detectability factor describes the relative ability to detect the event in advance

The RPN calculation is similar to the Risk expression described earlier, except a third factor Detectability is now used as a modifier. Detectability factor is a gauge of how well we can detect the event in advance and reduce consequences through timely action. This makes use of the Severity factor more straightforward, ranking it based on consequences of an event left undetected.

A generic ranking scale of 1 to 10 is commonly used for each of the three RPN factors with 10 being highest risk, but the scaling can be customized to meet specific needs of the organization or particular analysis. The ranking scale used should be cross-referenced with actual physical quantities when possible such as in the example Occurrence Rating Scale in Figure 3. An important note to make at this point is that Improvement Factors are a dimensionless ratio calculated by dividing an initial risk or RPN value by the final or expected RPN value for a particular failure mode. To remain valid, the calculation requires that ranking criteria are applied consistently throughout the analysis. Also, the ranking scale should be designed so that a proportional change in one of the RPN factors equates to the same proportional

System or Asset:	Pump Set		Customer:					Lead Engineer:					
Asset or Component:	Motor and Pump		OWM:					Team Members:					
Level:	Dominant Failure Modes		FMEA Date/Rev:										
Description	Function	Failure Mode(s)	Effect(s) of Failure	SEV	OCC	DET	Initial RPN	Recommended Corrective Actions	SEV	OCC	DET	Revised RPN	RPN Ratio
Motor	Convert Electric Power to xxx HP of Rotational Energy	Stator Winding Failure	Short to Ground, Motor Trips, out of service for ~ 3 days	8	2	9	144	On-line scanning condition monitoring of vibration,motor phase current	8	2	8	128	1.13
Motor	Convert Electric Power to xxx HP of Rotational Energy	Bearing Failure	Bearing Seizure, Motor Trip on over-amps, out of service for 24 hours	3	3	8	72	On-line condition monitoring of vibration	3	2	2	12	6.00
Pump	Pump Fluid at xxx GPM	Seal Failure	Fluid Leakage, EHS Riskout of service ~ 1.5 days	5	8	7	280	On-line scanning condition monitoring of vibration and process parameters - real time operator indications	5	4	2	40	7.00
Pump	Pump Fluid at xxx GPM	Bearing Failure	Bearing Seizure, possible motor trip, pump & impellor damage, out of service ~ 1 day	4	4	8	128	On-line scanning condition monitoring of vibration and process parameters - real time operator indications	4	3	2	24	5.33

Figure 5 - Revised RPN and Improvemnt Factor Calculation

change in an actual physical quantity such as cost (Severity), failure rate (Occurrence) , or percentage of failures that are undetected (Detectability).

The following steps outline the process for determining Improvement Factors and completing the analysis:

1) Determine Initial RPN

Initial RPN should be calculated by looking at dominant failure modes for the system/asset in question. For the four pump sets reviewed in Figure 4, the abbreviated FMEA and initial RPN values were developed based on dominant failure modes.

Initial RPN values shown are based on relative consequences, frequency, and detectability of failure based on the currently applied maintenance and reliability strategy for these machines.

2) Calculate Revised RPN

In the example of the four pump sets, revised RPN values were calculated based on benefits of applying an on-line scanning condition monitoring solution. This technology leverages permanently installed low-cost transducers and process variable inputs connected to a host system via a distributed network architecture with wireless capability. The system automatically cycles through the point architecture, collecting data at time intervals short enough to be considered "quasi-continuous" in most cases. Applied to a variety of fixed and rotating machinery equipment types, on-line scanning technology represents a less expensive solution where permanent monitoring is required and provides many benefits normally associated with on-line continuous systems:

- Early detection of potential failures
- Data repeatability
- Real-time monitoring of condition and process parameters by Operators
- Safe, automated sampling of data from hazardous or difficult access measurement points
- In-depth diagnostic capabilities

Each of the factors that make up the RPN calculation were re-ranked for each failure mode based on the improved situation. As shown in the table in Figure 5, the most pronounced reduction in RPN can be seen in Detectability factors for bearing and seal failures. Also note incremental improvement in the Occurrence factor as well for these same dominant failure modes.

Severity - As shown in Figure 5, the Severity factor remains unchanged. Keep in mind that the Severity factor, as applied here, is a ranking of the relative consequences of failure if left undetected. The ability to reduce overall risk through early detection is fully accounted for in the Detectability factor. Some examples of actions that can improve the Severity factor, though not considered in this particular model, are adding equipment redundancy to minimize impact on operations and optimizing repair plans/procedures to minimize forced downtime cost and duration.

Occurrence - This example also shows how the benefits of on-line scanning condition monitoring technology are not limited to Detectability. Incremental improvements in Occurrence factors for these same dominant failures are shown in Figure 5. The Occurrence factor is directly related to MTBF. There are a number of factors which impact MTBF, including design of the asset, service, and maintenance practices. Good alignment, balancing, and lubrication practices generally contribute to extended MTBF.

Operator practices can also dramatically impact MTBF. Operating a machine in a load or speed regime detrimental to the health of the machine will shorten its life – something which commonly happens when Operators are unable to see "real time" how their actions are affecting machine behavior. This is especially true with pump sets, where Operators may inadvertently run a pump well away from its design point and unknowingly induce cavitation that will accelerate impeller, bearing, and seal wear (as in the pump example shown in Figure 5). On-line scanning condition monitoring technology enables quasi-real time observation, allowing Operators to see the results of their actions and learn how to operate their assets in a safer and healthier manner. Just like improved balancing, alignment, and lubrication practices do, improved Operations practices extend machinery life, resulting in a positive shift in MTBF over time.

Another advantage of enabling Operators

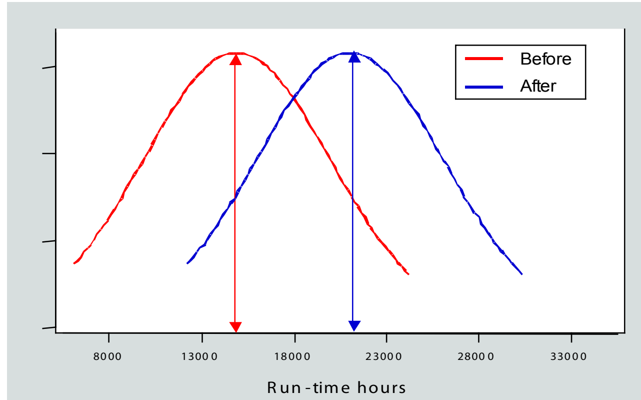


Figure 6 - MTBF Shift from Imroved Operator Practices

to observe machinery behavior real-time is evident when a machine is restarted after an overhaul. Operators receive nearly instantaneous notification of the new "baseline" condition of that machine as soon as they push the start button. In the event of an issue with alignment, balance, or problems introduced by improper machine reassembly, Operators will immediately know there is a problem. Without having to rely on the predictive maintenance team to take data upon machine startup, Operators can initiate steps to avoid putting operating hours on a problem machine and get the situation corrected quickly. The end result is that machines will be operating with fewer malfunctions, further increasing MTBF of the population over time. This is much better than the alternative of operating a machine with a malfunction, such as misalignment or a coupling assembly problem, which will lead to premature failure.

Detectability - This example also shows that when risks associated with failure modes of the asset demand closer monitoring than can be provided by a typical portable data collector program, on-line scanning condition monitoring technology provides several distinct advantages:

- Quasi-continuous data collection
- Data repeatability
- In-depth data correlation and diagnostic capabilities

A brief discussion of the P-F interval is helpful to understand these benefits and the level of improvement that can be achieved with on-line condition monitoring technology.

The P-F interval is commonly interpreted as the time (or other measurement unit such as operating hours) from when a potential failure (P) can first be detected to when actual functional failure (F) occurs[5].

As shown in Figure 7, the rule of thumb for the periodic data sample interval is that it should be no greater than ½ the P-F interval. The worst case lead time for data sampled periodically in this manner would be no greater than ½ the P-F interval. The average lead time would then be approximately ¾ the P-F interval.

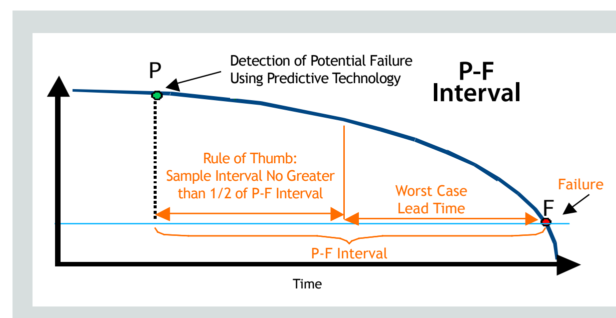


Figure 7 - P-F Interval

Error in judgment of the P-F interval and natural variability due to circumstances beyond the control of the data taker/analyst make this approach an imperfect science. For the majority of general purpose machinery applications, a few misses may be acceptable. However, when missed failures are too costly and unacceptable to the business, then the benefits provided by on-line technology are much more visible. Vibration and process variable data are sampled nearly continuously with this technology, so detection of potential failures will nearly always be at point "P". Everything else being equal, this represents a 33% improvement in average lead time over the portable data sampling from walk-around programs (see Figure 8). This also eliminates concern over how well the P-F interval was estimated in the first place and deviation of actual failure times from the estimated interval. Another important consideration is that fixed transducers utilized by on-line scanning technology also deliver highly repeatable and accurate data for trending purposes. This effectively eliminates data "outliers" that result

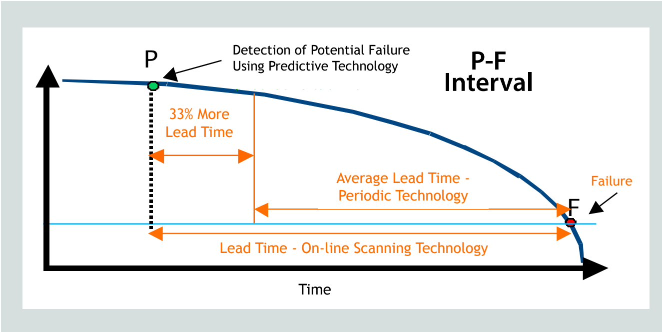


Figure 8 - P-F Interval and On-line Scanning Technology Lead Time

from highly variable hand-held readings, further improving Detectability.

In this example, when compared to a periodic data collection strategy or to a completely unmonitored machine, the sum total of benefits provided by on-line scanning condition monitoring technology greatly decrease the Detectability factor in the RPN calculation.

The initial Detectability factor (and the other two as well) should be based on the "baseline" scenario desired in order to make comparisons. For example, initial Detectability can be based on a completely unmonitored machine. Or it could be based on a machine already covered by a periodic data sampling program; hence this approach would directly yield the cost/benefit analysis of the on-line scanning solution over the current periodic program for that machine.

3) Calculate Improvement Factors

Improvement Factors are calculated as follows for each dominant failure mode (see Figure 5):

$$\text{Improvement Factor} = RPN_{initial}/RPN_{revised}$$

The Improvement Factor is a dimensionless quantity. As stated earlier, ranking scales used to calculate RPN's must be applied consistently throughout the analysis to result in valid Improvement Factors. The ranking scales must also be linear, meaning a proportional change in any of the RPN factors should correspond to an equal corresponding change in a quantitative metric (for example, a reduction in the Occurrence factor from 8 to 4 corresponds to a 50% reduction in failure rate, or 2X improvement in MTBF looking at the reciprocal).

4) Derive Annualized Cost Savings and Risk Reduction

Since the Improvement Factors were calculated individually for each of the dominant failure modes, they can be applied to the cost/risk profile previously developed for each failure mode. The original cost or annualized risk value is divided by the Improvement Factor to calculate a new cost or risk value which represents the new probabilistic cost. The difference between the original cost/risk value and new cost/risk value represents the annualized savings or risk reduction which can be expected by implementing the proposed solution (see Figure 9).

5) Perform Net Present Value Analysis

Now that estimated annual savings / risk

Improvement Table 1	Failures and Events:Improvement, Savings and Risk Reduction				
Failure Mode	Current Annual Cost or Risk	Improvement Factor	Reasoning or Basis	Proposed Situation	Annual Savings or Risk Reduction
Motor - Stator Winding Failure	9,635	1.13	On-line scanning - vibration, motor current	8,565	1,071
Motor - Bearing Failure	3,562	6.00	On-line scanning - vibration	594	2,968
Pump - Seal Failure	13,929	7.00	On-line scanning - vibration, process, real-time operator indicators	1,990	11,9892
Pump - Bearing Failure	5,015	5.33	On-line scanning - vibration, process, real-time operator indicators	940	4,075
				Annualized Risk Reduction/Savings Total	20,062

Figure 9 - Calculating Annualized Cost and Risk Reduction

THE BEST INFRARED CAMERA OFFER EVER!

INCLUDES
NEW FLIR FUSION SOFTWARE!

Buy One... Get One FREE!*

HIGH DEFINITION
ThermaCAM® P640

RUGGED & PORTABLE
InfraCAM™

Expand your infrared inspection program like never before!

Want to see more high definition thermal images?
Want to schedule an onsite demo?
Get all the details at:

www.goinfrared.com/wow

This offer ends soon - CALL TODAY!

For **Camera Rentals** & **Leasing Options**,
please call **1-866-477-3687**

Take advantage of this great offer and get:

- A New High Definition P640 IR camera with a 24° lens, 2 extra batteries, 12V DC Adapter
- FREE InfraCAM Thermal Imager
- Reporter™ 8.1 Professional Software - with FLIR Fusion!
- FREE ITC Training or Annual Conference Pass (Las Vegas, Oct.15-19) Visit: inframation.org
- Your choice of ImageBuilder™ composite or Database™ trending software
- Upgrade to InfraCAM SD for just $1,000!

SAVE ***$12,885!***

FLIR SYSTEMS™
The Global Leader in Infrared Cameras

1 800 464 6372
Canada: 1 800 613 0507
www.goinfrared.com/wow

*Offer valid in the USA only, and quoted in US dollars. Cannot be combined with other offers. Offer is for a limited time only. Some restrictions apply. Please call for details.

reduction have been calculated, comparison of the cost of implementing the solution with estimated benefits can be performed in a Net Present Value (NPV) analysis. This is a straightforward calculation which yields NPV, Rate of Return, and Payback Period while taking into account the time value of money (cost of capital).

The cost of implementing the solution must be based on supplying a solution that matches the level of cost/risk reduction used in the RPN and Improvement Factor calculations. In other words, the solution must target the dominant failure modes identified and reduce costs and risks as modeled in the FMEA. A low priced solution that does not adequately address dominant failure modes will have a poor payback. Likewise, a high priced solution that provides, at additional cost, more features and functions that do not impact the RPN factors may also have poorer payback. The FMEA-based cost justification methods described in this article enable "what if" analysis and ability to make comparisons to determine the level of solution that provides optimum return on investment.

The cash flow diagram in Figure 10 is an example of part of the output of an NPV analysis. The diagram shows a payback period of 1.7 years, based on annualized cost/risk reduction of approximately $20,000 and an initial investment of about $30,000 to implement the solution.

Conclusion

The FMEA-based methods for cost/benefit analysis described in this article help articulate the financial justification, where it exists, for implementing condition monitoring solutions to reduce costs and mitigate risk. As called for in the RCM analysis decision making process, proactive measures such as condition monitoring solutions must be both technically feasible and worth doing. By looking at initial cost and risk associated with dominant failure modes, and addressing the level of cost and risk reduction that can be achieved by the technology, a valid cost/benefit analysis can be performed that helps answer questions about solution effectiveness and value, and do so in financial units that are commonly used to evaluate competing projects.

The example used in this article also brings to light many of the benefits of on-line scanning condition monitoring technology. This includes improved Detectability over walk-around programs when closer machine health monitoring is needed than can be provided by a periodic data sampling program. The example illustrated improved (reduced) Occurrence, based on enabling Operators to improve operating practices and extend machinery life by providing them with real-time indicators of machine behavior and condition.

Food for thought: the FMEA-based cost justification methods described in this article can be extended and expanded to evaluate other solutions regardless of whether they are based on technology, improved practices, or combinations of both.

Rob Bloomquist has over 20 years experience delivering asset care and reliability solutions to the power and process industries, and is currently Reliability Services Training Manager for GE Energy. His experience includes specification and development of condition monitoring programs, reliability solution development and implementation, vibration analysis, machinery alignment and balancing, and customer training in reliability and condition monitoring. Rob has a Mechanical Engineering degree from California State University, Chico and is a Professional Engineer in the State of Colorado. Rob is a Certified Maintenance and Reliability Professional by the SMRP organization.

References

1. DiStefano, Robert, The Business Case for Reliability
2. Moubray, John, Reliability-centered Maintenance RCM-II, 2nd Edition, Industrial Press, 1997.
3. Troyer, Drew, Demonstrating Financial Benefits from Equipment Reliability Projects, Process and Power Plant Reliability Conference, Houston, TX, 2001
4. Andrews and Moss, Reliability and Risk Assessment, 2nd Edition, ASME Press
5. op. cit. 2

Mix It Up for Higher Efficiency

Using Infrared to Find Air Stratification in HVAC Systems

by John Cannamela

Over the past 20 years, I have been solving problems with Heating, Ventilating and Air Conditioning (HVAC) systems. I began using infrared (IR) thermography six years ago and have found air stratification (hot and cold air separation, or air that is not thermally blended) problems much easier to identify and correct since then. I wish I had started using it sooner because my ability to diagnose problems, especially those dealing with commissioning and start up of commercial systems, has improved tremendously with the use of IR.

There are many problems that arise in the engineering and design of commercial buildings, both before and after installation. Part of my job has been to ensure that the building systems are installed to the engineer's design specifications. At times, it seems there are unavoidable conflicts between the laws of physics and the laws of a stubborn architect. It's interesting that doctors get to practice medicine and lawyers get to practice law, but contractors have little flexibility to practice - they have to get it right the first time, whatever the costs.

Airflow Problems

One common issue is that the mechanical rooms, in which conditioned air is supplied to a beautifully designed building, are very small and confined causing problems with equipment installation. Air handlers, which are the heart of every HVAC system, deliver the air that is used to heat and cool the space. Heat is either removed or introduced into the air stream by mechanical means, such as a chilled water coil, a DX coil, or electric strip heaters.

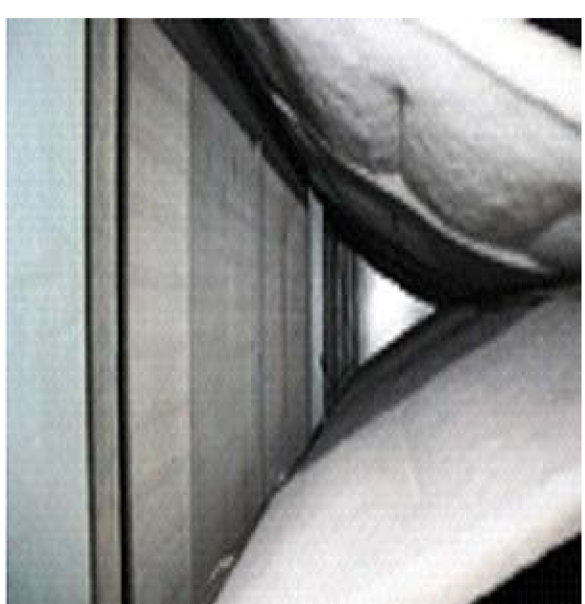


Figure 1 - Inside an air-handler unit, showing filters (right) and coil (left). Airflow is from right to left.

Laminar flow is the term used to describe air that is evenly distributed. Laminar flow through the air handler is essential to an effective, efficient HVAC system. Achieving this straight, even air movement often requires using ducts of several different diameters to straighten out the moving air.

We also need the proper velocity in order to use the entire cross-sectional area of the coil. Unfortunately, we don't always have these options because we are confined to tight mechanical rooms.

If the air does not flow straight and is not evenly distributed across these devices, energy is wasted or, even worse, components may fail or trip and the HVAC system goes down. We don't ever want that to happen! That's why we commission these systems and test them to run at the most efficient settings.

In the wintertime, conditions often permit the use of cold outside air as 'free' air conditioning. In such cases, the air handler's damper, which is connected to an outside louver, opens and the outside air is drawn into the system. We use 100% outside air when its temperature is above freezing, say between 35°F and 50°F, dry bulb.

When the outside air is below freezing, we have to mix the air with warmer building return air, which is generally 70°F -75°F. This is accomplished in a return air chamber called a mixing box. Once blended, the two mix to produce supply air at about 50°F -55°F to the building. If the outside air louver is too close to the mixing damper or box, the cold outside air is

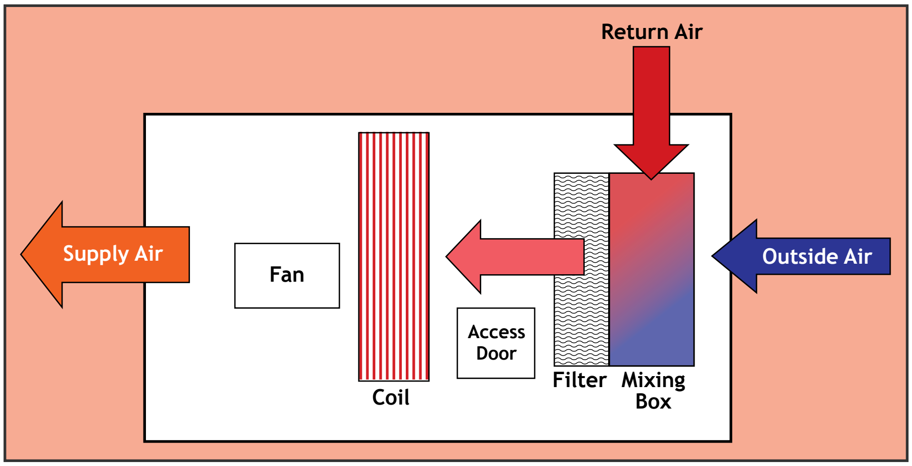


Figure 2 - Airflow when outside and return air need to be mixed.

drawn in closer to one side of the coil than the other, resulting in non-laminar flow that then causes stratification. This often causes the air handler to 'trip out' on low limit to protect the system.

