Considerations in Time to Failure Estimation™ Techniques

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Introduction

The concept of Time to Failure Estimation (TTFE™) is rooted in research performed in Motor Circuit Analysis (MCA) techniques. TTFE can also be applied to any technology or inspection that is repeatable or can be a measurement of condition. The ability to perform such an analysis will allow the user to provide risk-based decisions to management including some level of flexibility.

In this article, we will discuss one of the less rigorous methods of determining TTFE based upon the history of the equipment, the experience of the analyst and basic industrial engineering practices. We will also discuss how to handle the risk of failure should redundant systems be involved. This includes a methodology that is used for the change in the equipment between tests.

The Tools for TTFE

There are some basic mathematical tools needed for providing answers for the analysis. We have discussed some of these in the articles "Considerations for Planning and Scheduling," Parts 1 through 3, which are published on http://www.motordiagnostics.com/presentations.htm, but will be used in a different manner than for planning and scheduling. In the planning and scheduling scenario, the formulae were used with the Mean Time Between Failure (MTBF), Mean Time To Repair (MTTR) and their associated Failure and Repair Rates. In the case of TTFE, the formulae are used along with the Mean Time to Failure (MTTF) and Mean Time for Corrective Maintenance (M_{CT}) for fault detection and the combined use of the planning and TTFE methods for redundant systems.

The first important formulae to consider (Equation 1) are the MTTF and the Failure Rate (Equation 2) determined after detection.

Equation 1: Mean Time To Failure

$$MTTF = \left(\sum |Period\ Between\ Detection\ and\ Failure|\right)/n_f$$

Where the Period is the time between detection and failure and n_f is the number of samples of time after fault detection

Equation 2: Mean Time for Corrective Maintenance

$$M_{CT} = \left(\sum |Time\ for\ Repair|\right) / n_f$$

Where Time for Repair is total time repairing the faults in Equation 1 and n_f is the number of corrective maintenance tasks.

These formulae provide us with the basic information that is required. For instance, if we have the following results after contamination is detected (Table 1) on a winding and the motor progresses to a winding short:

Table 1: Example Number 1

n_f	**Period Between Detection and Failure (Weeks)**	**Time for Corrective Maintenance Tasks (Weeks)**
1	16	0.43
2	22	1.0
3	20	0.2
4	25	0.8
5	18	1.2
SUM =	**101**	**3.63**

Therefore, the MTTF would be (101 Weeks/5) = 20.2 Weeks and the M_{CT} would be 0.73 Weeks.

The next formula required is the Failure Rate (λ) which is simply 1 divided by the MTTF (Equation 3).

Equation 3: The Failure Rate

$$\lambda = 1 / MTTF$$

Finally, the next equation is the chance for failure over time, or the Modified Inherent Unavailability (Equation 4).

Equation 4: Modified Inherent Unavailability

$$F_V = 1 - (D)\left(e^{-t\lambda}\right)$$

Where t is the time being evaluated in the same measurement as the Failure Rate and D is the Severity Modifier.

The Severity Modifier

In order for an accurate determination of the Inherent Unavailability, a modification must be included based upon the severity of the fault detected. The simplest method for determining the D, for the simplified TTFE method, is to look at the slope of the change between the trended data prior to the point of detection and at the point of detection. The time between measurements must be measured in the same way as the testing frequency (ie: hours, days, weeks, etc.).

For instance, if a 12 week measurements of Fi (phase angle) from MCA increases from 74 to 78, and the Failure Rate is determined in weeks, then the slope would be 4/12 = 0.33. D would equal to one minus the slope and would be the multiplier times the Inherent Unavailability, in this case D = 0.67.

Understanding Series and Parallel Availability

While not used for TTFE, in most cases, an understanding of series and parallel reliability can be used, along with MTTF and M_{CT}, in order to evaluate the strategies around redundant equipment. The complete evaluation and discussion of Series and Parallel Reliability can be found in "Considerations of Planning and Scheduling Part 3."

