uptime®
dec/jan14
for maintenance reliability and asset management professionals
ISO 55000
It's All About the Value
uptimemagazine.com

Reliability Engineering for Maintenance

Re reliability engineering

Analysis of a Mechanical Seal Failure

Umeet Bhachu

Weibull analysis is an important statistical tool in the realm of reliability engineering. It helps in the modeling of increasing, decreasing and constant failure rates.

In maintenance organizations where time and cost of repair are crucial elements, it is of paramount importance for a reliability engineer to determine swiftly and accurately the failure modes and root causes underlying a particular issue to avoid further machinery breakdowns. This translates into cost savings because a pro-active approach, rather than a reactive maintenance attitude, forms a basis for implementing advanced programs, such as reliability centered maintenance (RCM), in the operating organization.

It is prudent, however, to assess the data (in our case time between failure) for randomness and distribution prior to performing such an analysis. Data following a renewal process is independent and identically distributed (iid), which means the data arises from a single population. If the failure data does not follow a renewal process, the Weibull analysis leads to incorrect predictions about the nature of machine reliability. This often causes inappropriate action on the part of maintenance, resulting in costly and unwarranted repairs. Improving or degrading trends in reliability leads to failure data that does not follow a renewal process. There are various methods, both graphical and analytical, to assess this data before inputting it for a Weibull analysis. We will use one such method called the Laplace trend test.

Consider the case of an API 610-compliant centrifugal pump, one of the most common and critical pieces of rotating machinery in a refinery. Mechanical seal failures are often the initial reason such pumps are brought down for maintenance or repair. Usually, this is not because of an incorrect seal design selection or a faulty seal, but simply because of the way the mechanical seal is operated. Mechanical seals are one of the weakest links in pumps and turbomachines. They fail due to vibration, misalignment, changes in process conditions, incorrect settings on the seal flush plans and various other reasons. Weibull analysis, when properly used in this context, helps the reliability engineer determine and qualify the failure mode without having to stop the machine or wait for the next failure to happen. By using the past failure and maintenance history of the machine logged in the plant's computerized maintenance management system (CMMS) to calculate Weibull parameters, such as the shape parameter Beta (β), Weibull can help in determining why the failure occurs.

As a related case, consider a charge pump in a hydrocarbon service, pumping volatile gas oil as the finished product. The pump has a pressurized dual mechanical seal with an API Plan 02/53B. The normal pumping temperature is 85 degrees C, with a maximum temperature of 120 degrees C. The seal experienced multiple failures in the past that have subsequently caused the unit to shut down for seal replacement on both the inboard and outboard ends of this critical pump. Thorough scans of the CMMS system revealed various work order (W/O) and seal failure histories that helped in determining the time to failure (TTF) during each event. TTF provides the input for analysis that will then help to understand and draw meaningful conclusions on why the seal is failing.

We first use the Laplace trend test to determine if the data is suitable for Weibull analysis. Detailed information on computing and using Laplace testing can be found in the various references provided at the end of this article.

$$L = \frac{\sum_{i=1}^{n}(t_i - T/2)}{T\sqrt{n/12}}$$

Where:

T = Total observation time

n = Number of failures, if the last failure is at the end of the observation time (tn = T), then use n-1 in all places having n.

ti = Time from a common start point to each failure event.

Using the Laplace equation data yields the following values:

	Laplace Score (L)	Observation Period (T) (dd/mm/yy)	Failures (n)
Before Upgrade	-0.14	12/01/10 – 09/18/11	4
After Upgrade	0.42	04/10/11 – 06/06/13	3

When the score is greater than +1.96 or less then -1.96, we are 95 percent confident that there is a statistically significant upward or downward trend. This disqualifies the data from being iid and coming from a single population, leading to a non-qualification from further analysis using Weibull.

However, in our case, the Laplace score is closer to 0, showing that no discernible upward or downward trend exists and the data is essentially random failures qualifying it for the Weibull analysis. So let us now proceed to performing a Weibull analysis on our failure data.

Weibull distribution can be created for any data and is flexible in modeling a wide range of data. In our example, we use only failure data to model this distribution without incorporating non-failure (also called censored or suspended) data. While the inclusion of suspended data provides a more accurate distribution, we chose to ignore it due to the quality and accuracy of the data from the CMMS. Table 1 shows the filtered data and the time to failure for each of the failure events. The red line item shows seal upgrade from a different seal vendor performed during April 2011.