Infrared Thermography to the Rescue

Poor laminar flow can have one or more causes. The most common cause is not enough distance between the return air plenum and the face of the device (such as a coil) that is the transfer medium. To better understand air flow, we need to measure the temperature of air in the HVAC system. Before using infrared, we characterized air stratification across a coil by hanging several temperature data collectors at different heights across the air stream. Unfortunately, it would take days to gather and analyze sufficient and useful data. By using thermal imaging, we can collect the same data in a few seconds.

I found that my infrared camera is an incredibly useful tool inside an air handler. It's best to be in a mechanical room with stable conditions. Opening the return door or an access door and taking an infrared shot could result in confusing imagery, but with most air handlers large enough to have a mixing box, the problem is usually minor. We see the temperature changes on the coil, not the air itself, so we can see exactly how the coil is affected. There should be relatively even temperatures with laminar flow. Rent an infrared camera, borrow one or pay your contractor a few more bucks during your next electrical IR survey to check your HVAC equipment. A procedure for doing this test is shown below.

Procedure

- Have two people; one taking the image and one on the service disconnect. Be aware that most of the time you are looking into the negative pressure side of the unit and objects can get drawn into it.
- Video tape the IR imagery, if possible.

- The system may not like the sudden change in pressure, so see what the limits are. The unit should be running at normal speed. In any case, make notes for later comparison.
- The unit should be in full cooling or heating mode with valves open.
- If you don't see any change, take a delta-T across the coil…if it is good, the airflow is good, if not, make sure the unit is in full cooling or heating mode with valves open.
- If there is a problem indicated in the IR imagery due the access door being open, block more of the opening.
- Save the image for further analysis.

Show what you have found to your HVAC expert and have them analyze the image and temperature data and make recommendations.

Conclusions

In conclusion, many systems aren't 100% maximized due to design and installation problems, especially, the filter rack and the bracing. If the unit is tripping, this is the best tool I have ever used to instantly quantify the overall performance of the equipment.

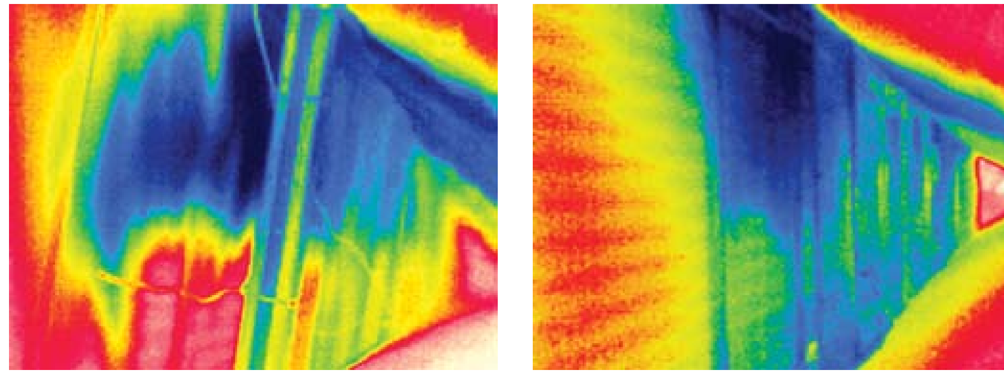


Figure 3 - Two thermal images of the same coil are shown. Image on the left shows the coil before modifications. Image on the right shows coil after modifications were made.

John J. Cannamela has over 20 years experience with HVAC (Heating, Ventilating and Air Conditioning) systems and building diagnostic techniques and has been an infrared thermographer for six years. His background includes commissioning, hydronic and airflow dynamics setting up and diagnosing various control systems in buildings. John holds a degree in HVAC, a Universal CFC Certificate, is a licensed journeyman in refrigeration, pipefitting and fuel burning, a member of the Vibration Institute, an ASNT Level II Certified Thermographer and an ASNT/ISO II Vibration Analyst. John owns Infrared Survey Company (www.infraredsurvey.com) and is an associate of MS Solutions (www.msssolutions.com). He can be reached by calling 704-200-6367 or by e-mail at fivecanns@carolina.rr.com

Don't Forget Your Spares

Keep Your Replacement Components in Operational Condition

by Kevan Slater

Many companies have performed rigorous evaluations to determine the most effective and cost efficient purchase and storage of replacement parts and components for their production equipment. This evaluation considers such items as age of the equipment, obsolescence, Original Equipment Manufacturers (OEM) support, component availability including lead time, historical performance, unit pricing, budgets, carrying costs, and warehouse space.

However, the efforts to ensure the quality of these parts for production equipment must not stop upon the issuing of the Purchase Order. Warehouse personnel, maintenance, production and the entire organization must ensure that the economic investment of these items do not have a chance to degrade prior to installation. A quality assurance program including areas such as receipt acceptance, possible functional testing and the implementation of an effective In-Storage Maintenance Program (ISM) can assist to ensure the parts will be both available and in pristine condition when required to perform.

While many OEM's provide long term in-storage maintenance instructions, the premise of these instructions are that the equipment in question will be stored in a dust-free and vibration-free environment with the following conditions:

- Equipment remains in the original OEM supplied packaging
- No externally detected damage to equipment
- Equipment identification labels and markings are legible
- Equipment has original supplied seals, caps and protective covers intact
- Adequate preservatives and coatings are maintained
- No detection of fluid leaks
- Warehouse personnel is trained in the handling and storage of equipment

The purpose of this article is to provide a general overview for establishing maintenance requirements and activities associated with long term in-storage maintenance (ISM) of lubricated rotating equipment. ISM monitors, detects and adjusts equipment and their conditions to prevent deterioration while under the direct control of the organizations supply chain. Due to the complexity of various spare parts including shelf life requirements, this overview will focus on the following groups of generic equipment without OEM specific lubrication storage instructions:

- Electric Motors (excluding actuating motors on valves)
- Pumps
- Fans
- Compressors

While in storage, the equipment or parts can be exposed to various environmental conditions that, if left unchecked, will result in the degradation of the components. The basic root causes of this degradation can be attributed to one or more of the following; humidity, frictional forces, and gravitational or vibration forces.

Humidity

Even within an air-conditioned environment, daily temperature variations or fluctuations in the storage facility increase the chances of condensate forming on the stored equipment. If the ambient temperature is monitored and maintained between 50°F and 95°F and the relative humidity level remains less than 70%, the facility should be acceptable for standard storage of most equipment. However, many storage facilities do not meet these requirements. OEM long term storage packaging and OEM installed equipment preserving methods are utilized, but they have to be maintained, remaining in tact and in their original condition. If the packaging includes equipment preserving desiccant packs, these packs should be changed on a quarterly basis by the implementation of planned maintenance (PM) activities.

Some manufacturers of electric motors require the use of space heaters to combat the effects of humidity followed up by regular assessments to detect possible insulation degradation. Monitoring the operation of the heaters should become a routine PM exercised by the facility's work management system. All electric motors stored outside of ideal conditions should have insulation checks (Meggering) on a regular basis (time frame will depend on the specific storage conditions). This insulation assessment process will provide an indication of the adequacy of the storage environment (moisture) and damage as a result of the humid environment. If insulation degradation is detected, the corrective action should be to improve the existing temperature and/or ventilation conditions after the initial insulation degradation conditions are corrected.

Frictional Forces

Binding and/or seizure of moving components is another condition that affects various sliding surfaces of components such as gears, bearings, linkages, etc. If a lubricant is allowed to drain out of the equipment or degrade due to environmental conditions while in storage, the result is usually seizure or stiction. Contamination or corrosive environments can exaggerate these conditions and typically the OEM original packaging and lubricants are designed to combat the effects.

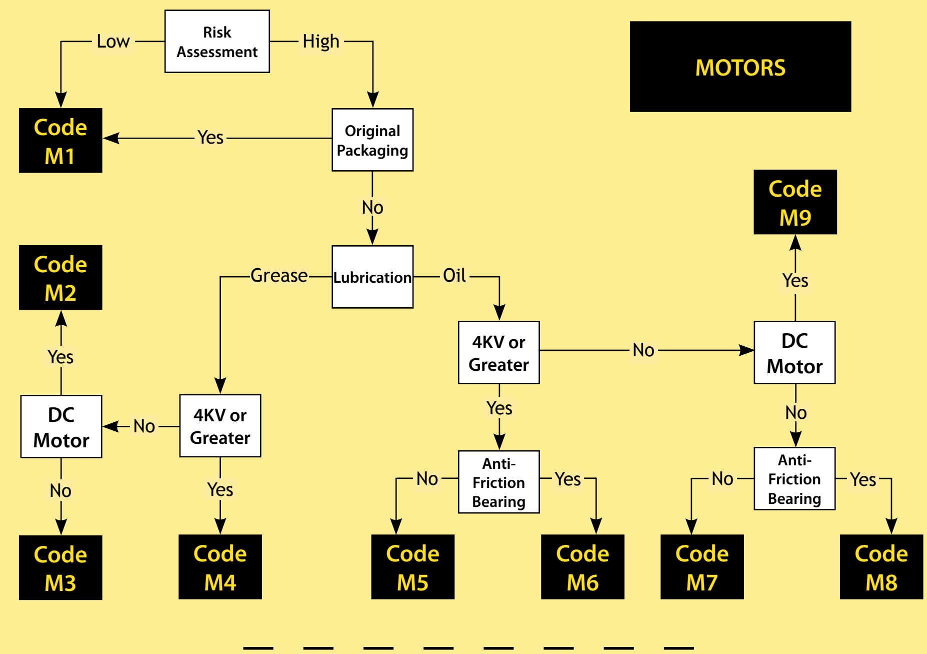
The lubricants are typically designed to combat the effect of vibration or gravitational effects. However, over time, and with the introduction of contamination such as dirt, dust, water and/or incompatible lubricants, problems like product separation (grease), additive depletion, gumming and/or caking, sludge, rust, etc. will occur.

Oil levels should be checked at intervals that coincide with shaft rotation requirements outlined in Figures 1-4, or at least on a quarterly basis. Greased components, including rolling element bearings, should be rotated or actuated to re-distribute the lubricant and provide the required protective film, unless they contain plain or journal bearings. The rotation of a shaft or rotor on equipment with journal or plain bearings may cause damage to the surfaces due to the inability of this sliding motion to create an acceptable fluid wedge. The proper protective lubricant film is required to reduce the frictional values of the surfaces and protect against the associated wear.

Gravitational or Vibration

The weight and shape of many metallic components are susceptible to deformation as the result of settling and/or strain. This change in shape, or in the properties of the materials, can result in increased bearing wear, can promote warping or poor mating of precision surfaces, and can have a significant effect on the dynamic balance of the equipment.

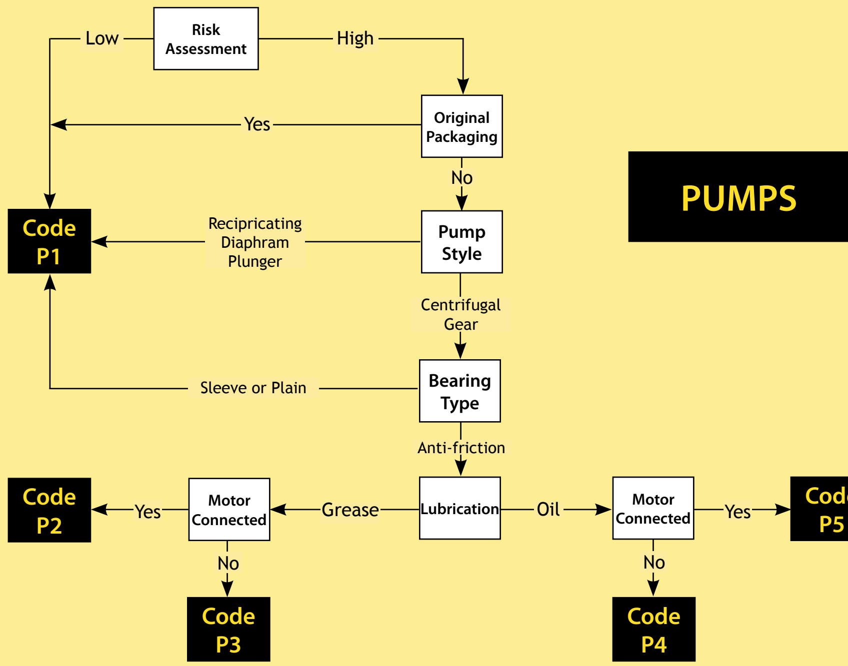
In addition, bearings stored for extended periods of time may show signs of fretting or self brinelling damage to the bearing surfaces due to the same gravitational and/or vibration forces. The effects of these gravitational or vibrational forces can be dramatically reduced if the shafts or rotors are rotated to a new stationary position that is approximately 90 degrees away from the original resting point. This 90 degree rotation will relieve the stress or strain patterns to minimize the effects of warping and also reduce the opportunity for fretting or self brinelling.



Motor Codes	
M1	No Planned ISM (In-Storage Maintenance)
M2	No Planned ISM (In-Storage Maintenance)
M3	*Rotate 10-1/4 turns (quarterly)
M4	*Rotate 10-1/4 turns (quarterly)
M5	Check Lubricant Levels and adjust as required using approved lubricant (quarterly)
M6	Check Lubricant Levels and adjust as required using approved lubricant (quarterly) *Rotate 10-1/4 turns (quarterly)
M7	Check Lubricant Levels and adjust as required using approved lubricant (quarterly)
M8	Check Lubricant Levels and adjust as required using approved lubricant (quarterly) * Rotate 10-1/4 turns (quarterly)
M9	Check Lubricant Levels and adjust as required using approved lubricant (quarterly)

* Restricted to driven component ISM requirements (if applicable)
(i.e. - if motor is attached to a pump and the pumps ISM does not allow for rotation, then motor must not be rotated)

Figure 1 - Flow Chart for Spare Motor Maintenance

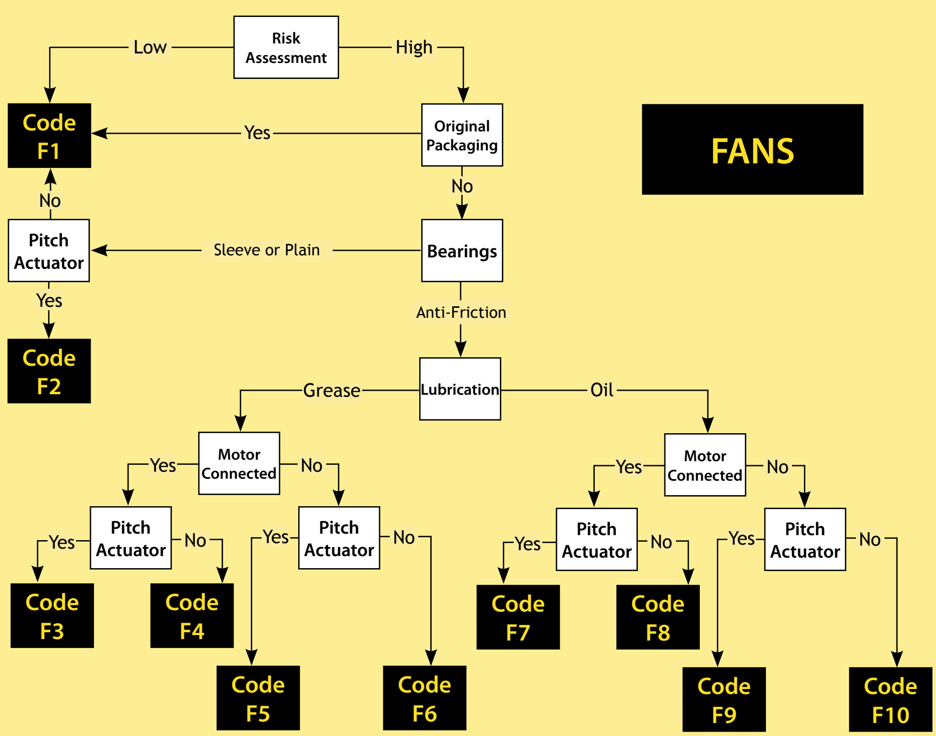


Pump Codes	
P1	No Planned ISM (In-Storage Mainte-nance)
P2	Follow instructions on "Motor ISM"
P3	Rotate 10-1/4 turns (quarterly)
P4	Check Lubricant Level and adjust as required (quarterly) Rotate 10-1/4 turns (quarterly)
P5	Check Lubricant Level and adjust as required (quarterly)

* Restricted to driven component ISM requirements (if applicable)

(i.e. - if motor is attached to a pump and the pumps ISM does not allow for rotation, then motor must not be rotated)

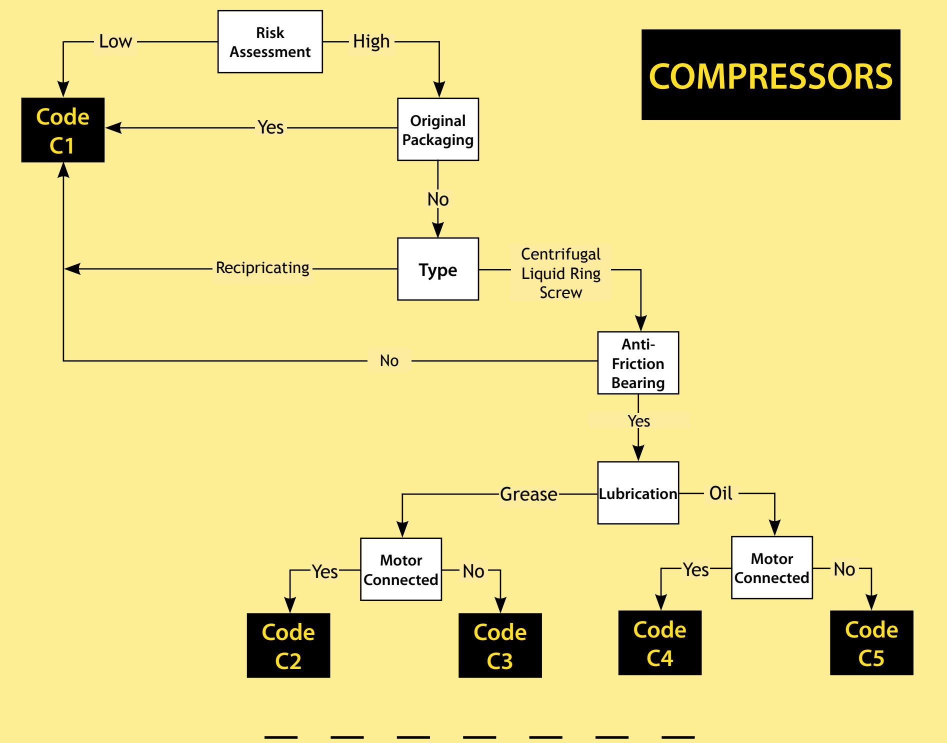
Figure 2 - Flow Chart for Spare Pump Maintenance



Fan Codes	
F1	No Planned ISM (In-Storage Mainte-nance)
F2	Actuate pitch control mechanism full stroke (quarterly)
F3	Follow instructions on "Motor ISM" Actuate pitch control mechanism full stroke (quarterly)
F4	Follow instructions on "Motor ISM"
F5	Rotate Fan 10-1/4 turns (quarterly) Actuate pitch control mechanism full stroke (quarterly)
F6	Rotate Fan 10-1/4 turns (quarterly)
F7	Check Lubricant Level and adjust as required (quarterly) - Follow instructions on "Motor ISM" - Actuate pitch control mechanism full stroke (quarterly)
F8	Check Lubricant Level and adjust as required (quarterly) Follow instructions on "Motor ISM"
F9	Check Lubricant Level and adjust as required (quarterly) - Rotate Fan 10-1/4 turns (quarterly) - Actuate pitch control mechanism full stroke (quarterly)
F10	Check Lubricant Level and adjust as required (quarterly) Rotate Fan 10-1/4 turns (quarterly)

* Restricted to driven component ISM requirements (if applicable)
(i.e. - if motor is attached to a pump and the pumps ISM does not allow for rotation, then motor must not be rotated)

Figure 3 - Flow Chart for Spare Fan Maintenance



Pump Codes	
C1	No Planned ISM (In-Storage Maintenance)
C2	Follow instructions on "Motor ISM"
C3	Rotate 10 - 1/4 turns (quarterly)
C4	Follow instructions on "Motor ISM" Check Lubricant Level and adjust as required (quarterly)
C5	Check Lubricant Level and adjust as required (quarterly) Rotate 10 - 1/4 turns (quarterly)

* Restricted to driven component ISM requirements (if applicable)

(i.e. - if motor is attached to a pump and the pumps ISM does not allow for rotation, then motor must not be rotated)

Figure 4 - Flow Chart for Spare Compressor Maintenance

Lubricated equipment or components can also be affected by many conditions that are outside the scope of this article including the exposure to both low and high temperatures. Temperatures that are below the pour point of the lubricant can affect the solubility of the oil additives resulting in "additives fall out". High temperatures will result in the degradation of the lubricant to the point the base stock will oxidize earlier than the originally planned replacement schedule. These and other contamination issues should be taken into consideration when developing and implementing an in-storage maintenance program.

The following items should be reviewed in the development stage of an ISM program:

- OEM's or vendors recommended ISM controls
- Existing storage and packaging policies
- Planned storage facility conditions and existing environmental controls
- ISM costs versus replacement costs

In general, the ISM program should be designed to protect the economic value of your spare parts or components from degradation while in storage. Figures 1-4 are intended as guidance for equipment that requires lubricant related activities during long term storage. The storage facility in our example is an environmentally controlled area (50°-95°F and Relative Humidity <70%), free of mechanical equipment that can produce damaging vibration and the absence of any other degradation contaminants.

