Machinery Lubrication

India September-October 2016
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INSIDE

SPECIAL OIL ANALYSIS ISSUE

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SPECIAL OIL ANALYSIS ISSUE

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India
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Publisher's Note

It has been estimated that over 40% of the equipment breakdowns are due to wrong choice of lubricants and/or improper handling of the lubricants. Besides this Lube Oil is the first to hear the bad news about any problem in the machine, as it flows and is in contact with all the internal moving parts of the machine . Based on research, it has been determined that on an average oil analysis has resulted in earlier detection of the impending failure when compared to vibration analysis. This is quite similar to the blood flowing in our arteries which when tested could indicate an infection or disease. Periodic Oil Analysis plays a vital role in the machine reliability.

This issue of Machinery Lubrication India features a cover story and several other articles on the subject of Oil Analysis and how it could impact reliability of machines.

Besides Oil Analysis other predictive maintenance techniques however minor are also great and effective tools, like vibration, thermography etc requires a considerable amount of training. Sensory inspection, on the other hand, can be performed by non-maintenance personnel such as operators. This can be an advantage when the maintenance staff is occupied with reactive maintenance tasks. Something as simple as detecting an oil leak or a gearbox that sounds weird could and often does lead to the prevention of a catastrophic failure, avoiding huge losses on account of spares, manpower and downtime. Therefore, the value of utilizing your senses should not be underestimated or overlooked.

Further there has been a numbers of suggestions on lube tips submitted by regular readers of Machinery Lubrication based on their practical ideas and experiences. We keep sharing some of them in this issue.

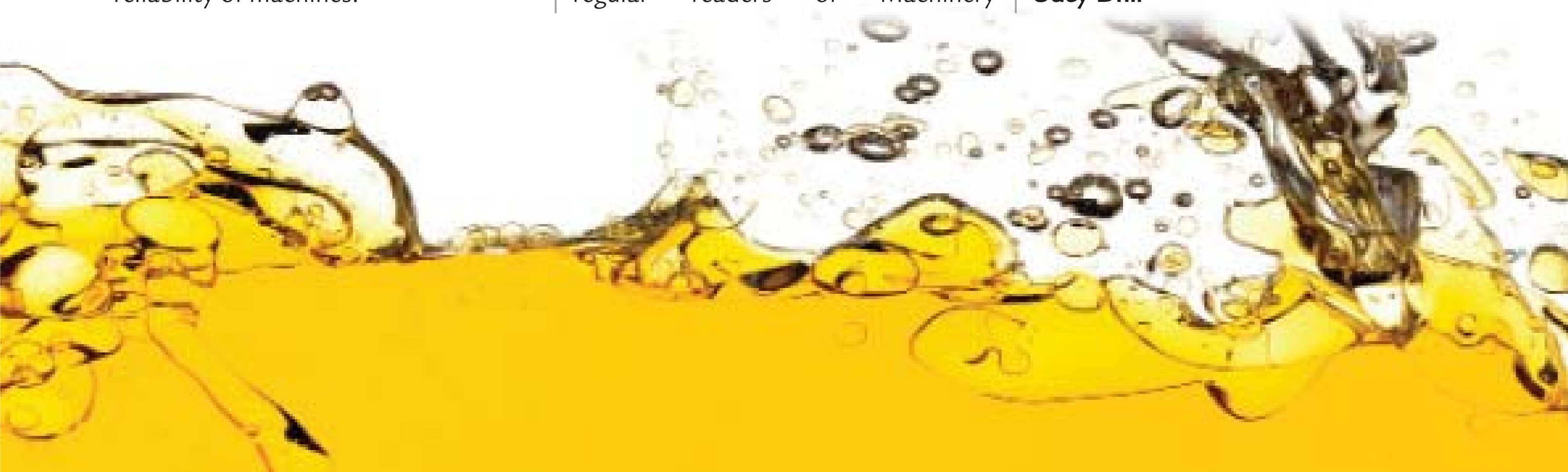
Lastly a report on Base Oil gives the recent trends of price and consumption of both base oil and crude oil. As indicated in the report, India's crude oil consumption is increasing at a fast pace and India looks to be one of the fastest growing markets till 2014.

We always welcome feedback from our readers helping us to provide you with the most cutting edge articles and best industrial experiences.

We would like to wish our readers, advertisers a Happy Festive Season.

Warm regards,

Udey Dhir



JIM FITCH NORIA CORPORATION

THE WRATH of Unscheduled DOWNTIME

Why Oil Analysis is a Wise and Effective Defense

There are 8,760 hours in a year. Few plants manage to produce at full capacity for all of those hours. Instead, there are periodic production stoppages due to tooling changes, product changes, scheduled PMs/inspections and unscheduled downtime (reliability issues). Every hour the plant's assets aren't utilized is an hour of lost revenue and profits.

Sadly, many plant managers play games with the numbers by ignoring the potential controllability of "scheduled" downtime. Yes, tooling and product changes are unavoidable, but in most other circumstances, there are often practical ways to minimize lost production from scheduled shutdowns. This can be seen in the difference between typical and top performers in the same industry. For instance, a standard 900-megawatt coal-fired power plant may produce at 86-percent capacity (44 weeks per year), while top performers can exceed 94 percent (48 weeks per year). This is a difference of four weeks of productivity.

Still, no classification of work stoppage causes more agony than unscheduled downtime. The reasons are quite obvious, as a recent online survey of *Machinery Lubrication* readers discovered. Following is a list of the top reasons unscheduled downtime is so unwelcome:

1. Production losses and schedule delays (business interruption)
2. Lost revenue and profit (unhappy management/ownership)
3. Promised delivery dates are missed (unhappy customers)
4. The blame game and damaged relationships between operations and maintenance (morale issues)
5. Hurried (botched) repairs cause future problems (cycle of despair)
6. Lack of available replacement parts and skilled trades prolongs the downtime interval
7. Repairs are at a "cost premium" due to rushed parts purchases, use of overtime labor and collateral damage
8. Scheduled "proactive" tasks are replaced by chaotic reactive tasks (leads to future problems)
9. Increased work pressure and job stress (job satisfaction issues)
10. Safety risks due to rushed work, unskilled work, inferior parts, cutting corners, job stress, etc.

What Oil Analysis Can Do

It's hard for a machine to fail without the oil knowing first. After all, when failures begin and progress over time, there is usually microscopic excavation of machine surfaces producing wear debris. Where does this debris go? It goes into the oil, of course. The oil is like a confessional for the machine. It gets all the bad news quick. For those trying to prevent unscheduled downtime by catching problems early, this is good news.

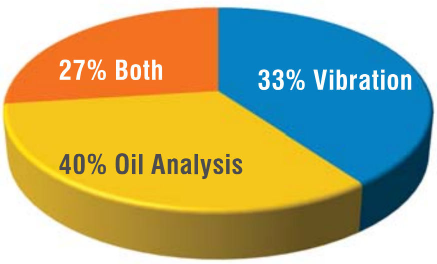


FIGURE 1. Bearing fault detection of early bearing failure (750 machines)

A few years ago *Practicing Oil Analysis* magazine featured two articles on the differences between vibration analysis and oil analysis in detecting machine faults and impending failure conditions. The articles, which can be viewed at www.MachineryLubrication.com, were written by vibration specialist Howard Maxwell and oil analysis specialist Brian Johnson from Palo Verde Nuclear Generating Station of Arizona Public Service. Palo Verde made a dramatic change in its approach to condition monitoring and machine reliability. The plant combined vibration analysis and oil analysis into a common group, brought its oil analysis onsite and began working as a team.

The pie chart in Figure 1 shows the impressive results. Of the 750 machines in the condition monitoring program, bearing faults were first detected 67 percent of the time using oil analysis and 60 percent of the time with

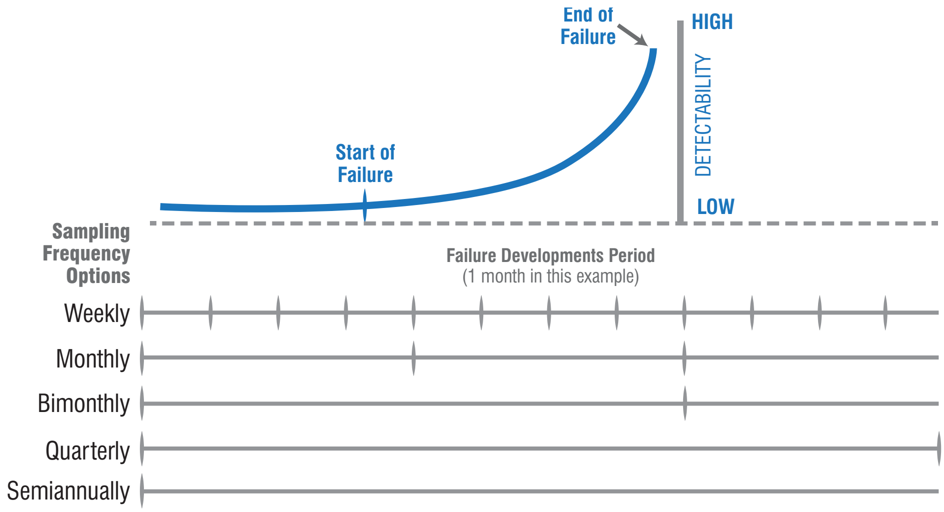


FIGURE 2. How condition monitoring frequency influences failure detectability

vibration analysis. Both technologies converged to catch bearing faults 27 percent of the time. It was noted that while oil analysis caught the faults 40 percent of the time ahead of vibration, eventually vibration analysis would have detected many of these faults as the problems progressed.

In research conducted at Monash University in Melbourne, Australia, failure in gearboxes was induced under controlled conditions. These conditions included misalignment, oil contamination, tooth fracture and others. During the progression of the failure, the gearboxes were monitored using vibration analysis and oil analysis (ferrous density). At the end of the study, the researchers determined that, on average, oil analysis provided 15 times earlier detection of impending failure compared to vibration analysis. In the case of tooth fracture, oil analysis gave no alarm at all, while vibration alarmed quickly. They further concluded that both are important companion technologies for the best early detection results.

The Magic of Frequency and Detectability

It's been said many times that early detection requires frequent detection. It doesn't matter how good your technology is; its effectiveness is limited if used infrequently. Even the most basic and unsophisticated technologies can win the day when they are used at short intervals. An example would be smartly performed one-minute daily inspections. Smart frequency beats smart technology.

This benefit is seen in Figure 2. The failure development period (FDP) is the time interval between the start of failure and the end of failure. In the illustrated example, the FDP time interval is one month. If failure detection methods (vibration, oil analysis and inspection) are performed less frequently than monthly, the chance of catching early faults is remote. Even monthly monitoring can fail to detect incipient faults due to limitations in alarming to weak failure signals.

As shown in Figure 2, the detectability of faults gets easier as failure advances. However, even silent alarms associated with incipient, early stage faults and failures can be heard when oil analysis and vibration analysis are performed with considerable skill. For instance, sampling machine return lines and keeping oil clean (to reduce data clutter) can sharply improve the signal-to-noise ratio to enable early detection of even the weakest signals. The earlier the detection methods are deployed, the less costly and disruptive the machine failure is to the organization.

What the P-F Interval Can Tell You

The smart money in machine reliability invests not only in frequent detection of faults and abnormal wear but also in

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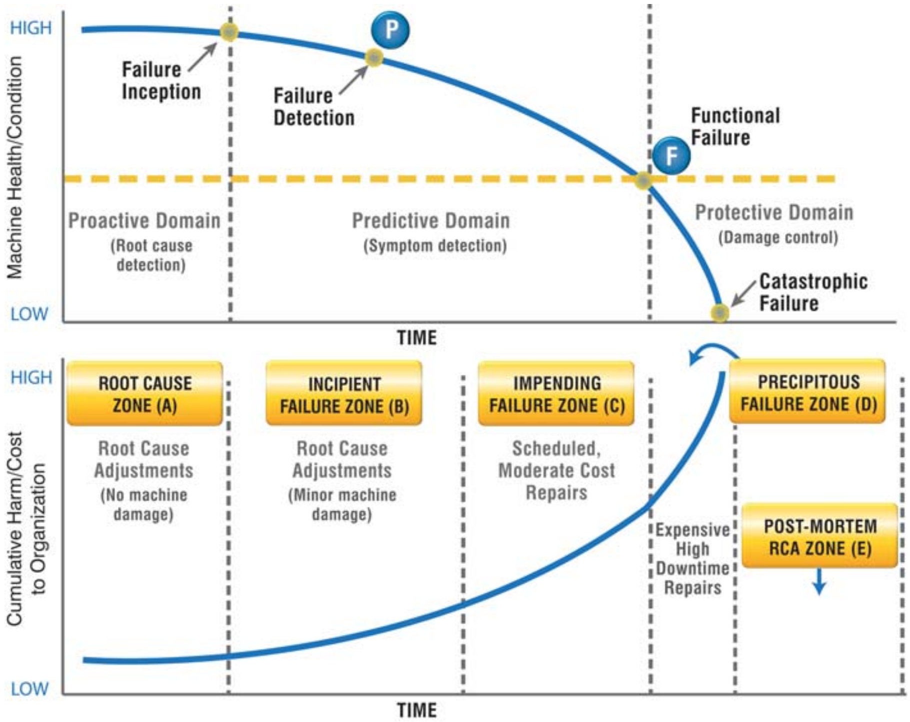


FIGURE 3. How the P-F interval relates to the cumulative harm/cost to the organization

frequent detection of root causes. Using the Pareto principle, you can concentrate efforts toward 20 percent of the root causes to gain 80 percent of the benefit. This is analogous to fixing the roof while the sun is shining. Correcting the cause of the leak is so much less expensive than correcting the damage caused by the leak (e.g., water damage to floors and furniture).

This concept is illustrated using the P-F interval in Figure 3. The proactive domain relates to vigilant monitoring and control of failure root causes (contamination, for instance). Corrections usually involve only minor adjustments (to remove the root cause) with no machine damage as shown in the root cause zone (A).

The onset of failure occurs at the beginning of the predictive domain. Ideally, it is detected early in the incipient failure zone (B). This requires high detection frequency and "pin-drop" detection technique (referring to condition monitoring techniques capable of detecting faint alarm signals). Once detected, the corrective action relates to root cause adjustments with only negligible machine damage.

