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Profitable Condition Monitoring*
*Conditions Apply

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ABSTRACT

Once upon a time condition monitoring was conducted only periodically. They meant teams of highly-qualified scientists poring over charts and graphs, analyzing spikes that could be indicative of machinery deviating out of balance. It was an expensive process, and only justifiable on the most costly assets or highest value production lines. But the picture has changed radically in recent years, with numerous off the shelf sensors providing simple indication that equipment is drifting out of tolerance. Such Condition Monitoring (CM) is vital on high value assets such as wind turbines, but emerging condition monitoring techniques and technologies mean that it can also provide cost-effective protection for smaller machines, enabling anyone to improve efficiencies, reduce energy consumption and eliminate downtime. Individual monitoring channels can be dedicated to any and every pump, fan, motor, centrifuge, turbine or vibrating screen, providing effective and affordable condition monitoring. Most of the time the condition monitoring techniques are sold as bells and whistles of maintenance. Hence in reality, majority of the industries who applied condition monitoring in their machinery may not financially reap the benefits. The reason may be improper implementation of condition monitoring without understanding the physics of failure and reliability concepts. This paper explore the proper application of condition monitoring based on reliability engineering principles with suitable case study.

Key words: Condition Monitoring(CM), Physics of failure, Reliability Centered Maintenance (RCM), P-F curve, P-F interval.

1. INTRODUCTION

In recent years, the operators of large industrial plants have benefited from major advances in plant monitoring sensors and automation. The cost of bringing state of the art automation technology to the plant is continually being reduced and more advanced sensors and instrumentation provide the required data for operators to make critical decisions about operations and maintenance in real-time. The driving force for plant operators to adopt these technologies is to improve the bottom line by increasing efficiency and optimizing O&M. EPRI conducted a survey of the driving influences for fleet-wide monitoring to the owners of electric utility plants [1]. The driving influences are as follows:

- Equipment/Process Condition Assessment
- Maintenance Optimization
- Reliability Assessment
- Efficient Use of Resources

The whole idea here is a need to identify the state of the plant and its components in real-time. This can only be done if the appropriate process data is available and analysis of the data against benchmarks or design parameters can be performed. Implied by the last bullet; efficient use of resources, is that all this must be done with a limited number of plant personnel. These needs are applicable for power industry, oil and gas, aviation, manufacturing, military operations and logistics and so on. Global competition, the escalating cost of energy and other factors has resulted in tremendous pressure throughout the industries to reduce O&M costs.

Maintenance costs are a major part of the operating costs of all manufacturing or production plants. Depending on the specific industry, maintenance costs can represent between 10 and 40 per cent of the costs of goods produced. For example in food related industries, the average maintenance cost represents about 15 per cent of the cost of goods produced; while in iron and steel, pulp and paper and other heavy industries maintenance represents up to 40 per cent of the total production costs. Past surveys of maintenance management effectiveness in the US manufacturing industry indicate that one third, 33 cents out of every dollar, of all maintenance costs is wasted [2]. Hence in reality, majority of the industries who applied condition monitoring in their machinery may not financially reap the benefits. The reason may be improper implementation of condition monitoring without understanding the physics of failure and reliability concepts. This paper explore the proper application of condition monitoring based on reliability engineering principles with suitable case study.

2. CASE STUDY BACKGROUD

In the arena of Reliability Centered Maintenance (RCM), one of the strategies for failure management is on-condition maintenance, also called predictive or condition-based maintenance. This strategy relies on the capability of maintenance personnel to detect potential failures in advance in order to take appropriate actions. Many technologies have been developed to monitor failure characteristics such as vibration analysis, X-ray radiography, ultrasonics, infrared thermography, oil analysis, acoustic emission, etc. This section provides basic definition of physics of failure such as P-F curves and P-F intervals. Also the relevance of these in the integration of RCM and CM.