It is also assumed that the facility's personnel use good warehouse and field practices (such as cleaning the storage area prior to installation), the original OEM item packaging is installed and not damaged, and any OEM installed shaft or rotator "blocking" removes the requirement to rotate the shaft.

Conclusion

A successful and comprehensive equipment maintenance management strategy is critical to machinery operation, plant reliability and equipment availability. It spans many diverse functions and responsibilities, ranging from designing maintenance jobs to providing and managing the resources needed to complete the work. An effective ISM program is only one small segment of the entire program, but the benefits in providing a spare component or part in the originally designed condition will ultimately prevent extended downtimes, elimination of chain reaction failures and improved precision of maintenance repairs.

Kevan Slater is the Field Service Manager at Trico Corp. Kevan has spent the last decade as a senior technical consultant improving the reliability of industrial equipment for numerous companies throughout North America, including assisting Ontario Power's Pickering Nuclear Generating plant. Extensive "in the field" experience has seen Kevan spear-head equipment maintenance audits, surveys and the development of in-house oil analysis programs. The result has been an increase in the reliability and performance of rotating equipment for many leading organizations. Kevan is a popular speaker with over 10 years of experience teaching college level courses, and providing public and private courses on fluid power, lubrication, lubrication management and oil analysis throughout North America. He is well known in the lubrication and maintenance fields as an author and presenter of numerous technical papers and presentations. To contact Kevan please e-mail kslater@tricocorp.com or call 416-439-9425 ext 223.

Looking Inside the DC Motor

Basic Maintenance and Testing of DC Electric Motors

by Howard W. Penrose, PhD, CMRP

So far in this series on motor testing we have covered AC induction motors only. We will now expand this evaluation of machine testing, maintenance and diagnostics to Direct Current (DC) electrical motors. In Part 1, we will discuss basic DC motor operation, application and general maintenance.

DC electric motors remain a large part of our industry, in both heavy and light manufacturing. In fact, according to the 2003 “Motor Diagnostics and Motor Health Study” [Penrose and O’Hanlon], approximately 60% of reporting companies were still using DC machines. Within industry, a majority of DC motors will be found in the heavy steel, mining and similar industries as well as for conveyors in the automotive and related industries. They are also prevalent in winding/unwinding machines, pulp and paper, cranes and other applications where high torque and variable speed is required.

Because of the contact surfaces in the DC electric motor, they require far more maintenance and adjustment than a three phase AC induction motor.

Construction of a DC Machine

There are three common types of DC machines which include the series, shunt and compound. The types refer to the connection and windings in the machines. An additional type, which will not be discussed in this article, is the permanent magnet DC machine. A typical, small, DC machine can be identified in Figure 1.

Figure 1 - Compound DC Motor

The Series Motor, as shown in Figure 2, is described because the power enters through the series coil, then through the interpoles, then the armature through the brushes and back out to the armature leads. The armature and interpole leads are labeled A1 and A2, the series fields are labeled S1 and S2.

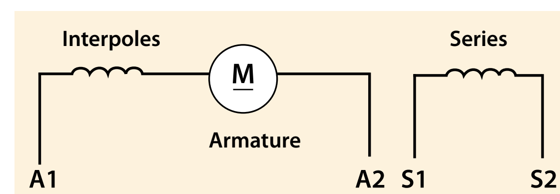


Figure 2 - Series Motor Connections

The interpoles are common to all of the DC machines we will be discussing and consist of a few turns of very large wire. The purpose of the interpoles is to compensate for a shifting magnetic field due to the amount of current and rotation of the armature. The armature is constructed of a core, which contains the armature winding, and a commutator which consists of a series of brass or copper-alloy sections separated by mica insulation.

The series field consists of a few turns of a heavy wire located on a ‘pole piece,’ which is made up of laminated steel. Very old machines would have cast pole pieces and cannot be used with modern DC drives. The result of the connection of the armature circuit to the series circuit is a machine that can provide a very high starting torque of up to 500%. The speed is regulated by the load and a load must be applied to an energized series machine, otherwise it will continue to accelerate until it mechanically fails. The speed is normally controlled through a rheostat. These machines are normally used in cases where very heavy starting torques are required such as: Traction motors; Locomotives; Hoists; Bridges; and, Car Dumpers. The lightest load that can be applied must not be below 15 – 25% of the full torque.

The Shunt Machine, as shown in Figure 3, is a more common machine meant for speed control and tends to be applied in pumps, fans, blowers, conveyors, machine tools, printing and similar applications. In this case, a winding consisting of many turns of a small wire is placed in parallel with the armature winding. This design provides approximately 250% starting torque, 5-10% speed regulation and the windings are separately powered and provide speed control by up to 200% with field weakening control and decrease speed by reducing armature voltage. The field wires tend to be very small as the circuit carries only a little current as opposed

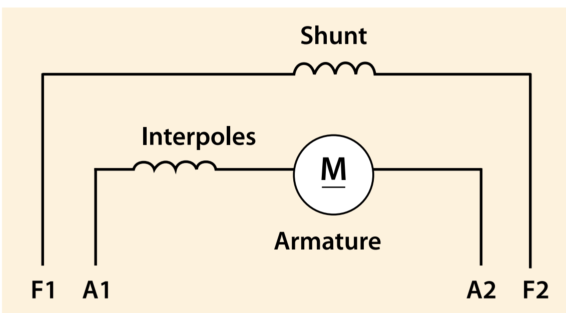


Figure 3 - Shunt Motor Connections

to the armature leads which can carry a very large current.

The final general type of machine to be discussed is the Compound Motor. This motor connection includes a combination of both the shunt and series windings, as shown in Figure 4. The compound motor provides a machine that can provide a good torque across a broad speed range, with the ability to provide excellent speed control to both high and low speeds. Compound motors tend to be used for applications requiring adjustable speed control, either constant or variable torque, such as rolling mills, paper mills, pumps, fans, conveyors and machine tools.

The conversion of electrical power occurs as a result of the interaction between the static DC fields and the armature magnetic fields which must be 90 electrical degrees from the static fields in or-

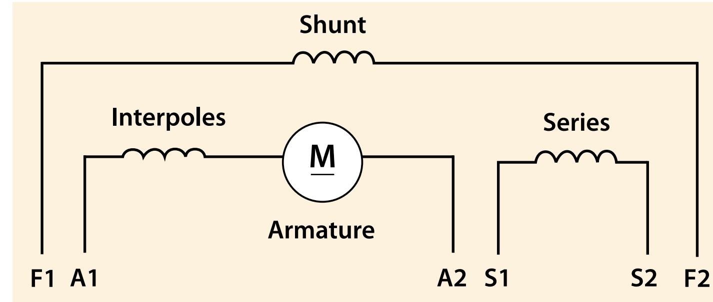


Figure 4 - Compound Motor Connections

der to produce the most efficient torque. This is done through the brushes and armature commutator, with the operation of the motor causing the fields to shift off-center as the machine operates at different speeds. This effect causes the need to 'tune' the motor by finding electrical neutral, which requires movement of the brush rigging.

Basic Considerations in Maintenance

Unlike the AC induction motor, the DC electric motor has a number of moving and wear parts that are in contact with each other. One of the more serious is the contact area between

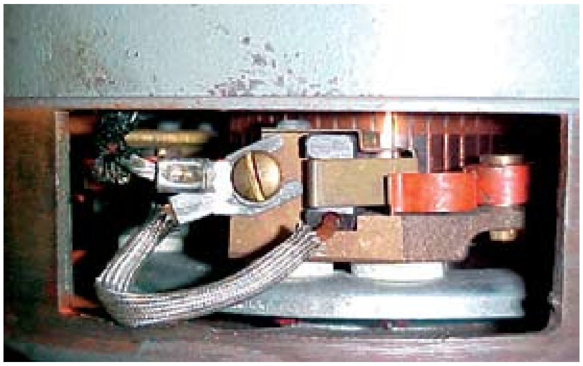


Figure 5 - Brushes, Brush Rigging and Commutator

the brushes and the commutator that generates heat and wear on the commutator and brushes, which generate contaminants within the components of the motor. In particular, one of the most common areas for carbon brush dust to collect is between the commutator and motor shaft with the next most common area being in the armature winding itself.

The result is that additional maintenance must be performed on a DC machine. The very basic steps include: Insulation resistance; Circuit resistance; and, Blowing out the motor. According to the latest IEEE Std 43-2000 (Reaffirmed in 2006), the insulation resistance value must be 100 MegOhms, adjusted for temperature. If the readings are low, it will normally indicate a buildup of carbon dust inside the motor that must be corrected. Resistance readings must also be corrected for temperature to the value that is often indicated on the motor nameplate. A few newer technologies provide earlier detection of armature winding contamination.

The correction for contamination is the use of low pressure dry air, where company and safety rules apply [NOTE: There are very specific OSHA safety rules where the use of compressed air applies, use this method of cleaning at your own risk]. Caution should be taken because if air pressures over 25 psi are used; particles can become embedded in the insulation system and cause failure. The other, and safer, method involves the removal of the electric motor, disassembly and cleaning of the armature and components in a motor repair shop.

Conclusion

Direct Current electric motors require additional maintenance efforts over those of AC induction motors. While there are several basic designs of DC machines, the general components wear over time causing contamination and degradation of the condition of the machine. In this series of articles, we will be discussing the maintenance and testing of these devices. In Part 2, we will focus on brush and commutator maintenance.

Bibliography

Penrose and O'Hanlon, ¬Motor Diagnostics and Motor Health Study, SUCCESS by DESIGN, Old Saybrook, CT, 2003. Download from: http://www.motordoc.org.

Howard W Penrose, Ph.D., CMRP, is the President of SUCCESS by DESIGN Reliability Services. SUCCESS by DESIGN specializes in corporate maintenance program development, motor management programs and maintenance and motor diagnostics training. For more information, or questions, see http://www.motordoc.net, contact info@motordoc.net or call 800 392-9025 (USA) or 860 577-8537 (World-Wide).


PdM-2007
&
LubricationWorld.com
Your Machinery is Talking...
Are You Listening?
Produced by
RELIABILITYWEB.COM™
2 Events 1 Price!!!
September 11-13, 2007
Orleans Hotel & Casino
Las Vegas, Nevada
The Predictive Maintenance Technology Conference & Expo
and
LubricationWorld.com

Listen

Dear Maintenance & Reliability Professional,

Life is good when your machinery is reliable. Fewer emergency calls from your facility equals a greater quality of life for you and greater profits for your company.

Maintenance would be easy if we could have an advanced schedule of machinery and equipment breakdowns. If we know the exact operating lifetime, we could simply schedule the repair or replacement of the system. Unfortunately, life is not as orderly as many would like and "random" failures are one of the dominant failure modes affecting maintenance and reliability.

We can also "fix" things much earlier than their useful life cycle to make sure we never suffer at the hand of "random" failures. Unfortunately the other dominant failure mode – is "infant failure" and it is usually caused by human intervention and time based maintenance. If only there was a way to know the condition of your machinery and equipment like a doctor knows the condition of a patient.

Great news! Right now "best practice" companies are using proactive maintenance techniques such as predictive maintenance and proactive lubrication to know the condition of their machinery and equipment. As a result, they can schedule required maintenance to optimize the production schedule, which, in turn, increases uptime, improves quality, enhances job satisfaction, minimizes safety and environmental incidents, reduces maintenance inventory and ultimately reduces maintenance cost.

That's right – "best practice" maintenance is actually much less expensive than "reactive" or time based maintenance programs. Not only are best practice programs less expensive but they actually contribute to profits by ensuring uptime and availability.

Reliabilityweb.com has created this conference so that in just 3 days, PdM-2007 – The Predictive Maintenance Technology Conference and Expo will not only change the way you look at maintenance, it will change the way you perform maintenance. With a series of full day workshops, short courses, learning zone sessions, networking events, interactive forums and an excellent exhibition showcasing the latest technologies and services – PdM-2007 offers a clear vision of what works and what doesn't.

Unlock the potential of your predictive maintenance program at PdM-2007. Learn how you can use a variety of predictive maintenance technologies and proactive lubrication to avoid unexpected downtime. Move from reactive "fire fighting" maintenance to proactive condition based maintenance. You will also learn to build a foundation for your maintenance program with an effective machinery lubrication program at LubricationWorld.

We are so confident that you will gain news ideas and knowledge from attending PdM-2007 and LubricationWorld we offer an industry best "100% satisfaction" guarantee – if you are not satisfied with your 3 day conference experience – simply let us know why and we will refund your entire conference fee.

We hope you will join us to transform the world of maintenance and reliability – one program at a time - starting with yours. Please make plans to attend while early bird and hotel discounts save you money on what is sure to be one of the best events of the year!

See you in Las Vegas.

Best regards,
Terrence O'Hanlon, CMRP
Publisher
Reliabilityweb.com
Uptime Magazine

PS: You can also sit for certification exams from the Society of Tribologists and Lubrication Engineers (STLE) and the Society for Maintenance & Reliability Professionals (SMRP) at PdM-2007 and LubricationWorld.

PdM-2007

Your plant machinery and equipment is actually telling you about its operating condition. All you need to do is know how to listen! In just 3 days – you can dramatically increase your knowledge about machinery condition monitoring technologies
and applications including:

- Vibration Analysis
- Ultrasonic Detection
- Precision Alignment
- Infrared Thermal Imaging
- Electric Motor Testing
- Oil Analysis & Machinery Lubrication

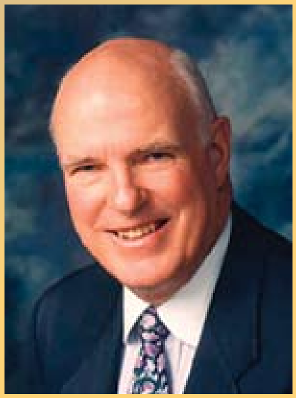
At PdM-2007, experts from around the world join together to share knowledge and experience. Award winning "Best Practices" companies share their roadmap, including the challenges they faced so you can chart your journey to improved reliability.

Highlights of PdM-2007 and LubricationWorld include

- 7 optional full day pre-conference workshops to jumpstart your learning experience
- 35 Short Courses, Case Studies and Learning Zone Sessions led by real world practitioners, trainers and subject matter experts
- Predictive Maintenance: Where we came from – Learn more about the early innovators and how predictive maintenance started with PdM pioneer, maintenance expert and author, John S. Mitchell
- PdM-2007 - LubricationWorld Expo – Meet over 40 leading Predictive Maintenance and Condition Based Monitoring Solution providers in a hand's on two and a half day Expo
- Birds of a Feather – Select a special name badge ribbon to indicate your focused area of interest. Simply watch for matching placards on meal tables to sit with others who share the same interest
- PdM and Lubrication Challenge Session – Post your questions in advance or bring them with you as the entire group meets to solve today's toughest issues in real time
- Professional Advancement – Sit for the Certified Maintenance and Reliability Professional (CMRP) Exam, the CLS and OMA exam by STLE and meet representatives from the Council of Certifying Organizations (CoCo), and the Institute of Electrical Motor Diagnostics (IEMD)
- Meet Editors from Uptime Magazine and Reliabilityweb.com to learn more about how you can publish case studies
- PdM Program of The Year Awards – Meet past year and this year's winners and learn how they made their programs successful
- Take-home Tools and Resources – All attendees receive conference CDs that contain the slides and detailed papers for every session
- There are several prize drawings including the Alienware Laptop PC Giveaway to be drawn at random during the Conference Wrap-Up Session

PdM-2007 Keynote

From Vibration Measurements to Condition Based Maintenance - 70 Years of Continuous Progress



By John Mitchell, Author, Physical Asset Management Handbook

Over the last 70 years dramatic improvements have occurred in the technology, equipment and practice used for machinery vibration measurement, condition monitoring and analysis. From yesterday's mechanical instruments that might capture a simple low frequency vibration waveform to today's high performance digital instrumentation, detailed fluid chemistry and oil debris analysis, motor current and circuit analysis, ultrasonics and infrared thermography - the changes have been striking - especially over the last 20 years. It is almost beyond belief that today's portable data collectors have greater functionality and performance than an entire truckload laboratory analysis instrumentation from 25 years ago. Today, the earliest stages of most flaws can be recognized in ample time to minimize the impact on production and avoid outright failure. Condition Monitoring has indeed come a long way and there is much to learn from history. The path taken and how we arrived is an interesting story - so please join Asset Management expert and noted author, John Mitchell for an enlightened tale about the origins of one of today's major proactive maintenance strategies.

Enhance your PdM-2007 and LubricationWorld learning experience by registering for pre-conference workshops. PdM-2007 and LubricationWorld already provides 12 hours toward CMRP and other professional re-certification. Each workshop is valued at 6 additional hours of credit toward CMRP Re-certification. A certificate will be provided for each workshop. PdM-2007 and LubricationWorld begins with 7 different Pre-Conference Workshops.

Workshops

Workshop 1 PdM Managers' Workshop by Jack Nicholas Jr., CMRP

This one day workshop is aimed at helping attendees start up new predictive maintenance programs and improve, update or expand existing ones. Attendees should already be familiar with the application of one or more predictive technologies such as Vibration Analysis, Infrared Thermography, Lubricant and Wear Particle Analysis, Electric Motor Testing, and/or Ultrasonic Detection and Analysis. This workshop provides information on the following subjects for supervisors, senior (lead) technicians and "champions" involved with or considering a predictive maintenance and condition monitoring program and its expansion and improvement:

* Predictive Maintenance Philosophy, Goals and Objectives
* Functions of a Predictive Maintenance and/or Condition Monitoring in the Overall Strategy and Processes of a Maintenance and Reliability Program
* Commonly Used Predictive Analysis Methods
  - Trend Analysis
  - Pattern Recognition
  - Tests Against Limits or Ranges
  - Relative Comparison
  - Statistical Process Analysis
  - Correlation Analysis
* Predictive Maintenance Program Alternatives and Cost Benefits
* Planning for Implementation, Expansion and Integration of a PdM Program
* Cost Justifying and Budgeting for a PdM Program
* Recruiting and Training Personnel for PdM Positions
* 15 Ways of Strengthening a PdM Program and Assuring Its Continuation
* Auditing Your Present PdM Program to Determine Gaps Needing Attention (new this year)

This workshop provides case studies from some of the most successful predictive maintenance programs and practitioners in the world. The workshop leader uses many graphics and photo images for ease of understanding. Attendees will receive the latest edition of the text Predictive Maintenance Management by Jack R. Nicholas, Jr., P.E., CMRP and co-author R. Keith Young. The text is indexed for future use by attendees as a workplace reference. Each attendee will also receive a workshop attendance certificate. This classroom event stresses management, supervisory and interpersonal relationship aspects unique to the high tech world of Predictive Maintenance and Condition Monitoring in manufacturing; transportation systems and vehicles; military and government civilian applications, medical, academic, public service facilities and utilities.

Workshop 2 Vibration Analysis Techniques

by Jason Tranter

Part 1 - Bearing Fault Detection: Three Keys to Great Results

If you can detect bearing faults from an early stage, and understand the nature and severity (and root cause) of the fault condition, then you will deliver the best return on the investment you have made in vibration analysis. In this workshop we will explain the progression of the fault condition, from the inception of the fault condition through to the ultimate failure of the bearing. We will touch on all of the testing methods that are used: ultrasound, PeakVue, demodulation, the shock pulse method (and spike energy), amplitude modulation, time waveform analysis and of course spectrum analysis.

Part 2 - Phase: How Such a Simple Measurement Can Tell You So Much

Do you ever struggle to distinguish between unbalance, misalignment, bent shaft, cocked bearing and looseness? Or do you ever suspect a resonance but struggle to find the evidence that confirms this destructive problem? Phase analysis is a simple tool that can reveal all this and more. In this section of the workshop we will explain what phase is; demonstrate how easy it is to collect the readings; and teach you how it can be used to diagnose a wide range of fault conditions.

Part 3 - Time for Time Waveform Analysis

Every time you collect a spectrum measurement you could also save the time waveform. And from that time waveform you can learn a great deal about your machine – you can learn about fault conditions that are difficult (or impossible) to diagnose with the spectrum alone. We will discuss the best ways to collect the time waveform and how to analyze and interpret the time waveform pattern.

All of these sessions will utilize the Mobius iLearn simulators, animations and "live" samples of case study data. If you think it will be difficult to understand these topics; think again! The Mobius iLearn training aids make it all fun and easy to understand.

… the PdM Conference was a G-R-E-A-T experience! I would like to thank you, your staff, and everyone. We took away several important things to help and improve our program. The workshops were a very important factor in this.

Nick Bohonik, RELIABILITY - Thermography Group, Johns Manville

Workshop 3 Electrical PdM Basics

Part 1 - Electrical Inspection using Infrared Thermography by John Snell

Part 2 - Electrical Inspection using Airborne Ultrasound by Jim Hall

Reliability managers and technicians should attend this one day course to learn more about electrical applications for infrared thermography and ultrasonic detection. Whether you already own equipment, are "shopping around" to add the technology or just want to find out more, spending a day to learn about infrared and ultrasound will pay large returns. Some of the topics John Snell and Jim hall will discuss include:

- Motor control centers, panels, and components
- Exterior substations and components
- Distribution and transmission systems
- Transformers, circuit breakers, and buswork
- Infrared inspection windows

The workbook for this course consists of the presentation slides (in color) and several useful background articles.

Workshop 4 The Business of Infrared Thermography

by Greg Stockton

This workshop goes far beyond the typical infrared seminar and delves into many unique infrared applications that can greatly expand the benefit of any infrared program. Areas covered are designed for plant thermographers and contract thermographers... as well as those who may be considering becoming a contract thermographer.

The workshop includes a detailed overview of many different applications, a candid discussion about the impact of NFPA 70E, a primer on how to buy and sell infrared services and which type of IR camera works best for a given application.