If too much time passes and/or the detection methods are insensitive, you will enter the impending failure zone (C). Here, the cost of correction or repair is greater, but usually it can be scheduled with limited loss of production. The vast majority of predictive maintenance "saves" are in zone C. Both oil analysis and vibration analysis are excellent zone C technologies. When performed with considerable skill, daily inspections are extremely effective as well.

The Dreaded Unscheduled Downtime Zone

Unscheduled downtime occurs in the precipitous failure zone (D). This is not early detection, and the damage is unforgiving. Certain types of failures produce runaway conditions. In such cases, the FDP is too short for detection (sudden death). For new machines, this is called infant mortality. The costs of these failures can be enormous due to business interruption, collateral damage (chain reaction failures), high repair bills and the potential for personal injury. Precipitous failure is the inverse of machine reliability.

Next is the post-mortem root cause analysis (RCA) zone (E). Use failure as a teacher to discover what went wrong and how to prevent its recurrence. Also, learn the incipient signs of failure so the condition monitoring program (frequency and technique) can be refined accordingly.

What It All Means

Early detection doesn't prevent failure. It does, however, do the following:

- Keeps failures minor (e.g., moderate damage, not catastrophic)
- Reduces risk of collateral damage
- Allows scheduled repairs and no unscheduled downtime
- Provides time to obtain spare parts and tools
- Provides time to find skilled trades to perform the repairs
- Provides time to schedule repairs with minimal production losses
- Provides time to inform customers of production delays

Early detection is aspiration-driven, not crises-driven. Yes, a crisis puts the focus on reliability. An expensive failure is usually the perfect time to bring awareness to the importance of condition-based maintenance and investing in lubrication-induced machine reliability. Don't let a perfectly good failure go to waste. Take action now.

About the Author

Jim Fitch has a wealth of "in the trenches" experience in lubrication, oil analysis, tribology and machinery failure investigations. Over the past two decades, he has presented hundreds of courses on these subjects. Jim has published more than 200 technical articles, papers and publications. He serves as a U.S. delegate to the ISO tribology and oil analysis working group. Since 2002, he has been director and board member of the International Council for Machinery Lubrication. He is the CEO and a co-founder of Noria Corporation. Contact Jim at jfitch@noria.com.

JEREMY WRIGHT

How to LEVERAGE MULTIPLE Predictive Maintenance Technologies

Have you ever seen a mechanic open a toolbox that only had a single wrench or a carpenter with a tool chest containing just one type of saw? For these individuals to be considered true professionals, they must amass giant collections of tools so they can properly complete a task or job.

In a similar way, a predictive maintenance (PdM) professional's inspection "toolbox" should comprise a host of options, including infrared thermography, electric motor circuit analysis, vibration, oil analysis and ultrasonic/sonic analysis, as well as visual, tactile and acoustic (sensory) inspections.

Field experience has demonstrated that by appropriately combining and relating the results of different inspection options, these professionals can create a synergistic solution. This approach is much more thorough than one based on only one test or on several non-integrated inspection methods. This article will explore how these technologies and tools can work together to achieve far more than when implemented independently.

The Human Senses: A Valuable Condition Monitoring Technique

EFFECTIVELY USING SOME CONDITION MONITORING TOOLS, LIKE VIBRATION or oil analysis, requires a considerable amount of training. Sensory inspection, on the other hand, can be performed by non-maintenance personnel such as operators. This can be an advantage when the maintenance staff is occupied with reactive maintenance tasks. Something as simple as detecting an oil leak or a gearbox that sounds weird could and often does lead to the prevention of a catastrophic failure, avoiding tens of thousands of dollars in losses. Therefore, the value of utilizing your senses should not be underestimated or overlooked.

Infrared Thermography Analysis

Heat is often a symptom of eminent machine failure or malfunction. A non-contact infrared imager can be used to quickly obtain a multipoint temperature profile that can easily be assessed. This inspection can be performed with little to no disruption to the facility's operations. When utilized as a screening tool as part of a daily or weekly inspection, it can frequently be the first method used to witness a pending component failure.

Sonic/Ultrasonic Analysis

These instruments generally sense sounds in the 20- to 100-kilohertz range and convert them to either auditory or visual signals that can be heard/seen by a technician. These high frequencies are the exact frequencies generated by worn and underlubricated bearings, faulty electrical equipment, leaky valves, etc. This can also be a great way to detect an impending machine failure before it becomes catastrophic.

Motor Current Analysis

In the realm of electric motors, the current signature can be measured and recorded. In its infancy, it was primarily employed to detect rotor bar problems, but today with demodulated spectrums, the technology can be used to identify issues with belts and couplings through trending and baselining.

Vibration Analysis

In its simplest form, vibration analysis is a measurement of displacement over time. By measuring displacement, velocity or acceleration, you can get insight into bearing failures, imbalance, misalignment, wear, looseness, etc.

Oil Analysis

The lubricant is considered the lifeblood of the equipment. Much like a doctor assesses your health through blood analysis, the same can be done for machine health. Oil analysis can be broken down into three main categories: lubricant health, machine health and contamination. Every test performed on an oil sample can be categorized in at least one of these areas.

Sensory Analysis

While some visual or audible observations require interpretation, many are intuitive and only involve a system to manage and act on the information. Most operators and technicians are familiar with the machinery they maintain or operate, and consequently are aware of the "normal" sounds of that machine, making them qualified to identify unusual conditions.

Part of any strong PdM program is the ability to verify a fault with more than one technology. This not only ensures the validity of the fault but also helps make a more accurate and precise repair recommendation. The importance of verification with a second technology is never more evident than on a critical piece of equipment that requires plant outages for repair. For instance, consider the following scenarios:

Infrared Thermography and Vibration

While making a routine inspection of an electrical panel located on a mezzanine catwalk, a technician noticed a tiny, but clearly anomalous heat signature below in the direction of a smaller component on the ground. Upon further inspection at ground level, the tech discovered an anomaly in the coupler between a small motor and pump. He was able to spot the issue from a quick scan at more than 30 feet away.

The apparent temperature at the coupler was not very high, but it was enough relative to the surface temperatures of the motor and the pump to make the technician suspicious. He performed a slow-motion study using a strobe light, setting its frequency to the shaft's revolutions per minute. This essentially "froze" the shaft for inspection. The two halves of the coupler, which were joined by a flexible insert, appeared to be contacting one another. At this point, vibration analysis detected both mechanical looseness and misalignment.

During scheduled downtime, the pump was shut down, and the entire assembly was disassembled and inspected. Four of the insert's eight legs were seriously damaged, allowing the coupler halves to make contact and produce vibration and excessive heat. A new coupler and insert were installed, and the pump was put back into service.

In this case, infrared thermography was used as a screening tool, while a strobe light, sensory inspections and vibration analysis were employed to validate the potential failure, which would have gone unnoticed if only thermography had been used.

> "By applying and integrating the results of different inspection options, PdM professionals can make better and more informed decisions."

Thermography, Vibration and Oil Analysis

During a routine thermography route, the drive-end bearing of a large, oiled electric motor was found to be running 15 degrees hotter than any of the prior samples. Vibration testing showed nothing out of the ordinary based on the previous six months of data. An oil sample was taken, which revealed a viscosity increase of more than 100 percent. The analysis also indicated signs of cross-contamination between lubricant types based on elemental analysis. It was determined that the wrong oil had been added to the motor during the last top-up. To correct the issue, the motor was drained, flushed and refilled with the proper lubricant.

Thermography, Vibration and Motor Current Analysis

During a routine infrared PdM inspection, a technician determined that a motor was operating at an excessively high temperature. The 7.5-horsepower motor powered a coolant pump in the machining center responsible for critical machining of a key component in the assembly plant. Failure of this seemingly insignificant cooling pump could cause the entire plant to shut down.

The PdM program at the plant included a broad spectrum of predictive/preventive maintenance technology options. A work order for additional analysis was generated to determine if the root cause of the fault was electrical or mechanical.

Initially, motor current analysis confirmed that the motor and cabling tested electrically sound. Follow-up vibration analysis identified a bearing fault in the motor. Close monitoring allowed the motor to be run until the scheduled downtime, when it was replaced. A post-installation infrared scan confirmed that the new motor was operating within normal parameters. Subsequent cost analysis of this one incident showed a 100-percent return on investment for all the instruments used.

Ultrasound, Thermography and Vibration

When used in conjunction, these technologies can be employed in a wide variety of applications, including leak detection in pressure and vacuum systems, bearing inspections, detection of valve blow-by, steam trap inspections, detection of corona, tracking and arcing in electrical gear, detection of cavitation in pumps, checking the integrity of seals and gaskets in transformers, etc.

Technicians can easily use infrared thermography and ultrasound analysis to inspect steam valves. First, touch

the upstream and downstream sides of the valve with an ultrasonic sensor's contact probe. Steam passing through a leaking valve producing turbulence can be heard through headphones as a gurgling or rushing sound. A blockage will emit no sound. Since valve blow-by in steam systems will generate a higher temperature reading downstream, infrared thermography can be used to detect the thermal anomaly along the pipe run and confirm the analysis.

Heat can be a good indicator of a leaking hydraulic valve. The frictional forces of fluid moving through a leak can produce heat as a byproduct. This has been useful in aircraft inspections. However, not every leaking hydraulic valve will generate heat, and the proximity of valves in certain configurations can lead to a potentially inaccurate diagnosis due to heat (and in some instances sound) transference.

This inspection process can be aided by incorporating ultrasound with infrared thermography. A leaking valve will emit a louder sound downstream. By comparing infrared results with upstream and downstream ultrasonic readings, you can quickly make a positive diagnosis.

Ultrasound and Thermography in the Name of Safety

Technicians can use airborne ultrasonic translators to detect corona, tracking and arcing. Ultrasound can detect faults through small openings or door seals on switchgear cabinetry, through the outer shell of oil-filled transformers, and in the switchyard emitting from bushings, busbars and insulators. Using highly sensitive airborne sensors, these ultrasonic detectors can isolate electric faults on high-tension transmission and distribution lines at distances of more than 150 feet.

Note that corona and tracking do not show up with an infrared scan in electrical systems having a potential of less than 240 kilovolts and that ultrasonic detection can find electric faults in systems well below this threshold. This alone demonstrates the need for the inspection and safety industry to marry temperature imaging and ultrasound scanning techniques.

For example, in one case both an infrared camera and airborne ultrasound were used to inspect 15 13.8-kilovolt rectifier panels during a routine inspection with the panels closed. Thermography did not detect noteworthy temperature anomalies through the closed panels. However, significant levels of airborne ultrasound were detected at the lower right corner of one of the panels. Keep in mind that many technicians employ only thermography to quickly scan the panels for issues.

Several qualified electrical technicians were able to safely listen to the signal, identify its signature as that of a breaker and take definitive action. The vacuum breaker was removed, and a direct current was applied to it, revealing a fault. The intervention averted the loss of electrical power, a shutdown of the plant's compressed-air system and possible injury to personnel from fire or shock. Since then, airborne ultrasound inspection of all switchgear has been added as part of the regularly scheduled infrared preventive/predictive maintenance program.

While all of these technologies can be used by themselves, the advantage of utilizing multiple technologies is that problems can be cross-diagnosed and decisions to make or delay repairs can be made much more confidently. Success will come to those organizations that have a versatile and experienced workforce from diverse engineering backgrounds and with formal training and certification in various PdM technologies.

The return on investment is clearly positive and substantial, providing management and purchasing decision-makers with verifiable data to justify procurement of the diversified toolbox that defines the modern PdM professional. ■

"SERVO POWER MEET 2016"

Shri KL Murthy Executive Director (Lubes) Indian Oil Corporation Ltd. delivering the keynote address

"SERVO Power Meet 2016", an All India one day mega technical event was conducted by Indian Oil Corporation Limited on 23rd September 2016 at Delhi NCR. The theme of the meet was "Lubricants for conventional & non conventional energy sources". Around 180 delegates from more than 60 Power Plants comprising of Coal, Gas, Hydro, Nuclear, Wind, Solar energy (like NTPC, Tata Power, DVC, BHEL,CESC, NSPCL, Paharpur Cooling Towers, NETRA, Rosa Power Supply Co, UPRVUNL, LANCO, Toshiba JSW, ;Neyvelli Lignite Corporation, AP GENCO, TS GENCO, Godavari Green energy, Premium Transmission, TERI, BGR Energy etc participated)

Shri AK Jha Director (Technical), National Thermal Power Corporation, in the capacity of Chief Guest of the meet, inaugurated the event. While appraising the importance of lubricants for power plant operations Shri Jha elaborated on the lubrication practices at NTPC units, Initiatives taken by NTPC research wing, NETRA in improving efficiency of lubricants, Fire Resistant Fluids, Nano lubricants etc

In the keynote address Shri KL Murthy Executive Director (Lubes), IndianOil appreciated the efforts made by power sector in improving the quality and ensuring most of the regions were surplus with power. He observed power sector was critical for the growth of the country and contributes a lot to the nations GDP. He appraised the delegates the efforts made by IndianOil in providing high performance, long life turbine oils by meeting with the stringent OE specifications, fire resistance turbine governor fluid, energy efficient gear oils etc. with the help of its world class R&D at Faridabad. He thanked all for making SERVO the most trusted brand and market leader in the segment with maximum market share.

Shri Amit Kr Basu General Manager (I/c) Indian Oil Uttar Pradesh State Office-II , Shri C Radha Krishna Director (Projects) Telangana State Generation Corporation ,Shri MP Sunder Singh Director (Thermal and Projects) Andhra Pradesh Generation Corporation Shri JS Solanki GM (Works) Godawari Green Energy, Naukh Shri Rajenthiran, AVP Service, Gamesa Wind, Chennai also spoke at the Plenary Session. 18 papers by eminent speakers from industry were presented in the 3 technical sessions.

Follow the Chain of Success for Oil Analysis Optimization

By Bennett Fitch, Noria Corporation

How often should I take an oil sample? From which machines should I sample? These are typical questions I'm asked when visiting plants during the development of a lubrication program. While they are good questions, I always follow up my answers with an explanation of why effective oil analysis requires consideration of several important factors. If one of these factors fails, then the entire oil analysis program will likely fail as well.

"Sometimes just one finding, such as the discovery of elevated wear debris levels on a critical machine, can justify the cost of the oil analysis program."

This article will describe each of these key factors, which form a chain of success for oil analysis optimization. The three main elements in this chain involve obtaining a representative oil sample, ensuring reliable testing and determining the optimum course of action. As the illustration on the next page suggests, each link in the chain relies on those above it. If a link fails (becoming the weakest link), then all the links below it are compromised.

