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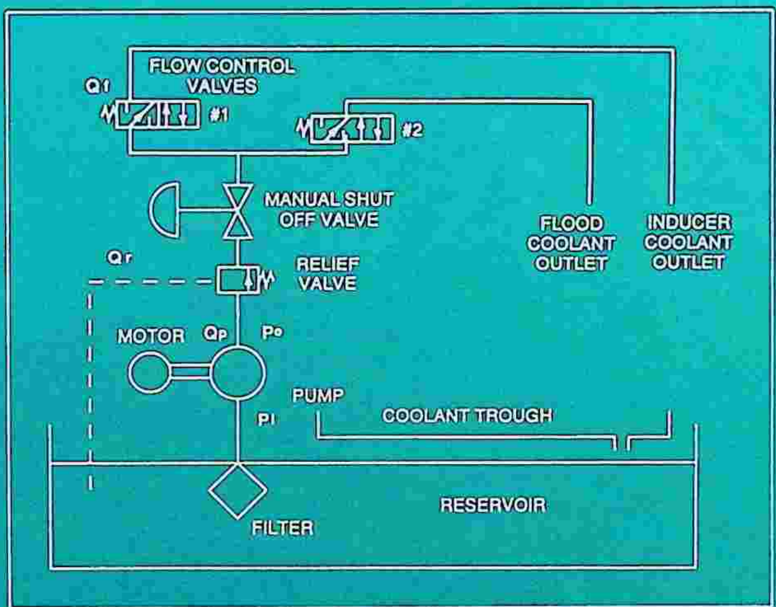
Profitable Condition Monitoring



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INTERPRETING CONTAMINANT ANALYSIS TRENDS INTO A PROACTIVE AND PREDICTIVE MAINTENANCE STRATEGY

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ABSTRACT

Condition monitoring can be easily performed by following a few simple principles. Among these principles include monitoring two sets of conditions:

1. The operating and environmental conditions that precede failure, and
2. Early-stage failure symptoms

Several models are presented that show the benefits of monitoring machine conditions, as well as the consequences of ignoring them. Also discussed is the integration of both proactive and predictive maintenance techniques to extend machine life.

1.0 INTRODUCTION

When you strip away the high-tech facade, the science of machine failure can be reduced to a few simple principles. Understanding these principles can allow condition monitoring to be performed with unbelievable simplicity. While the specific techniques involved depends on the machine design and application, the strategy remains the same.

Two sets of conditions must be monitored. The first condition is one that presents a risk to a machine's health if allowed to persist. These conditions are not symptoms of failure but are root causes, i.e., operating and environmental conditions that precede failure. Examples of root cause conditions are misalignment, lubricant contamination, and overheating. This activity of detecting and correcting root causes is referred to as proactive maintenance.

The second set of conditions to be monitored relates to early-stage failure symptoms. While it is the objective of proactive maintenance not to allow root cause conditions to progress to the point of early-stage failure, realistically all root causes can not be effectively controlled. Conditions that reveal the processes of failure are called "symptomatic conditions." Examples are wear debris, certain abnormal vibrations, and corrosion. The monitoring of symptomatic conditions is referred to as predictive maintenance.

Strategically, both proactive and predictive maintenance must operate with the same discipline. Both are condition-based maintenance and both, when well applied, can significantly increase machine availability and reduce operating costs. The extent of the benefit is a matter of quality assurance, as relates to the activities of proactive and predictive maintenance.

2.0 OBJECTIVE OF PROACTIVE MAINTENANCE

The single objective of proactive maintenance is to extend a machine's operating life (MTBF) without the guesswork associated with preventive maintenance. This is achieved by removing the underlying causes of failure by stabilizing healthy operating conditions. The state of conditions are monitored using field-level nondestructive instrumentation. Decisively, conditions that trend out of "stability" are adjusted/corrected before structural or surface harm is done to the machine. For instance, moisture is known to incite corrosive damage to metal surfaces. Regular monitoring and control of moisture contamination can remove this root cause as a source of future failure. The practice does not commission a repair, only remedial action of an unstable condition. Repairs are costly and result in downtime; remedying conditions do not. The emphasis is on machine wellness, not machine sickness. Success depends on new maintenance habits, similar to the fitness habits associated with cholesterol control, exercise, and proper diet.