Attendees will learn more about the specifications that separate quality thermography from substandard thermography. This course will conclude with advances in infrared technology and a comprehensive look at the types of imagers available on the market today.

Workshop 5 Electric Motor Theory, Application and Analysis

by Howard W Penrose, Ph.D., CMRP and Robert Apelgren

In this course, we will provide hands-on instruction in electric motor operating theory. The workshop will begin with demonstrations of electro-magnetic theory and work through to the assembly of a simple electric motor by each attendee. The class will also include hands-on demonstration of electrical insulation systems. This instruction will be followed by discussion and demonstrations of how different common test instruments are used to detect defects in each component of the electrical machine.

This course is designed for both novice and advanced motor testing personnel. The goal is to provide a deeper, hands-on approach to the understanding of rotating machinery operation to assist the analyst in determining the test results of their instrumentation. The course does not require any level of industrial electrical or mechanical experience.

Workshop 4 Outline:

1) Electrical/Mechanical Apps: Quick Review
2) Beyond Switchgear: Unique Infrared Inspection Applications Explained
3) The Truth about NFPA 70E
4) Process Control and Infrared R&D
5) Buildings...Green-Thinking, Moisture Control and Quality-Assurance
6) Up on the Roof
7) How to Buy and how to Sell Infrared Inspection Services
8) IR Cameras – Current Technology Available

Workshops

Workshop 6 Introduction to Oil Analysis & the Oil Analysis Game

by Ray Thibault, CLS,OMA and Paul Goldman

This hand's-on workshop will give you the tools necessary to select the right program for your equipment and to interpret report data on making the correct decision for your equipment.

The class will be divided into two sections:

Report interpretation- Many real life situations will be examined by the use of oil analysis reports. Proper evaluation techniques will be stressed. After this session you should feel comfortable analyzing your own reports.

The second half of the course will involve team work in evaluating reports. Each team will be given basic data and "PdM Bucks" to purchase additional data to evaluate a piece of equipment. Five real world case studies will be evaluated. The team who utilizes the data most economically and effectively will receive a prize. A prize will be given for each of the five case histories.

Workshop 7 Roadmap to PdM Excellence: A Comprehensive 3 Day Experience at PdM-2007

Allied Inspired Reliability

Reliabilityweb.com creates the technical program at PdM-2007 and LubricationWorld knowing that many of you seek specific areas of knowledge and expertise to close the gaps in your existing maintenance programs. This year we have also worked closely with Allied Reliability to create a 3 day workshop - with times syncronized to the conference program to allow you to attend keynotes, the Expo and social networking - that tells you everything you need to build and sustain a predictive maintenance program at your plant or facility.

Day 1 - Before You Even Start

Building the foundation for a successful Predictive Maintenance Program is as important as the technologies you use and the skills of the people in the program. Taking time to create foundational elements will increase the chance of success and sustainablity. Topics include:

- Building a Business Case
- Getting Leadership Commitment
- Foundational Elements
- Elemental Timeline
- Commitment to Active Learning

Day 2 - Getting Started (Designing the Program)

Day 2 will focus on building the Program - determining levels of targeted coverage, lean out your PMs, selecting equipment, developing standards for personnel qualifications and detailed technology standards, building the databases, deploying work flows and KPIs. Topics include:

- Conducting an assessment
- Getting an accurate asset list and criticality
- Develop process flows/RASIs, and KPIs,
- Build a 100% Coverage/Resource Model
- Evaluate Sourcing Options
- Refine your Business Case and Timeline

Day 3 - Pulling It All Together (Integration) and Asset Health Management followed by Models of PdM Excellence.

You will hear from several companies who have created successful Predictive Maintenance programs and learn the obsticles they faced as well as how they overcame them.

Workshop attendees should take away a clear roadmap to create a world class PdM program.

PdM Best Practices Learning Zone

Wednesday Sept 12

Practical Root Cause Analysis – It's all in the detail: Can you make the call? by Mark Latino, Reliability Center Inc.

This short course is about being practical when performing a root cause analysis. Many times we are focused on the most obvious damage and miss the small details that uncover the true causes of the failure. See if you can see the detail in the examples presented during this presentation. This short course is about being practical when performing a root cause analysis.

Precision Maintenance at the National Institutes of Health by Ken Gilliam and Jeff Evans

The emphasis of this program has been placed on improving the reliability of new and old equipment for heating, ventilation, air conditioning and other critical equipment in six major buildings and several other vital areas such as Bio-safety Level 3 & 4 Labs on the huge campus in Bethesda, MD.

In its 6 years of operation, the program has been expanded to support the design, installation, commissioning operation, maintenance and re-engineering of facility equipment. This program is the **Uptime Magazine Best Precision Maintenance Program Winner 2006.**

Sustaining a Best Practices PdM Program at Duke Energy by Dennis Roinick, Predictive Maintenance Program Engineer, McGuire Nuclear Station, Duke Energy

Winner: Uptime Magazine Best Overall Predictive Maintenance Program 2006

McGuire Nuclear Station is one of three Duke Energy operated nuclear stations. The Predictive Maintenance and Monitoring Program (PdM) provides program structure, defines individual responsibilities, and documents detailed description of the PdM Program. Highlights of the program also include a long range (3-year) training plan for PdM team members and an annual PdM Program Health Report, which looks in depth at every aspect of the effort being undertaken in this important area of plant maintenance. A summary of proposed action items in the Health Report establishes a Long Range Plan for program growth and refinement. These key elements help formulate a successful PdM Program.

Thursday Sept 13

Pump Condition Monitoring by Ray Beebe, Author, *Predictive Maintenance of Pumps Using Condition Monitoring*

This short course shows how condition monitoring can be applied to detect internal degradation in pumps so that appropriate maintenance can be decided upon based on actual condition rather than arbitrary time scales. The presentation focuses on the main condition monitoring techniques particularly relevant to pumps (vibration analysis, performance analysis). The philosophy of condition monitoring is briefly summarized and field examples show how condition monitoring is applied to detect internal degradation in pumps.

Driving Change using Condition Based Maintenance by Brett Anders Boeing

What will Site Services Look Like in 2008? Attend this presentation to learn how to create a Lean organization that is responsive to customer needs, acting as a NASCAR pit crew with customers seeing us as the preferred provider for all Facilities Functions and Services

Sidor's Predictive Maintenance Program by Luis E. Marval V. Ternium Sidor

Sidor's steel-making operation in Puerto Ordez, Bolivar, Venezuela has a comprehensive program overseeing 6300 pieces of rotating machinery with vibration, ultrasound, infrared thermography, laser alignment, lubrication & wear particle analysis, flow pattern analysis and non-destructive testing. In addition, the quality of Root Cause Failure Analysis reporting is outstanding in support of improving machine reliability.

Sidor was awarded **Uptime Magazine's Award of Merit in 2006** for its PdM program.

Best Practices

Mechanical

Mechanical Predictive Maintenance Learning Zone

Wednesday Sept 12

Alignment Fundamentals
by Jason Tranter, Mobius iLearn

Have you ever wondered why precision alignment and soft foot correction is so important? Have you ever wondered how to align a machine with dial indicators or laser alignment systems? In this one hour session we will provide this information and much more. Using the Mobius iLearn 3D alignment animations, we will reinforce the importance of shaft alignment and explain the various alignment methods, including a discussion of the pros and cons of each method.

A Proven Method for Documenting a PdM Program Savings by Mark Roether, Timken

This presentation details the steel manufacturer's method for providing a monetary business case for creating and sustaining a predictive maintenance program.

Managing Condition Monitoring in a Distribution Center by Mark Burgett, Dell Inc.

Learn about Dell's journey to establishing and sustaining a Predictive Maintenance Program for critical distribution centers that are designed to efficiently supply PCs to the world.

Thursday Sept 13

Building an Effective Continuous Vibration Monitoring System
by Jack Dischner, Commtest

Condition monitoring on critical assets may be more appropriate for a continuous vibration monitoring system. This session features a discussion that explores the current technology and software available to provide 24/7 protection on critical machinery.

Electric Motor Bearing Greasing
by Howard Penrose PhD

One of the most important components of any electro-mechanical maintenance program is the lubrication of bearings. Yet, this vital aspect of preventive maintenance remains one of the least understood functions of maintenance. There is constant debate concerning whether a bearing should be 'flushed,' a limited amount of grease added, how often or if the motor should be operating or tagged-out. There are specific physical properties for this process in the motor bearing housing and in order to protect motor windings from contamination. This short course explores motor bearing greasing in detail.

Front Line Condition Monitoring using Shock Pulse for Bearing Damage Detection and Lubrication Condition by Lou Morando, SPM

The way Shock Pulse signals are separated is really what makes this technology unique. Unlike vibration analysis that monitors a broad vibration band and then tries to isolate unique frequencies, the Shock Pulse Method was developed to monitor only the high frequency signals of antifriction bearings. With the development of a defined database the analysis became functional. The ability to analyze lubrication changes versus surface damage becomes more practical and repeatable. There will be a real time demonstration with on-line modules of ball and roller bearings where lubrication condition will be disrupted and comparisons will be made to bearings with actual damage.

I was very impressed with the degree of professionalism shown by the speakers, one and all (at PdM-2006 in Chattanooga). The class content was just what I was hoping for, very to the point and easy to understand. The facilities were outstanding, couldn't have been better in my opinion…Food was excellent… I learned much and had a great time at it. Thank you for all your efforts. I will definitely be looking to attend future PdM events. Job well done.

Jeff Curtis, Vibration Analyst, Alcoa

Electrical Predictive Maintenance Learning Zone

Electrical

Wednesday Sept 12

NFPA70E for Predictive Maintenance Professionals by Art Stout, Electrophysics

Arc Flash incidents can be devastating to both humans and companies. The National Fire Protection Association (NFPA) has developed guidelines for electrical safety that are rapidly standardized in companies in order to protect from arc flash incidents. This short course details the dangers of Arc Flash and explores details of the standard so you can ensure safety at your company.

Sky Train Case Study: Improving Reliability and Lowering Operating Costs by Utilizing an Effective Motor Testing Program

by Deda Dedovic, Sky Train and Tim Thomas, Baker Instrument

In Vancouver, British Columbia, Deda Dedovic, Vehicle Technical Analyst for Sky Train, the light rail system, has documented over $800,000.00 in savings and countless down time hours since adding static motor testing to his maintenance program. Deda will present, in his own words, the issues he has faced in maintaining a safe and continuous operation of the over 200 cars in his fleet. He will describe the methods and tests he instigated and aggressively followed in order to reach the level of performance he has achieved.

Do Your Critical Motors Make the Grade?

by Harvey Henkel TransAlta Utilities

This presentation is about the criteria TransAlta uses to predict how many more years of life critical motors have left in them. The criteria and the basis for using them in the report card are fully explained. The use of the report card has been extremely valuable and contributed to winning **Uptime Magazine's Motor Testing Program of the Year Award in 2006**. Sometimes we don't like what the report card tells us, so we will also discuss what we can do to change the score or extend the predicted life.

Thursday Sept 13

Infrared Windows – How to Get Started

by Martin Robinson, IRISS

Infrared Windows help Predictive Maintenance (PdM) thermographers comply with NFPA 70E by allowing them to scan the electrical equipment without opening or removing covers of electrical enclosures. Scanning without opening enclosures greatly reduces the risk of Arc Flash, it makes inspection faster, and takes away many of the triggers of an arc flash. This short course explains the materials used for IR Windows and how to best apply them for superior results.

Predictive Maintenance at Chugach Electric, Anchorage, Alaska

by Scott Girard, PE, Senior Substation Technician, Chugach Electric Association

This presentation illustrates how Chugach Electric in Alaska has developed and implemented a Reliability Centered Maintenance based PdM program for substations. Technologies applied include infrared thermography, partial discharge detection, dissolved gas, vibration, airborne and ultrasonic analysis as well as other equipment specific online diagnostic tests.

The program has experienced avoided costs of over US$2.2M to date with additional avoided costs of US$700K scheduled in the near future. This program earned the **Uptime Magazine Special Award of Merit in 2006.**

Continuous Thermal Monitoring Mitigating Risk for Power Critical Organizations

by Ross Kennedy, Exertherm

Periodic Infrared Inspection may not provide enough protection for mission critical power applications. This short course defines the technology of continuous thermal monitoring systems to ensure 24/7 protection.

...best conference I've been to in years. Great job by by your entire team. Thanks for inviting me and I look forward to next year.

Kenneth D. Peoples, Boeing IDS-Wichita Site Services

LubricationWorld Learning Zone 1

LubeWorld 1

Wednesday Sept 12

Oil Analysis Report Interpretation – Science or Black Magic!
by John Underwood (CLS, OMA)DuPont Company

What do you do with those used oil analysis reports from your oil analysis vendor?

In this interactive session, you will study copies of the original used oil analysis test results and some basic background information regarding the application and will be asked to determine the root cause of the abnormal conditions identified on the report. Hopefully after attending this presentation participants will be empowered and respond with: "I forwarded them to the organization with corrective action recommendations!"

Combining On Site and Off Site Oil Analysis
by Bruce Sackman, Westar Energy

In 2002 Westar Energy made the decision to aggressively implement a lubrication management program throughout its 6 plant facilities. The Oil Analysis program started out utilizing a professional lab service and quickly evolved to an in-house program consisting of seven PdM technicians who are actively involved in the oil sample collection and data analysis process.

Now Westar Energy's program combines in-house lubricant analysis backed up by sample analysis from an external laboratory. Best practices for lubrication, sampling and analysis have been incorporated into all procedures at Westar Energy. Westar Energy was awarded **Uptime Magazine's Oil Analysis Program of the Year Award in 2006**.

Lubricant Analysis of Pumps and Motors Techniques and Case Studies
by Richard N. Wurzbach, MRG Power Labs

Oil analysis is a valuable tool for pump and motor diagnostics, troubleshooting, and root-cause investigations. Advanced techniques such as FTIR spectral analysis, RULER, and microscopic particle examinations drive capabilities beyond "package" oil analysis programs. Too often facilities rely on the basic "low-bid" oil analysis test slate, not only for trending of critical equipment, but also in troubleshooting high-impact failure events. When grease lubricated equipment is involved, lubricant analysis is often overlooked as an effective monitoring technique. With new developments in grease sampling technology, grease lubricated equipment can be regularly sampled, and the information that can be extracted from grease samples can be of significant value.

Thursday Sept 13

Strategies for Effective Contamination Monitoring and Control by Paul Dufrense, Trico Corp.

It has been estimated that the prevention of system contamination costs about 1/10th of what it costs to remove contamination once it has entered our system. This presentation will evaluate the options associated with the exclusion of contamination verses removal. Advances in proactive maintenance have produced many products that will prevent the ingression of contamination. We will look at the proactive options for maintaining lubricant and mechanical reliability and for sealing our systems from their surrounding environments. At the conclusion of this presentation, you will have a road map for success in developing strategies for effective contamination monitoring and control.

Case History; Air Force World Class Lubrication Program by Johnny Dillon, Tinker Air Force Base

Learn about the elements of a world class lubirication program including the manpower, test instruments, (Ferrography, Spectroscopy, Viscosity, Particle Count), how to trend data, Point/Lube ID program, best practices for oil storage and labeling, database cross referencing, and several case histories of cost saving, trends. Lots of pictures of one of a kind equipment.

Turbine Oils, Past, Present & Future
by Ted Naman, ConocoPhillips Company

This presentation will cover the history of turbine oils and the changes in technology to address OEM requirements. Turbine oil chemistry and formulation technology for gas and steam turbines in power generation have undergone significant changes in performance to meet the stringent OEM requirements for oxidative stability, extended service, bearing & gear protection, and deposit control.

This change in technology was accompanied by widespread use of electrostatic oil cleaners and improved filtration to control contaminants. As a result, unforeseen problems have been identified, which has prompted interest among end users about the performance of their lubricants in conjunction with these systems.

LubeWorld 2

LubricationWorld Learning Zone 2

Wednesday Sept 12

Five Rights of Lubrication
by Ray Thibault, CLS,OMA

Today the more progressive companies are practicing Reliability Centered Maintenance and recognize the importance of lubrication in achieving their objectives on extended equipment reliability. The discussion will focus on applying the right techniques to implement the five rights in your lubrication program.

A world class lubrication program must adhere to the five rights of lubrication to be successful. These are as follows: Right Type, Right Quality, Right Amount, Right Place and Right Time.

Revolutionary Contamination Control Technologies for Lubricants by Greg Livingstone, EPT

Relatively little has happened in the last several decades in terms of technologies to keep lubricants contaminant free. Sure, our understanding of the impact of contamination is much greater and we now have more analytical tests to measure fluid contamination and degradation. Filters have become tighter. Vacuum dehydration systems use PLCs. But, all of these changes have been evolutionary.

But we are now seeing the development of truly revolutionary contamination control technologies that will not only allow lubricants to stay contaminant free, but will also remove the by-products of lubricant degradation and additive depletion. This presentation will review the latest advancements in lubricant contamination control technologies and provide insight as to what is just around the corner. Indeed, the future of lubricants looks clear and bright.

Recent Developments in Filtration
by Robert James, Pall Corporation

Update your background on filtration advancements over the last few years that can impact on plant reliability. a) Impact of the industry change from AC Fine Test Dust to ISO Medium Test dust on automatic particle counters and filter rating systems. Understand how to compare old and new data. b) Electrostatic discharge-resistant filters. What is ESD and how can it affect filtration. Availability of ESD-resistant filter technologies. c) Cyclic stabilization testing, a test to more closely simulate the real world stresses seen by hydraulic and lube service filters. How filters are impacted under the new test. Now officially recognized via SAE ARP4205.

Thursday Sept 13

Hand's On Grease Workshop
by John Geyer, Chevron Global Lubricants

Grease, The Mystery Lubricant? - For those of you who feel that grease is still a mystery in your plant, this grease workshop offers an informative presentation about all things grease-related. The first part of the workshop covers grease technology - components and formulations. The second part of the workshop addresses the practical application of grease as a lubricant. In the workshop, grease will be discussed in simple, easy to understand terms, from its makeup to its applications and uses, while helping participants better understand this often misunderstood and often misused product. Participants will be encouraged to participate and ask questions as well, so it should be fun and entertaining while learning about this unique lubrication product. Grease does not have to be a mystery any longer.

I personally would like to thank you and your staff for making our group from Spring Hill feel welcome. Throughout my career, I have attended many conferences, the PdM conference ranks among the best. Our objectives were to validate our current processes and learn what the rest of the maintenance world is doing. We were able to accomplish both. With this knowledge we are able to continue developing both our long and short term strategies. Our jobs are to help get our plant more proactive, and then spread the practices and knowledge throughout GM.

I think I can speak for our group in saying , this was time well spent.

Thank You Again.
Joseph A. Schwab, Powertrain QNPM Coordinator, Spring Hill Manufacturing

PdM-2007...Las Vegas

what happens here, doesn't stay here...it goes back to work.

The Orleans Hotel and Casino
4500 W. Tropicana Ave.
Las Vegas, NV 89103

Special Group Rate: $70 per night
Reservations #: 800-675-3267
Mon-Fri: 7:00am - 11:00pm Pacific
Sat/Sun: 9:00am - 5:00pm Pacific
Group Name: REL0907 - PdM-2007

The Orleans proudly offers 1886 beautifully appointed rooms and suites featuring the ultimate in luxury and comfort. Our oversized rooms are actually "Petite Suites" with separate sitting areas. The Orleans' exquisite one and two-bedroom suites provide all the conveniences of home. Spectacular views face the glittering Las Vegas Strip or the sweeping mountain panoramas surrounding the Las Vegas Valley. Free shuttle service is available to our sister property The Gold Coast as well as the Las Vegas strip.

PdM-2007 and LubricationWorld are generously

sponsored by

TIMKEN Where You Turn

commtest incorporated

PHILADELPHIA MIXING SOLUTIONS

MIKRON INFRARED

Allied Inspired Reliability

DES-CASE CORPORATION

HAWK I.R.