Obtaining a Representative Oil Sample

Select the Right Machines for Oil Analysis

Each sample obtained for oil analysis can be costly, so sampling every machine in a facility with thousands of lubricated machines is not feasible. The best method is to determine the Overall Machine Criticality (OMC) and the Overall Lubricant Criticality (OLC), which are based on machine and lubricant failure causes in terms of probability and severity.

Takeaway: Sometimes just one finding, such as the discovery of elevated wear debris levels on a critical machine, can justify the cost of the oil analysis program. If money is spent for oil analysis on every machine or machines are poorly selected for oil analysis, these returns may not be realized.

Clean and Correct Sampling Containers and Extraction Tools

One of the main objectives of oil sampling is minimizing data disturbance. Using the right sampling tools and ensuring their cleanliness will be vital. Oil sampling bottles should be certified to one of the three cleanliness levels: clean, superclean or ultraclean. As for extraction tools, nothing in the fluid's pathway from the machine to the bottle should further contaminate the sample and disturb the data.

Takeaway: In oil analysis, it only takes a small amount of contamination to cause concern. If the sample becomes further contaminated during the sampling process, the results can trigger premature cautionary or critical alarms.

Correctly Located Sampling Ports and Sampling Frequency

The precise location where an oil sample is extracted must be carefully chosen so the analysis results will be representative of the oil in the machine's wear protection zones. Two samples taken from the same machine but in different locations can potentially have different results for tests such as particle counts, elemental analysis and Fourier transform infrared (FTIR) spectroscopy. Similarly, the sampling frequency should be often enough to detect dangerous spikes in unfavorable results but not too often so that time and money are wasted.

Takeaway: Both the sample location and frequency have the ability to significantly affect your oil sampling objectives but in different ways. Without the proper location, the sample result may not be representative. Without the proper frequency, a crucial oil analysis result may be missed before it is too late.

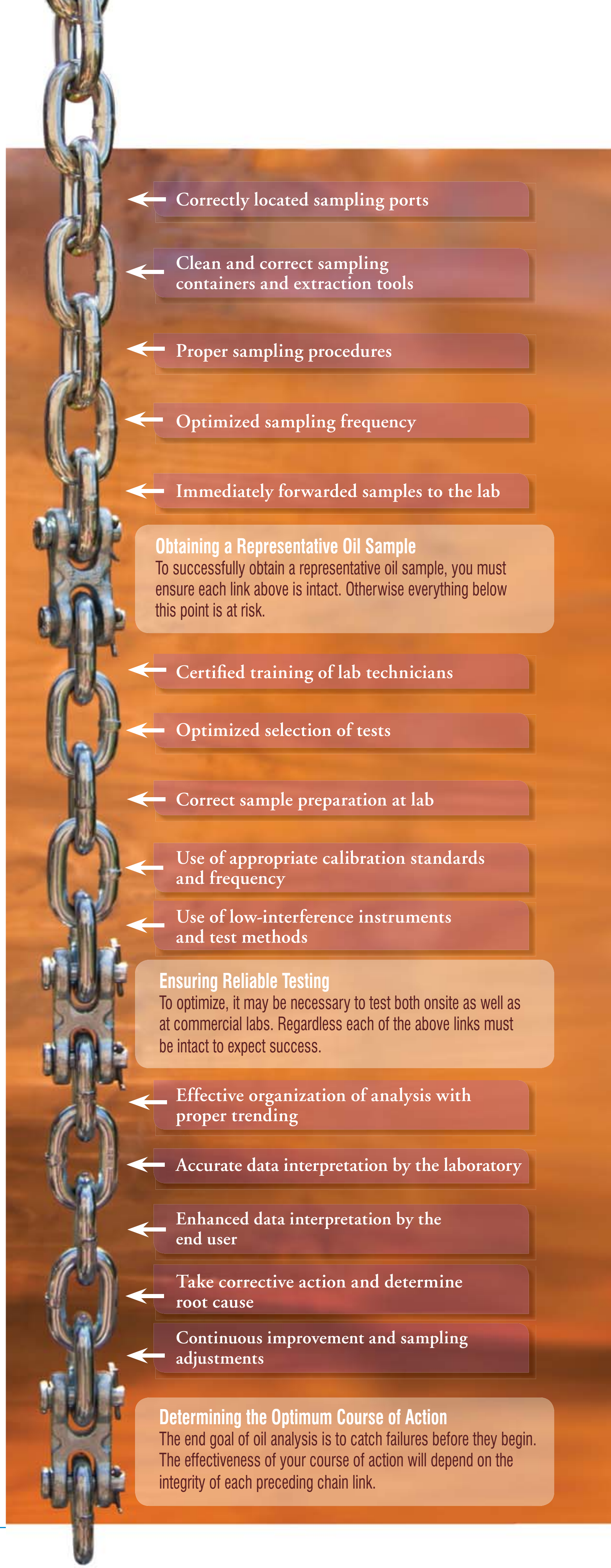
Proper Sampling Procedures

During the sampling process, an oil sample can be altered in a variety of manners, many of which are not apparent. Understanding the best method for preserving a representative sample from the machine to the bottle is imperative. Also, knowing how to obtain a proper sample is not instinctual. If samples are not drawn by the same person or the sampling procedure isn't followed consistently, it is likely that different practices will be employed.

Takeaway: Following a proven sampling procedure is vital for one of the most important oil analysis objectives — obtaining a representative sample.

Forward Samples Immediately to the Laboratory

Just like the blood in your body, oil can offer hidden clues regarding a machine's past, present and future condition. For example, one day you may go in for routine blood work and then receive a call soon afterward with results indicating a life-threatening condition that must be addressed immediately, even though you may not have had any known symptoms. The same is true with oil analysis. When a serious mechanical failure occurs, don't be the one with the recent sample still sitting on your desk awaiting to be sent out for analysis.



Takeaway: Machines can be extremely expensive, and the downtime associated with their failure could be even more costly. Don't wait any longer than necessary to assess the state of your machines. Tens of thousands of dollars could be at risk.

21% of lubrication professionals perform oil analysis on equipment at their plant on an annual basis, according to a recent poll at MachineryLubrication.com

Ensuring Reliable Testing

Certified Training of Laboratory Technicians

Many people assume that their laboratory will have a staff of properly trained and certified technicians who know how to operate all the lab's instruments, but this may not always be true. Perhaps the reason a particular laboratory is less expensive is because it is using cheap labor. A quality-control program should be in place with written procedures for consistently providing the best instruments for your oil analysis.

Takeaway: The tests performed on your oil samples deserve uniformity. Without it, accurately comparing one sample result to another will be impossible.

Optimized Selection of Tests

A typical laboratory will have an assortment of oil analysis tests from which to choose. Don't allow the lab to select just the standard test slate for all your samples. Unless the appropriate tests are chosen for each sample point, early warning signals may be missed. More often than not, opportunities for maintenance cost savings are overlooked.

Takeaway: Test slate optimization requires a two-pronged approach with routine and exception testing. This methodology should be used with all test packages for each machine type and criticality.

Correct Sample Preparation at the Laboratory

The importance of not disturbing an oil sample during the sampling process has already been discussed. However, this would be a waste of time if the laboratory does not properly prepare the sample for analysis. Each testing procedure has written preparative instructions that must be followed for admissible results.

Takeaway: A lot of time and effort can be spent on sample preparation by the end user, but don't stop there. Ask your laboratory the right questions to ensure it is using the appropriate sample preparation methods.

Use of Calibration Standards, Low Interference Instruments and Test Methods

You also should not make assumptions about other practices at the laboratory. Be sure the lab you select performs appropriate calibrations and utilizes methods and instruments known for low interference.

Takeaway: Due diligence is required when choosing a laboratory. Ask the necessary questions to ensure the lab will take your oil analysis seriously.

Onsite Oil Analysis and Inspections

An excellent way to enhance your oil analysis program, regardless of whether a commercial (offsite) laboratory has been selected, is to incorporate onsite oil analysis and inspection methods. Certain types of tests are quite standard and should be conducted on every sample, such as particle counts and moisture content. The instruments for these tests have dropped significantly in price, making them even more feasible for onsite use.

Takeaway: Onsite oil analysis tests and simple inspections can further optimize your ability to obtain quality information and become more cost effective over time.

Determining the Optimum Course of Action

Effective Organization of Analysis with Proper Trending

Although laboratories generally attempt to display oil analysis results in a user-friendly manner, they may not always be easily understood by end users. Comprehending how results are organized will be necessary for proper interpretation. For example, with certain types of tests, trending with graphs is required to detect a fault. Therefore, you should be aware of how the data is organized and investigate whether it can be improved for easier interpretation.

Takeaway: The organization of oil analysis results is the laboratory's responsibility. The more effective the organization is for interpretation, the less likely a preventable machine failure will be missed.

Accurate Data Interpretation by the Laboratory

Oil analysis results typically come with a summary paragraph that suggests actions the end user should take. The accuracy of this lab-based interpretation depends on the integrity of each preceding link in the chain as well as on the information provided about the machine's operating and environmental conditions.

Takeaway: End users often do not have enough time to interpret oil analysis results and must rely on the laboratory for interpretation. Without an accurate interpretation, effective oil analysis cannot be achieved.

Enhanced Data Interpretation by the End User

Following the laboratory's interpretation, the end user must make the final decision. No one knows the machine's history and application better than those who see the machine on a daily basis. If these individuals were trained to interpret oil analysis reports, the program's success could be improved.

Takeaway: The end user is primarily responsible for the data interpretation and understands the machine's operating conditions better than anyone else. There is not a more qualified individual to include in the data interpretation.

3 Objectives of Good Oil Sampling

1. MAXIMIZE data density
2. MINIMIZE data disturbance
3. SELECT the proper frequency

Take Corrective Action and Determine the Root Cause

Obtaining a representative oil sample and using a capable laboratory are pointless if corrective actions are not taken to prevent a failure. You should not expect a return on the time and money spent unless action is performed as a result of the oil analysis. Be sure to always follow up on the results and form a consensus on what the corrective action should be. Remember, the problem will only persist if the root cause isn't discovered and resolved.

Takeaway: Oil analysis cannot be justified without findings that lead to the prevention of a mechanical failure. Optimizing oil analysis only makes sense when it is used as a tool for greater reliability.

Continuous Improvement and Sampling Adjustments

Oil analysis never seems to get enough credit. Whenever it is effective in providing proactive maintenance, machine failures cease. Over time, people may forget that the lack of failures is attributed to oil analysis. Maintaining this awareness through continuous improvement will be key for success. Making adjustments to alarms and limits or sampling frequencies may be necessary for true optimization.

Takeaway: Just as important as determining the sampling frequency for each sample port, periodic adjustments to these frequencies should be addressed as further evidence of how change can be achieved through oil analysis.

Utilizing Oil Analysis as a Key Performance Indicator (KPI)

Oil analysis performance indicators are essential for realizing the overall health of a plant over time. In comparison, analytics are conducted on blood work results throughout a hospital or even throughout a certain geographic region to identify potential trends of a growing health concern or a dangerous outbreak. Likewise, while oil analysis KPIs may be beneficial for your machines, they also can prove to be valuable indicators of the progress made in improving your plant's overall health as well as the advantages of oil analysis.

Takeaway: KPIs help you to recognize when there is a weak link in the chain. A performance indicator like a regression in oil analysis returns should be a call to action to re-evaluate which of the previous chain links has been compromised. Justifying a plant-wide oil analysis program will require these types of metrics.

About the Author

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Alejandro Meza NORIA CORPORATION

KEEPING Your OIL Analysis PROGRAM UP TO DATE

Over time, any oil analysis program can become stagnant if few or no improvements are made. This can cause the program to lose value, as it may not fully support the plant's improvement initiatives, such as achieving certain reliability objectives. What's worse is that the program manager may not even be aware of the decline.

In order to determine whether your oil analysis program is up to date, ask yourself the following questions:

- Do you review the program's objectives at least on a yearly basis?
- Have you implemented new reliability objectives for machines in the oil analysis program without updating the program's objectives or parameters?
- Have you implemented other predictive technologies for machines in the oil analysis program without updating the program's objectives or parameters?
- Has your program been in use for years without being reviewed?
- Is your plant analyzing historical information to assess the program's effectiveness?
- Is there at least one person in your facility who has the formal training and experience to design, implement and manage the oil analysis program?

> "The benefit of staying updated is that you will develop a stronger oil analysis program that can fully support your reliability strategy."

If you answered "no" to more than one of these questions, it may indicate that your program needs to be updated or reviewed. Fortunately, the solution is not overly complex. A systematic approach along with a good understanding of oil analysis will enable you to update your program. Following are several tips to help ensure the continuous improvement of your program.

Reviewing Program Goals

First, you must review the program's goals. Assess how the program is fulfilling the current reliability needs. When the program was implemented, there likely were goals and expectations. Now it may be time to reassess or confirm whether the objectives should change or remain the same. It's also possible that the original objectives were not specifically defined. If this is the case, you must take the time to properly define them according to the reliability program.

For instance, the objectives may be predictive (monitor wear debris), proactive (help control contaminants in the oil) or focused on specific initiatives (verify lubricant life/ performance). The objectives should be based on the machine's typical failure modes and the use of other predictive technologies. Be as specific as possible because this will be the reference information that will be used to update the program.

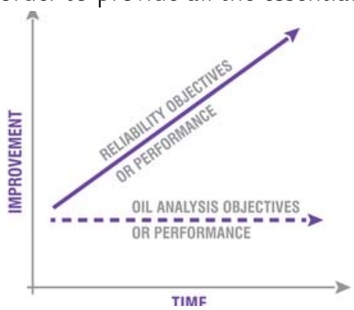
A good question to ask is whether management and the program manager are satisfied with the program's capabilities and results. If there are concerns about the quality of the program or a perception that the program is not fulfilling needs or expectations, these issues should be discussed and considered as part of the review. Of course, the program manager should have a solid grasp of oil analysis interpretation and program management to be able to coordinate this task effectively.

Updating the Program

Once the objectives have been reviewed, the next step is to verify that all of the factors involved are fulfilling their purpose within the program. These factors include test slates, sampling frequencies, sample locations, sampling technologies, procedures and lab service. The necessary adjustments should then be made to each of these elements and supported by appropriate training of field personnel.