A. P-F Curves and P-F Intervals

A common curve that illustrates the behavior of equipment as it approaches failure is the P-F curve. The curve shows (Figure-1) that as a failure starts manifesting, the equipment deteriorates to the point at which it can possibly be detected (P). If the failure is not detected and mitigated, it continues until a "hard" failure occurs (F). The time range between P and F, commonly called the P-F interval, is the window of opportunity during which an inspection can possibly detect the imminent failure and address it. P-F intervals can be measured in any unit associated with the exposure to the stress (running time, cycles, miles, etc). For different failure modes, the P-F interval can vary from fractions of a second to several decades. For example, if the P-F Interval is 200 days and the item will fail at 1000 days, the approaching failure begins to be detectable at 800 days [3]. Hence the frequency of inspection is determined wholly and solely based on the P-F interval [4].

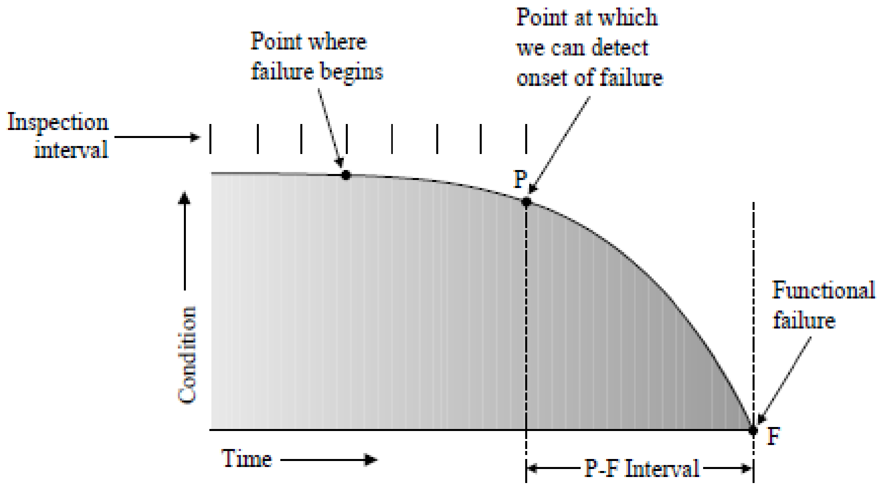

Figure 1 P-F Curve

B. Integration of RCM and CM

When we think of the integration of RCM and CM technologies, two conversations come to our mind. While both of these conversations involved vibration analysis, they could have as easily involved any of the other CM or predictive maintenance technologies.

The first conversation involved a plant that used large fans during their production process. While talking with one of the maintenance engineers, he mentioned that they use vibration analysis to tell them when the fans need cleaning. Later in the conversation, he stated that they shut the fans down every 6 months to clean them. The obvious question is, why do both? If the vibration analysis adequately predicts when the fans need to be cleaned, why have a scheduled shutdown just to clean them? On the other hand, if the plant is already being shut down, and cleaning the fans at that time will let them operate for another 6 months, why do vibration analysis?

The second conversation involved a plant that uses a lot of pumps. The plant maintenance personnel stated that they perform vibration analysis on the pumps once a month. When asked why, the response was that this is what the vibration equipment vendor recommended. Upon further questioning, the technicians revealed that the pumps would run about 6 months after a potential problem is detected by vibration analysis. A reasonable question in light of the 6 month warning is, why perform vibration analysis every month, why not every 2 or 3 months? An additional piece of information is that the plant requires 100 percent pump availability in the summer months, but can accept pump failures during the winter months. This raises the question, why do vibration analysis in the winter months at all?

The key point is that CM technologies are often as an end product rather than one of many possible function preservation tools. The RCM analysis process is designed to provide a well- documented, structured way to evaluate these and other function preservation strategies.

3. CASE STUDY

A large haul truck from one of the major manufacturers supplied to a large coal mine has been considered in this paper. There are 23 trucks in the fleet. Each truck has two wheel motors which contain 40 – 50 litres of synthetic final drive gear oil ranging between 460-680 cST@ 40º C depending on the model and climate. Preventive maintenance requirements are for the final drive oil to be kidney looped with off line filtration during service. This procedure only provides temporary clean up and protection of wheel components, with contamination levels rising during normal operation. As a result, contamination levels with significant wear debris can rise to unacceptable levels between PM intervals which results in wearing of components and shortened life of the synthetic lubricant. The present case study consider the lubrication monitoring program differential and final drive of haul trucks. Most oil samples are taken based on a fixed schedule (500 hrs).