3.0 OBJECTIVE OF PREDICTIVE MAINTENANCE

If proactive maintenance is the first line of defense against failure, predictive maintenance is the second line of defense. When a machine is experiencing slow tribological destruction, the rate and severity of the condition can usually be detected by monitoring symptomatic conditions. Unlike proactive maintenance, predictive maintenance alone does not reduce the frequency of failure, only the severity of failure. Most importantly, chain-reaction failures associated with gear systems and hydraulic systems can be routinely avoided. The benefit is reduced downtime and repair cost.

When predictive maintenance targets early-stage failures, say using wear debris monitoring, only the condition that led to the wear process need be corrected. Although the surface degradation can not be reversed, the progress towards breakdown is stopped. With later-stage failure prediction, using vibration monitoring for instance, the failure is usually too far advanced to avoid the repair. Albeit, the repair can often be conveniently scheduled, reducing downtime and other costs. It should be noted that dynamic balance and precision alignment, normally associated with predictive maintenance, are in fact proactive maintenance functions since these conditions are failure root causes.

4.0 CONTAMINANT MONITORING IS A STRATEGIC "PROACTIVE MAINTENANCE" TECHNIQUE

It has been well established in various published studies that contamination suspended in lubricants and hydraulic fluids is the number one cause (root cause) of mechanical failure. As illustrated in Figure 1, contamination can alter critical lubricating properties or can directly attack machine surfaces. Without the presence of contamination, the processes of wear can be abated.

This fact has been documented for mechanical machines such as bearings, engines, gear systems, and hydraulic systems. Four studies in particular are worth mention:

4.1 Bearings

According to work done by SKF, bearings can have "infinite life" when the influence of particle contamination is eliminated. This is illustrated in Table 1 where it can be seen that more than a 75 times life extension is achievable by simply improving lubricant cleanliness. It is noted that the relative life of very clean fluids at half the recommended viscosity is the same as contaminated lubricants at twice the recommended viscosity. Restated, the relative penalty of a contaminated lubricant equals that of a lubricant with just 25% of normal viscosity.

4.2 Diesel Engines

A number of tests have been conducted to evaluate the influence of contamination on engine wear and overhaul frequency. One of the more significant studies in this area was conducted by General Motors. GM compared the effect of filter performance to the rate of engine wear. Numerous tests were performed with different filters and different engines. The relationship was very distinct, Figure 2. As stated in their report, "compared to a 40-micron filter, engine wear was reduced by 50% with 30-micron filtration. Likewise, wear was reduced by 70% with 15-micron filtration."

4.3 Gear Systems

Monash University studied the influence of contamination on the rate of wear of gear systems using ferrography. After introducing particle contaminants during a test they note, "the SIO (ferrographic) values increased, indicating the occurrence of abnormal wear. . ." They further note that ferrography "responded sharply to increased wear caused by contamination."

4.4 Hydraulic Systems
While this is probably the most documented area of machine contaminant sensitivity, it is still common for hydraulic equipment users to underestimate the benefit of exceedingly controlled cleanliness. No work is more convincing than the field studies done by the BHRA. The relative life extension afforded to clean machines is shown in Figure 3. The study involved 117 different hydraulic systems monitored for a period of three years.

4.5 When contamination control, incorporating contaminant monitoring, is used as a proactive maintenance technique, a machine's life can be extended many fold, particularly when rigorous cleanliness levels are targeted and achieved. The correct steps in implementing a proactive contamination control program are:

1. Set cleanliness targets for each fluid system, sufficient to achieve machine life extension.

2. Upgrade or add filtration, as necessary, to achieve and stabilize cleanliness to within target.

3. Monitor contaminant levels at frequent time intervals, based on target cleanliness and environment, to insure cleanliness is achieved.

In considering the correct machine target, one technique which is useful is the Life Extension Method. Table 2 shows a chart for hydraulic systems based on the BHRA study. By using the chart, a new target cleanliness can be defined based on the current normal contaminant level and the life extension factor desired. Example, if the current and typical cleanliness level for a given machine is ISO 18/15, a five-times life extension can be achieved by moving the cleanliness to ISO 12/9. Contact the author for charts on other machine types, such as bearings and engines.

Contaminant monitoring is essential to success as it provides critical feedback on cleanliness stability. Without feedback, there is no control. Instability of contaminant levels is commonly associated with ineffective filtration and abnormally high ingression. Using contaminant monitoring, changes in filter performance and ingression rates can be readily detected.