Continuous Improvement

An oil analysis program should be flexible and dynamic in order to provide all the essential information about your lubricant. You may need to update the program policies so you can implement best practices. Use the questions at the beginning of this article as a guide. Determine what would be required to achieve an affirmative answer to all of the questions.



Remember, a world-class program may have temporary or specific objectives based on reliability needs, such as assessing filter quality, investigating a particular root cause or conducting additional tests to learn more about a product's performance.

The benefit of staying updated and operating with more flexibility is that you will develop a stronger oil analysis program that can fully support your reliability strategy. ■

About the Author

Alejandro Meza is a senior technical consultant with Noria Corporation. He has more than 20 years of experience in the lubricant industry, technical services, quality assurance, training, consulting and development in the United States, Brazil, Mexico and the Americas region. Contact Alejandro at ameza@noria.com to learn how Noria can help you update your oil analysis program.

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Advice for Greasing Electric Motors

When using an audible or ultrasonic grease gun attachment for lubricating motors, be sure that the motor grease fitting tube and grease gun coupler do not touch the rear fan bell section of the motor or the coupling guard at the front of the motor. If there is any touching in these areas (even just the paint), the bearing noise is not likely to be the dominant sound heard or registered on the meter. To get a true reading, you may have to snap the coupler to the Zerk and pull it away from the contact zone while greasing. A pistol-grip grease gun will make this easier.

Copper Levels Indicate Problems

Copper readings can be particularly alarming when increases are in the hundreds of parts per million. However, huge increases are typically insignificant in terms of component wear. Ironically, subtle increases in copper are of a higher concern and should be examined closely. Copper alloy component wear is generally accompanied by lock-step increases in alloy metals such as lead, tin, aluminum and zinc. The amount of alloy metal present in brass/bronze components is only a small percentage of the total copper content. Changes in these alloys may be only a few parts per million but should be taken seriously when present with copper increases.

Laser Level Lube Check

To determine the correct oil level in rotating equipment, use a laser level technique. First, determine the center line of the shaft and inscribe a line on the outside of the housing representing this point. Next, measure down one-half of the bearing pitch diameter (mean diameter) and inscribe another line. The pitch diameter is the bore diameter plus the outside diameter divided by two. The lower inscribed line would be halfway up the lowest rolling element. Project the laser line to this lower inscribed line representing the correct oil level.

Check Grease Compatibility

When selecting a grease, always consider the base or thickener. Many thickeners are not compatible, such as lithium complex and bentone. When combined, the bases soften, and the lubricating oil pools and drops away from the bearing. Even if both greases are listed as general-purpose grease and have the same NLGI designation, viscosity index, work stability, dropping point, etc., don't assume they are the same. Non-compatible greases will contribute to lubrication failure in bearings. So check a compatibility chart to know if the grease you intend to use is compatible with the grease in the machine.

Filter Change Reminder

When installing particulate-type breathers, use a Sharpie marker to write the month and year of installation on the breather. Then you can easily see when you make your weekly checks which ones need to be changed.

Caution on Gearbox Retrofits

When retrofitting gearboxes for service and filtering, consider using stainless-steel piping instead of black iron piping. After a short period of time, the inside of the black piping begins to crust and flake off into the gearboxes, giving false test results. This is more predominant in high humidity and frequent washdown areas.

Seal the Deal on Breathers

Keeping water out of oil seems to be a never-ending battle. Water may well be the No. 1 contaminant, reducing run-to-failure time by a factor of 10. Breathers with threads may allow water to wick its way down the threads, contaminating the lubricant.

Other forms of contamination such as rust and wear particles can develop around the threads. Air gaps between the threads form a hiding place where rust can develop. Overtightening with a wrench may stop water ingression but can cause pieces of thread to spall off and fall into the lubricant.

Placing a small amount of thread sealant on all breathers using pipe threads will greatly reduce this risk. Thread sealant will fill the air gaps, lubricate the threads and seal out the water. ■

By Daniel C. Carroll and Ronald F. Reimer, Eli Lilly and Co.

How to Create a Global Reliability Program

Like many organizations, pharmaceutical company Eli Lilly has been in pursuit of reliability for many years. Pinpointing when the journey started is difficult, since manufacturing is always asking for increased performance or throughput. However, usually the improvements are achieved through brute force: longer hours, faster response, stocking many spare parts, etc.

The desire to improve manufacturing output created the need to look for ideas to help reduce the risk of interruptions. Since the 1990s, several programs have been implemented at various manufacturing sites with variable success. A few examples of the programs include:

- Vibration routes and analysis to determine bearing health and to plan corrective actions before failure.
- Infrared routes and analysis to determine electrical distribution equipment health and corrective actions before failure.
- A lubrication program for correct lubricant handling and equipment lubrication.
- Failure mode and effects analysis (FMEA)/reliability-centered maintenance (RCM) on critical systems to determine appropriate maintenance strategies for equipment.
- Root cause failure analysis (RCFA) to determine how and why failure occurred along with actions implemented to prevent recurrence.
- Precision maintenance training to improve craft understanding and practices for the assembly and installation of equipment.
- Computerized maintenance management systems (CMMS) to capture equipment information and manage maintenance activity.
- Planning and scheduling to improve the efficiency of maintenance activities.

These programs have impacted Eli Lilly's manufacturing business in various degrees. In some areas, the value generated by the program has been very high. In other areas, less value was created. Two critical attributes of successful implementations were determined. The first was the implementer of the program. These individuals had to be passionate in their belief that the program truly added value and that not implementing it would be a mistake. The second was if the receiving organization recognized the benefit of the program and required the benefits from the program. Unsuccessful implementations were missing one or both of these attributes.

As a corporation, overall reliability was not improving at the rate required for the changing business climate. Senior leadership recognized that a few manufacturing areas were delivering consistent reliability improvements while other areas were not. They started believing in the importance of improving reliability. Eventually, the manufacturing units that did not have reliability wanted to get it, and the areas that had some success wanted more. This was a significant change. The organization began to ask for a reliability program. Typically, reliability professionals were "pushing" programs into the organization. Now, manufacturing had created the desire for improved reliability by establishing a reliability philosophy and implementing the appropriate programs.

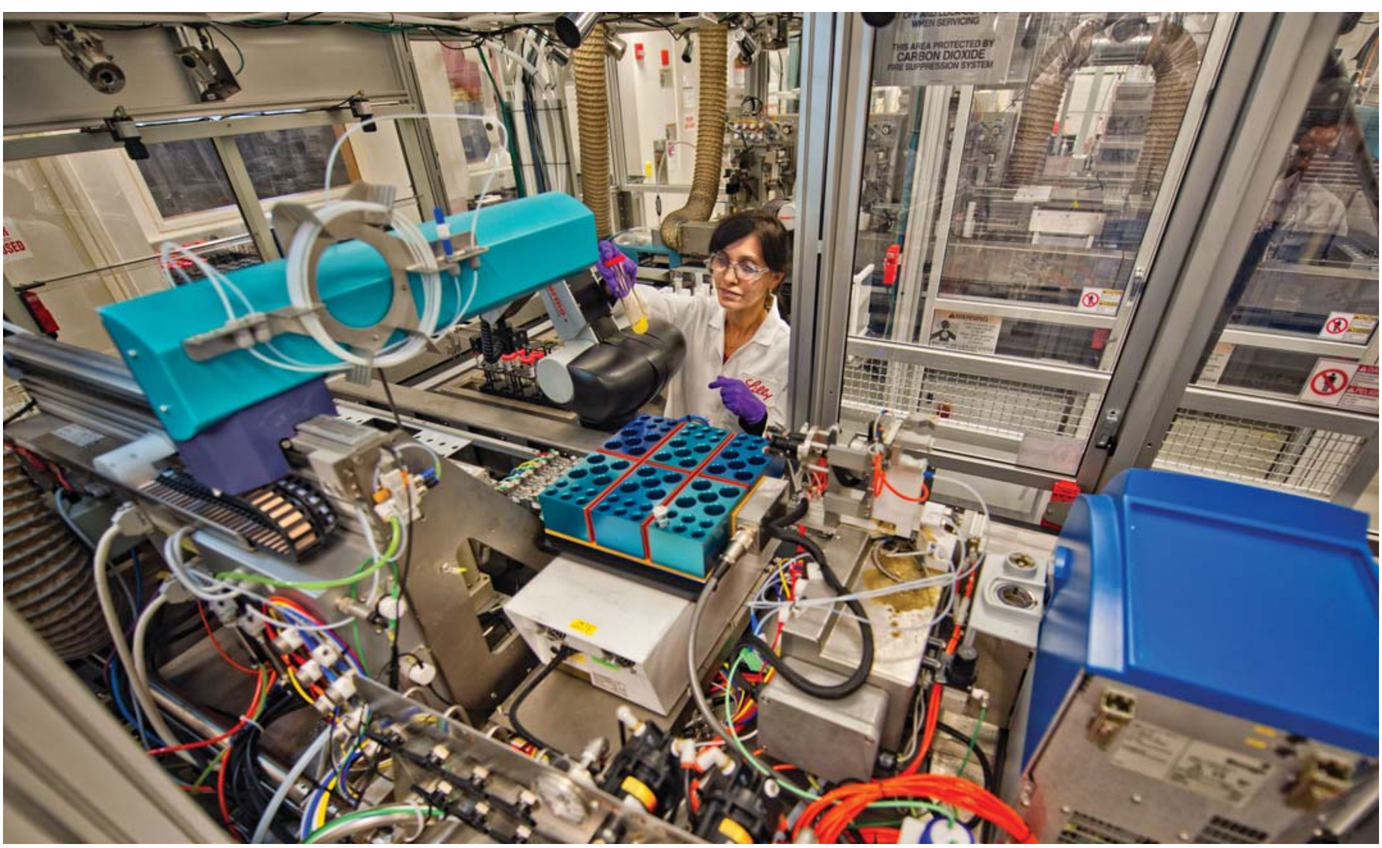
In 2011, a small reliability steering team was commissioned to develop the next-generation reliability process for Eli Lilly. The team was composed of successful reliability engineers and managers. The team's goal was to define and document reliability as well as the governing principles and tools, prove concepts were valid through demonstration projects, and form a recipe for implementation.

Early in 2013, a "reliability book" was written, training was established, three demonstration projects were providing significant results, and a flexible rollout plan was developed.

Training and the Reliability Book

The purpose of the reliability book was to present a consistent methodology to improve equipment reliability in manufacturing. This document was written for personnel involved in the design, operation and maintenance of equipment used in manufacturing, both direct production and support equipment. This included all the interactions of people, processes, raw materials, spare parts and utilities associated with the manufacturing equipment. Although this focus was on manufacturing equipment, the principles described generally apply to all equipment.

The reliability book consists of eight chapters and several appendices in 93 pages. It describes Lilly's reliability vision, important reliability principles and models. Three training classes accompany the book: Reliability Overview, Reliability Leadership and Reliability Book Understanding. The overview class is intended for all employees involved in the manufacturing of products. The class provides general training on the content of the reliability book. The leadership class offers training for all employees in positional leadership roles. The class is an open discussion with leadership to discuss behaviors and methods to advocate and support the content of the reliability book. The final class is simply a test to verify reading and understanding of the reliability book.



About Eli Lilly

ELI LILLY AND CO. WAS FOUNDED IN 1876 BY A PHARMACEUTICAL CHEMIST and Civil War veteran, Colonel Eli Lilly. The company is based in Indianapolis and markets products in 125 countries around the world. Lilly has 38,000 employees and sales of $22.6 billion in 2012. It is the 10th largest pharmaceutical company in the world. Lilly owns and operates more than 20 manufacturing sites in 13 countries.

Lilly's business units are divided among bio-medicines, diabetes, animal health and oncology. However, each business unit has three major activities, including discovery (finding and testing new medicines), sales and marketing (informing and selling the medicine), and manufacturing (making and packaging the medicine).

Demonstration Projects

Three demonstration projects were performed in 2011-2012 to help validate the reliability tools and concepts that were included in the reliability book. The first project consisted of improving net output from a device assembly work center. In 2010, the demonstrated production rate of the manufacturing line had a standard rate of 77 units per minute. By the second quarter of 2012, the same manufacturing center had a demonstrated standard rate of 125 units per minute. This was a 60-percent improvement in output — a record output. The production output value to the business far exceeded any change in maintenance costs. Examples of projects that impacted reliability included a redesigned glue system, an improved changeover time from 4.3 hours to 3.5 hours and better service practices of the glue system and robot head.

The second project involved improving the output from a vial-filling work center. In 2011, the demonstrated production rate of the manufacturing line had a standard rate of 190 units per minute. By the second quarter of 2013, the same manufacturing center had a demonstrated standard rate of 230 units per minute. This represented a 21-percent improvement, which was a record output. Examples of projects impacting reliability included scale modifications, automated tank filling, improved changeover times, better setup instructions, enhanced machine knowledge and run rules, and better service practices.

The third project consisted of improving the mean time between failures (MTBF) of a rotary screw conveyor. This asset showed up on the site's list of 20 worst MTBF assets. Upon investigation, it appeared the conveyor was tripping off-line because the downstream transfer line was plugging. Further research determined the reason for the line plugging was due to the automation sequencing of the various system assets. Once this sequencing was changed, the MTBF increased by a factor of four. The problem wasn't with the screw conveyor; it was just the first visible sign of a downstream problem.

The Importance of Culture

Any change must take into account the effect on the culture. The prevailing culture may help or hinder the desired changes. An entire chapter of Eli Lilly's reliability book was dedicated to the cultural challenges of moving a successful reactive manufacturing organization toward a proactive philosophy.

The nature of a reactive culture is described in both the reliability book and in the reliability training. The diagram on page 34 shows a reactive culture in action. This culture accepts equipment failure as a normal event. The organizational belief is that equipment is going to fail. The goal is to fix the equipment as fast as possible to get production back into operation. The repairs generally do not address the root cause of the failure but have only a short-term focus on fixing what broke. Once the equipment is running, the mechanics, supervisors and engineers receive praise and recognition for the prompt fixing of the problem and then move onto the next problem. These actions translate into eventual raises and promotions. This behavior establishes reactive craftpersons, supervisors, engineers and management as role models for the manufacturing organization to follow, which reinforces the reactive culture.

In contrast to the reactive culture, the second diagram on page 34 represents a proactive culture. It starts with various reliability-based actions. These actions include many things such as equipment design, equipment setup/changeovers, predictive maintenance, operating techniques, equipment walk-throughs, world-class lubrication, etc. Unfortunately, these reliability actions, by their nature, are much less visible than a failure in the reactive culture. For example, a pump failure is much more visible than inspecting incoming lubricants for possible contamination.

