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Reliability Analysis in the Formulating Of Maintenance Program

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Abstract: *Over the years, modern maintenance cost has gradually built up, often frighteningly outpacing material or labor costs in cost of production. This is however brought about the need to develop new maintenance strategies that can effectively reduce the cost, while at the same time adequately maintain the integrity of the equipment, this work takes a look at various concepts of reliability such as Fault Tree Analysis (FTA). Failure Mode and Effect Analysis* ***(FMAE),*** *Reliability Centered Maintenance (RCM), the usefulness of data associated concepts such as Mean- Time- To- Failure (MTTF), instantaneous failure rate, lifetime of components and others in uncovering the root causes of the failure associated with an Ingersoll- Rand compressor.*
Keywords: *Reliabilty, Maintenance, cost, Valve, Failure rate.*

Nomenclature

MTBF	Mean Time Between Failure	
FMEA	Failure Mode and Effect Analysis	
MTTF	Mean Time To Failure	
RCM	Reliability Centered Maintenace	
FTA	Fault Tree Analysis	

Failure Mode and Effect Analysis
MTTF Mean Time to Failure

I. Introduction

Reliability engineering is engineering that emphasizes dependability in the lifecycle management of a product. Dependability, or reliability, describes the ability of a system or component to function under stated conditions for a specified period of time.[1] A reliability program plan is used to document exactly what "best practices" (tasks, methods, **tools**, analysis and tests) are required for a particular (sub) system, as well as clarify customer requirements for reliability assessment. For large scale, complex systems, the reliability program plan should be a separate document. Resource determination for manpower and budgets for testing and other tasks is critical for a successful program. In general, the amount of work required for an effective program for complex systems is large.[2]

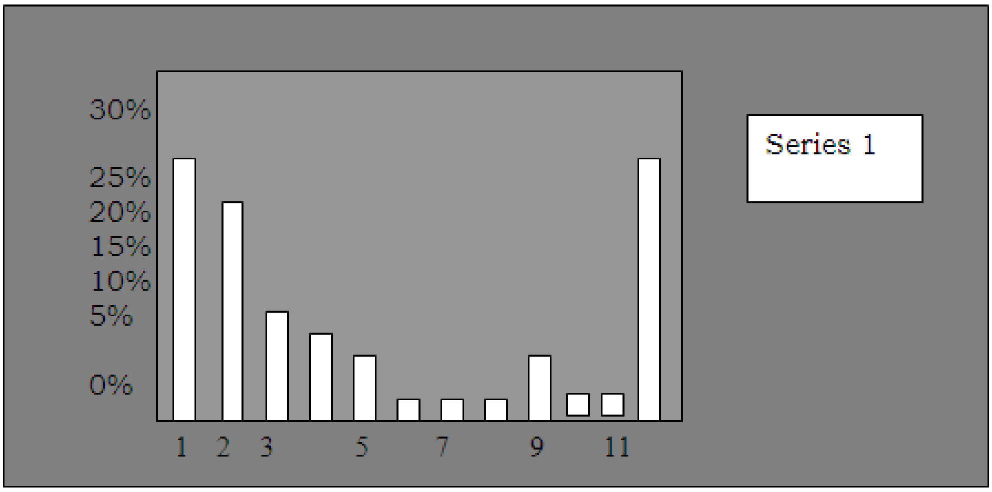
"Reliability is after all, engineering in its most practical form" as once stated by James R. Schlesinger, Former US Secretary of Defense.[3] Many engineering techniques are used in reliability engineering, such as reliability hazard analysis, failure mode and effects analysis (FMEA), failure modes, mechanisms, and effects analysis (FMMEA) fault tree analysis (FTA), material stress and wear calculations, fatigue and creep analysis, finite element analysis, reliability prediction, thermal (stress) analysis. Furthermore, reliability design requirements should drive a (system or part) design to incorporate features that prevent failures from occurring or limit consequences from failure in the first place! Not only to make some predictions, this could potentially distract the engineering effort to a kind of accounting work. A design requirement should be so precise enough so that a designer can "design to" it and can also prove -through analysis or testing- that the requirement has been achieved, and if possible within some a stated confidence. Any type of reliability requirement should be detailed and could be derived from failure analysis (Finite Element Stress and Fatigue analysis, Reliability Hazard Analysis, FTA, FMEA, Human Factor analysis, Functional Hazard Analysis, etc.) or other any type of reliability testing. Also, requirements are needed for verification tests e.g. required overload loads (or stresses) and test time needed. To derive these requirements in an effective manner, a systems engineering based risk assessment and mitigation logic should be used. These practical design requirements shall drive the design and not only be used for verification purposes. These requirements (often design constraints) are in this way derived from failure analysis or preliminary tests. Understanding of this difference with only pure quantitative requirement specification (e.g. Failure Rate / MTBF setting) is paramount in the development of successful (complex) systems.[4] However, humans are also very good in detection of (the same) failures, correction of failures and improvising when abnormal situations occur. However, humans are also very good in detection of (the same) failures, correction of failures and improvising when abnormal situations occur The policy that human actions should be completely ruled out of any design and production process to improve reliability may not be effective therefore. Some tasks are better performed by humans and some are better performed by machines. [5]