LSC Lubrication Systems Company

Chevron

ConnectIR

Media Sponsors

uptime the magazine for PdM & CBM pros

RELIABILITY WEB.COM

MRO-zone.com Search engine

Toll Free 888-575-1245

PdM-2007 & LubricationWorld

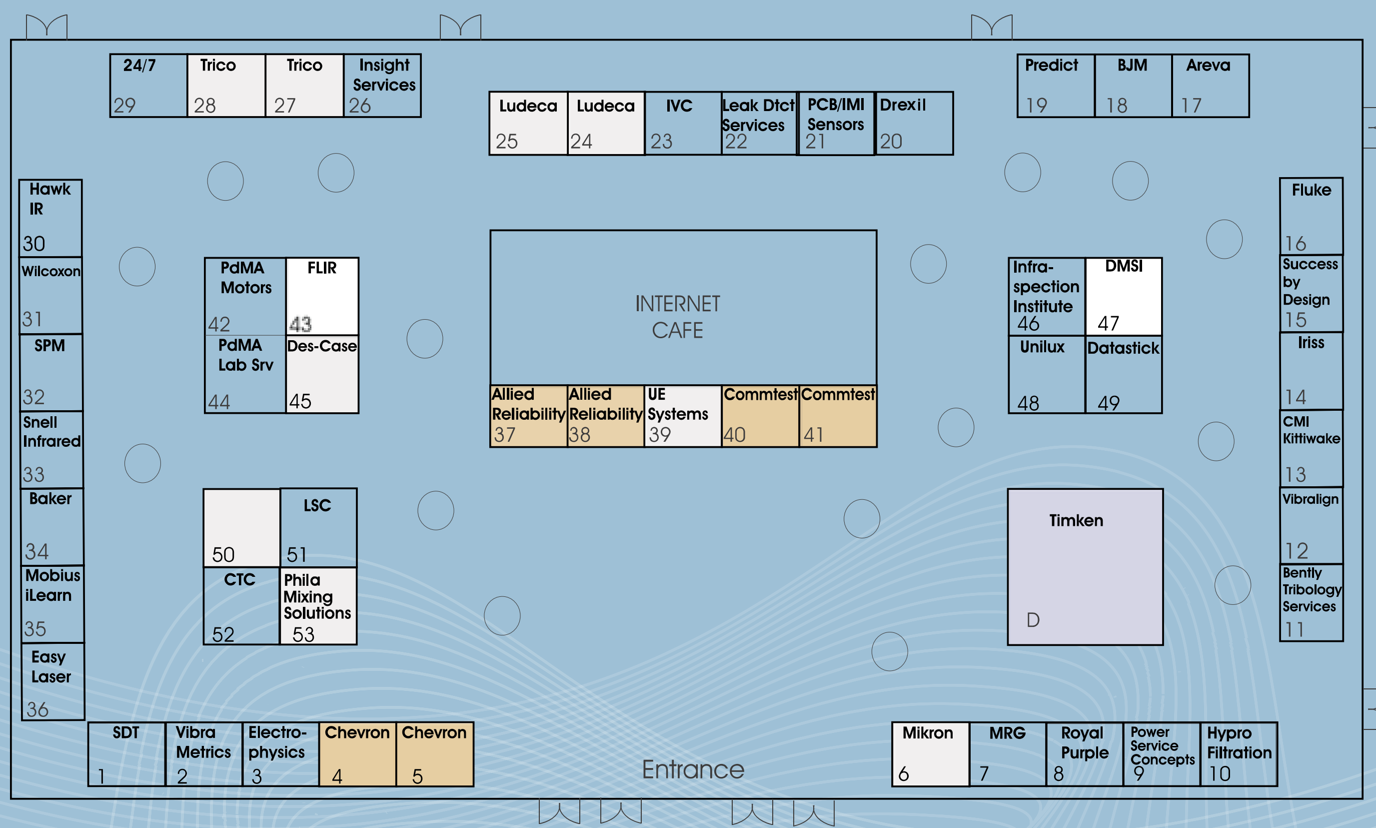
PdM-2007 and LubricationWorld Expo

Expo Dates

Tuesday, Sept 11th
Wednesday, Sept 12th
Thursday, Sept 13th

No other maintenance and reliability focused event brings more products, services, software and training providers than the PdM-2007 and LubricationWorld Expo.

No other event does as much to help you make sense of the numerous purchasing options. The PdM-2007 and LubricationWorld Expo is the place to find solutions as you make develop and build your own best practices. Please find a quality solution provider by using the alphabetical list below.



PdM-2007
September 11th - 13th

The Orleans Hotel
Las Vegas - Mardi Gras Ballroom

PdM-2007/LubricationWorld Exhibitors List

- Allied Reliability
- ALL-TEST Pro
- Areva
- Atlas Inspection
- Baker Instrument
- Chevron
- CMI Kittiwake
- Commtest
- ConnectIR.com
- CTC
- Datastick
- Des-Case
- DMSI
- Easy-Laser
- Electrophysics
- Framatome ANP
- FLIR Systems, Inc.
- Fluke
- Hawk IR
- Hypro Filtration
- Insight Services
- IRISS
- IVC
- Leak Detection Services
- Lubrication Systems Company (LSC)
- Ludeca
- MasteringMaintenance.com
- Mikron Infrared, Inc.
- Mobius iLearn
- MRG
- MRO-Zone.com
- PCB/IMI Sensors
- Philadelphia Mixing Solutions
- PdMA Corporation
- Power Service Concepts
- Predict
- Reliabilityweb.com
- Royal Purple
- SDT North America
- Snell Infrared
- SPM
- Stockton Infrared
- Success By Design
- Timken
- Trico Corp.
- Ultra-sound Technologies
- Unilux
- Uptime Magazine
- Vibralign
- Vibrametrics
- Wilcoxon
- 24/7

PdM-2007 and LubricationWorld

schedule at a glance

Tuesday September 11th

7:00am - Breakfast						
8:00am - Workshops						
PdM- Best Practices	**PdM - Mechanical**	**PdM - Electrical**	**Infrared & PdM Contractors**	**Electric Motors**	**LubeWorld 1**	**PdM Excellence**
Workshop #1 PdM Managers Workshop by Jack Nicholas Jr.	Workshop #2 Vibration Analysis Techniques - Part 1 by Jason Tranter	Workshop #3 Part 1 - Electrical Inspection using Infrared Thermography by John Snell	Workshop #4 The Business of Infrared Thermography Company by Greg Stockton	Workshop #5 Electric Motor Theory, Application and Analysis by Howard Penrose, PhD	Workshop #6 Introduction to Oil Analysis by Ray Thibault and Paul Goldman	Workshop #7 Roadmap to PdM Excellence
Noon -1:00pm - Lunch						
Workshop #1 PdM Managers Workshop by Jack Nicholas Jr.	Workshop #2 Vibration Analysis Techniques - Part 2 & 3 by Jason Tranter	Workshop #3 Pt 2 - Electrical Inspection using Airborne Ultrasound by Jim Hall	Workshop #4 The Business of Infrared Thermography Company by Greg Stockton	Workshop #5 Electric Motor Theory, Application and Analysis by Howard Penrose, PhD	Workshop #6 The Oil Analysis Game by Ray Thibault and Paul Goldman	Workshop #7 Roadmap to PdM Excellence
4:00pm – 6:00pm - Welcome Reception and Expo						
4:15pm – 6:15pm - SMRP and STLE Certification Exams						
9:15pm -11:00pm - Bowling Night Sponsored by MRO-Zone.com						

Wednesday September 12th

7:00 am - Breakfast					
8:00am - Short Courses					
PdM- Best Practices	**PdM - Mechanical**	**PdM - Electrical**	**LubeWorld 1**	**LubeWorld 2**	**PdM Excellence**
Practical Root Cause Analysis – It's all in the detail: Can you make the call? By Mark Latino, RCI	Alignment Fundamentals by Jason Tranter, Mobius iLearn	NFPA70E for Predictive Maintenance Professionals by Art Stout, Electro-physics	Oil Analysis Report Interpretation – Science or Black Magic! by John Underwood, CLS, OMA, DuPont Company	5 Rights of Lubrication by Ray Thibault	Roadmap to PdM Excellence Day 2
9:00 am – 9:45 am - Refreshment Break and Expo					
10:00am – 10:45 am - Keynote Presentation - John Mitchell From Vibration Measurements to Condition Based Maintenance - 70 Years of Continuous Progress					
10:45am - Noon - Uptime PdM Program of the Year Award Presentations 2007 - Meet the 2007 Uptime Program of the Year Winners and learn what made them winners.					
Noon - Lunch and Expo					
1:30 pm – 2:15 pm - Learning Zone Sessions					
Precision Maintenance at the National Institutes of Health by Ken Gilliam, US Navy and Jeff Evans, MSI	A Proven Method for Documenting a PdM Program Savings by Mark Roether, Timken	Improving Reliability and Lowering Operating Costs by Utilizing an Effective Motor Testing Program by Deda Dedovic, Sky Train and Tim Thomas, Baker Instrument	Combining On-Site and Off-Site Oil Analysis by Bruce Sackman, Westar Energy	Revolutionary Contamination Control Technologies for Lubricants by Greg Livingstone, EPT	Roadmap to PdM Excellence Day 2

Wednesday September 12th (cont.)

2:30 pm – 3:15 pm - Learning Zone Sessions					
Sustaining a Best Practices PdM Program at Duke Energy by Dennis Roinick, PdM Program Engineer, McGuire Nuclear Station, Duke Energy	Managing Condition Monitoring in a Distribution Center by Mark Burgett Dell Inc.	Do Your Critical Motors Make the Grade by Harvey Henkel, TransAlta	Lubricant Analysis of Pumps and Motors Techniques and Case Studies by Richard N. Wurzbach, MRG Power Labs	Recent Developments in Filtration by Robert James Pall Corporation	Roadmap to PdM Excellence Day 2
3:15 pm - 4:00 pm - Refreshment Break and Expo					
6:00 pm – 9:00 pm - Mardi Gras Dinner and Uptime Magazine PdM Awards Celebration sponsored by Timken, Chevron, Allied Reliability and Commtest - Join us to celebrate the PdM Program of the Year winners with music, fun, food and drinks. Everyone is invited.					

Thursday September 13th

7:00am - Breakfast					
8:00am - Short Courses					
PdM- Best Practices	**PdM - Mechanical**	**PdM - Electrical**	**LubeWorld 1**	**LubeWorld 2**	**PdM Excellence**
Pump Condition Monitoring by Ray Beebe Author	Building an Effective Continuous Vibration Monitoring system by Jack Dischner, Commtest	Infrared Windows – How to get Started by Martin Robinson, IRISS	Strategies for Effective Contamination Monitoring and Control by Paul Dufrense, Trico Corp	Pt 1 Hand's On Grease Workshop by John Geyer, Chevron Global Lubricants	Roadmap to PdM Excellence Day 3
9:00am – 9:45am - Refreshment Break and Expo					
10:00am – 10:45am - Learning Zone Sessions					
Driving Change Using Condition Based Maintenance by Brett Anders, Boeing	Electric Motor Bearing Greasing by Howard Penrose, PhD	Predictive Maintenance at Chugach Electric, Alaska by Scott Girard, PE, Sr. Substation Tech Chugach Electric Assn	Case history; Air Force World Class Lubrication Program by Johnny Dillon, Tinker Air Force Base	Part 2 - Hand's On Grease Workshop by John Geyer, Chevron Global Lubricants	Roadmap to PdM Excellence Day 3
11:00am – 11:45am - Learning Zone Sessions					
Sidor's Predictive Maintenance Program by Luis E. Marval V.,Ternium Sidor	Front Line Condition Monitoring using Shock Pulse for Bearing Damage Detection and Lubrication Condition by Lou Morando, SPM	Continuous Thermal Monitoring Mitigating Risk for Power Critical Organizations by Ross Kennedy, Exertherm	New Development in Turbine Oils by Ted Naman, Conoco Phillips	Pt 3 - Hand's On Grease Workshop by John Geyer, Chevron Global Lubricants	Roadmap to PdM Excellence Day 3
Noon - Lunch and Expo					
1:15pm - Biggest PdM and Lubrication Challenges - Please join us as the entire group discusses the biggest challenges as reported by conference participants. In past sessions, discussions have been lively and many common problems are reported and several solutions have been discovered.					
3:00pm - Alienware Giveaway and Conference Wrap Up - All Reliabilityweb.com conferences end with our famous Alienware Laptop giveaway.					

Conference Fees

Full 3 Day PdM-2007/LubricationWorld Conference Pass (Sept 11-13)	2 Day PdM-2007/LubricationWorld Conference Pass (Sept 12-13)
$899 Early Bird	**$699 Early Bird**
$1099 After Aug 1st	**$899 After Aug 1st**

Conference Passes includes Proceedings CD, Daily Breakfast, Lunch, Refreshments, Mardi Gras Banquet and Bowling Night.

Early Bird Special Save $200 off any 2 or 3 Day Pass if you register before August 1st

for more info, visit: http://www.maintenanceconference.com

4 Easy Ways to Register

Online www.maintenanceconference.com

Telephone Toll free: (888) 575-1245 or International: (305) 735-3746 to speak with one of our conference specialists

Fax or Mail One of our specialists can email you a registration form or you can download one at the conference web site for fax or mail

Reliabilityweb.com
PO Box 60075
Fort Myers FL 33906
Fax: (309) 423-7234

Purchase Order Company Purchase Order: Specify your workshop choice and send us your PO by fax, mail or e-mail at customerservice@reliabilityweb.com

Group Registrations Bring 5 people from the same company and get the 6th FREE! Call for details.

I wanted to thank you once again for putting together the best conference I've ever attended. I did more networking and talking to others in the field than ever before.

I let your team know how excited my upper management at Medtronic was that we were runner up in Uptime's Program of the Year in Thermography. I want to thank you and Uptime for helping bring more visibility to predictive maintenance programs.

Jon Kvamme
Medtronic,Inc
Fridley, MN

The Predictive Maintenance Technology Conference & Expo

and

LubricationWorld.com

ReliabilityShopper

Top 10 Reliability Solution Providers

Excellence in
Maintenance & Reliability Services

1

Reliability Solutions, Inc. • Continuous Improvement

Leading the World in RCM
585-349-7245
www.reliabilitysolution.com

2

Allied Inspired Reliability

Maximizing the Return on Asset Reliability
918-382-9400
www.alliedreliability.com

3

LCE Life Cycle Engineering — Redefining Maintenance • Delivering Reliability

Redefining Maintenance, Delivering Reliability
843-744-7110
www.LCE.com

4

IVARA WORK SMART

Experts in Making Reliability Work
1-877-746-3787
www.ivara.com

5

ARMS RELIABILITY ENGINEERS

Reliability Software, Training & Engineering Services
509.928.5083 / 5084
www.reliabilityusa.com

6

Reliability Center Inc.

Root Cause Analysis
804-458-0645
www.reliability.com

7

RMG

Masters of Reliability Process Implementation
952-882-8122
www.rmgmpls.com

8

wyle laboratories

RCM, Lean, Six Sigma, Asset Management
904-264-8570
www.wylelabs.com/products/vrcm.html

9

PCA

Improving People, Process & Technology Performance
770-717-2737
www.pcaconsulting.com

10

IRISS iR Infra Red Inspection Support Solutions

Infrared Inspection Windows and Installation Services
941-373-1528
www.iriss.com

To learn more about these
Top 10 Maintenance & Reliability Solution Providers please visit

www.reliabilityshopper.com

Tackling A Heavy Issue

Understanding Correct Placement of Trial Weights

by Gary James

The first part of this article will focus on the placement of weights on rotors where no historical data exists and the second will look at a few scenarios that happen depending on where the weight is placed, such as heavy spot or light spot above or below shaft resonance, etc. When performing a balance job, one of the challenges is determining where to place a trial weight and how much weight to apply. What we will address here is what we have found to be an effective method of deciding both where and how much weight to safely place on a rotor to both reduce the amplitude of the vibration and avoid any harm to the rotor, the base, or the structure itself.

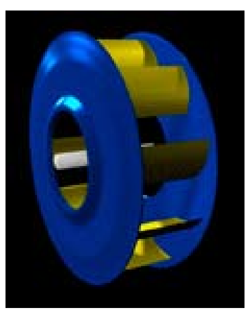


Figure 1 - Fan Rotor

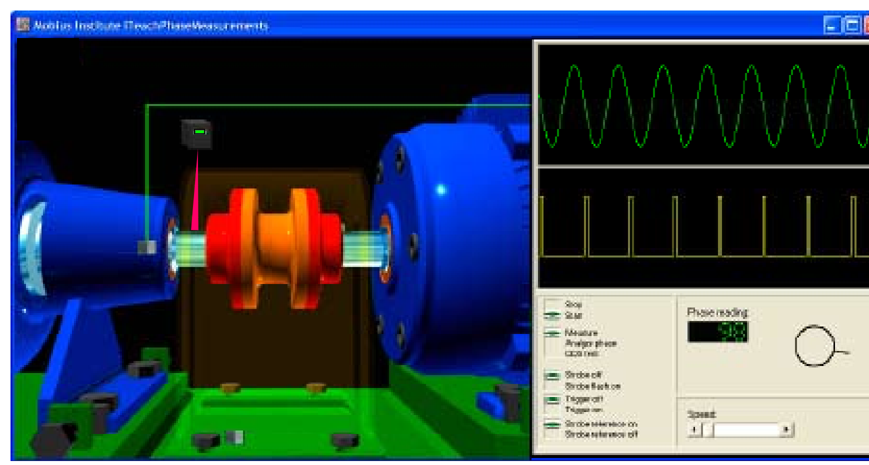


Figure 2 - Balance Job - Tachometer and Sensor Placement

For this discussion we will use a center-hung fan as our example. When deciding on where to place a trial weight there are a couple of pieces of information we need. First we need to have collected the ‘as is’ or ‘as found’ phase reading, the location of the phase pickup, and the location of the vibration sensor in relation to the phase pickup.

Estimating the Heavy Spot

The following formula is one that we use for estimating the heavy spot location:

$$\text{Heavy Spot} = A + P + U - L$$

where:

A = the angle between the phase pickup and the vibration sensor
P = the displayed phase angle
U = Angle correction in degrees for the measurement amplitude units used
L = the system lag angle

For clarification, the phase pickup is the sensor used to get a once-per-revolution pulse; this can be a stroboscope with TTL output, an optical pickup, infrared pickup, laser tachometer or one of several other devices. The vibration sensors can be proximity probes, velocity pickups, or accelerometers. The measurement amplitude unit of choice determines the value of (U) in the formula as follows: for displacement U=0°, for velocity U=90°, and for acceleration U=180°. The system lag (L) is determined by the proximity of the shaft critical to the operating speed.

Let’s assume for a minute that we are going to balance a fan. The phase pickup is located at the 12:00 o’clock position and the vibration sensor is located at the 9:00 o’clock position.

The fan rotates clockwise, looking from the coupling towards the fan, so starting to count from the phase pickup and stopping at the vibration sensor, (A) is equal to an angle of 90°. We will assume for this example that the fan has a 60° system lag which is fairly typical for small to medium-size rotors and means that the rotor is operating below its first critical. This means that the heavy spot passes the vibration sensor 60° ahead of the high spot.

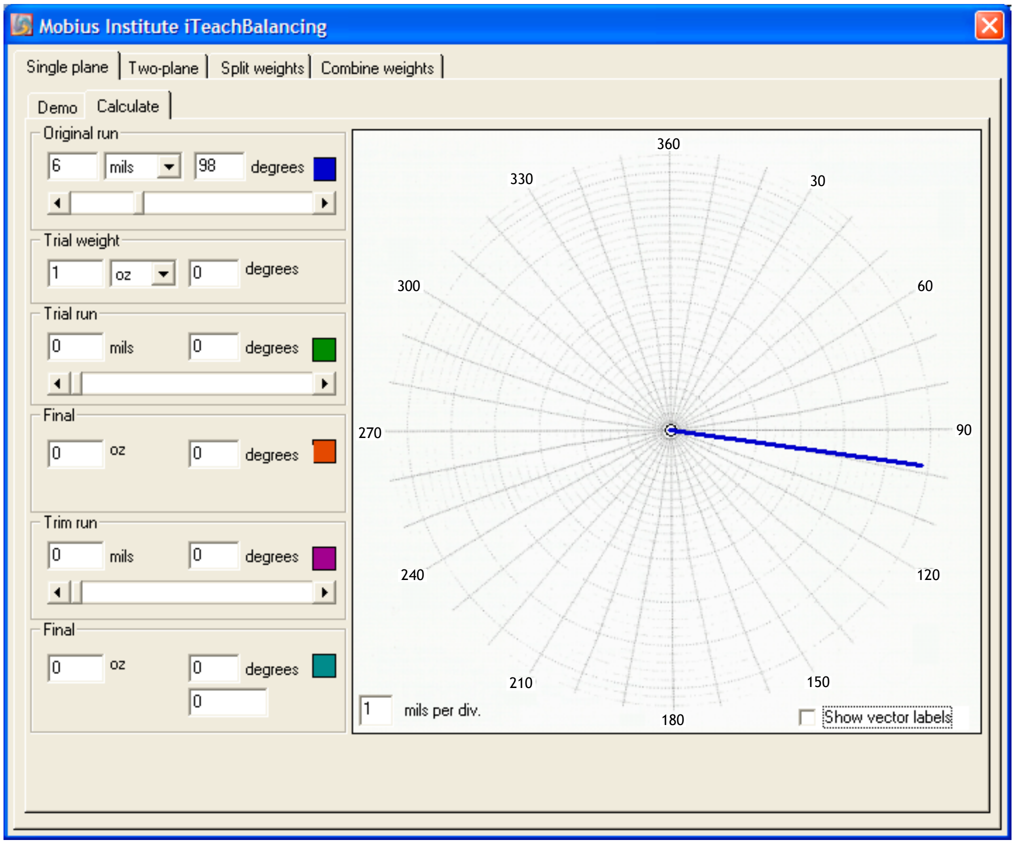


Figure 3 - Balance Job - Original Run Data

The initial run produced a phase angle of 98° with an amplitude of 6 mils peak to peak.

With this information, we can calculate an estimate of the heavy spot location. If the system lag is not known, but you know if the rotor is operating above or below its shaft critical, you can use a system lag of 45° if below or 135° if above. Now let's calculate the estimated heavy spot using the information from figure 3 to enter into the formula.

$$\text{Heavy Spot} = A + P + U - L$$
$$\text{Heavy Spot} = (90° + 98° + 0°) - 60° = 128°$$

The heavy spot is estimated to be at 128 degrees from the leading edge of the tape on the rotor (opposite rotation). In this example we would want to place a trial weight at 308°, or 180° from the heavy spot.

Estimating the Amount of Balance Trial Weight

The amount of trial weight is determined by several factors. We will discuss a few of them here. One method used by some is to simply look at the rotor for any existing balancing weights and try to place a similar amount on the rotating mass. Another method is to base the decision on experience with balancing similar machines. A third method is to calculate a weight that when placed on the rotor will not generate a force greater than 10% of the rotor mass. This is accomplished by knowing the rotor weight, the rotational speed, and radius at which the weights will be placed.