A. RCM Approach

Oil analysis results from a fleet of 23 haul truck wheel motors were analyzed along with their respective failures and repairs over a nine-year period. Detailed data cleaning procedures were applied to prepare data for modelling. After analysing the failure data, it was observed that there are evidence of two significant failure rate behaviour. Hence the data has been segregated with the consultation of the O&M engineer. Some of the trucks exhibited age based failure rate behaviour. Random behaviour has been observed in another group of trucks. This case scenario has been handled in RCM (Figure 2) to evaluate the financial implications of maintenance strategy based on the failure rate behaviour.

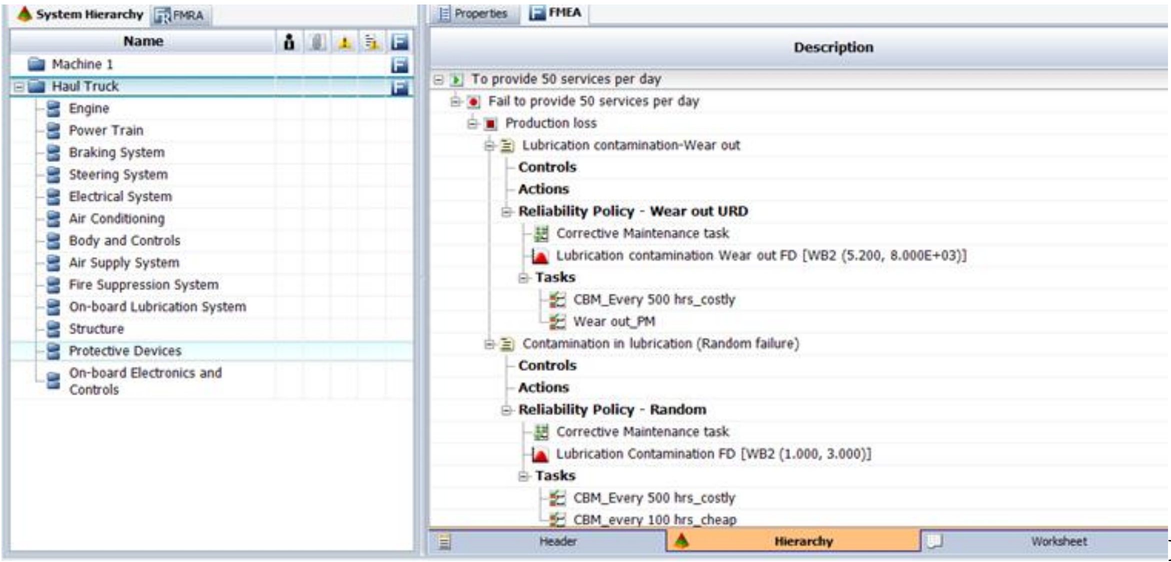

Figure 2 RCM Analysis of Haul Truck

[1] Scenario-1:

Lubrication contamination due to age based failure rate behaviour is dealt in scenario-1. The input to the analysis is provided in Table 1.

Table 1. Scenario-1 input

Model	**Parameters**	
Reliability Model	β=5.2, η=8250 hrs	
Downtime Rate	Rs.20,000	
Corrective Maintenance	Duration:10 Days; Crew cost:Rs.350/hr/person; Spare cost:Rs.7800	
Preventive Maintenance	Interval:5500 hrs; Duration:5hrs; Spare cost:Rs.7800	
Condition Monitoring	Duration:2hrs;Crew cost:Rs.1000/hr/person	
Cases	**Inspection interval**	**P-F Interval**
Case-1	500 hrs	5000 hrs
Case-2	1000 hrs	5000 hrs
Case-3	2500 hrs	5000 hrs
Case-4	3000 hrs	5000 hrs

[2] Scenario-2:

Lubrication contamination due to random behaviour is dealt in scenario-2. The input to the analysis is provided in Table 2.