Equation 5: The Reliability Function (Inherent Availability)

$$F = e^{-t\lambda}$$

Where t is the time being evaluated and λ is 1/MTBF

Equation 6: Series Availability

$$F_S = (F_1)(F_2)\ldots(F_n)$$

Equation 7: Parallel Availability (2 systems)

$$F_P = (F_A + F_B) - (F_A)(F_B)$$

Equation 8: Parallel Availability (3 or more identical systems)

$$F_P = 1 - (1 - F)^n$$

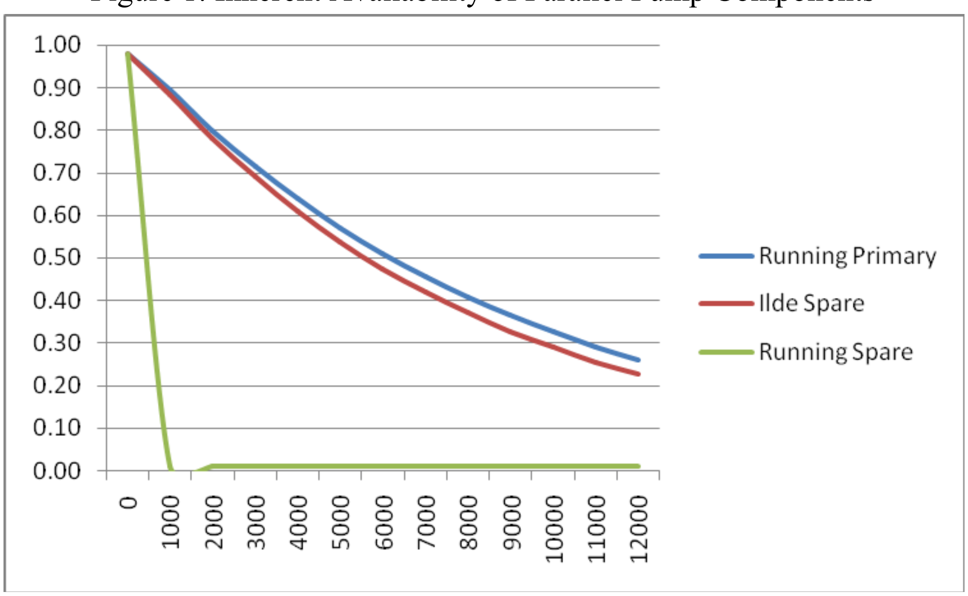
With this information, we can evaluate the impact of system redundancies. For the purpose of this paper, we will consider the following system consisting of a redundant pump system. A review of the history of the pumps reveals that the following occurs:

1. One pump is used as a ready-spare, the other runs constantly at 6,000 hours per year;
2. Over 5 years of operation, the seal has had to be replaced on the primary pump twice, the M_{CT} is determined as 96 hours, with the last failure at the end of year five;
3. Over the same period, the bearings have failed in the motor once at 22,000 hours with the same M_{CT};
4. Upon operation of the spare motor, the bearings became noisy at 13,500 hours due to false brinelling; and,
5. The spare motor shows a low insulation resistance level at 20,000 hours.

At a five year point, in the primary pump: The Failure Rate of the seal is 6.7×10^{-5} failures per hour; The Failure Rate of the bearings is 4.5×10^{-5} failures per hour. The spare has a bearing Failure Rate of 7.4×10^{-5} and a winding Failure Rate of 5.0×10^{-5} when sitting idle. The total corrective maintenance time (operating time of the spare) is 288 hours. This means that there is an operating failure rate of 6.9×10^{-3} with the other failure rates related to the idle time of the pump.

If evaluating the availability of each machine, the graph would look like that in Figure 1.