One of the first challenges is to know the rotor weight. This can be determined from the manufacturer's drawings, using a dynamometer and actually weighing the rotor. One excellent source is to have a rigging group look at the rotor and give you an estimate of its weight. Usually, the estimates given by experienced riggers are very close. The formula that we use to calculate the maximum trial weight amount is as follows:

Formula to estimate the maximum safe trial weight in grams:

$$TW = \frac{((W \times 0.1) \times 28.375)}{(1.77 \times ((RPM / 1000)2) \times R)}$$

Formula to estimate the maximum safe trial weight in ounces:

$$TW = \frac{W \times 0.1}{(1.77 \times ((RPM / 1000)2) \times R}$$

where:
TW = Maximum safe balance trial weight
W = Rotor weight (pounds)
RPM = Rotor speed in rpm
R = Radius of the weight placement in inches

Example: A rotor weighs 4000 pounds and rotates at 1191 rpm. The balance weight radius is 39 inches.

$$TW = \frac{((4000 \times 0.1) \times 28.375)}{(1.77 \times ((1191 / 1000)2) \times 39)} = 115.9 \text{ grams}$$

or

$$TW = \frac{4000 \times 0.1}{(1.77 \times ((1191 / 1000)2) \times 39} = 4.08 \text{ ounces}$$

Calculating the Force Due to Imbalance

Imbalance produces a centrifugal force that is destructive to mechanical components. The force due to imbalance can be calculated by using the following formula. The first one will show the results using grams and the second one will show the result using ounces.

Formula to estimate the force from a known imbalance in grams:

$$F = (1.77 \times (RPM / 1000)^2) \times (w \text{ in grams} / 28.375) \times R$$

Formula to estimate the force from a known imbalance in ounces:

$$F = (1.77 \times (RPM / 1000)^2) \times (w \text{ in ounces} \times R)$$

where:
F = Centrifugal force in pounds
RPM = Rotor rotational speed in rpm
w = Unbalance (in grams or ounces depending on formula used)
R = Radius of the unbalance weight in inches

Example: An 80 gram (2.82 ounce) weight will be placed on a 1191 rpm rotor at 39 inches radius.

$$F = 276 \text{ pounds}, \quad (1.77 \times (1191 / 1000)^2) \times (80 \text{ grams} / 28.375) \times 39$$

or

$$F = 276 \text{ pounds}, \quad (1.77 \times (1191 / 1000)^2) \times (2.82 \text{ ounces} \times 39)$$

There are other methods, and are some probably simpler, but these are the ones we

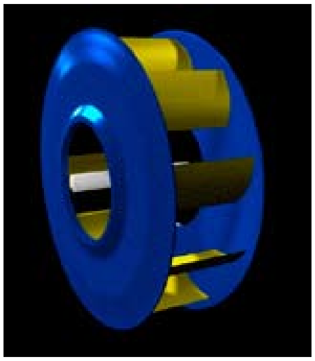


Figure 4a - Rotor Without Weight Added

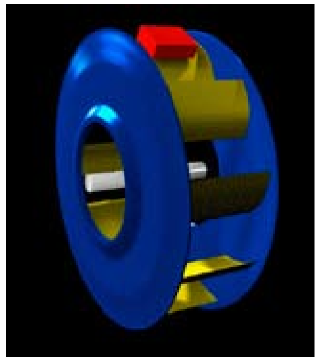


Figure 4b - Rotor With Weight Added

have used for several years that work for us.

The purpose of balancing is to bring the center of mass and the mechanical or rotational centers to the same point.

Rotors are usually balanced to a specified tolerance in units of unbalance such as ounce-inches or gram-millimeters or to a specific balance quality grade (G). Another option is to balance the rotor until the vibration resulting from the force is at an acceptable level. In other words, we want to reduce the magnitude of the original run vector (Figure 3) until we are within the tolerance or be as near to zero as possible. Figure 5 shows an example of a tolerance bull's-eye at .5 mils.

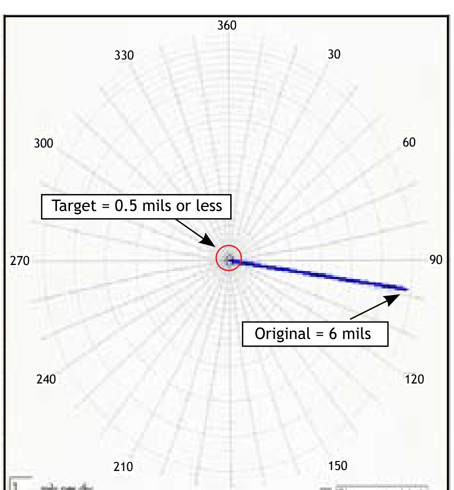


Figure 5 - Balance Job - Original Run Data with target vibration level

A heavy spot on a rotor can be caused by several factors such as buildup coming off the rotor, damage from something striking the rotor, erosion / corrosion, or rework to name a few.

If we blindly place a weight on a rotor we could inadvertently put it on the heavy spot and cause the vibration to increase, or if we put the weight on the light spot we would reduce the vibration. A third possibility, and the one most likely to occur, is that the trial weight is placed at a point other than the heavy or light spot, which could increase or decrease the vibration.

To illustrate an example of unbalance force, imagine swinging a ball on a string above your head. The higher the speed, the more force there is. The ball is the heavy spot. As it rotates, it is constantly trying to fly away from your hand and the force is pulling your arm off of vertical. The deflection of your arm is a response to the unbalance force. On a rotating shaft, the deflection of the shaft is called the high spot.

Unbalance and Shaft Resonance

Vibration increases with rotor speed. Actually, the force due to imbalance is proportional to the square of the rotor speed. The effect of unbalance on a rotating shaft depends on the relationship between rotor speed and the natural frequency of the shaft (shaft critical or resonance). Figures 6, 7, and 8 show the relationship between unbalance and shaft resonance at three different operating speeds: 1) well below shaft critical, 2) at shaft critical and 3) above shaft critical. For this example, the sensor and the tachometer are both located in the vertical position.

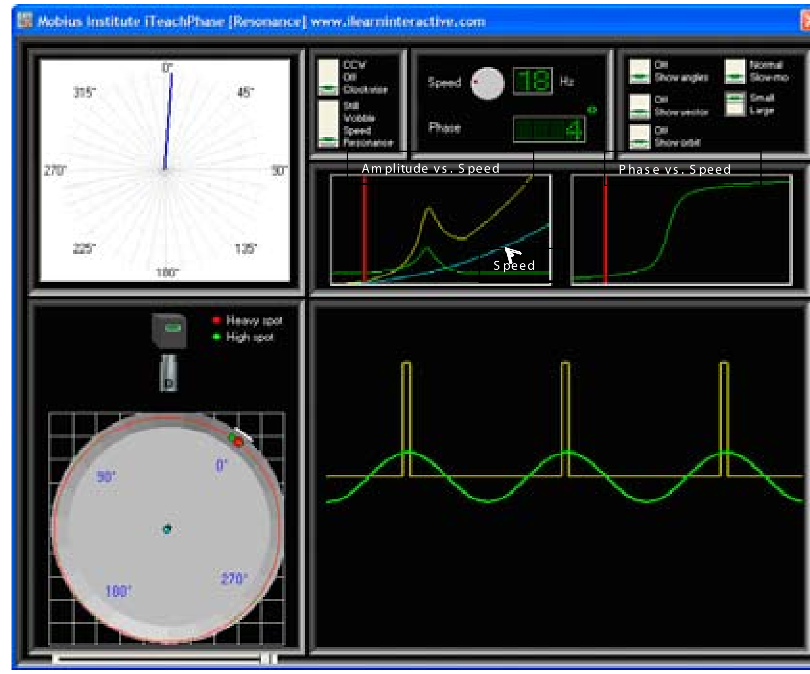


Figure 6 - Heavy Spot and High Spot in Phase when rotor is running well below resonance

System lag is a measure of the angle (in degrees) between the heavy spot and the high spot. The system lag angle is very important to know when performing a rotor balance. It helps determine where to put the trial weight. As the rotor increases in speed the heavy spot and high spot will move apart as rotor speed approaches the shaft critical. Here are the details:

- At speeds much less than rotor critical, the rotor's heavy spot and the resulting rotor deflection (high spot) are virtually on top of one another. The system lag is close to 0°. As long as the operating speed is well below the rotor critical, the heavy spot and the high spot remain at near zero degree lag regardless of rotor speed. The relationship between the heavy spot and high spot at speeds well below critical is illustrated in Figure 6. The plus sign (+) indicates the rotor's mechanical center of rotation. The green dot near the center of the shaft is the rotor's center of mass. The red dot on the outer edge indicates the unbalance heavy spot and the green dot on the outer edge indicates the high spot. Notice that the red and green dots on the outer edge are almost on top of each other indicating a near zero phase lag.

- As the rotor rotates faster, the rotor's heavy spot begins to lead the high spot creating what is known as system lag. For a machine rotating below but near critical, the angle between the heavy spot and the high

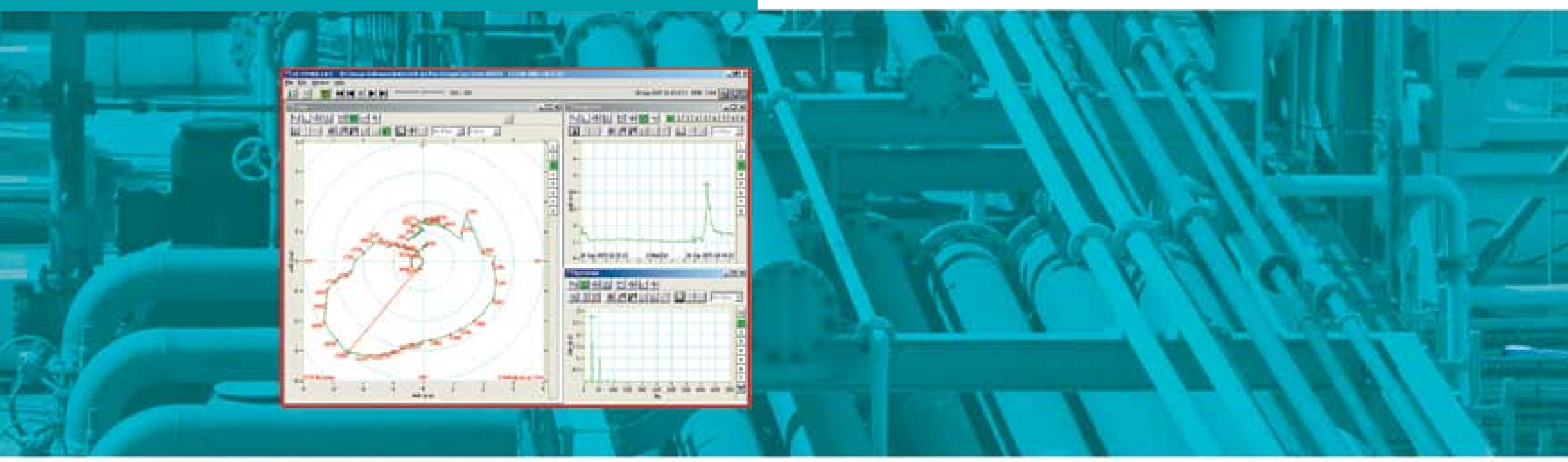

A journey of a thousand miles begins with a single step.
Lao-tzu (604 BC - 531 BC)
RELIABILITY™ WEB.COM
Regardless of where you are on the journey from reactive maintenance to predictive maintenance to reliability asset optimization, Reliabilityweb.com offers opportunities to meet peers, subject matter experts and solution providers who can make a difference in your program. Over 90% of past participants report making immediate improvements at work as a result of attending.
The Community of Learning at a Reliabilityweb.com conference provides an opportunity for a new attitude, new ideas, practical solutions and powerful inspiration from networking with others who are already on their journey to reliability.
PdM-2007 - The Predictive Maintenance Technology Conference & Expo
September 11-13, 2007 The Orleans Hotel & Casino Las Vegas, NV
Vibration Monitoring and Analysis, Infrared Thermography, Motor Testing, Ultrasonics, Non-Destructive Evaluation
LubricationWorld
September 11-13, 2007 The Orleans Hotel & Casino Las Vegas, NV
Practical Plant Machinery Lubrication, Contamination Control, Oil and Fluid Analysis
IMC-2007 – The 22nd International Maintenance Conference
December 4-7, 2007 Hilton Daytona Beach/Ocean Walk Village Daytona Beach, FL
Reliability, Maintenance Management, Planning & Scheduling, Business & Financial Aspects of Maintenance, Root Cause Analysis, Technology Innovations
CMMS-2007 - The Computerized Maintenance Management Summit
December 4-7, 2007 Hilton Daytona Beach/Ocean Walk Village Daytona Beach, FL
Computerized Maintenance Management Systems for Small to Midsize Companies
RCM-2007 - The Reliability Centered Maintenance Managers' Forum
March 18-20, 2008 The Orleans Hotel & Casino Las Vegas, NV
Reliability Centered Maintenance (RCM), Reliability Analysis, Failure Analysis, PM Optimization, Reliability Incident Management
EAM-2007 – The Enterprise Asset Management Summit
March 18-20, 2008 The Orleans Hotel & Casino Las Vegas, NV
Enterprise Asset Management (EAM), Computerized Maintenance Management (CMMS), ERP Integration, MRO and Spares Inventory, Handhelds, RFID and Bar Coding
Events produced by Reliabilityweb.com
Events supported by Uptime Magazine, RELIABILITY® Magazine, MRO-zone.com and the International Proactive Maintenance User Group (IPMUG).
for more info or to register
www.maintenanceconference.com

Your Complete Data Acquisition Solution

High-Speed **ROTATING MACHINE** *Monitoring*

It's never been easier to increase your facility's EFFICIENCY, RELIABILITY, & SAFETY than by using IOtech's **eZ-TOMAS** *Out-of-the-Box* machine vibration monitoring system.

> *Contact IOtech today for an on-site demo*



- Each channel can define up to 14 spectral bands
- Each spectral band can define 4 alarm level sets for up to 5 separate RPM ranges
- Automated fault log file generation and fault notification by email or text messaging — 24/7
- Monitor, limit check, analyze, and store machine transient and long-term vibration data
- Remotely monitor hazardous areas
- Rotating machinery analysis using interactive displays

High-channel expandable
ZonicBook/618E

Low-channel
IOtech 600 Series

*Visit **iotech.com/eztomas** for complete specifications, ordering information, and a free 30-day trial package of eZ-TOMAS*

IOtech®

iotech.com/eztomas
call us (888) 890-3011
email us sales@iotech.com

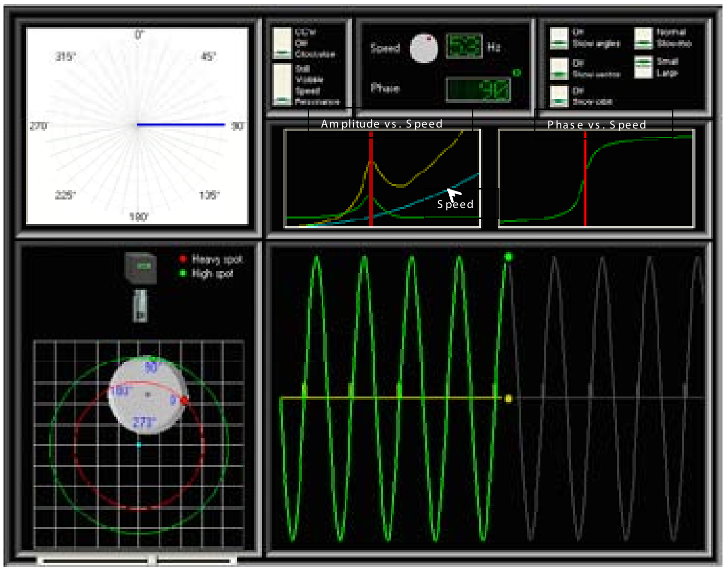


Figure 7 - Heavy Spot leads the High Spot by 90° at shaft critical

spot will be between 0° and 90° (Figure 7). Another way to think about this is that below (but near) critical the heavy spot and high spot have separated, but they are still in the same quadrant. At shaft critical the system lag is 90°.

- As the machine speed increases above shaft critical, the lag angle increases above 90° up to 180°. The system lag is 180° at speeds well above shaft critical (Figure 8).

Much of our rotating equipment, especially small and medium-size machines, operate below shaft critical. As a result, the high spot and the heavy spot are not on top of each other. There is a system lag between them. Usually it is less than 90°. For large or high speed rotors, the rotor speed may be above shaft critical and the phase lag can be up to 180°.

Gary James is the Training Manager for Ludeca, Inc. in Miami, Florida. He joined Ludeca in 2006. Gary comes to Ludeca from a petrochemical background where he worked in the maintenance service and rotating equipment areas, as well as plant operations during his 19-year career with the Dow Chemical Company. Gary spent the last eight years at Dow in the Vibration Services Group where he performed turbo machinery startups, acceptance testing, field balancing and diagnostics of equipment. Before his time in the Vibration Services Group, Gary started in plant operations where he gained valuable experience and worked up through the ranks to Shift Supervisor at Dow Chemical. Gary has spent the last 18 years either performing vibration analysis or teaching. At Ludeca, Gary teaches a variety of courses including Omnitrend, VibScanner, VibXpert, and Dynamic Balancing.

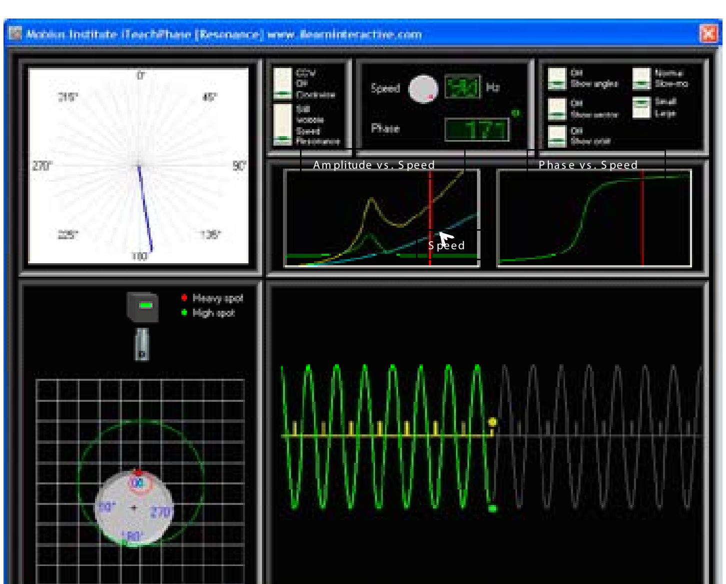


Figure 8 - Heavy Spot leads the High Spot by 180° well above shaft critical

To see more information on the relationship between the heavy spot and high spot as it is influenced by shaft resonance, please visit:

http://www.ilearninteractive.com/iteachphaseresonance

where you can watch a 12 minute video on the subject provided by Mobius Institute. Many thanks to Mobius Institute for the graphics in this paper. Please visit http://www.mobiusinstitute.org for more Vibration Technology Training-related information.

Airborne Ultrasound

The Most Versatile Tool Since The Wheel

by Jim Hall

The wheel was a nice little addition to commerce, and life, sometime between 3500 BC and 4000 BC. Needless to say, it made quite an impact. Airborne Ultrasound was discovered a little later than that. However, when first introduced into a maintenance program, it can also have dramatic and far reaching effects.

Think of the airborne ultrasound receivers as an extension of your ears. Ponder these examples: A 5 psig compressed air leak (.050) can be heard at 50 feet away, an underground steam/condensate leak can be heard 6 feet underground, a failing gearbox can be heard at 40 kHz (40,000 hertz), a bearing can be diagnosed as needing grease and corona can be heard clearly before opening high-voltage panels.

The airborne ultrasound instrument receives the ultrasonic signal and converts it to a low-frequency signal so that you and I can hear it through a set of headphones. When listening for leaks with our human ears in a noisy plant, many times we cannot distinguish between the background noise, or an air leak. However, the airborne ultrasound receiver, unlike our own hearing, only hears frequencies above 20 kHz. Pressure and vacuum leaks are typically 38-40 kHz and are easily heard with an ultrasound receiver. Corona cannot be seen by infrared imaging under 240 kV, airborne ultrasound can hear corona at 1 kV or higher.

Interestingly, there are less than ten airborne ultrasound manufacturers. Most of you may only be able to name three, possibly four of these manufacturers.

Many of you have been tasked with learning technologies like vibration analysis, lube analysis or infrared imaging. Consequently, you may have not been introduced to this technology. Now, I won't call it the "Ole Man", but it has been around for better than 35 years. It may surprise you to learn that this particular predictive maintenance tool has more uses directly applicable to predictive & preventative maintenance than any of the other technologies combined.

We will look at power generation plants in this article. We'll highlight power generation plants because, other than petro-chemical plants, they are among the largest group of airborne ultrasound end-users.

I will list several airborne ultrasound applications, many that are common and some that are not so common.

While you're thinking about these applications, try to think about how some could be used in your plant or industry. For instance, we can all relate to compressed air leaks, but the concept of leaks can be taken further. In the automotive industry, a tone generator is used to find "wind/water leaks" in automobiles. This would relate to locating leaks on an aircraft for cockpit pressurization, fuel cell leaks, rail systems for wind/water leaks, watertight hatches, cargo bay hatches and/or tank integrity inspection, to name just a few. I say this a lot, but it's true. Ultrasound is useful for much more than just compressed air leaks!

Power Generation Plants

There are several applications in an electrical generating plant in which airborne ultrasound is used :

Rotating Equipment - Most plants have a large amount of rotating equipment such as gearboxes, motors and pumps. Vibration personnel cannot possibly check all rotating equipment, but luckily airborne ultrasound provides an easy way to collect data. Instead of vertical, axial or horizontal readings, you have one reading or point on which to collect data.

It's simple and effective. Place the sensor on the bearing give it 5-10 seconds, press the button or manually write down the reading and move-on to the next bearing or point to read.

Figure 1 - Trending motor bearings can be easily done with "One Point" inspections.

Figure 2 - Cavitation can be heard on pumps using airborne ultrasound.

One plant I visited recently had some 68,000 bearing points on the conveyors. Touching each point would be impossible, but scanning these points periodically with an "airborne scanner" would save thousands of man-hours a year and, quite possibly, a lot of unscheduled downtime.