Table 2. Scenario-2 input

Model	Parameters	
Reliability Model	β=1, η=2160 hrs	
Downtime Rate	Rs.20,000	
Corrective Maintenance	Duration:10 Days; Crew cost:Rs.350/hr/person; Spare cost:Rs.7800	
Preventive Maintenance	N.A.	
Condition Monitoring	Duration:2hrs;Crew cost:Rs.1000/hr/person	
Cases	**Inspection interval**	**P-F Interval**
Case-1	300 hrs	1000 hrs
Case-2	500 hrs	1000 hrs
Case-3	700 hrs	1000 hrs

4. RESULTS AND DISCUSSION

Monte Carlo simulation (ReliaSoft's RCM++) provides a better understanding of analysing industrial reliability problems [5]. The same has been used in this study. Life cycle cost running the haul trucks for 10 years of the above two scenarios with various combinations of P-F interval and inspection window has been obtained. The results of Scenario-1 and Scenario-2 are presented in Table 3.

Table 3. Simulation results of different scenarios

Scenario	Maintenance Strategy	Case	Cost/operating hrs	Availability
1	Run to Failure	-	602.28	0.9705
	Preventive Maintenance	-	492.38	0.9755
	Condition Monitoring	1	1556.95	0.9638
		2	741.12	0.9638
		3	594.66	0.9709
		4	562.66	0.9724
2	Run to Failure	-	2069.68	0.9321
	Preventive Maintenance	-	-	-
	Condition monitoring	1	1646.20	0.9197

Scenario	Maintenance Strategy	Case	Cost/operating hrs	Availability
		2	1636.08	0.9198
		3	1632.56	0.9200

In scenario-1, it is evident that the preventive maintenance strategy becomes the lowest cost per hours of truck operation. Majority of the industrial practice of oil sampling interval is based on the OEM suggestion. But the real failure behaviour based on the data analysis clearly indicate as age based. Hence the condition monitoring interval of 500 hrs (i.e. lubrication monitoring) has not revealed fruitful results as expected. Also it reduced the truck availability.

In scenario-2, the lubrication contamination showed a random behaviour. There are several reasons, such as: introduction of the wrong oil, introduction of contaminants or contaminated oil, Human agency failures (dead-heading pumps on restart, not opening suction lines, not removing cleaning solvents, loosening machine parts, etc.). Here potential failure ‘P’ and P-F interval has observed as random. Hence the fixed interval of 500 hrs monitoring may not be an optimal option.

5. CONCLUSION

Application of condition monitoring technique without the knowledge of P-F interval did not provide the expected benefit. RCM theory states that on-condition inspections related to safety should be performed at an interval that will reduce the probability of experiencing a failure to an acceptable level. Several factors that determine the interval include: the acceptable probability of failure (dependent on the severity of the failure), the detection probability (dependent on the type of inspection) and the potential to functional failure (P-F) interval. However, the intervals for inspections that are not related to safety are cost-based decisions meant to maximize the useful life of the equipment. The costs of performing inspections (and any necessary corrective actions) are balanced out with the costs associated with allowing an item to fail. If the inspection interval is increased greatly, the inspection costs are lowered. However, more failures can be expected due to the smaller number of inspections. On the other hand, many inspections will most likely produce fewer failures, but the inspection costs are greatly increased. Therefore an optimal inspection interval that minimizes the total expected cost should be determined.

6. REFERENCES

[1] R. Shankar, *EPRI Fleet wide Monitoring Interest Group*, July 14-15, 2005, Charlotte, NC.

[2] International Atomic Energy Agency (2007) IAEA-TECDOC-1551: *Implementation strategies and tools for condition based maintenance at nuclear power plants*. Available at http://www-pub.iaea.org/MTCD/publications/PDF/te_1551_web.pdf accessed August 2014.

[3] *On-Condition Maintenance Using P-F Interval or Failure Detection Threshold (FDT)*, Reliability Hotwire, Issue 76, June 2007 [Accessed August 2014]. Available in http://www.weibull.com/hotwire/issue76/hottopics76.htm

[4] Daryl Mather, *Common Myths of P-F Intervals in Predictive Maintenance* [Accessed August 2014]. Available in http://reliabilitysuccess.blogspot.in/2013/06/common-myths-of-p-f-intervals-in.html

[5] Mohamed Altaf Jaffer, Muthukumar Udaiappan, Tarun Kumar Taisum and Saravanan Srinivasan, *Reliability Availability and Maintainability Study: A Business Perspective* International Journal of Performability Engineering, Vol. 9, No. 4, July 2013, pp. 445-454.

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