II. Reliability Analysis

Primarily, a maintenance programme specifically aims at eliminating or reducing to the bear rest minimum, consequences of failures and thereby improve availability of the asset. Beside this, it also aims at reducing the cost of maintenance, time spent on maintenance or downtime by effectively planning the maintenance tasks. Before going further, it is worth noting the asset (compressor) has being placed under a maintenance scheduled that is presently being utilized by Dresser- Rand team of engineers in ensuring asset operational readiness. Therefore it will be only be realistic that whatever schedule or programme that is developed should be an improvement on the effectiveness of the present methods or means by which maintenance tasks are planned and executed. This can only be done by carrying out a careful study of the peculiarity of the failures associated with the system (compression process), operating in its present conditions. As a result, the process was segmented into 12 sections and a statistical count of failures associated or emanating with/from section was done. The result is presented in table 1.1. From the table, it become obvious that the predominant failures will be associated with the compressor valves which account for about 24% and 27% of the total failure recorded over a period of eighteen (18) months. Next is the failure associated with the cylinder packing which account for between 23% to 24% of compression process failure. This is followed by the process cooler with 9% to 10% of the compression process failure. However, it does not take into consideration the severity of components or subsystem failure. While it is obvious that the valve failure will contribute significantly to downtime as well as cost of maintenance in the overall consideration. Failure associated with components such as crankshaft no doubt are of greater implication.

Table 1.1: Components/ system failures and the rate of occurrence in percentage

Component/ system	**% of failure**	**Component /system**	**% of failure**
Valve (1)	24-28%	Conn . Rod (7)	2.5-3.0%
Packing (2)	23-24%	Main Bearing (8)	2.0-3.0%
Process cooler (3)	9-10%	Scrapper Ring (9)	4-5%
Piston rod/ rings (4)	6-8%	Relief Valves (10)	2.0-3,0%
Separators (5)	5.5 -7%	Mainframe lubricator (11)	2.5-3.0%
Cylinder lubricator (6)	2.0-3.0%	Other (12)	17.5-3%



Did you plot the bar chat or copy and paste? And what is on the horizoantal?
Figure 4.1a Bar chart showing the difference rate of components failure.

From the above statistic, it is obvious that a greater parts of downtime is as a result of valve failure, followed by the packing and the process cooler. The table shows that valves and packing failure combined account for about 47% to 56% of the total failure encountered in the compressor. The above do not however take into consideration, the severity of components or subsystem failure because some components or subsystem can significantly affect asset integrity, cost or repair and the associated downtime more than others. Valve failure though far less likely to occur, when compared to valve, will be of greater implication.

III. Data Analysis

The objectives of this analysis is to utilize mathematical models in establishing the optimum time for which decision could be taken to affect restoration/ discard maintenance tasks or the commencement of on-condition monitoring tasks.