Cavitation can sometimes be heard unaided with our ears, but most of the time the background is too loud to hear it. Ultrasonically it can be easily identified.

Acoustic lubrication of motors is another application. More and more plants are using ultrasound to lubricate bearings. The key here is to have an airborne ultrasound instrument that one can easily identify a decibel or level. Grease the bearing slowly, preferably half-strokes of the grease gun. The decibel level will decline and stop. Give the bearing a few seconds to decline again. If it does not and tends to increase upwards, stop lubricating.

Figure 3 - Listening to bearings of a motor with an AccuTrak® VBE-1000 Ultrasonic Instrument.

Compressed Air - Compressed air can be used for many different tasks such as instrument or control air, soot blower air, etc… Cryogenic or compressed cylinder gases such as hydrogen, oxygen, nitrogen and helium are among some of the gases commonly found.

Heat Rate Problems - Try using your ultrasonic receiver to inspect the boiler walls for leakage. Heat loss from decaying boiler casing walls can be heard rushing out from the walls. This heat loss is energy produced, and loss occurs through openings like cracks, broken ducts or leaking couplings to name just a few.

Figure 4 -Heat rate problems such as holes in boiler walls may be heard as rushing air from between boiler plating.

U-Tube Type Heat Exchanger (on/off-line) - U-tube type heat exchangers found in generation plants are typically inspected hydrostatically. That is, they use water under-pressure to test leaks by time, which is also known as pressure decay testing.

Airborne ultrasound can be most effective on heat exchanger leaks by inspecting the heat exchanger on-line before bringing it off-line. Simply take the contact probe of your instrument and section the vessel into 4 segments. Use the points of a compass (north, south, east & west) for direction, touch the vessel and listen for the leak. The sound of two mediums of substantial varying temperatures can be very loud. Some say it sounds like steam flashing (metallic popping sound). As you move the contact probe from point to point, segment to segment, anywhere sound resembling a leak is heard, it is safe to assume the heat exchanger is leaking.

Once, you go off-line, the next procedure would be to expose the tube-sheet and pressurize the shell with deck air or a dry nitrogen source using your plant's recommended pressure rate. Be sure to evacuate any water or moisture from the tubes. When leaks are present, you can hear air leaking not only from the tube, but from the rolled end of the tube as well. Take a handful of corks and place in the tube to identify the leaking tubes. With U-tubes, you will have an even number of corks placed when you are finished.

Condenser - The condenser is the largest heat exchanger in the condensate/feedwater system, and is generally located under the steam turbine generator. As the steam exits the turbine, it passes over cool pipes that condense it to liquid water. This liquid, purified water, is then pumped back to the boiler to be heated into steam again. The same purified water is boiled and condensed over and over.

The clean side of the condenser must be kept from contaminated water such as water from a river. Typically, river water is used to cool the pipes that condense the steam to purified water. If this fresh water leaks into the purified or clean side, corrosion throughout the

system is possible and can reduce operating hours and the life of the system.
Airborne ultrasound can find leaks in the waterbox too. Be sure that the instrument you use is sealed, so that moisture and heat do not affect the instrument's performance.

Expansion Joints - We have inspected expansion joints for air in-leakage at many plants both up close and from 20-30 feet away using long range horns and/or parabolic reflectors. Close-up my favorite tools to use are the Flexible 36-inch Scanning Module (by SDT) or the Close Focus Module (by U.E. Systems, Inc.). For distances, a long range horn or a parabolic dish can be very beneficial.

Compressor Turbine Inspections - It always amazes me to walk-up next to this monstrous machine and to listen for "air in-leakage" around the turbine shaft and associated components, such as panels, access plates and the bolts securing these panels and access plates. The noise is deafening to the naked ear but not to the ultrasonic receiver.

Hydrogen gas inspection on the compressor is another plus for using airborne ultrasound (see Uptime, May 2007).

Steam Traps and Valves - Widely known for steam trap inspections, airborne ultrasound can easily hear what is going on inside the trap. For instance, in an inverted bucket trap, you can hear the bucket moving up and down or not, blow-by, or too much condensate. In disk type traps, you can hear the trap fluctuating or if badly worn, "motor boating". Degradation of operating condition can be also detected in many other types of traps, such as float and thermodynamic.

High pressure steam valves and ducting can be a major source of loss, of both energy and money. Hundreds of thousands of dollars are lost each month due to high pressure valves leaking past their seats. To this day, I still remember a time several years ago when a southeast utility worker was telling a classroom of utility workers how the utility had been losing several millions of dollars because of leaking high pressure steam valves in the system. These valves, which had been replaced with newer equipment, were left in the steam piping and had become weak. Due to "knifing", a term used to describe steam making its way past and through the seats of valves, they had been losing steam that should had been used to produce electrical energy. Millions of dollars is a lot to lose, and it made an indelible impression on me.

Figure 5 - Testing steam valves in steam plant using an SDT170®.

Electrical Switchgear, Transformers and Substations - I recently wrote about finding nitrogen blanket leaks on a step-up transformer at a power plant (Uptime, April 2007). Others before me had not been successful in finding the leak, mainly because they did not have an ultrasound receiver available at the time. Soapy water alone is not the solution. Airborne ultrasound heard the largest leak within 2-3 seconds, just about the amount of time it took to turn on the unit to listen. The sound of the leak was easily heard even without aiming. These transformers are normally

Figure 6 - Scan high pressure steam ejector piping and ducts for leaks.

set at 1-1.5 psig of continuous pressure. Just like in any other industry switchgear needs to be periodically scanned for anomalies - especially before opening the panel! I feel very strongly that lives and personal injuries have been avoided due to the use of airborne ultrasonic for switchgear inspection.

I was recently involved in a situation where one company avoided a partial plant shutdown by scanning 13.8 kV rectifier panels with the ultrasound receiver. This particular case history was a large southeastern chemical plant with a row of 15 13.8 kV rectifier panels, all with vacuum breakers mounted at the lower right hand corner of the panel. While instructing this company's technicians on how to use airborne ultrasound, we discovered this high amplitude of destructive corona discharge and arcing. We heard a lot of popping sounds, which meant this condition was critical. It was enough sound to make me look for an exit quickly. This anomaly was easily heard by the ultrasound receiver, but it could not be heard with the naked ear. This vacuum breaker was removed, and when dc current was applied, the breaker had failed due to a hole in the breaker. Even after this incident, this company did not purchase an ultrasound receiver. The technicians could not convince anyone with purchasing power that the new $50k infrared thermal imager

Figure 7 - Scanning electrical switchgear can be done quickly using an SDT170®.

was not enough for their inspections. Please don't make the same mistake. For electrical inspections, an airborne ultrasound receiver is imperative for the safety of maintenance personnel.

Substation Maintenance - Using airborne ultrasound within a substation should be the normal application by every plant that either performs routine maintenance or would like to implement an inspection program.

Unlike infrared imaging, airborne ultrasound does not need "line-of-sight" to be effective. However, those entering a substation to scan with an ultrasound receiver should always walk the substation from several angles including front, side and rear of electrical grids. Ionized molecules being sent into the atmosphere are subject to wind direction. For instance, when scanning with a parabolic dish or long range horn, you should be downwind and scan upwind for optimum inspection.

Nuisance corona can be identified as a steady egg frying sound. Destructive corona can be heard as an egg frying sound but with loud intermittent popping sounds. Of course, other conditions such as arcing and tracking can also be detected using the airborne ultrasound receiver. If any of these conditions are present, it's wise to remedy the problem as quickly as possible.

The invention of the wheel dramatically altered the course of human history. So too, will you alter the course of the maintenance of your facility, and your organization's bottom line, by introducing Airborne Ultrasound into your maintenance program.

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

Vibration & Condition Monitoring

From Daily to Diagnostics

By Thomas J. Murphy

Condition monitoring works. It is a well-proven technique that helps keep planes flying, power stations generating, paper machines making paper and presses printing. Actually, the concept of vibration monitoring using a portable digital vibration analyzer is roughly the same age as the PC. The difference in how these technologies are viewed is quite interesting. If the PC fails to perform we re-boot it and carry on, but if vibration monitoring fails to perform it is because the technique "doesn't work".

The common perception of condition monitoring and vibration analysis is one of the trouble-shooter called out to solve the acute problem. The large majority of the money lost in the operation of any plant is not from the acute problems. It is what could be saved by addressing the regular, chronic problems which everyone has become accustomed to solving in order to "keep things going".

Optimum performance depends upon the integration of all critical functions within the organization. Just like maintenance and production - engineering, purchasing and many other functions also have a direct impact on the availability and total operating costs. Each of the critical functions must work in conjunction with both production and maintenance before measurable plant improvement can be achieved.

Many of the factors that adversely influence production capacity and total operating costs can be directly attributed to failures in the design, purchasing or installation of critical manufacturing systems. Maintenance best practices can establish design, purchase and installation criteria that will ensure optimum performance levels from all plant systems over their full useful life. Based upon realistic life cycle costs, this will assist the development of standard procedures and equipment evaluation methods that will eliminate certain limiting factors before they arrive with the installation.

Condition monitoring is a vital element in maintenance best practice. It is the tool which closes the feedback loop and which identifies where the "best laid plans" are not making it to the shop floor.

How to Make Condition Monitoring Work

In order to make any tool work properly, you need to know not only how to use it, but also when to use it and you must want to use it. All too frequently instruments have been purchased without regard to the range of application of the instrument. The salesman said that the instrument could be used to solve many problems and the novice user is launched headlong into tackling the really sticky problems first – and quite possibly failing.

To make condition monitoring really work, you must start with the most basic of questions – what do I expect to get from condition monitoring? In other words, what problems do I hope to solve by applying these techniques, what techniques work well and where do they work? Once you have the expectations, it makes sense to do some research to find out how realistic those expectations are and what will it take to make them achievable.

Condition monitoring is not a magic wand nor a shield – it is a kit of tools which can be applied to solve engineering problems. The best benefits of condition monitoring are only achievable by integrating the technique with a much broader approach to maintenance best practices.

How to Attract the Manager's Attention

Seek out chronic problems and solve them first.

Anyone who travels to work by car will understand the concept of threshold shifts. If your journey to work involves slow traffic, you soon shift your threshold to a position where you are no longer intrinsically sensitive to the jam but to changes from the norm. Phrases like "the traffic was bad today" or "better than usual" are heard.

This same de-sensitisation occurs in maintenance. If the maintenance department has become so adept at replacing a gearbox "on the run" and has all the spare parts on hand to repair the faulty one in a day, then there is a serious chronic problem waiting to be solved.

Solving these chronic problems has a direct impact upon down-time, maintenance efficiency and costs. Removing unnecessary maintenance routines reduces costs and increases engineering availability for other functions – such as condition monitoring and other inspections.

Most important of all is communication. What does go on in all these morning, weekly and monthly meetings? Why do the people who need to know rarely find out? How many organizations have someone directly representing maintenance at the board level? My guess would be not very many at all. So, whenever you save money: cost it, document it and report it. Psychologically, this is very important. When you want to be able to buy that new vibration instrument or some more sensors or that alignment equipment, it would be a very ineffective manager who could ignore the evidence of the savings if the savings are already documented.

Integrating CM Concepts into Specifying, Purchasing, Installing and Operating

This is where many companies go wrong. The first step is a critical evaluation process. The requirements of the plant must be defined by machine, by process and by operation. It is essential at this stage that every effort is made to identify weaknesses in the existing processes.

The evaluation should include financial, management philosophy, and performance of various plant functions as well as the operating efficiency of critical plant production systems. Properly conducted, the plant evaluation will establish a baseline of current plant condition; identify inherent problems and provide direction for improving productivity.

This evaluation program, coupled with a comprehensive predictive maintenance program, will provide management information required to optimize performance. The most important planning function is predictive maintenance. This should be developed to monitor, on a regular basis, the actual operating condition of all critical plant machinery and systems. This program should not be confused with predictive maintenance programs whose sole purpose is to schedule maintenance tasks or equipment replacement.

The second requirement is to evaluate, on a regular basis, a series of plant specific indices that will accurately quantify the effectiveness and efficiency of critical plant functions. These plant functions should include plant engineering, purchasing, production and maintenance.

Typical performance indices which can be used are: percentage non-scheduled repairs, percentage repair re-works, percentage availability, mean time to failure and mean time to repair.

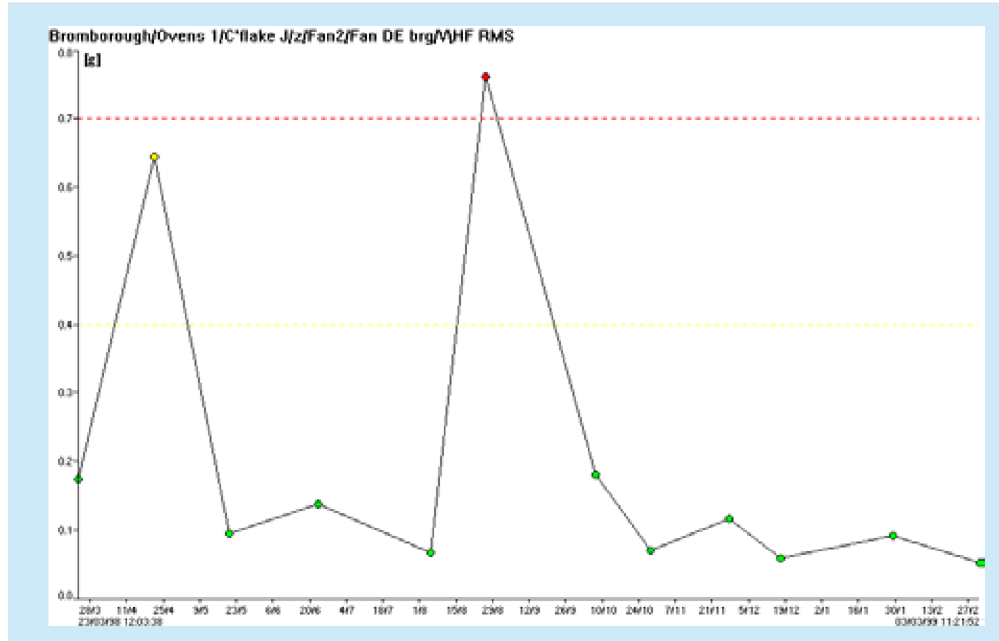


Figure 1 – Initial greasing of this bearing reduced levels, following a strip down of the bearing and removal of the old grease when levels had increased again, levels have remained down.

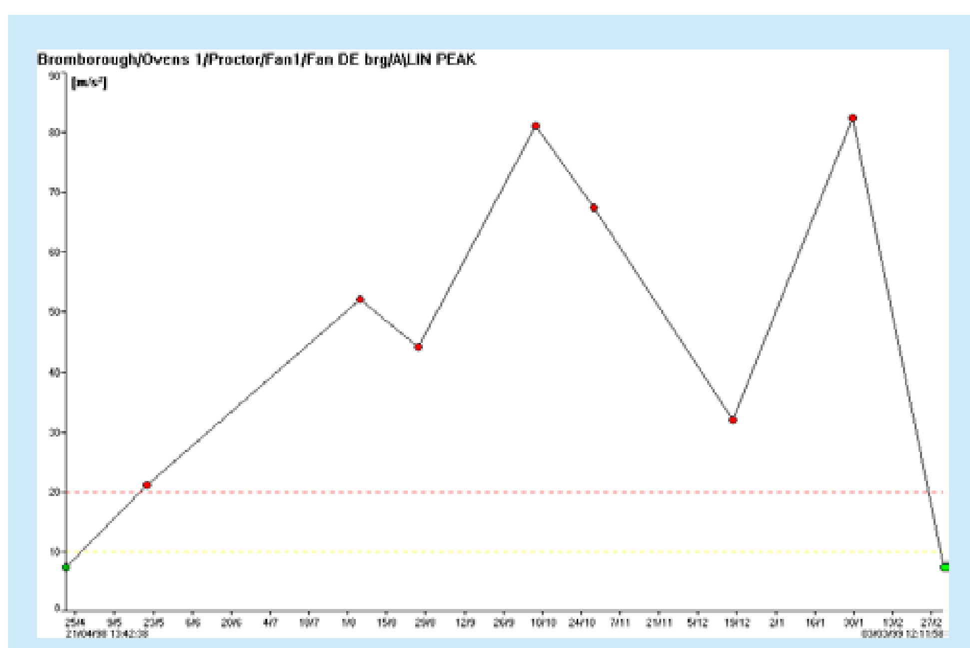


Figure 2 – This machine is less than 2 years old. The first reduction in levels followed an inspection of the bearing which revealed that the grease pathways were incorrectly fitted. The second reduction followed replacement of the bearing.

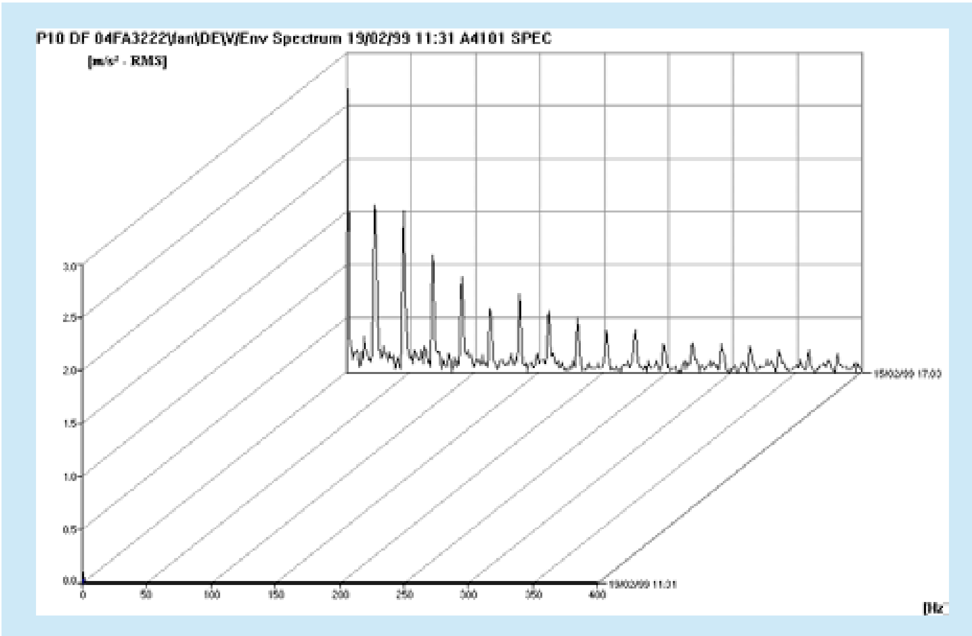


Figure 3 - Looseness of a bearing on fan shaft. Damage had occurred within 2 weeks of fitting new bearings to an old shaft. The smudge on the axis in the foreground is the repaired condition.

In addition to the development of these statistical methods, analytical information must also be obtained to understand the reasons for poor performance. Only then can steps be taken to improve performance.

Part of the development of these ideas will require an understanding of true life-cycle costing and the use of that data to identify weaknesses in the system.

Equipment selection, both new and replacement, is critical for optimum performance. All too often the decision is to purchase from the lowest bidder. Sometimes the purchasing department personnel can be penalized for not doing so. This concept is not conducive to maximum availability and maintainability of the plant. To compound the severity of this problem, equipment vendors have also suffered from the same problems that affect your company. Their product quality and reliability may also have declined to a point where their claim of reliable, maintenance-free operation of their products is suspect.

Many vendors appear to have adopted a strategy of "planned obsolescence" in order for them to maintain acceptable profit margins. They may also cut corners, reduce safety margins and generally reduce the reliability of their equipment. In many cases, the only profit that a vendor makes on his equipment will come from spare parts. Under such circumstances it is unwise in the extreme to hand over the maintenance contracts of the equipment to that self-same vendor. Companies who do not insist on reliability, and maintenance-free equipment, will get just what they ask for - constant production problems and high operating costs.

Therefore the manufacturer of the machinery is rarely the best person to rely upon for its maintenance. What must be developed is a mediator, a person or group with a declared vested interest: the ownership of the machinery and a genuine desire to make the plant run efficiently and cheaply.

Equipment, machinery and systems must be purchased based on the best life-cycle evaluation. This must include initial capital cost, operating cost, and maintenance cost. Equipment must be selected based on the total cost of equipment, not just the initial purchase price. As in design, it should not be one person, but a team from engineering, operations, maintenance and purchasing that makes the final decision on purchases of plant machinery, systems, equipment and replacement parts. Once again, the development of the team, the sense of ownership and of the information required to make these decisions is paramount to achieving that ultimate goal of optimum performance.