WO Number	Order Date	Work Order Description	WO Type	Time to Failure (Hrs)
XXX	1/12/2010	REPLACE SEAL	4	
XXX	9/29/2010	REPLACE ALL SEALS 2 BEARINGS	3	6240:00:00
XXX	11/11/2010	NEED TO TROUBLESHOOT AND REPAIR SEAL	3	1032:00:00
XXX	11/22/2010	REPLACE SEALS	4	264:00:00
XXX	9/18/2011	REPAIR PUMP INBOARD SEAL	3	7200:00:00
XXX	11/4/2011	INSTALL UPGRADED MECH SEALS (Diff Seal Vendor)	3	
XXX	10/4/2012	LEAKING MECANICAL SEAL	2	8040:00:00
XXX	10/12/2012	UPGRADE SPARE MECHANICAL SEAL	3	192:00:00
XXX	11/6/2012	NDE PRIMARY SEAL S LEA	3	600:00:00

Table 1 - CMMS data on W/O and failure histories

In order to plot the Weibull distribution, a free online service called statgraphics (www.statgraphicssoftware.net/SGLive.aspx) was used with the TTF derived from Table 1. Rank regression estimation was used for plotting the distribution.

In reliability engineering, the bathtub curve is used to represent failure rates with passing time. The shape parameter, also called Beta (β), helps us in understanding if the failure rate is increasing (wear out conditions) where $\beta>1$, constant (random failures) where $\beta=1$, or decreasing (infant mortality) where $\beta<1$.

In Figure 1, prior to the upgrade, and Figure 2, after the upgrade, it is seen that β is less than 1, pointing to the fact that these seals are failing in the infant mortality zone. It should be noted that we have a small sample size (failures) for both situations. However, it has been observed by Dr. Robert B. Abernethy, a leading expert in Weibull statistics, that the Weibull method works well for performing engineering analysis, even with such small sample sizes.

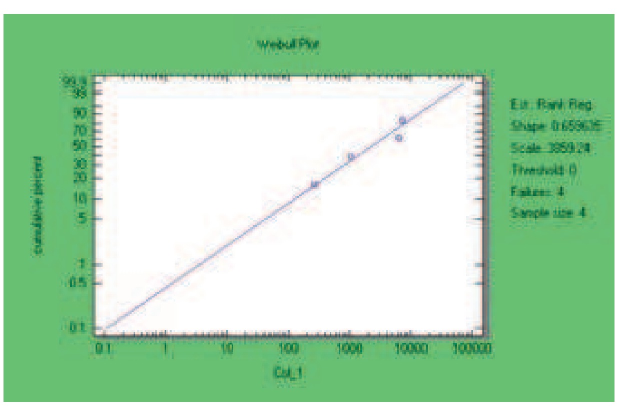


Figure 1: Weibull plot showing failures prior to the mechanical seal upgrade, $\beta<1$, $\eta=3859.24$, p value of 0.96808 and a sample size of 4

It is interesting to note that despite the upgrade on the mechanical seal, the failure pattern was not significantly altered. The seal was unable to clear the infant mortality zone successfully. One of the reasons leading to infant mortality in mechanical seals is connected to the incorrect design and application of the seal. When a mechanical seal is incorrectly designed or selected for a given application, there seems to be an increase in the number of failure incidents during the early life of the seal. The Weibull plot helps draw our attention to the fact that careful consideration needs to be implemented when selecting the right seal design for the application.

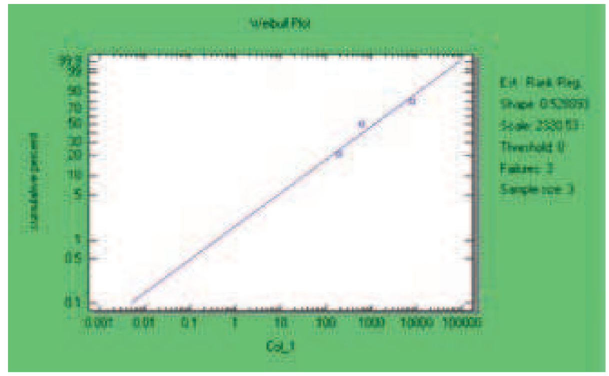


Figure 2: Weibull plot showing failures after the mechanical seal upgrade, $\beta<1$, $\eta=2320.53$, p value of 0.92837 and a sample size of 3

Further assessing the probability of failure for these seals given the two-parameter Weibull equation:

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

Where:

F(t) = Probability of failure at time (t)

η = Scale parameter or characteristic life, this gives the time when 63.2 percent of the parts are expected to fail

β = Shape parameter or the slope, as discussed previously

t = Time period selected for calculating probability of failure (hrs)

e = Exponential function

Results of calculations using this equation are tabulated in Table 2.