Variables, which will be determined, will include the Mean- Time- Between- Failure (MTBF), the failure probability, instantaneous failure rate, and others. However, this cannot be done for all components that make up the asset (lngersoll –Rand compressor) for obvious reasons. Therefore, two components –valves and packing- will be analyzed using the quantitative analysis because of their significant contribution to the overall failure of the compressor.

The cumulative frequency table is presented in table 4.3 and in figure 1.3 a plot of the cumulative against the lifetime of valves was done.

Table 1.2 Cumulative frequency table with class mark.

Mark range	Class mark	Frequency (%)	Cum. frequency (%)
1400-1600	1500	4.2	4.2
1600-1800	1700	6.4	10.6
1800-1200	1900	12.8	23.4
2000-2200	2100	19.1	42.5
2200-2400	2300	21.3	63.8
2400-2600	2500	19.1	82.9
2600-2800	2700	10.6	93.5
2800-3000	2900	4.2	97.7
3000-3200	3100	2.1	100

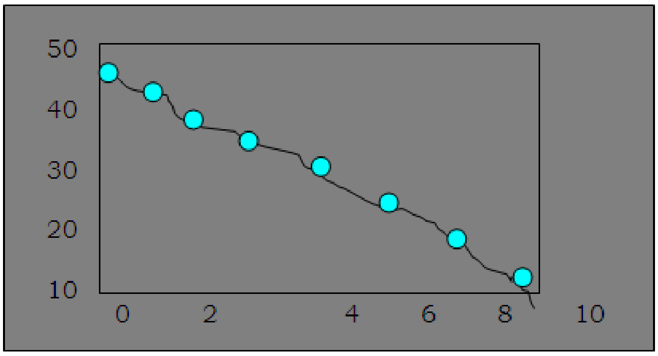


Figure 1.3 showing a plot of the number of survivors of valves at the end of each period.

If this is plotted by you, I suggest you indicate what those values indicates both on the vertical and horizontal axis

Weibull Reliability Calculation

From the cumulative frequency distribution curve of lifetime of valves, the following data were generated using random numbers.

130 1590 2230 2600 2915 3406 2980

To obtain the cumulative failure function F(t), the mathematical expression below was utilized

β =3.8

η = 2660

The location parameter is assumed to be zero since the origin of time is known.

The Mean-Time- To failure (MTBF) for the valve is found thus:

$$MTBF = \int R(t)dt = \eta\tau\{1x1/\beta\}$$

Therefore

$$MTBF = \int 2600 = \tau\{1x1/3.8\}$$

MTBF = 2600F (1.263)

Where ^ denotes the Gamma function. Using the Gamma table and interpolating between 1.2 and 1.3 the above become:

= 2600x 0.91

= 2420.6 hours, or 3/13 months

Using the formulas below to calculate the instantaneous failure rate and Reliability at three different points of lifetimes (t=1590, 2240, 3199), the values obtained are presented in table 4.6.

$$\lambda(1) = f_{(1)} / R_{(t)}\ \beta / \eta\{[t-\lambda]/\eta\}^{\beta-1}$$

R(t)= 1-F(t) = exp. $\{-[(t-\gamma)/\eta\}^{\beta}]$

Table 1.4: Showing reliability, R(t) and the instantaneous failure rate λ(t).

Lifetime (hrs)	Reliability, R(t)	Instantaneous failure Rate λ(t)	Main- time – to failure MTBF
1590	0.87	0.00034	2420 Hours
2240	0.6	0.00088	Or
3199	0.133	0.0024	3 1/3 months

What this means is that lifetime beyond 2240 or approximately three (3) months, reliability of valves drop drastically that is warrant restoration or discard tasks. Failure rate begins to increase rapidly as well.