To ensure that new and replacement equipment meets the life cycle costs and maintenance-free criteria, the purchasing department should develop standard acceptance criteria that will become an integral part of

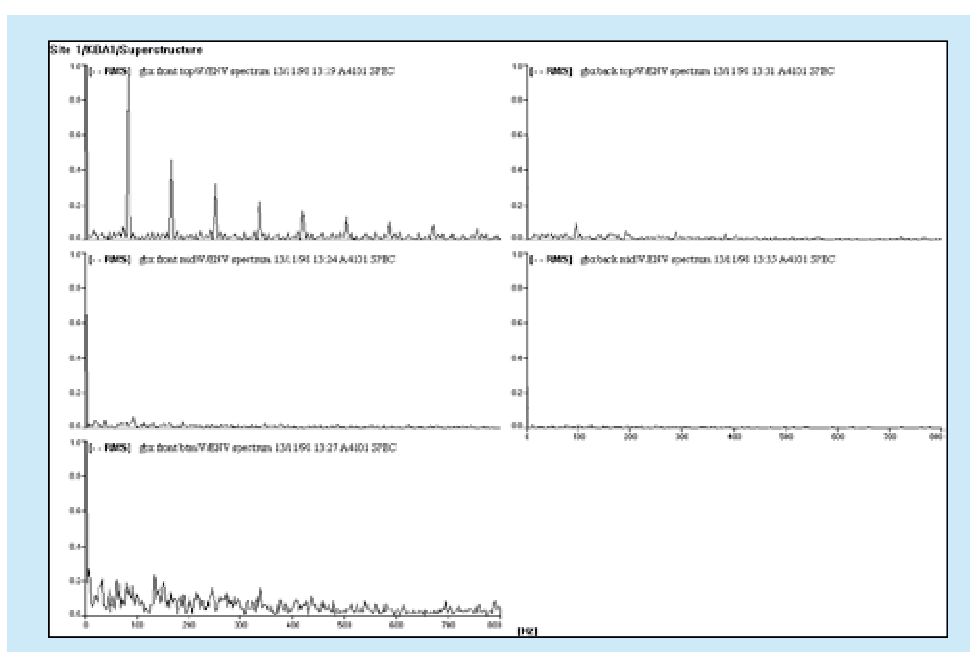


Figure 4 - One of these 5 folder gearboxes has a problem - expertise in diagnostics should not be required in order to decide which one!

every purchase order. The acceptance criteria should define the specific performance levels, maintenance cost and life cycle costs that is expected from the equipment and testing procedures that will determine acceptance by the company. These factory and site acceptance tests must be well-defined and accepted by the vendor prior to placement of the purchase order.

A system which ensures that you do not buy into maintenance problems should be common-sense. Unfortunately there are many companies who don't seem to agree!

Hand-held vs. Continuous On-line Monitoring

There is much debate about the cost and complexity of vibration monitoring. At one end there are companies who "cannot justify the cost" no matter how cheap. At the other end, there are companies who can invest $200,000+ and see real benefit. How can there be such a wide diversity of opinion?

The primary reason that most organizations fail to develop the correct regime of monitoring is due to a fundamental lack of understanding of the problems and the costs at board level. There is understanding regarding photocopiers and company cars, but not maintenance.

In the final analysis the choice is not an either or, it is both. There will be some parts of a press or paper machine where continuous monitoring will be the only way to provide the depth of operating condition information necessary to make an informed judgement about incipient failure. At the other extreme, monthly checks on a pump or fan using a portable instrument will probably be more than sufficient.

Figure 5 - This cable was the yellow phase on the incomer to a bindery. There was a ground cable resting across the top of this cable which showed signs of burning due to the contact with this cable. Had we not been there to force someone to open the cabinet there would have been a big bang quite soon!

One of the biggest problems with portable monitoring is the periodicity, or frequency of measurement. Once again, price becomes an issue with the false economy of quarterly or bi-annual surveys. Condition monitoring measures the condition now. If the condition is good and the prognosis is good then all is, apparently, well. Two months from now – maybe even two weeks from now the story may be different. That change may result in a failure before the next scheduled visit. And the unfortunate conclusion will be that the technique does not work!

A simple car analogy would be checking tire condition. Routine checks will reveal wear problems and some prediction towards the onset of poor handling or illegality may be made. But, even daily checks cannot predict a puncture. There will always be mechanisms for potentially catastrophic machine failures (e.g. blockages in a shared lubrication system), which if overlooked, and not present at the time of the routine survey will inevitably lead to premature machine failure.

It is for these reasons, as well as the need to gather and process significantly larger amounts of data than can sensibly be collected by hand, that on-line systems have their rightful place in the toolkit. The most important aspect must be the integration between the two. It is essential that the on-line and off-line should use the same database and present the same user interface. By doing so, all data is accessible to all people and in an understandable format.

Advanced Diagnostic Methods

The same tools we use for routine monitoring can also be used to perform a variety of more complex diagnostic and remedial techniques. With the addition of nothing more than a laser tachometer and the appropriate software, a mundane vibration data collection system can be transformed into a powerful diagnostic tool for operating deflection shape testing, phase analysis and in-situ balancing.

Almost all of the vibration analysis we use is dedicated to the micro level - looking inside the machine and deducing the condition of a motor, gear or bearing. ODS looks at the macro level - it is a very powerful technique for visualizing defects associated with how a machine or structure moves in operation.

Many companies still pay large amounts of money to have fans and motors balanced externally by manufacturers. In fact, nearly all of this work could be performed in-house for a fraction of the cost using the existing vibration equipment.

Benefits of Multiple Approaches

It is often heard “we use thermography” or “we use oil analysis” as if that is the only technique which works and is used to the total exclusion of all others. In fact, most of the techniques are complementary rather than mutually exclusive.

Oil analysis is fantastic for identifying wear and trapping damage due to incorrect lubrication. You might be tempted to say “only”. However, since wear and inadequate lubrication are two of the biggest killers in industry, it really wouldn’t be appropriate.

Thermography works by detecting infrared radiation. If you have a defect which generates heat (or the lack of it) and that heat conducts or convects to a surface which you can see, then you can use thermography. It is a quick, easy method of detecting many of the common problems found in manufacturing industry. Thermography has one significant advantage over vibration because it is inherently understandable, and, even with the best will in the world, a spectrum is not. Thermography needs very little interpretation whereas vibration needs a lot of post analysis. Apart from the common electrical surveys, thermography can be used to investigate mechanical problems, lubrication problems and product quality issues.

Oil analysis can tell you if a gear is wearing, thermography can tell you if the bearings are warm or if the oil is warm, but only vibration can tell you if a gear is eccentric, how significant the wear is, if there is a bearing defect or if there is an internal misalignment of a meshing pair.

Thermography can tell you if you have a phase imbalance on a large motor. Vibration can show the influence of this imbalance in the dynamic behavior of the motor.

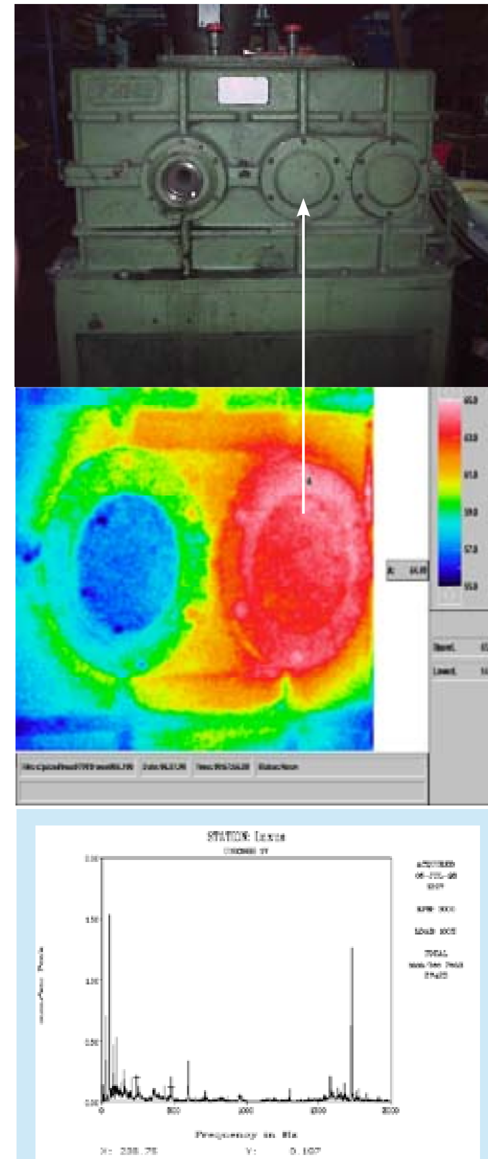
Looking at Other Industries

There is a lot to be gained from looking outside for inspiration. Every industry perceives itself to be unique and to have financial and production constraints which far exceed those of any other industry. Generally this position does not stand up to close scrutiny.

With the possible exceptions of some petrochemical, nuclear power stations or similar industries where machine failures can kill, most of us have a relatively simple set of problems to deal with. I know one nuclear power station which has 3 64-channel on-line monitors, 6 data collectors and a network licensed software with 40 users. This might sound impressive, but to put it in context, I know some paper mills with similar levels of investment.

One lesson which is clear across many industries is that productivity must continue to increase, staffing levels continue to fall and downtime for maintenance is constantly squeezed. Under conditions like this it is vital that we develop tools and strategies which can give us as much information as possible about our machines while they are in operation – and this is where condition monitoring delivers.

Tom Murphy is an Acoustics graduate from Salford University and has 25 years experience in the world of industrial vibration measurement – 15 of those years have been involved with the use of ODS techniques in the paper, printing, petrochemical, power generation, pharmaceutical and food industries. Tom is the Managing Director of Adash



A gearbox on a plastic extrusion machine caught by chance on a thermal imaging camera shows a warm bearing. Subsequent vibration analysis identified a series of peaks at 238Hz which corresponded reasonably well with the predicted inner race defect frequency of the SKF22318 bearing on the input shaft.
One month later the machine was stopped and the bearing was removed in several pieces.

3TP Limited, based in Manchester, England, a company specializing in the application of vibration, infrared and ultrasonic technologies to improve maintenance. More info can be found at www.reliabilityteam.com and Tom can be contacted at +044 161 788 9927 or at tom@adash3tp.co.uk


Learn at your own pace
in your own place.
Now with our affordable computer based distance learning courses you are free. Free to learn when you want and where you want. Each course includes narrated slides and lectures on CD, text book, access to student/instructor message boards , quizzes and assessments online and personalized coaching through MaintenanceForums.com
Our unique training program offers all of the training without the hassles and expense of travel.
Courses offered include
5 Pillars: Maintenance & Reliability Professional Certification Review
by Dave Krings, CMRP
Achieving Total Productive Maintenance (TPM)
by Terry Wireman, CPMM
Benchmarking Best Practices Maintenance
by Terry Wireman, CPMM
Change Management For Maintenance & Reliability Professionals
by Steve Thomas
MRO Excellence
by Kevin Lewton, CMRP
Developing Key Performance Indicators
by Terry Wireman, CPMM
Level 1: AC Induction Motor Maintenance & Diagnostics
by Howard W. Penrose, PhD, CMRP
Time Management for Maintenance Professionals
by Joel Levitt
20 Steps to World Class Maintenance
by Joel Levitt
Mastering Maintenance
Learning Resources For Maintenance & Reliability Professionals
Lean Maintenance in a Nutshell
by Joel Levitt
Reliability Centered Maintenance (RCM) For Everyone
by Neil B. Bloom
The 3 Phases of Reliability Centered Maintenance (RCM)
by Neil B. Bloom
Turning Maintenance into A Profit Center
by Kris Bagadia
Reliability Centered Maintenance Training Seminar on DVD
by Anthony "Mac" Smith
www.MasteringMaintenance.com
888-575-1245 ext 118 (USA)
305-735-3746 ext 118

Precision laser alignment is just 3 simple steps away with the

OPTALIGN® smart

Misalignment is one of the most common problems in rotating machinery. The effects of misalignment are many: machinery vibration, seal wear, bearing damage, coupling damage and, ultimately, shorter machinery lifespan and higher costs. So it makes perfect sense to do everything you can to keep your machinery properly aligned. The OPTALIGN smart laser alignment system by Prüftechnik is a powerful tool that can help you perform alignments more quickly and more accurately. We recently chatted with Alan Luedeking, manager of training and tech support at Ludeca, Inc, about what sets the Optalign smart apart from other laser alignment systems. We like the fact that the tool comes packed with am impressive array of standard features, has a solid, ergonomic design and is very accessible and easy to use....and the happy and sad faces are kind of cool too.

The OPTALIGN smart System

There are quite a few laser alignment options out there these days. What are a few of the system's characteristics that set the OPTALIGN smart apart from the competition?

Its patented Continuous Sweep technology, fully automatic tolerance evaluation, ultra-stable concentric reflected beam, and the fact that it is fully modular, or customizable to meet the customer's exact requirements and budget. I also love the graphical alignment displays, full color screen and Bluetooth® wireless communication to name just a few.

The Continuous Sweep seems like it could provide much more accurate results. Why don't you go into a little more detail about this feature.

Continuous Sweep literally means the system is taking hundreds of readings continuously as you rotate the shafts, rather than just three discrete points. This is like shooting a movie rather taking single flash pictures. This allows the data to be statistically analyzed for quality, yielding a far higher degree of accuracy and reliability. The end result of Continuous Sweep is that the user gets the alignment done right, quicker— it means fewer unnecessary moves and repeat readings.

Today we always seem to think that more is better. Please explain why you chose to use one laser instead of two in the system.

Well, it is a fact that low part count is one of the best ways to improve reliability. Only one laser/sensor unit means your setup time is cut in half– only one laser to adjust! Furthermore, if you do choose to use the cable connection rather than wireless, there's only one cable to worry about, giving you much greater freedom of movement and placement. This is critically important when aligning spacer shafts (such as in cooling towers.) The power consumption required by two lasers and sensors is twice or more that of a single laser system. And lastly, the accuracy of readings taken by a single laser transducer is not dependent on axial play and is virtually unaffected by rotational play, or coupling backlash. The concentric reflected beam in a single beam system means that anything that happens to the beam outbound (due to vibration, air density differences in the path of the beam, heat waves and the like) happen to it equally in reverse on the way back, rendering the system totally immune to the nasty influences of such conditions on the accuracy of your readings. Even our high end PERMALIGN® system used to continuously monitor positional change on running machinery uses our single laser reflected beam technology.

Please tell us a little about the software, storage and reporting capabilities of the OPTALIGN smart?

Depending on the firmware options chosen, the OPTALIGN smart can store up to 500 alignment files on board, and by this I mean fully functional files that you can reopen and continue working with at any time in the future, including RPM in the Dimensions screen, any target values you may have input, soft foot readings, and so on. The OPTALIGN smart can connect directly to a USB printer and print a complete alignment report. Best of all, the Alignment Reporter software for your PC is free of charge! This lets you download and archive files, and print reports directly from the comfort of your PC.

How reliable is the OPTALIGN smart, and what support options underpin it?

The OPTALIGN smart is very rugged. It is shockproof, and is certified IP-65 waterproof and dustproof. The laser and prism are rated even higher, at IP-67, the only ones so rated in the industry. The Optalign Smart is extremely reliable, but if your Optalign Smart ever needs service, we offer a 24-hour turnaround, and if we can't service something that fast, there's always a free loaner component or system available, so our customers are never without an alignment system. We stock all optional accessories and precut SS shims. We also offer advanced training and free tech support. Making sure our customers are always taken care of is our number one concern. This is our basic business philosophy.

The powerful, fully customizable OPTALIGN smart system provides quick and accurate laser alignments

What are the top three reasons a company should invest in the OPTALIGN smart?

Ease of use, Continuous Sweep, and fully modular design. The fully customizable design means the customer decides what features they want. You get to design your own alignment system, with the exact features you need, and simply add more capabilities as your job demands grow, or when your budget allows it.

What is time frame for a return on the investment in the OPTALIGN smart system?

That depends greatly on the industry, number of machines installed, current alignment methodology, frequency of alignment and so forth. Nevertheless, virtually all of our customers see a return that pays for the tool in a year or less, and some with just one alignment on a critical machine! We have a very sophisticated Return On Investment spreadsheet that allows us to assist our customers with calculating this return for their individual situation, and it considers such things as repair costs, cost of power, and many other factors. It is very conservative, yet we have found that in the vast majority of cases, the cost savings that can be expected from implementing laser alignment in the plant with a good laser system is such that it will pay for itself very quickly and many times over.

Give us a success story or two from facilities using the OPTALIGN smart system for their alignment needs.

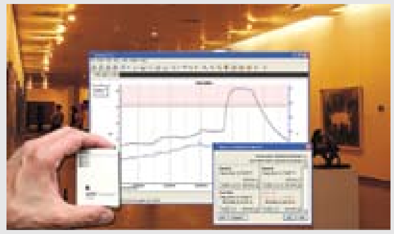
I know of one large paper mill in the southeast which has reduced pump repair part expenditures from over $200,000 per year to around $35,000 per year from the implementation of good laser alignment techniques and lubrication systems. And this figure does not even touch on the commensurate labor savings, reduced unscheduled downtime, increase in productivity, reduced power consumption, etc. There are hundreds of similar success stories, so it is hard to pick any one over another. Laser shaft alignment is simply an essential ingredient of good maintenance, and we are proud that the Optalign Smart plays such a large part in this field.

How can interested people get more information about OPTALIGN smart?

Simply visit us at http://www.ludeca.com/optalignsmart.htm or call us at 305-591-8935. We will be happy to answer any questions, provide training, etc.

Alan Luedeking is manager of training and tech support at Ludeca, and has over 25 years of field experience in alignment. He enjoys numismatics and reading, and struggles to keep up with his four children when they ask him for help with their homework.

Onset Computer Corp has announced the Alarm and Readout Tool, a plug-in software module for use with HOBOware Pro® software. The new Alarm and Readout Tool automatically notifies users via cell phone text messages or email when temperature, humidity and other conditions exceed user-defined limits. It also enables data from networked HOBO data loggers to be automatically offloaded and stored onto a centralized computer. This is particularly useful in applications where numerous locations are being monitored throughout a facility.



http://www.onsetcomp.com

Retrofitting old machines for in-process force measurement can present many challenges, including sensor integration, and high production cycle rates. Sometimes the existing sensing system or PLC just can't respond fast enough for reliable performance. PCB Piezotronics (PCB®) has developed an effective solution for these applications with the new In-Process Force Measurement system, which consists of a Series M240 ICP® Strain Sensor and Model 410A01 ICP® signal conditioner, featuring Peak Hold. The Peak Hold feature of the in-process measurement system allows older PLC systems to stay in synch with high-speed production cycles.

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

This is iT!!

The iT401 is Wilcoxon's relay alarm for vibration transmitters and loop powered sensors This DIN-rail mountable alarm module has three programmable relays for use in Condition Based Monitoring or Process Control systems.

HOT features include:

- Three programmable relays – high and low setpoints, and a BOV monitor of sensor or cable connection malfunctions
- 4–20 mA signals accepted from the iT Transmitter or any loop powered sensor, including Wilcoxon's popular LPS™ Series
- PLC or DCS network compatible
- Precise programming of 1%-accurate high and low alarm setpoints
- User-programmable delay timers and hysteresis levels.
- Power relays with the capacity to switch 250VAC, 8A-resistive or 1/3HP inductive machines, eliminating the need to link up with a PLC or DCS.

The iT Alarm is ideal for systems that utilize vibration monitoring of fans, motors, pumps, blowers, compressors, chillers, gearboxes, and mixers. The iT Alarm can

Wilcoxon Research

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

Designed for medium-sized motors, the newly enhanced 369 Motor Protection System from GE Multilin, delivers advanced motor health reporting, graphical and data rich fault diagnostics, simple six-step setup and complete traceability of setting changes, enabling industrial facilities to maximize process up-time and optimize rated motor output

www.geindustrial.com

The newly designed CTC website includes a Vibration Calculator for frequency conversions, belt and web speeds, bearing faults, gear mesh and other common conversions. This free tool is available on the web or fully downloadable for access on your desktop.

Check out CTC University: Technical Tips and Free Tutorials

This effort seeks to harness the strength of the vibration community by encouraging contributions to the interactive "ask the experts" board. Users can also input tips related to specific applications.

www.CTConline.com

Department of Corrections

In the April issue, on pages 30 and 31 in the article entitled "Motor Testing, The Next Level" we inadvertantly switched the captions on Figures 1 and 2. The corrected captions for the figures are shown below. We apologize for the confusion.

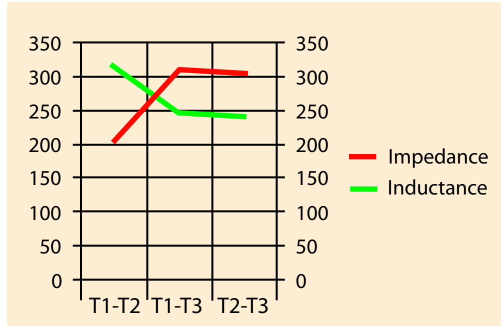


Figure 1 - Bad Impedance and Inductance Pattern

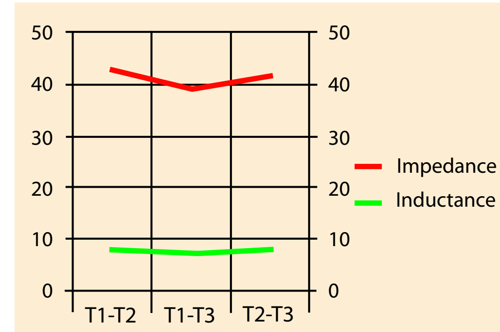


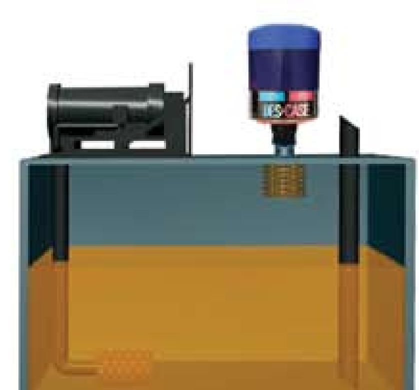
Figure 2 - Good Impedance and Inductance Pattern

The closer you look, the more you'll find to like.

You'll find more to like than ever before in Des-Case breathers. Once again, we've raised the standards with higher vibration resistance and enhanced chemical compatibility.

At Des-Case, we understand the importance of oil cleanliness and the role it plays in reliability optimization. That's why we've spent more than 20 years pioneering solutions specific to your industry applications that help maintain lubricant quality and maximize equipment reliability.

Our disposable desiccant breather virtually eliminates the entry of dirt and moisture. This means your equipment and lubricants can run longer and harder. Protect your investments with our contamination control solutions, such as desiccant breathers, oil handling products, or specialty breathers.



DES-CASE®
CORPORATION
Keeping contamination under control.®

Telephone: 615.672.8800
www.des-case.com • sales@des-case.com