The outcome of these reliability actions is fewer equipment failures. This will take time to be noticed, as there may be a significant time delay of up to several years. This delay, along with the lesser visibility of reliability-based actions, is one of the reasons why managing a reliability-based culture is much more difficult than managing a reactive culture.

Rewards and recognition should follow the improved equipment performance. However, due to the amount of time required before the results of equipment improvement may be seen, rewards and recognition may be better tied to performing reliability-based actions. For example, recognition might be given to a craftsperson for completing a good root cause exercise or proper recording of a precision alignment following an intervention. Another example would be to recognize the person who detects and reports an early defect before it becomes a significant failure or quality issue. As these people are identified and recognized, they become role models for others to follow. They start performing and valuing reliability-based actions. This in turn reinforces the culture around reliability principles and values.

For the proactive culture to survive over the long term, it takes significant management energy as well as a strong commitment from all levels of the organization.

Leadership

The role of site management is essential for the successful creation of a reliability-based culture. Merely having management support reliability is insufficient. The changing of a reactive culture will take considerable time, energy and focus. Site management must be passionately engaged in order to overcome the organizational inertia built around a reactive culture. In the past, companies that were successful in making the proactive transition were under intense economic pressure — they had to become reliable or go out of business. If management energy is removed, the culture will quickly return to being reactive.

There are many similarities between a proactive safety culture and a proactive reliability culture. In the past few decades, new ways of thinking about safety have emerged. The previous safety culture assumed that accidents "just happened" and that safety was the concern of the safety department. Now, many sites have adopted a culture that views accidents as preventable and an injury-free workplace as achievable. In order to reach the goal of an injury-free environment, safety had to become a major concern of everyone and not just the safety department. In a similar manner, this same type of cultural shift also applies to a reliability-based culture.

Reliability Metrics

Three key global metrics for reliability were defined: downtime, mean time between failures (MTBF) and deviations.

Downtime

Downtime (along with its inverse, uptime) provides an indication of manufacturing performance. More important than the downtime/uptime value are the reasons for downtime. The manufacturing area must collect and analyze the causes of downtime. The organization then should focus resources to investigate and resolve the significant contributors to downtime.

Downtime measurement across the various manufacturing sites was inconsistent and underutilized. Some sites were measuring downtime but were using different parameters. One site had more than 50 different downtime reasons. Others were measuring downtime only during a production run.

To standardize this important metric, a list of 12 reasons for downtime was developed under two broad headings: unscheduled downtime and scheduled downtime. The metric is also based on a 24-hours-a-day, seven-days-a-week schedule or 8,760 hours per year. This way, all reporting times and percentages have the same common denominator. By using this metric, the chronic contributors to the loss of production can be determined, and the correct resources can be applied to the problem area.

MTBF

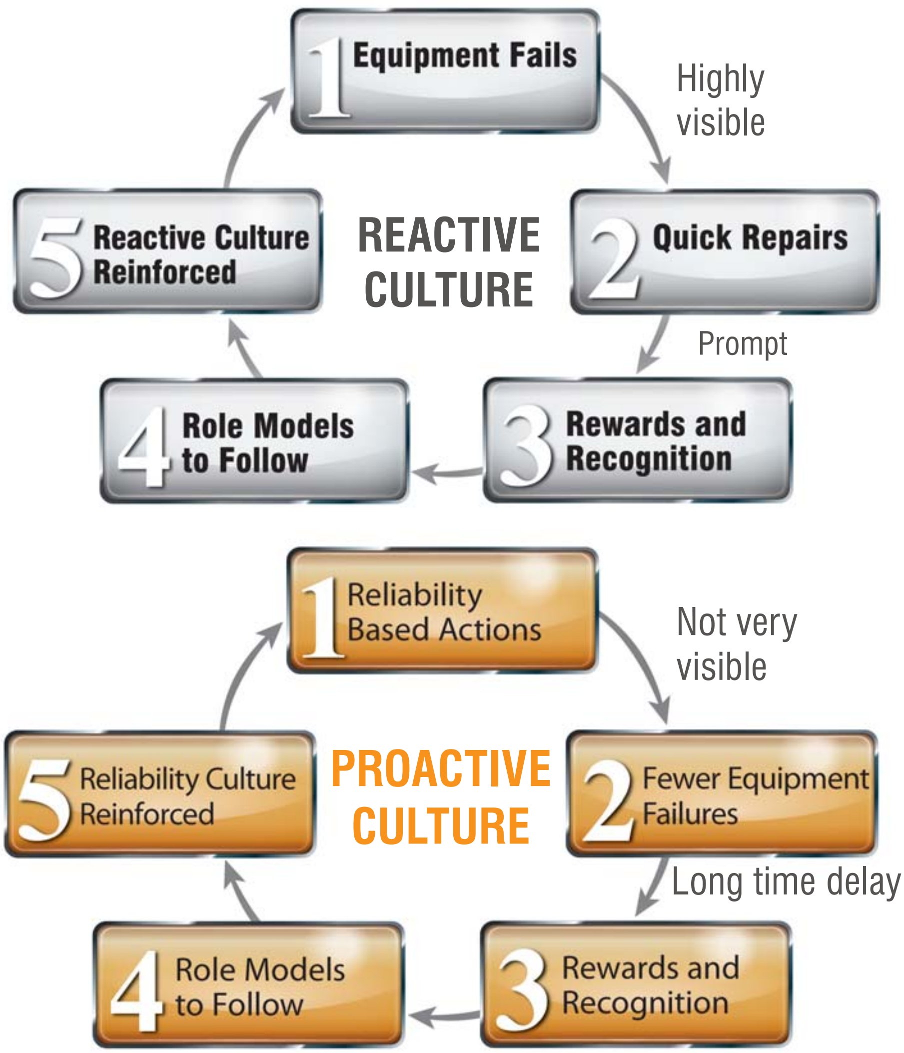
MTBF is used to identify assets that are experiencing high rates of failure. Assets are ranked from worst to best, and the worst 20 assets for each site are reported. Some of these assets have problems that are well-known, while others may be a surprise to the organization. The goal is to improve reliability by reducing their failure rate. Sometimes the downtime data and MTBF report overlap, while at other times the failures may have little impact on the overall manufacturing output. Both metrics should be reviewed to establish the best use of resources.

Deviations

Manufacturing upsets or failures are tracked as non-conformances. Each non-conformance must be investigated to determine the impact on the product and the corrective action required to reduce or eliminate recurrence. Tracking non-conformances helps identify the chronic equipment issues that are causing the upsets in the manufacturing processes and offers another way to focus on the high-priority equipment problems requiring further investigation and remediation. These upsets are usually the significant contributors to floor and factory loss.

Reliability Implementation Plan

Traditionally, reliability efforts have been implemented as programs. Various reliability concepts such as predictive maintenance, planning and scheduling, etc., have been applied as stand-alone programs or projects. All of the programs are elements needed to support the reliability model. Each will have an impact on the manufacturing output. However, universal organization support is



difficult to achieve from the operational partners. They do not always see the immediate value, as manufacturing output may not significantly change.

The philosophy for Eli Lilly's implementation plan was to have each site focus on improving the reliability of an asset or line that was impacting the site's performance. By targeting chronic failures and the weaknesses limiting manufacturing output, significant improvements can be made. The organization is focused on the important and urgent issues. Employees have a higher sense of value by working on critical issues, and the plant's net output increases. The reliability professional earns the credibility to continue the reliability journey.

Eli Lilly operates more than 20 manufacturing sites around the world. All of the sites are at different places in their reliability journey. Each site also has cultural or organizational differences. The implementation plan is not a one-size-fits-all approach. Instead, flexibility was built in the rollout plan to allow for sites to adjust the concepts to fit their business needs. The reliability book provided the framework for the sites to build their program.

For 2013, each manufacturing site was asked to perform the following:

- Name a reliability champion from the management ranks to be the site champion and point of contact.
- Determine the site's 2013 reliability plan, including a reliability-improvement project on a troublesome asset based on any combination of the three metrics discussed earlier, and a training plan involving the three reliability courses and a subset of the site personnel.
- Measure downtime on a 24-hours-a-day/seven-days-a-week basis and categorize into Pareto charts.
- Participate in global reliability forums.

The sites have responded well to this plan. Several have already completed their reliability-improvement project and are demonstrating improved performance of the asset or line. All sites are in various stages of training, and many people outside of engineering and maintenance are talking about reliability as a part of their normal job functions.

Keep in mind that reliability is an outcome. It is more than maintenance. It is the result of how equipment is selected, installed, operated, serviced and improved. The consequence of all this activity is the probability that the equipment or systems will perform their designed functions correctly when needed.

Changing the culture means eventually changing everyone. Most organizations have previously been successful with a reactive culture. The reactive culture is natural and normal to many people. However, the changing business environment means that your assets must produce more cost-effective, high-quality products. It will take significant leadership and management energy to change the culture from its formerly successful reactive culture to a proactive culture. Remember, the ability to improve long-term reliability business practices will be earned through sustainable manufacturing output improvements.

By Steffen Bots, Oelcheck

A Practical Approach for Evaluating Oil Analysis Results with Limit Values

The evaluation of oil or grease analysis results is often a tough job for a diagnostician, demanding experience in mechanical engineering and chemistry. However, modern tools and statistical methodologies can support and improve the process. The first step is to define a proper set of test methods that delivers sufficient parameters for answering important questions about the sample while still being as economical as possible.

After determining the test parameters, the next challenge is to set up limit values and guidelines for the evaluation. In some cases, general limit values are available. However, in many cases, oil, component or equipment manufacturers cannot or will not supply complete limit sets. So how can a meaningful diagnosis be created? One way is with the help of an experienced engineer who knows the application and when critical values are exceeded. It is also easier if previous samples exist. Developing parameters over a period of time can identify layers or single parameters that move away from the regular trend line. Absolute limit values must also be applied in order to have a fixed reference point for the critical region.

An adequate set of oil analysis results from the same or comparable equipment/application is the baseline for statistical methods. ASTM D-7720 describes an approach for identifying alarm limits by statistical methods, but a large set of data and statistical guidelines do not automatically provide proper limit values. The quality of the data set can have a significant impact on the statistical results. It may make the difference between having reasonable statistically based limits or nonsense.

This article will show how carefully filtered data sets within a sophisticated structure can deliver valuable limit values. The system, which is based on an application matrix, enables oil samples to be categorized with as much detail as the sample information allows. Combined with an advanced evaluation program, this is the basis for defining limit values, applying them with evaluation guidelines and proving them on a regular basis.

Analyzing an Oil Sample

The analysis of a used oil sample produces a lot of data. A typical lab report contains in the range of 20 to 40 single measurement results. In order to provide a proper diagnosis or trigger the necessary actions based on the analysis, typical or normal ranges for each element must be known. The oil type, construction, maintenance and operating conditions are the four main influencing factors for evaluating an oil sample.

A single rating for each oil analysis parameter does not cover the complexity and interdisciplinary knowledge in the fields of mechanical engineering, chemistry, tribology and lubrication that must be applied. If an evaluation is based on one element that has exceeded a limit, incorrect interpretations are possible. Some labs offer a comment for every oil sample, pointing out critical areas of the analysis along with recommendations for the next maintenance action. However, lab reports generally do not contain limit information in order to avoid misinterpretation by the end user.

Limit Values

Most oil analysis reports from commercial laboratories contain a rating based on the traffic-light principle. This utilizes a three-stage color code (green, yellow and red) to quickly indicate the severity of a sample result. If a large number of samples must be handled, it may make sense to filter the yellow- and red-flagged samples in order to decide what kind of maintenance action is necessary. Green-flagged samples can be stored for trending and documentation.

The coding system should not be too complicated. Otherwise, it loses its advantage of providing quick and simple decision guidance. At the same time, it must be reasonable and consistent for comparable oil analysis patterns. Proper limit parameter sets that can be both absolute or trend-based are the basis of this consistency.

Standardized processes for the creation and revision of limit values combined with well-founded guidelines for the recognition of failure modes and the identification of normal conditions are fundamental for a high-quality oil analysis program. The opposite of such a methodology is an empirical approach based on the knowledge of an experienced diagnostician. This expert knowledge is very valuable and should be used to prove whether limits are reasonable. However, empirical knowledge is not the right methodology for managing a standardized oil analysis program with a proactive maintenance approach.

A Different Perspective

Looking for existing limit sets for specific applications can reveal different results. While limit information may not always be available, there are industrial fields where detailed guidelines exist. Among the groups that set limit values include component manufacturers, original equipment manufacturers (OEMs), oil companies, laboratories, and technical groups and associations.

Component manufacturers often define limits for single parameters that have a direct impact on the component's lifetime or performance. Examples would include manufacturers of hydraulic components offering recommendations for oil cleanliness or a roller bearing manufacturer stating that a bearing reaches the calculated fatigue lifetime only if the contamination level is within a certain range. This information is valuable, but it is often too general and limited to certain aspects of an oil sample. Nevertheless, component limits are a good reference point if OEM limits are not provided.

ANALYTICAL LIMIT VALUES FOR USED ENGINE OILS SAE 40

	TEST METHOD	LIMIT VALUES
Viscosity at 100°C (mm^2/s)	ASTM D445 DIN 51562	Max. 17.5 Min. 11.5
Base number (mg KOH/g)	ASTM D2896 ISO 3771	Min. 3 and BN >AN
Acid number (mg KOH/g)	ASTM D664	New oil value +2.5
ipH value		Min. 4.5
Water (% by volume)	ASTM D6304 EN 12937 ISO 6296	Max. 0.2
Glycol (mg/kg)	ASTM D2982	Max. 100
Oxidation (A/cm)	DIN 51453	Max. 20
Nitration (A/cm)	IR method	Max. 20
Wear elements (mg/kg)	RFA, ICP	
Iron		Max. 30
Lead		Max. 20
Aluminum		Max. 10
Copper		Max. 20
Tin		Max. 5
Silicon		Max. 15

FIGURE 1. An example of an official limit table

If OEM limits are available, they should be considered, especially if they are related to warranty issues. For some types of equipment, detailed OEM limits exist, including information about wear values, oil condition and contamination. Their main purpose is to clearly define the conditions for safe equipment operation.