Packing

The same method was employed in generating data for the cylinder packing. The data generated are presented below;

2244 1960 1800 1240 2390 1790
1690
1090 1620 2085 2300 1900 1400 904
1830 2280 1580 1715 1330 1764
1760
2489 2190 1614 1414 1880 1640
1610
2040 2660 1920 2220 2450 1670
1490
1530 2002 2160 1564 1214 1390
1742
1470 1504 1960 1300 1230 1840

These data presented in a tabular form with a class interval of 200 (hrs) in table 1.7

Table 1.5: Showing frequency distribution of lifetime packing

Range mark (hrs)	Class Mark (hrs)	Number of occurrence	Frequency of occurrence (%)
00.00-1300	1200	6	11.54%
1300-1500	1400	8	15.37%
1500-1700	1600	1118	21.15%
1700-1900	1800	9	17.30%
100-2100	2000	7	13.46%
2100-2300	2200	5	9.6%
2300-2500	2400	4	7.7%
2500-2700	2600	2	3.8%

The above is represented in a frequency distributed curve as shown below.

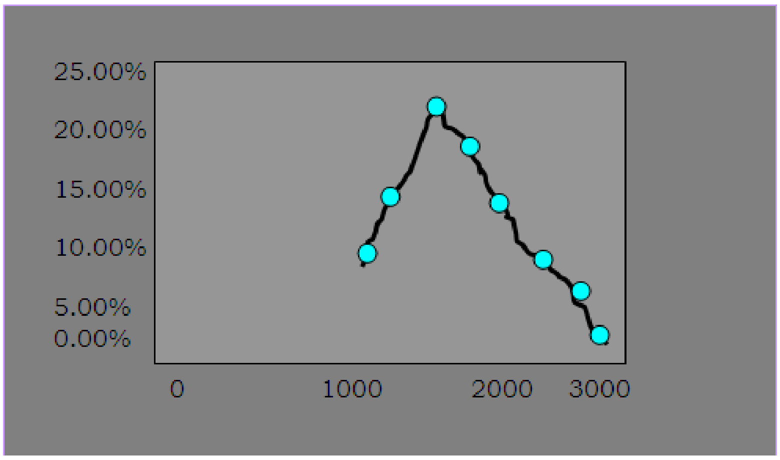


Figure 1.5, showing the frequency distribution curve of the lifetime of packing against frequency of occurrence.

A cumulative frequency table and a table showing the number of survivor at the end of each period was also generated from the data and these tables are shown below.

Range mark	Class Mark	Number of Occurrence	Frequency of Occurrence (%)	Cumulative frequency (%)
00.00-1300	1200	6	11.54%	11.54%
1300-1500	1400	8	15.38%	2.12%
1500-1700	1600	11	21.15%	48.27%
1700-1900	1800	9	17.30%	65.57%
1900-2100	2000	7	13.46%	79.02%
2100-2300	2200	5	9.6%	88.63%
2300-2500	2400	4	7.7%	96.33%
2500-2700	2600	2	3.8%	100%

The cumulative frequencies was plotted in the y-axis against the lifetime of packing on the x-axis to produce a cumulative frequency distribution curve. This is shown below.