5.0 CONTAMINANT MONITORING IS A STRATEGIC "PREDICTIVE MAINTENANCE" TECHNIQUE

There are very few forms of internal machine failure that don't result in particles being released into the lubricant (or hydraulic fluid). In fact, the author is only aware of valve stiction and orifice obliteration as examples of non-particle generating failures. And, these are non-permanent failure modes, i.e., correctable by simply flushing the contaminants out of the internal mechanisms.

Viewing increases in particle contamination as a predictive maintenance tool is indeed important. Table 3 lists the range of failure types detectable using contaminant monitoring. While contaminant-induced failures can be detected in the proactive maintenance regime (before degradation), all types of failures (except stiction and obliteration) can be detected in the predictive maintenance regime (during degradation). This is a double benefit.

To be successful, the contaminant trending process must be sufficiently rigorous. All trend sampling points must be upstream of filters. Filters can remove the signs of failure and contaminant ingression. This is critical data to a contaminant monitoring program. Also, monitoring must be at frequencies defined by target cleanliness levels and contaminant environment severity. When well implemented, even failures not caused by particles can be efficiently detected, long before aberrant vibration signals are present. Examples are:

	Failure Root Cause:	Revealed by Particle Generation From:
1.	Moisture in Oil	Corrosion Debris
2.	Additive Depletion	Wear Debris
3.	Chemical Contamination	Debris From Corrosion and Wear
4.	Viscosity Change	Wear Debris
5.	Misalignment & Imbalance	Wear Debris
6.	High Pump Inlet Vacuum	Cavitation Debris

Abnormal particle trends are the early symptoms of several non-particle induced conditions. Once the abnormal trend is established, a more detailed evaluation of the lubricant (fluid) or machine malfunction can be pursued.

6.0 INTEGRATION OF BOTH CONDITION-BASED MAINTENANCE STRATEGIES

The flow chart shown in Figure 4 illustrates the approach for integrating contaminant monitoring into a combined proactive maintenance/predictive maintenance strategy. Starting at the top, (1) samples are taken and analyzed on a frequent basis using inhouse particle counter (portable or benchtop). If the contaminant level is within the target (2), no action is taken and the next sample is scheduled. Note, if a significant level increase is noticed, even though the current sample is below target, then this condition accelerates the time to the next sample. If the current sample is above the target, steps (3) or (4) are triggered.

Step (4) is better suited to an engine, bearing, gear system, compressor, or turbine. Step (3) is best suited for a hydraulic system or other systems where multiple sample points can be located between critical components and ingression sites. In such cases, a problem can be localized by sampling before-and-after suspect areas (3). In many cases it will be found that an ineffective filter is the source of the problem.

Taking the step (4) path, a wear debris density test (several bench-level techniques are available) is taken on samples indicating over-target particle levels. High metallic debris levels (6) suggest wear or cavitation type failures. Low metallic debris levels (5) signal external particle ingression problems or a failed filter. In such cases, the ingression problem should be isolated and corrected. If the metallic debris density is high, a complete fluid analysis should be performed (6). This determines whether the lubricant is degraded and helps identify the ailing component, using spectroscopy and/or ferrography. If the fault is revealed from the analysis, the problem can be corrected before excessive harm occurs (7). If the source of the fault is not revealed, more sampling and analysis should be done to further isolate the problem (8).

The success of an integrated proactive and predictive maintenance program using contaminant monitoring depends on frequent sampling. The assumption is that if particle counts, ahead of filters, are low, then; (a) the condition of the filter, (b) the health of the lubricant (fluid), (c) the rate of the ingression, and (d) the rate of wear, should all be considered normal. Otherwise, instable particle counts would result. The benefits are reduced oil consumption, lower cost of outside fluid analysis, extended filter life, reduced machine repair costs, and substantially reduced downtime.

7.0 CASE STUDIES

7.1 Duvha Opencast Coal Mine (South Africa)

Duvha applied many of the concepts of an integrated proactive and predictive maintenance program with marked success. They operate several large fleets of diesel powered earth-moving equipment in opencast coal mines. The subject of their program was diesel engines using an approach combining:

A) Management of an oil condition monitoring program, and
B) The application of fine lube oil filtration.

Particle counting techniques were used for particles five microns and larger. Spectrographic wear debris analysis was also applied to evaluate the rate of wear processes. Filtration was upgraded from OEM standard 45-micron filters to higher performance 10-micron filters. They noted that silica particles were a major source of their wear-related problems.