Figure 1: Inherent Availability of Parallel Pump Components



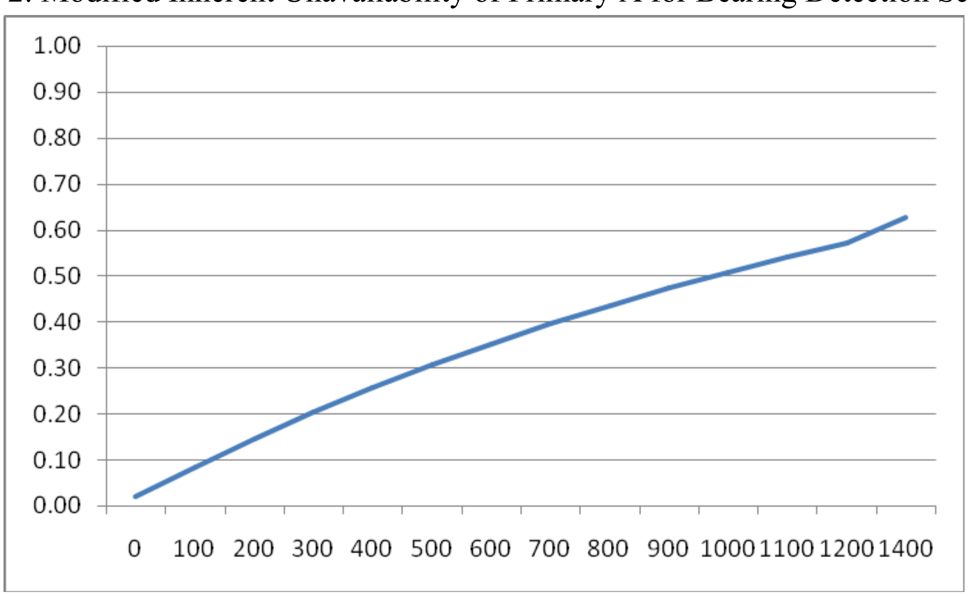
Now, the difference is that the times are based upon the actual time following each repair. Therefore, the representation that each of the lines show in the graph is not the actual representation of how they relate to each other, with the exception of when they were originally installed or if they failed and were repaired at the same time. Using the above information, we can actually model the availability of the complete system if we know the running hours for each one. Here is how we would evaluate a scenario: 5,000 hours operating time with the primary pump and 96 hours of operation with the spare that has been idle a total of 2,500 hours.

1. The availability of the primary is calculated by taking the availability of the Seal and the Bearing and multiplying them together, based upon 5,000 hours. In this case, the availability is 0.57 (57%).
2. The availability of the secondary is calculated at 2,500 hours as idle, as in step 1, and 96 hours for operation, they are both then multiplied together with a resulting availability of 0.37 (37%).
3. Both are now considered as a parallel system in which (0.57 + 0.37) – (0.57)(0.37) = 0.73 or 73%.

If we now consider them both to be primaries, switching at the beginning of each week, then the evaluation will be based upon both pumps having the same failure rate as the primary. The total linear time for the evaluation is about 5,000 hours or 10 months.

If we now take the same scenario, where Primary A has been alternating and running for 5,000 hours and Primary B has been alternating and running for 2,500 hours since the last repair, the availability at that time (20 months for Primary A and 10 months for Primary B) will be 0.57 for Primary A and 0.76 for Primary B resulting in a system reliability of (0.57 + 0.76) – (0.57)(0.76) = 0.90 or 90%.

Figure 2: Modified Inherent Unavailability of Primary A for Bearing Detection Scenario



In the next scenario, we use the alternating pump system (Primary A and B) and perform inspections and testing on the bearings and seals. We know that vibration should be performed every six weeks in order to detect bearing failure and a monthly seal inspection in which a slight leak indicates failure in 2 months. In the above scenarios, the bearing in Primary A shows a signature with a slope of 0.02 with a result of D = 0.98 and the MTTF of 1440 hours (12 weeks times 120 hours). At that point, the Primary B has an availability of 0.76 or 76% while Primary A is now on a new time clock with an availability curve as shown in Figure 2. With this information, a decision can be made as to the optimal time to perform corrective maintenance, which will have a minimal impact on the Availability of the system.

Conclusion

The concepts of Time to Failure Estimation (TTFE) can be used to provide an estimate of the time to failure when a good history and proper testing frequencies are observed. By understanding the MTTF, the Modified Inherent Unavailability can be determined. Points can be identified to show a graph or to calculate the unavailability at a specific time.

The TTFE can be used along with the WFC/DFM concept and planned failure methods outlined in "Considerations for Planning and Scheduling" Parts 1, 2 and 3. Each of these tools can be used together to improve the maintenance scheduling and planning decision processes.

Bibliography

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