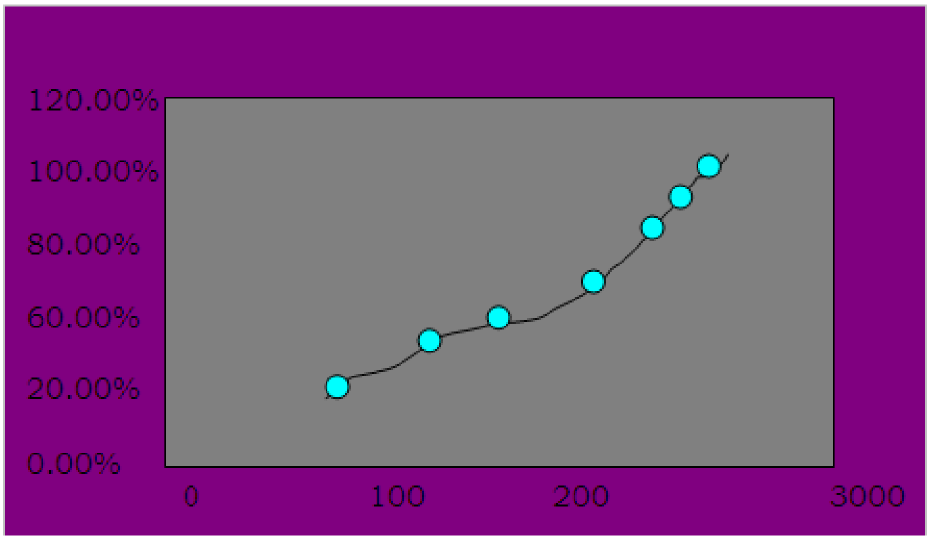


Figure 1.6 showing the cumulative frequency curve of the lifetime of packing

Table 1.7: Showing the numbers of survivor at the end of period

Mark Range	Class range	Number of survival
00.00-1300	1200	46
1300-1500	140-0	38
1500-1700	1600	27
1500-1700	1600	27
1700-1900	1800	17
1900-2100	2000	11
2100-2300	2200	6
2300-2500	2400	2
250002700	2600	0

A plot of this was done as shown below

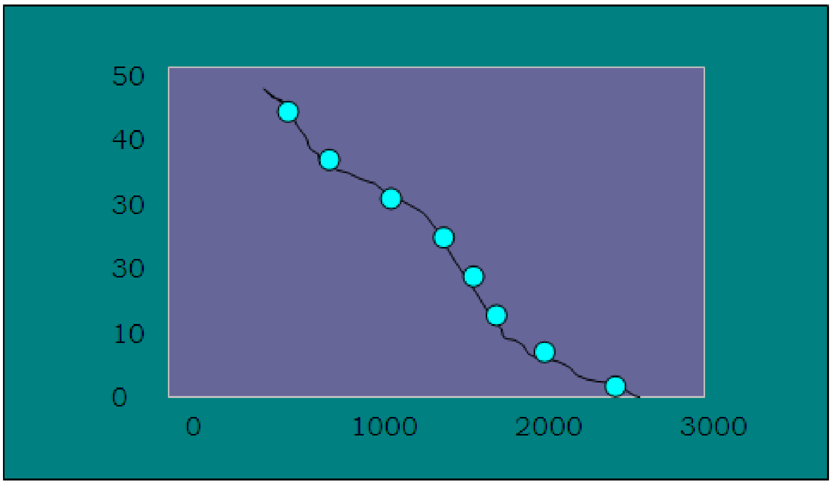


Figure 1.7 showing the number of survivors of packing at the end of period

Using the cumulative frequency distribution curve of the lifetime of packing, the following data were generated (Monte- Carol).

1130 1140 1160 1360 1470 1884
1920
2079 2340

To obtain the cumulative failure function F (t), the mathematical expression below was utilized

Where

n= number of data

β= 3.28

η= 1860

γ is assumed to be zero since the origin of time is known.

The Mean- Time- Between – Failure (MTBF) is found thus:

$$MTBF \quad \int R_{(t)}\, dt \ \ \eta \text{^}[1x1/\beta]$$

$$MTBF \ \ 1860\text{^}[1x1/3.28]$$

MTBF = 1669.35 HRS

Or $2^{1/2}$ months

A computation of the reliability and the instantaneous failure rate at three different points was also done and the results is presented in table 1.1. The mathematical expression below was used for computation of the reliability values and the instantaneous failure rate values.

R(t) = 1 F(t) = exp { -1(t-γ)/η]β}

and

$\lambda = f_{(1)}\ R_{(1)} = \{\ \beta/\eta\ [\ (t-\gamma)/\eta]^{\beta-1}\}$

Table 1.8: Present the result of the computation using the above formulas.

Lifetime (hrs)	Reliability, R(t)	Instantaneous failure Rate λ(t)	Main- time – to failure MTBF
1140	0.82	0.00025/hr	1999.35 Hrs Or 2 1/3 months
1810	0.4	0.0017/hr	
2340	0.12	0.003/hr	

What this means is that it will be appropriate to commence maintenance tasks at 16669.35 hours, precisely two months after the packing assembly has been in service.