According to Duvha, the program resulted in "an increase in the control of incipient or imminent failures, together with improved component service life, and machine availability." The availability and cost savings figures are quantified below:

Earth-Moving Equipment	Availability (%)			Costs $/Hour		
	1987	1988	1989	1987	1988	1989
130-Ton Haulers	71	70	73	130	107	98
80-Ton Rear Dumpers	77	78	85	50	68	50
Scrapers	73	83	86	52	42	41

Figure 5 illustrates the influence of the program on the presence of wear metals and silica in the diesel lube oil of a track dozer. While noting the limitations of spectrometry, the trends are evident.

7.2 Nippon Steel, Nagoya, Japan

Nippon Steel, one of the worlds largest steel producers, using contaminant monitoring applied the concepts of proactive and predictive maintenance to hydraulic machinery. They established fluid cleanliness targets, developed a contaminant monitoring program, and implemented high performance off-line filtration. Additionally, ferrography was used as the principle failure prediction tool.

The new program was successful in reducing contaminant concentrations by 75% as compared to previous levels. The life of hydraulic pumps, as a result, averaged seven times longer. This led to pump overhauls being reduced to one-tenth of previous levels. A ten-year pump replacement curve is presented in Figure 6. The reduction in oil consumption is also worth noting.

8.0 CONCLUSIONS

The benefits associated with a rigorous program of fluid contaminant monitoring can be dramatic when well implemented. New disciplines must be established and skills applied to succeed.

Viewing particle contamination as both the principle cause and result of mechanical failure is the essence of the integrated philosophy. Establishing cleanliness targets for each fluid-dependent system followed by rigorous monitoring and control extends machine life and predicts impending failures. The flow chart (Figure 5) is the recommended approach for accomplishing this.

Improved filtration is usually necessary to achieve the challenging cleanliness targets that extend machine life. According to Duvha, "whatever caused a filter to plug, also causes wear. Do not blame the filter." They conclude that the benefit is "not extended oil drain period, but extended component life and machine availability." This is the philosophy of proactive maintenance.

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Table 1: Influence of Contamination on Bearing Life

Bearing Type & Lubricant Cleanliness	Relative Bearing Life: Half The Recommended Viscosity	Relative Bearing Life: The Recommended Viscosity	Relative Bearing Life: Twice The Recommended Viscosity
Radial Ball Bearings:			
Very Clean	6	≈80	≈ 300
Normal	2.5	50	≈ 200
Contaminated	0.6	2.5	4
Radial Roller Bearings:			
Very Clean	0.6	5	15
Normal	0.3	1.8	3
Contaminated	0.2	0.4	0.5
Thrust Ball Bearings:			
Very Clean	1.3	18	48
Normal	0.7	5	9
Contaminated	0.3	0.7	1.2
Thrust Roller Bearings:			
Very Clean	0.3	1.5	3
Normal	0.3	0.7	1
Contaminated	0.15	0.3	0.35

Ref: SKF

Table 2: The Life Extension Method is an Effective Cost/Benefit Technique for Setting Machine Target Cleanliness Levels

Hydraulic Systems: Required New Machine Cleanliness (C)

A: Current Machine Cleanliness (ISO) \ B: Life Extension Factor	2	3	4	5	6	7	8	9	10
26/23	23/21	22/19	21/18	20/17	20/17	19/16	19/16	18/15	18/15
25/22	23/19	21/18	20/17	19/16	19/15	18/15	18/14	17/14	17/14
24/21	21/18	20/17	19/16	19/15	18/14	17/14	17/13	16/13	16/13
23/20	20/17	19/16	18/15	17/14	17/13	16/13	16/12	15/12	15/11
22/19	19/16	18/15	17/14	16/13	16/12	15/12	14/11	14/11	14/10
21/18	18/15	17/14	16/13	15/12	15/11	14/11	14/10	13/10	13/10
20/17	17/14	16/13	15/12	14/11	13/11	13/10	13/9	12/9	12/8
19/16	16/13	15/12	14/11	13/10	13/9	12/9	12/8	11/8	11/8
18/15	15/12	14/11	13/10	12/9	12/8	11/8	—	—	—
17/14	14/11	13/10	12/9	12/8	11/8	—	—	—	—
16/13	13/10	12/9	11/8	—	—	—	—	—	—
15/12	12/9	11/8	—	—	—	—	—	—	—
14/11	11/8	—	—	—	—	—	—	—	—
13/10	11/8 (1)	—	—	—	—	—	—	—	—
12/9	11/8 (2)	—	—	—	—	—	—	—	—

(1) Life Extension Factor = 1.8

(2) Life Extension Factor = 1.45

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