Limit values and evaluation guidelines can also be standardized. Standards may be independent and official, such as those from ASTM, or based on the work of other specialized associations or organizations. Often these limits are available for equipment with strict safety and reliability requirements. In these cases, the limit values should be considered very closely.

Limit values from oil companies are generally focused on oil condition. The main intention is to provide guidelines for detecting when the oil is no longer fit for further use.

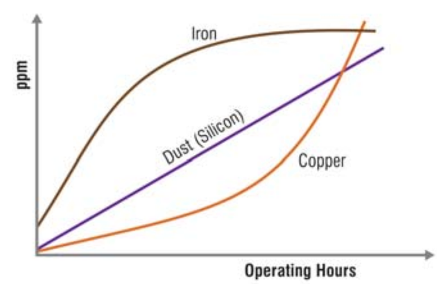


FIGURE 2. The function of trend over time

FIGURE 3. Absolute vs. trend limits

Some laboratories use sophisticated computer software to support the creation and administration of equipment- and oil-type-related limit sets based on statistical and trend-based methodologies. Actual samples are connected using a matrix code with corresponding limit sets. This allows a computerized flagging of every parameter. The automated system can increase the speed and quality of the evaluation.

Absolute vs. Trend Limits

The limit information described previously is mainly absolute and does not reflect historic trend development. However, sometimes limit values relating to operating hours or distances are available, especially from engine manufacturers. This means the permissible change of a parameter over time is defined, such as iron per 100 hours of operation. Still, in most cases, absolute limits are valid for a typical overhaul or oil drain interval. If no limit is exceeded, no maintenance actions are necessary and the interval may be extended.

The evaluation of analysis results based on absolute limits has numerous benefits. For instance, it provides simple handling, quick orientation and can be statistically proven. However, there are also limitations, such as often being valid only for defined intervals. Nevertheless, absolute limits can be effective in some cases. Generally, this is when the failure modes and root causes are known, or the oil property requirements are closely defined and a change in these properties can be directly connected to problems during operation.

The surrounding conditions and the goal of the oil analysis are also important. If the samples are always taken during the oil change and the aim of the analysis is to identify repair actions or upcoming problems, statistically based absolute limit values will be sufficient for the evaluation.

The longer the oil drain intervals and the higher the priority of a proactive approach for an oil change, the more important trend limits become. This is especially true for oil analysis parameters that are a function of time.

Trend limits offer several advantages, including a more detailed evaluation, greater consideration of historic data and actual operating conditions, and an early warning of upcoming problems.

Of course, trend evaluation is only effective if enough previous samples are available. The sampling procedure and location can also have a significant effect on the final results. For trend evaluation, a sample must always be taken from the same location using the same procedure. If the operating or maintenance conditions change, they also can impact the trend line and must be considered. For most samples from the field, a combination of both methods seems to be the best approach.

Defining Properly Set Test Methods

Oil analysis can be compared to a puzzle with every piece related to a single test. If only single pieces are available, the complete picture will not be captured.

Oil-aging factors, oil properties, contaminants or wear information depend on the application from which the oil sample is taken. Properly set test methods with sufficient parameters are important to be able to provide the right answers. At the same time, the test set should be as economical as possible in order to support trend-based analysis.

Statistical Methodologies

For the statistical evaluation of limit values based on historical data, two basic methods can be applied: statistical process control (SPC) or a cumulative approach.

SPC Method

SPC is a statistical methodology for the optimization of production and service processes. The SPC theory was developed by Walter A. Shewhart in the early 1920s. Shewhart defined two mechanisms based on the idea that the quality of a product depends on the variation of every part from which the product is made. The first mechanism is a common source variation from the average that is controlled and natural for the process. The second mechanism is a special source variation that is unnatural and can be caused by machine or material failures. These two mechanisms must be clearly identified for a set of parameters that describe the process quality. If the parameter set is normally distributed and the diagram is bell-shaped, the standard deviation can be applied for the definition of limitations.

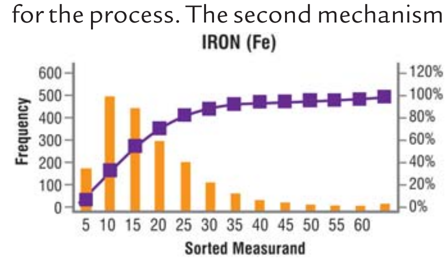


FIGURE 4. An example of the iron distribution for a wind turbine gearbox

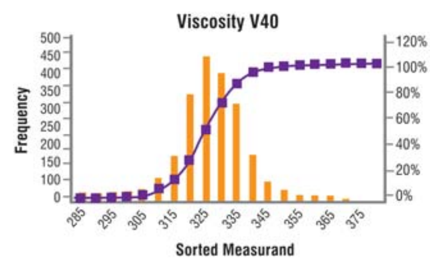


FIGURE 5. An example of the viscosity distribution for a wind turbine gearbox

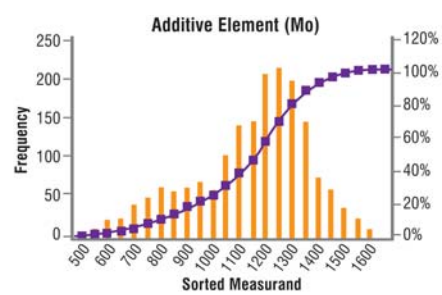


FIGURE 6. An example of the additive distribution for a wind turbine gearbox

According to these limits, a decision is possible on whether the variation is normal for the process (common source) or outside the control levels (special source). For production processes, these considerations have led to the introduction of quality cards containing upper and lower control limits. Today, the SPC methodology can be used to control any type of process. In the case of alarm limits based on historical sample data, the standard deviation is also a valuable tool.

Besides the parameter, the application also has an impact on the distribution of the data. This means that the distribution for every parameter or measured value from a data set must be evaluated in detail and that the same parameter can fit into different distribution schemes for various applications.

Practical Examples

The following examples demonstrate how statistically based limits become more precise if the population is broken down to specific machine types. In the second example, the statistical analysis revealed failure modes by drawing attention to the samples with special cause variation.

MODEL	SIZE	# SAMPLE	FE-GREEN	FE-YELLOW	FE-RED
A	1.5 MW	1804	<32	32-53	>53
B	600 kW	1349	<106	106-149	>150
B	1.5 MW	4762	<72	72-115	>115
B	2.5 MW	2597	<79	79-104	>104
C	250 kW	926	<26	26-78	>78
C	600 kW	495	<21	21-35	>35
C	660 kW	1025	<22	22-42	>42
C	1.75 MW	1183	<38	38-70	>70
C	2.0 MW	4069	<28	28-46	>46
C	3.0 MW	1930	<30	30-52	>52

FIGURE 7. Iron limits for different wind turbine models

Cumulative Method

If the distribution of the measured values does not fit the normal distribution, the standard deviation cannot be applied. This is the case when the mean and median are different or the distribution is skewed or bimodal.

A zero-reference skewed frequency distribution is common for applications where the oil is not changed according to defined intervals and parameters increase over time. Typical parameters include wear, oxidation, acid number, color and contaminants. A high-reference skewed frequency distribution is normal for applications without static oil changes but with parameters that start with an initial value and decrease over time. Standard parameters would include additives, base number and viscosity.

Limit Values from Wind Turbine Gearboxes

The wind industry has experienced tremendous progress during the last 20 years. The power output of modern wind turbines has increased 50 to 100 times in comparison to the first models of the 1990s. As a result, gearboxes have become much larger. This progress has also had an impact on lubricant requirements and maintenance practices. The trend for modern turbines has been toward high-performance synthetic lubricants. Although the price of these products is higher, their aging stability is significantly increased, which provides an opportunity to reduce the overall maintenance costs by extending oil drain intervals based on oil analysis results. Of course, this means the limit values must be modified.

Figures 4, 5 and 6 show the distribution of iron as a wear element, molybdenum as part of the additive system and viscosity as an important parameter for fluid film formation. The distribution of iron is typical for an application where no fixed oil drain intervals are defined. The iron content initially is low but increases over time due to normal wear processes. For this zero-reference skewed frequency distribution, a cumulative method should be applied to define the limit values. The iron range for this population is quite small, which indicates that no significant amount of sample with special cause variation is included. The statistical approach should deliver reasonable limit values.

The viscosity distribution is bell-shaped. The median and mean are in the same range. SPC and the standard deviation can be used to identify alarm values. Limit values already exist for this parameter based on the ISO viscosity grades. In this case and for this special oil, the limits could be defined more precisely according to the statistical evaluation.

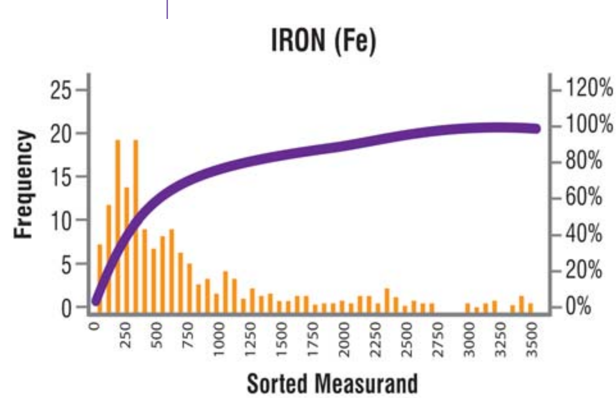


FIGURE 8. An example of iron distribution for a crawler drive

TYPE	# SAMPLE	METHOD	FE-GREEN	FE-YELLOW	FE-RED
A	610	1 (CUM)	<835	835-1850	>1850
B	774	1 (CUM)	<1508	1508-2313	>2313
C	1528	1 (CUM)	<864	864-1331	>1331

FIGURE 9. Limits influenced by special cause variation

TYPE	# SAMPLE	METHOD	FE-GREEN	FE-YELLOW	FE-RED
D	2128	2 (CUM)	<75	75-160	>160
E	1291	2 (CUM)	<98	98-264	>264
F	565	2 (CUM)	<364	364-475	>475

FIGURE 10. Typical iron limits for final drives

The evaluation of the additive molybdenum also shows a bell shape, but the distribution is slightly high-reference skewed and bimodal. The median and mean are different, which indicates that the cumulative approach should be chosen. The population should also be investigated to identify samples with special cause variation.

Figure 7 contains warning values for iron in different wind turbine models. It illustrates how statistical methods can be much more precise. These statistical-based limits can be combined with trend-based limits to help determine whether an increase in iron is within the acceptable range when compared to the previous sample.

Limit Values for Hydraulic Final Drives

Another example comes from hydrostatic final drives. These systems are used as crawler drives for excavators and agricultural machinery. Oil samples are often taken from these systems during the oil drain procedure with static intervals between 1,000 and 2,000 hours. The main purpose of the oil samples is to confirm that the right lubricant is in use, contamination levels are below permissible limits and wear rates are normal.

In general, the evaluation of oil analysis results for this application is suitable for absolute limit values. Figure 8 shows the distribution of iron for a crawler drive. Results for different models were from the same manufacturer, and for all samples, a comparable oil type was used. The main goal of the statistical evaluation was more precise wear limits.

Figure 9 shows the results of the cumulative method. Unfortunately, the new statistically based warning limits differed significantly from the actual limits in use based on experience. The new calculated limits seemed too high, and the unusual wide range of iron distribution supported this estimation. A closer look at the last 20 percent of the distribution revealed that the data population contained a large number of variations associated with uncommon causes. Two independent but major effects were identified: a loss of viscosity due to contamination with hydraulic oil and high silicon content, which indicated high dust levels due to damaged seals.

Figure 10 shows the statistically based limits for newer models from the same manufacturer. The wear limits are significantly lower and correspond with the previously experienced wear levels for normal conditions. The two problems of the older final drive generation have been solved for the newer generation.

In conclusion, it is important to keep in mind that oil can talk and that limit values are an essential tool for evaluating analysis results from used oils in order to rate a machine's wear, oil condition and level of potentially harmful contaminants. While limit information can be provided by a variety of sources, in some cases it may not be available. General or global limit sets also are not usually valuable for condition monitoring. Depending on the application, absolute or trend-based limits, or a combination of both, often deliver the best results. ■

WES CASH NORIA CORPORATION

WHY ONE OIL Sampling POINT Isn't ALWAYS Enough

The starting point of any great oil analysis program begins with obtaining representative samples. The goal of sampling is to maximize data density while minimizing data disturbance. You maximize data density by sampling in the right location with the right equipment at the right time. Often, the right location is a "live zone" within the machine where oil is flowing in a turbulent manner. This allows you to capture a sample containing all the useful information needed for trending without losing any data via particle fly-by or settling. The right equipment includes the use of minimess sampling valves, vacuum sampling pumps, disposable tubing and other accessories for taking samples as cleanly as possible. Depending on the criticality of the machine or how poorly it is operating, the sampling frequency may be very long (every six months) or very short (every two weeks). Drawing consistent samples helps to trend wear debris, contamination levels and lubricant health.

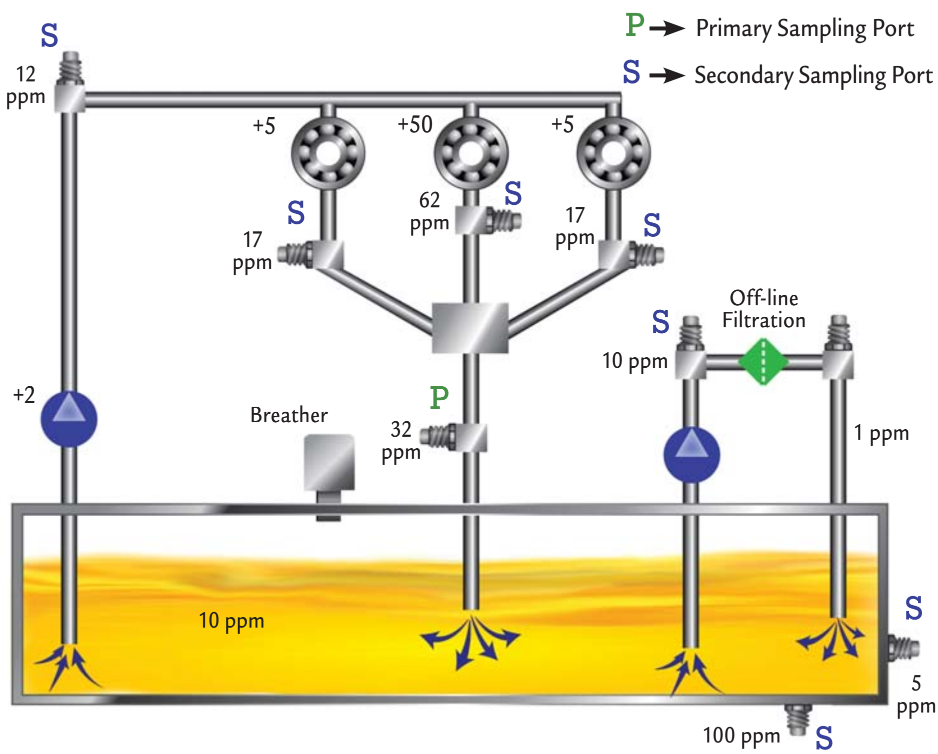
Minimizing data disturbance depends on how well the sample extraction process is designed. A common mistake is failing to flush the sample equipment as part of the procedure for drawing a sample. If you are using disposable tubing and a vacuum sampling device, the tubing must be flushed to get a true representative sample. Flushing between five to 10 times the dead volume from all sampling equipment is recommended. This ensures that any contaminants inside the tubing are cleared out and that the sample will be representative of the conditions inside the machine.