From Table 2, the reliability of the seal actually dropped further after performing the seal upgrade by the new vendor. This reflects the fact that the upgrade did not have the desired effect on improving seal reliability in this particular application.

Based on the root cause analysis performed on these mechanical seals (both prior and after the upgrade), we have seen them running at higher temperatures and causing face distortion and other issues leading to early

	Beta	Eta (hrs)
Before seal upgrade	0.659635	3859.24
After seal upgrade	0.528693	2320.53

Before seal upgrade		
Time (hr)	Survival Probability	Reliability (%)
500	0.2286	77.1246
1000	0.3366	66.3438
1500	0.4150	58.5002
2000	0.4770	52.2999
3000	0.5713	42.8726
5000	0.6946	30.5354
10000	0.8465	15.3516
100000	0.9998	0.0192

After seal upgrade		
Time (hr)	Survival Probability	Reliability (%)
500	0.3586	0.6414
1000	0.4731	0.5269
1500	0.5479	0.4521
2000	0.6032	0.3968
3000	0.6819	0.3181
5000	0.7770	0.2230
10000	0.8853	0.1147
100000	0.9993	0.0007

Table 2 - Seal reliability values before and after upgrades

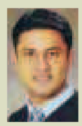
failures. The higher running temperatures were attributed to cooling limitations during operation, resulting from the inability of the selected seal flush plan to cool the seal sufficiently in conjunction with the seal design. The initial seal design selected for the pump prior to upgrade was not an effective design, particularly in regards to the seal face orientation for this application. Weibull modeling is a good tool in predicting reliability and determining gross failure modes for many simple and complex engineering and maintenance related equipment breakdowns. The distribution finds prominent use in implementing maintenance strategies in many world-class organizations by quantifying failures. When failures are random (β=1), a good condition monitoring program coupled with effective preventive maintenance practices help prolong equipment life. When failures are in the infant mortality zone (β<1), as we have seen with the mechanical seals, then careful attention needs to be given to the design, fabrication, operating procedures etc. And finally, when failures belong to the wear out zone (β>1), then a decision has to be made to either run the equipment to failure or develop a proper program for maintenance and overhaul of such equipment, which would include availability of spares as required. It is noteworthy that Weibull modeling information also acts as a valuable asset in project engineering by giving the project team important information during design and selection of machinery based on past equipment performance.

Plenty of papers dealing with Weibull do not stress the importance of pre-qualification testing of the data before performing analysis.

This article demonstrates the importance of using a pre-qualification test, such as Laplace, prior to performing a Weibull analysis. Negligence in performing a pre-qualification of the data can lead to incorrect analysis, subsequently causing costly and unwarranted repairs. Plenty of papers dealing with Weibull do not stress the importance of pre-qualification testing of the data before performing analysis. Detailed root cause analysis should have been the key focus after the initial failures on the first seal. However, in the absence of this approach, the second seal upgrade was also found ineffective due to potential incorrect seal/elastomer design and selection, consequently resulting in repeated failures in a short span. The second upgraded seal failed again in the infant mortality zone due to the similar reasons that caused the first seal to fail. The Weibull method is not the be-all and end-all solution to maintenance reliability problems. However, it is but one tool, and an important tool, in complementing other analysis and empirical methods used to troubleshoot and proactively ensure a higher uptime for the plant.

References

1. Maintenance Technology. *Reliability Activities and Their Impact on Weibull Shapes.* http://uptime4.me/maintenance-tech
2. www.statgraphicssoftware.net/SGLive.aspx
3. The LaPlace Test - http://uptime4.me/nasa-gov
4. Trindade, David C. Confirming Trends in Repairable System Reliability. http://uptime4.me/trends-pdf



Umeet Bhachu, P.Eng, is a registered engineer in the province of Alberta and is working as a Reliability/Rotating Equipment Engineer for the Canadian Natural Resources Ltd, Canada. He is presently based out of Krakow, Poland, with the CNRL major projects division. His work with CNRL involves reliability simulations, selection and technical assessment of rotating and turbo-machinery.