The RCM Process Analysis

The analysis in this stage will utilize the reliability' centred maintenance information worksheet, decision diagram and Decision worksheet.

The analysis will be carried out on all components and subsystem of the compressor and its process. All feasible failures will be considered in an attempt to ensure that present and anticipated failures modes and effects are look into. This will ultimately lead to drawing up of the maintenance schedule or programme.

IV. Conclusion and Recommendation

Conclusion

All maintenance program or schedules are basically designed with the intention of mitigating the failure effects or consequences of any component or asset or if possible, preventing the consequences of such functional failure. They are geared towards anticipating future failure occurrence with aim of preventing them. In the early parts of this report, a great number of assets failure were attributed to failure pattern F which account for more than two- third of the total failure of an asset. Therefore, in formulating a maintenance program, the basic problems that brings about this failure pattern (infant mortality) needs special attention.

In the case of the asset under review (an Ingersoll- Rand compressor), six major causes of infant mortality will be considered. These causes include:

1. Incorrect installation
2. Incorrect commissioning
3. Incorrect operation
4. Unnecessary routine maintenance
5. Excessive invasive maintenance
6. Bad workmanship

Incorrect installation and correct commissioning could certainly have brought about some functional probably in areas with high failure frequency such as package and valves. Besides, instances have been recorded where a Crosshead shoe only lasted for two (2) hours and another for three (3) hours. While in the final program (schedule), tasks that deal with these factors were not explicitly stated, nevertheless, the were considered at the analytical stage of formulating the program. It is expected that during the process, it would be impressed on those concerned in order to reduce/ eliminate failures that come about as a result of this factors.

A prominent failures characteristic of the compressors at the Pakchil gas plant is Crankshaft failure. Prominent in the sense that seems unique coupled with its huge cost. After carefully considering all possible causes, incorrect operating (loading and unloading) was picked as the most likely reason for the Crankshaft failure. The compressor is expected to coast to a stop but in situation where backpressure builds up within the cylinder, this is ultimately transmitted as cyclical stress to the Crankshaft that leads to bending.

A great deal of failure could result from routine maintenance tasks that are unnecessary, or unnecessarily invasive. They tend to disrupt or disturb the equipment and so needlessly by upset basically stable systems. The maintenance program (schedule) avoids this by employing condition- monitoring tasks that temper less with the compressor process or components. This is done with the view to also reduce cost of maintenance while at the same time increase asset availability by reducing downtime of asset (compressor).

The work favours condition- monitoring tasks as against scheduled overhauls. The approach is to estimate the likely lifetime of components whose failure will stop the system without reference to historical data. The objectives is to:

1. Increase asset availability and thereby reduce the number of trains needed to supply the needs of a service
2. Avoid- in- service failures with the potential for service disruption.
3. Improve assets (compressor) integrity with reference to environmental and safety considerations.

Based workmanship no doubt is a problem also just like the other causes of infant mortality (poor design and poor manufactures) this can only be adequately tackled by comprehensive management policy.

Recommendations

While the maintenance program is meant to provide means by which failure that are about to occur, are occurring or have occurred are detected, and thereby prevent or mitigate their consequences. There are some gray in the process that cannot be taken care of through these means. Suggestions are therefore proffered as a means of reducing the cost of maintenance.

1. At the Pakchil plant the area dehydrating (Glycol) unit, has been out of operation for quite sometime. While historical data cannot be provided to buttress ones observation. It is true that the failure of this unit has considerably contributed to the high failure rate of cylinder(s) valves and packing. Therefore, there is an urgent need to put it back in serve and this will help to reduce cost of maintenance in the long term.
2. A prominent failure at the Pakchil Integrated service limited plant is crankshaft failure. Out of the four compressor units a total of three has experienced crankshaft failure. At the analytical stage, the compressor (s) foundation was ruled out because some compressor has experienced crankshaft failure after being replaced. The only cause that this failure.

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