Using the proper cleanliness specifications on the sample bottles will also help reduce the signal-to-noise ratio that can skew particle counting efforts. If you put oil into a dirty sample bottle, the results will show that the oil in the system is dirty when that isn't necessarily true. Make certain that sample bottles are cleaned to the

Primary vs. Secondary Sampling Ports

PRIMARY SAMPLING PORTS/VALVES should be properly located and installed at the factory, and provide an overall look at the entire machine.

SECONDARY SAMPLING PORTS/VALVES should be installed on many circulating systems and enable you to focus on individual components inside a system.



Examples of primary and secondary sampling port locations in a circulating oil system

> Even though sampling can be a great predictive maintenance tool, a single sample port may not always be adequate for diagnosing abnormal conditions inside a machine.

specifications required to hit your target cleanliness goals. If you receive sample bottles from a laboratory, call them and ask what quality-control process they have in place for the bottles and if they are certified to a specific cleanliness standard.

Choosing the correct sample location can be challenging. When I'm in a plant and am asked where to install a sample port, I look for a single spot where I can gather as much useful data about the entire system. This is called the primary sampling location. At this location, the goal is to be able to draw a single sample that acts as a snapshot of the entire system. In most circulating systems, this will be on the main return line before the reservoir. By sampling from this one spot, you can check the wear debris from the rest of the system as well as the particle count to get an idea of the total contaminants in the system.

Although the primary sampling location is a great place to start, it often leaves behind a lot of valuable data. This is why secondary sampling locations should be installed on most systems. The goal of a secondary location is to be able to pinpoint the cause of any fault seen on an oil analysis report. Unlike the primary port, which provides an overall look at the entire machine, secondary ports enable you to focus on individual components inside the system.

Most circulating and hydraulic systems should have both a primary and secondary sampling location to ensure that any identified failure mechanism can be tracked back to the component causing the problem. Not only can a secondary port be used to help determine the source of wear debris or particles, but by installing sampling ports behind filters, you can monitor how well the filter is removing particles. So while the primary port may get the most use, the secondary port is invaluable once a fault has been detected.

In the circulating system shown on page 36, the primary sampling port is on the main return line before the reservoir. This is a great location, as the entire system can be actively monitored from this single port. In looking through the circuit, you will see secondary sampling ports after each component in the system. This can be quite useful. For example, it was determined through research and historical information that whenever the system exceeds 22 parts per million (ppm) of metal at the primary port, there is a problem with the system. The last sample taken indicated 32 ppm metal. Without secondary ports, there would be no way of knowing where the additional metal was originating.

34%

of lubrication professionals have secondary sampling ports installed on equipment in their plant, based on a recent survey at MachineryLubrication.com

However, the engineer was wise and installed secondary ports throughout the system. By sampling at each location, it became apparent that the middle bearing was the one causing the high wear metal count.

This illustration provides an excellent case in point for why secondary ports are needed. Remember, even though sampling can be a great predictive maintenance tool, a single sample port may not always be adequate for diagnosing abnormal conditions inside a machine.

About the Author

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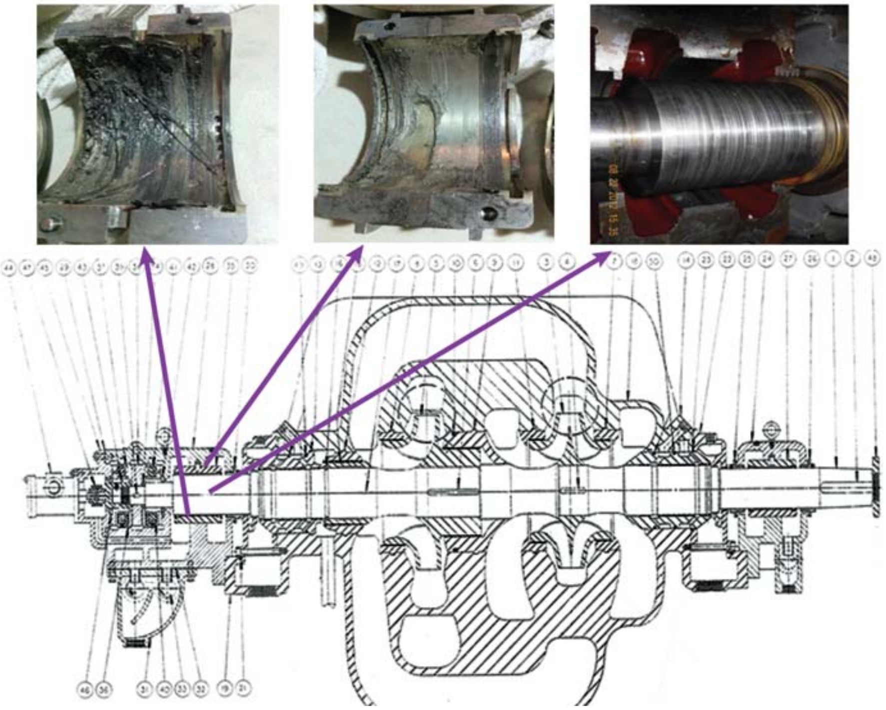
By Michael Schilling

Wire Wooling
Bearing Failure: A Case Study

A nuclear plant recently experienced wire wooling on the journal bearings and shaft of one of its feed water pumps. This was detected by the color of the oil turning black during a post-maintenance acceptance run. The equipment did not have any form of filtration installed but just a rough strainer in the reservoir. The pump was turned off, and the strainer inspected.

Examples of inadequate foreign material exclusion practices on oil piping removed from the system

The pump in question has a double volute design, which assures radial balance. It has specially constructed bearing housings that contain the thrust (outboard end) and radial (coupling end) bearings. The radial bearing is a split-sleeve journal bearing.



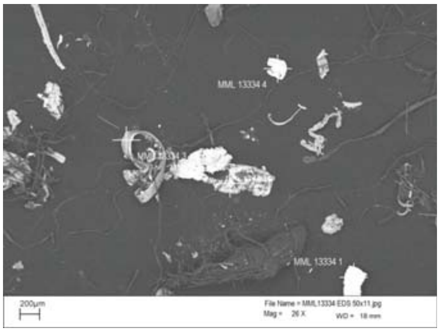
Left to Right:
Pump Outboard (Journal) - Bottom Half
Pump Outboard (Journal) - Top Half
Pump Outboard - Journal Section of the Shaft

The thrust bearing combines a split-sleeve journal bearing with a pivoted shoe bearing, thrust disc and locating ring.

Oil Lube System

The oil lubrication system furnishes lubricant under pressure to the pump and motor bearings. The lubricant for the motor is an ISO 32 grade turbine oil and is compatible with the lubricant required for the pump. For this design, the pump bearing housings are furnished with an oil deflector. The oil deflector has a nose ring that inserts between the labyrinth seal cast in the bearing housing and the pump shaft. There is also an outer ring that overlaps a lip, which is cast into the upper and lower bearing housings. The tight clearance between the oil deflector and pump shaft minimizes water intrusion as well as oil leakage.

During normal operation, all oil is supplied by the shaft-driven gear pump, while a motor-driven auxiliary oil pump is on standby. The pump's lubrication system configuration is designed to



During analysis, debris consistent with machine (metal) cuttings was revealed.

start the motor-driven auxiliary oil pump when the main pump's oil pressure falls below 7 pounds per square inch (psi). The intent in this configuration is to provide sufficient lubrication to the pump bearings in the event the shaft-driven gear pump fails while the pump is in normal operation. The motor is a 7,000-horsepower horizontal induction unit that is connected to the pump via a flexible coupling.

The pump's rotating assembly (including impellers, shaft, wear rings, balance sleeve, journal bearings and balance stage pieces) was recently replaced to provide increased feed water flow to the boilers following the maintenance period. This change also modified the pump recirculation system and seal water injection system.

Pump shaft damage

As noted previously, the pump requires a lube oil system. Its purpose is to provide lubrication and cooling to the pump thrust bearing, two radial journal bearings and the motor bearings. The lube oil system is self-contained and includes a shaft-driven oil pump, heat exchanger, strainer, pressure-relief valves, thermometers, pressure gauges, oil drain sight flow glasses for each bearing bracket, a reservoir, and an auxiliary motor-driven lube oil pump. The primary lube oil pump is mounted on the end of the main pump shaft. The auxiliary lube oil pump is mounted adjacent to the lube oil reservoir and is used as a backup to the main lube oil pump during startup. The lube oil cooler is utilized to cool the lube oil and receives cooling water from a separate cooling water system.

Signs of Bearing Problem

In 2012, the modified feed pump was started to perform a pre-operational test. During the first portion of the run, vibrations (casing mounted) were noted as abnormal but acceptable. Audible noises resembling air expulsion and water spewing out from the pump seals were also noted. Following the test run, the pump oil sample showed an abnormal black color and particle content. An additional oil sample was obtained and sent for independent lab analysis.

The elemental spectroscopy showed abnormal levels of iron and tin. Because lead was not seen in the sample, it initially was reported that no bearing damage had occurred. Based on these results and in-depth discussions, a visual inspection of the main oil pump suction filter was performed. This showed visible debris/

shavings consistent with shaft and bearing materials.

In order to determine where the debris was generated, the covers of the outboard and inboard bearing housings were opened. When the outboard bearing cover was lifted, maintenance personnel discovered strings of metal that appeared to be shavings of bearing metal (Babbitt). The outboard radial bearing was completely destroyed. The shaft also had radial grooves that were similar in appearance to those made by a cutting tool.

The inboard bearing showed signs of having the same outcome given enough time. The thrust bearing shoes appeared to be in as-new condition, but both the inboard and outboard thrust seal rings had linear indications and discoloration due to extreme heat.

The rotor was removed from the casing and inspected. All close-clearance mating components (case rings, impeller hub, balance sleeve, balance bushing, throttle bushing and throttle sleeve) exhibited contact, with the most contact occurring at the second-stage case ring and impeller eye hub. Subsequently, a plan was developed and executed to inspect the bearings of the similar redundant pump, which had also been upgraded. The pump bearing housing caps were removed along with the upper radial bearing halves. Fine metal particles were found. This prompted the development of a more rigorous flushing plan for the pump's lube oil system.

Based on a preliminary review of the vibration data and physical inspection of the pump's bearing and rotor, it was concluded that the bearing damage was caused by foreign material introduced into the journal regions. This foreign material could be emanating from the closed-loop oil lubricating system, as supported by the metallic grit found in the other pump's bearings. The shaft journals are not chrome-plated, which makes these areas susceptible to wire wooling.

The bearing damage was initiated on the outboard end of the feed pump. This was evident by the greater damage on the outboard journal bearing as well as by the greater wear on the most outboard case ring, which acts as the water-lubricated outboard bearing once the journal bearing fails.

Wire Wooling Failure

The failure mode supported is a condition known as "wire wooling." Wire wooling requires shaft material chromium content between 3 to 20 percent and foreign particulate (hard or soft). The failure sequence entails the following:

- Introduction of foreign particulate into a tight clearance (in this case, the bearing-to-journal annulus) and filtered to less than 15 microns.
- Generation of frictional heat due to particle rub at high speeds (greater than 3,700 feet per minute).
- Conversion of chromium to hard chromium carbide in the steel shaft and in the presence of hydrocarbon oil.
- Embedding of chromium carbide particles in the stationary component (bearing) acting as a cutting tool.

Air ingestion had no factor in the bearing failure. This condition would have been seen first as a hydraulic imbalance in the first-stage impeller. If air ingestion had been the failure mechanism or contributed to the failure mechanism, then the inboard bearing would have been more distressed and would have initiated the


Pump casing oil drain


Upper bearing housing


Lower bearing housing

> *The cleanliness controls were insufficient for ensuring the health of the feed water pump when the lube oil system was completely disassembled and its components reused.*

event. Air ingestion also would have caused extreme transient axial loads that would have exercised the thrust bearings and left indications or damage on the inboard and/or outboard thrust shoes.

If air ingestion produced high radial loads, then air would have resided in the wear ring annulus locations, significantly reducing the stiffness and damping of these water-lubricated bearings (Lomakin effect). This would have resulted in more contact between the impeller hub and wear rings than was found during the rotating element inspection.

The loss of wear ring stiffness would have led to increased rotor motion with a resulting increase in vibration amplitude. The only increase in vibration during the event was at vane pass frequency, which was caused by the exiting air impacting the volute cutwater.

Air ingestion was addressed by revising the procedure for venting the pump casing prior to startup.

The Root Cause

The pump experienced a significant equipment failure due to the introduction of foreign material into the lube oil system.

Debris Size and Type

Predictive maintenance (PdM) analysis revealed debris that was consistent with machine (metal) cuttings. The foreign material was possibly introduced into the pump bearing through the lube oil supply/return lines, bearing housings and oil reservoir.

The piece was analyzed with a scanning electron microscope using energy dispersive X-ray spectroscopy semi-quantitative analysis. The composition of the debris was consistent with stainless steel. Furthermore, the morphology resembled a piece of cold drawn wire.

Prior to this event, the primary PdM technologies in use consisted of surface-mounted accelerometers, thermography and oil analysis. Vibration data was somewhat useful during the event. However, oil analysis was the main technology utilized to identify the problem. This led to further investigation. Subsequent to this event, proximity probes and bearing resistance temperature detectors (RTDs) were installed on this and three other similar pumps.

In reviewing the damaged components, it was discovered that the motor bearings and pump radial/thrust bearings were all affected by the foreign material.

Conclusion

The nuclear plant relied upon existing maintenance activities for lube oil system cleanliness control. These cleanliness controls were insufficient for ensuring the health of the feed water pump when the lube oil system was completely disassembled and its components reused. ■

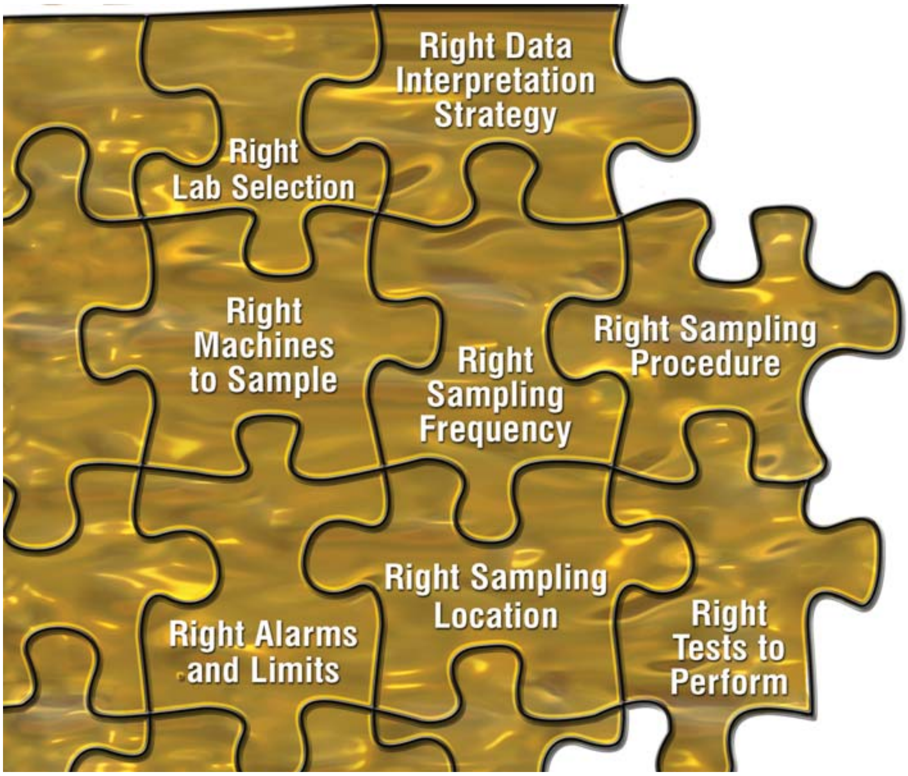
Loren Green | NORIA CORPORATION

Understanding the Rights of OIL ANALYSIS

It has been said that oil is the lifeblood of a machine. By monitoring contaminants and additive health, you can keep this "blood" healthy and minimize the risk of a failure. But what are the necessary elements for establishing and maintaining a successful oil analysis program? Consider the eight "rights" of oil analysis.

Right Lab

You must first decide whether to keep your oil analysis in-house or outsource it. Previously, having an onsite laboratory was cost-prohibitive. As technology has advanced and costs have decreased, this has become a viable option. If an in-house lab is the choice, it is important to select the proper test equipment and to have certified personnel performing the tests. Some organizations use an in-house laboratory for basic tests like viscosity, particle counts and moisture content but utilize an outside lab for exception testing.



Setting Alarms and Limits

THE PRIMARY PURPOSE FOR ALARMS OR LIMITS IS TO FILTER (funnel) data so that the technologist spends his time managing and correcting exceptional situations instead of laboriously perusing the data trying to find the exceptions. The alarm serves as a "trip-wire" to tell the analyst that a threshold has been passed and that action is required. Some data parameters have only upper limits such as particle counts or wear debris levels. A few data parameters employ lower limits like base number, additive elements, flash point and oxidation stability. Other data parameters like viscosity use both upper and lower limits. These generally relate to important chemical and physical properties of the lubricant where stability of these properties is desired.

If the decision is made to use an offsite laboratory, there are a couple of options to consider. Most lubricant suppliers will provide oil analysis as part of their service offering. The majority of these suppliers have excellent labs with qualified technicians performing the tests. Just be aware of the possibility of allowing the "fox in the henhouse."

Many laboratories also offer excellent oil analysis services. However, as testing equipment becomes less expensive, a number of labs are springing up with technicians who are not certified and with equipment that may not be correctly calibrated.

Whichever option you choose, I suggest conducting random spot checks of the laboratory. Use blind samples to verify the lab's accuracy. Send in two samples drawn at the same time from the same reservoir but marked as different pieces of equipment. If the results are not the same, it may indicate that you need a new lab.

Right Test Slate

Frequently, companies enter into a relationship with a laboratory without really knowing what they want. They rely on the lab to steer them in the right direction regarding the tests to run. In some cases, the "standard" test slate may not capture the information needed to make the best maintenance decisions. Therefore, it is imperative to work with your laboratory to determine your individual needs and develop the proper test slate.

Right Sampling Location

It is critical that samples are taken from the proper location, i.e., from a "live zone." If a sample is drawn just below the surface of the oil in a gearbox, the particle counts will not be very accurate. The same holds true when sampling from a drain plug on the gearbox. Most of the particles will settle to the bottom of the reservoir.

If you have a high particle count when sampling from the top of the reservoir, there is a serious contamination issue. Likewise, if you are sampling from the bottom of the reservoir, you should expect elevated particle counts. Of course, neither of these locations will give you an accurate count of the particles at the gear mesh, which is where the damage is actually occurring.

In a circulating system, samples should be taken at an elbow on the return line prior to the filter. In the gearbox example, I recommend that a minimess sample connection be used in conjunction with a pitot tube to allow samples to be drawn consistently from a location near the gear mesh.

Each of these rights must be addressed and applied correctly. Otherwise, your time, effort and money will be wasted.

Right Frequency

If you are only sampling your equipment on an annual basis, I would surmise that in most cases this is not enough. Several factors should be considered when determining the sampling frequency such as the age of the equipment, the age of the lubricant, the machine's criticality, etc.

Right Procedure

You also must ensure that each sample is representative of the fluid in the reservoir and not affected by outside contaminants. A minimess allows a sample to be drawn without opening the reservoir. In addition, by keeping the sample bottle in a plastic bag, you can prevent airborne contaminants from entering the bottle. Drawing a sample from a drain valve with the cap off the bottle enables airborne contaminants to enter the sample. Depending on the environment, this can lead to severely elevated particle counts, essentially rendering the sample useless.

Right Equipment

Sampling equipment should be kept in a clean environment and cleaned after each use and prior to storage. Use minimess sample connections and select sample bottles based on the cleanliness targets. Sample bottles come in three categories: clean, superclean and ultraclean. In every manufacturing process, a certain amount of particles is generated. A bottle's cleanliness relates to its signal-to-noise ratio. Ultraclean bottles generally are made of glass and are shipped in hermetically sealed vacuum packaging.

Right Alarms and Limits

Many of the plants I visit have robust oil analysis programs. Sadly, several of these programs have improperly set alarms and limits. In the July-August 2011 issue of *Machinery Lubrication*, Jim Fitch explained how world-class organizations are taking charge of their own alarm settings to ensure that specific objectives are met. He also detailed how the advent of sophisticated oil analysis software has put this objective within reach of most anyone who desires it. To learn more about how to set both proactive and predictive limits for oil analysis, see http://www.machinerylubrication.

54%

of lubrication professionals utilize offsite oil analysis testing, according to a recent survey at MachineryLubrication.com

com/Read/28520/setting-oil-analysis-limits.

Right Data Interpretation Strategy

Even if the right lab has been selected, the right test slate is chosen, the right sampling equipment is used, the right procedures are followed and samples are taken from the right location, if you don't employ the right data interpretation strategy, it is the same as having an all-encompassing encyclopedia and never opening the book. To make the best use of your oil analysis data, you may need to do a bit of homework. Elemental analysis of the lubricant can give you an idea of the composition of the wear metals in a given sample, but if you aren't familiar with the metallurgy and internal machine configuration, you are likely to suffer some confusion and have to guess as to where the wear material is being generated.

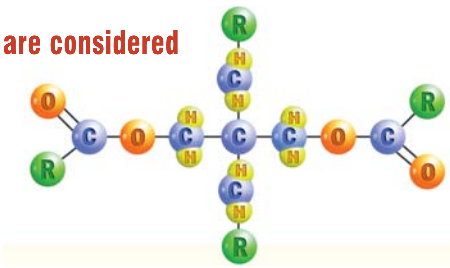
Keep in mind that the rights of oil analysis are all equally important. No one specific right takes precedence over another. Each of these rights must be addressed and applied correctly. Otherwise, your time, effort and money will be wasted. When used properly and combined with other condition monitoring technologies, oil analysis can enable your maintenance program to reach its full potential. ■

TEST your KNOWLEDGE

This month, *Machinery Lubrication India* continues its "Test Your Knowledge" section in which we focus on a group of questions from Noria's Practice Exam for Level I Machine Lubrication Technician and Machine Lubricant Analyst. The answers are located at the bottom of this page. The complete 126-question practice test with expanded answers is available at store.noria.com.

1. Polyolester synthetic lubricants are considered members of what API Group?

A) I
B) II
C) III
D) IV
E) V

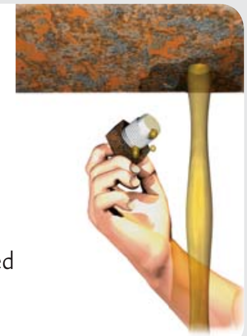


2. Live-zone sampling a circulating oil system means:

A) Always using a live sample pump to take the sample
B) Taking a sample from a static (non-flowing) straight piece of pipe in laminar flow
C) Taking a representative sample from a flow line that contains flowing oil
D) Taking a sample hot
E) Taking a sample from a zone in the system that contains the most wear debris

3. The proper time to drain the oil from a gearbox is:

A) At the end of the shift
B) At the end of the day
C) At the beginning of the following shift
D) While it is still hot from operation
E) After it has cooled and the particles and water have settled near the bottom



Answers:

1. E
Polyolester synthetic lubricants are considered to be members of API Group V. Polyolesters have excellent low-temperature properties, good lubricating properties and low volatilities.

2. C
Live-zone sampling means avoiding stagnant oil in any dead leg within the system. However, it is important to ensure that the flow in the live sampling zone is highly turbulent. Elbows and sharp bends are good examples of high turbulence areas. Sampling from a laminar flow area (straight line) results in a substantial reduction in particle concentration entering the sample bottle because of particle fly-by.

3. D
Oil will be less viscous at high temperatures, which can help to drain the maximum amount of oil. In addition, oil at high temperatures has better solubility, so it can hold more contaminants and degradation byproducts that need to be removed with the oil change.

DHIREN SHAH

BASE OIL REPORT

India's crude oil imports peaked in August as refineries stepped up purchases to meet record domestic fuel consumption. Indian refiners imported 18.81 million metric tons (about 4.45 million barrels a day) of crude oil during the month, a 9.1 percent increase over last year. The International Energy Agency expects India to be the fastest-growing crude consumer in the world through 2040. Indian State-run Indian Oil Corp. aims to increase its capacity by 30 percent, or about 2 million barrels per day over the next six years. According to the oil ministry, country's 23 refineries have a total capacity of 230 million tons a year and total fuel demand was 183.5 million tons during the financial year that ended March 31.

During January to July 2016, India imported 1.65 million MT of Base Oil:
Jan: 193786 MT, Feb: 208150 MT, Mar: 229985, April: 257118 MT, May: 197892 MT, June: 290324 MT and July: 277855 MT. Compared to June 2016, import of the country shrunk by 4% in July 2016 but increased by 19% in comparison to July 2016 with July 2015. There has been 21% surge in import during Jan-July 2016 compared to January-July 2015 which was 1.37 million MT.

The Indian base oil market remains steady with inventories at optimum levels with surplus of imported grades. During July 2016, approximately 277855 MT have been procured at Indian Ports of all the grades, which is a 4% fall down compared to June 2016. Indian State Oil PSU's IOC/HPCL/BPCL basic price for SN – 70/N – 70/SN – 150/N -150 marked up by Rs. 1.60 per liter, while SN - 500/N - 500 up by Rs 0.30 per liter with hefty discounts on sizeable quantity. Bright Stock prices down by Rs. 4.10 per liter effective September 01, 2016.Group I Base Oil prices for neutrals SN -150/500 (Russian and Iranian origin) are offered in the domestic market at Rs. 36.50 – 36.75/38.75 – 39.20 per liter, excluding Vat and other charges.

The Indian domestic market Korean origin Group II plus N-60–70/150/500 prices at the current level are up by for lighter grades while it is down for heavier grades. As per conversation with domestic importers and traders prices for N – 60/ N- 150/ N - 500 grades and at the current level are quoted in the range of Rs 37.70 – 38.25/39.75 – 40.40/45.75 – 46.50 per liter in bulk respectively (with other charges as applicable). Light Liquid Paraffin (IP) is priced at Rs. 39.75 – 39.95 per liter in bulk and Heavy Liquid paraffin (IP) is Rs.52.25 – 52.75 per liter in bulk respectively excluding taxes.

Approximately 10696 MT of Light & Heavy White Oil has been exported to different nations in July 2016 from JNPT, Chennai, Petrapole, Raxaul, Village Ponneri and Mundra which is 2% more compared to June 2016. Almost 3815 MT of Transformer Oil has been exported on July 2016 from JNPT, Raxaul, Ahmedabad and Chennai to numerous countries.

Base Oil Group I & Group II CFR India prices (USD) :-

Month	Group I - SN 500 Iran Origin	N-70 Korean Origin	J- 150 Singapore Origin	Bright Stock-150
May 2016	475 – 485 PMT	500 - 505 PMT	515- 525 PMT	915 - 920 PMT
June 2016	530 – 550 PMT	535 - 550 PMT	565 - 575 PMT	970 - 980 PMT
July 2016	565 – 575 PMT	555 - 575 PMT	585 - 595 PMT	980 - 990 PMT
August 2016	595 – 605 PMT	585 - 605 PMT	615 - 625 PMT	1010-1020 PMT
September 2016	565 – 575 PMT	575 - 585 PMT	590 - 605 PMT	985 - 995 PMT
Price change	90 PMT (+19%)	75 PMT (+15%)	80 PMT (+15%)	70 PMT (+8%)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