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"A STUDY ON RELIABILITY, VALIDATION OF BATH TUB CURVE AND CONCEPT OF MADHAB'S HAT CURVE OF RELIABILITY"

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ABSTRACT

"Zero defect" – one of the basic demands of the current generation. Everybody wants a defect free and reliable product. On the other hand this is a big challenge for the manufacturers to fulfill the demand of the customers. But to survive in this competitive globalization era an industry has to be excellent in all the aspects to make a qualitative product with a cost effective manner. To maintain high Reliability and least failures of equipments is a good example of Global Manufacturing Practice. Equally it is the biggest challenge for the engineers/managers to maintain a culture of "zero defect" and 100% reliability of the equipments in any Industry. The first step to achieve the target is to understand the basic concept of reliability, then to analyze and find a way. The reliability engineers are working day and night to improve the way forward. This study is a small step towards a big mission of "Zero Defect" the way the world is moving on. In this thesis a set of industrial fans used in a particular cement plant has been considered for the reliability study. As we know industrial process fans used in different industries like cement plants, steel plants, sponge iron plants, refractory plants etc are considered as important equipments. Any failure or down time associated with the process fans leads to the plant stoppage and production loss. In addition to this the maintenance cost also increases. So it is important to analyze the situation and actions should be taken to prevent the unwanted failures of the equipments in turn improve the reliability. In the first phase of the study, the Validity of Bath Tub Curve has been checked by the help of failure data analysis. In the second phase of the study, the concept of Hat curve of Reliability has been established by the help of MINITAB software, using the equipment failure data and reliability analysis. This would be known as Madhab's Hat Curve of Reliability. In the third phase of the study various methods of reliability improvement has been discussed briefly.

1. INTRODUCTION

1.1 Reliability:

The reputation of a company is very closely related to the quality of its products. Reliability is a major factor for determining the quality. The best quality with high reliability is must for any product in this competitive age. In the other hand it is also important for maintenance engineers in any industry to maintain the equipments availability to a highest level to achieve uninterrupted manufacturing with high OEE (Overall Equipment Effectiveness).To achieve high availability of the equipments the number of failures should be as less as possible.

In other terms MTBF (Mean Time Between Failures) should be as high as possible which in turn yields a higher reliability.

The overall manufacturing cost of a product including product liability cost is also highly dependent on the product reliability. If any equipment fails intermittently and not performs as per the warranty terms and conditions the repair cost or rework cost is just like an overburden for any manufacturer. It increases the overall Cost due to Poor Quality which is also known as Cost of Poor Quality (COPQ).It also spoils the brand image if it happens with more customers frequently. Reliability analysis is an important tool which will be helpful to take corrective actions. It is just like a customer satisfaction study with more concentration on Reliability. The cost of failure or poor quality must be taken into consideration with the manufacturing cost to find out the overall manufacturing cost of the product. Then a calculated call must be taken to upgrade the design and manufacturing method to a higher level.

Definition: We can get a number of definitions of Reliability already existing in different books and journals devised by great engineers and scientists**.** In simplest terms "Reliability is the probability of performance for which the equipment or system is designed". The equipment should perform as committed by the manufacturer within its warranty period and if it performs well after its warranty period also, it indirectly helps to increase the reputation of the manufacturer.

There are two basic things related to reliability those are reliability evaluation and reliability improvement. The reliability evaluation of a product or process includes the study of different phases of product life cycle and its failure analysis. It can be expressed in a quantitative term. The Reliability improvement is the process of preventing all the chances of failures in other words to seal all the loop holes in designing, manufacturing, operation and maintenance practices involved with the particular product. To improve the reliability of the product all the stake holders have to contribute throughout its life cycle.

1.2. Reliability Calculations:

It is important to express the reliability with the help of a quantitative term. In the design stage itself the design engineer must have to know the reliability value for which he is going to design the equipment, because all other design parameters are dependent on the value of reliability. Maintenance engineers also need to calculate the value of reliability of plant and machineries in reliability analysis phase based on which they can take necessary actions to improve the reliability level. As we know reliability depends on different factors, so based on those factors there are mainly four methods to calculate and quantify the reliability. Those are:

- Use of failure data method
- Density functions method
- Reliability function method
- Hazard and failure rates method

* Only the first method that is Use of failure data method is discussed below in brief which is used further in this article for Reliability calculations.

RELIABILITY CALCULATION BY USE OF FAILURE DATA:

In this concept the Reliability of any system is mainly affected by its failure rate. As a thumb rule we can say less failure results in more reliability and vice versa. **Failure rate** is the number of failures of a system or component per unit time, for example, failures per hour. It is often denoted by the Greek letter λ (lambda).
The mean time between failures (MTBF) is often used instead of the failure rate in practice. MTBF is the mean time gap between two failures of any system or equipment. The failure rate is simply the multiplicative inverse of the MTBF (1/λ).We can determine the Reliability by using following mathematical relationship established by Weibull.[1]

$$\text{Reliability}(R) = e^{-(T/M)^{\beta}},$$

Considering β = 1 (constant failure rate)

$$\text{Reliability} = e^{-T \times \lambda}$$

Where T = Total time period
M= MTBF
λ = Failure rate

2. EXPERIMENTAL WORK

For conducting this experiment a set of data has been collected for ten number of industrial process fans in a particular cement plant for ten consecutive years. The number of failures in each year has been recorded for all the individual fans. To generalize and to establish the relationship through the data table and graphs, all the failures in each year are added together to find out the total numbers of failures of fans per year. Then the average numbers of failures per year also calculated by dividing the total numbers of failures by total numbers of fans. With the help of these data the Bath tub curve will be validated in first phase of this experiment, the concept of Madhab's Hat curve of Reliability will be established in the second phase of this experiment and the reliability improvement methods will be discussed in the last phase of the experiment.

2.1. Validation of Bath Tub curve:[2]

As we know the **bathtub curve** is widely used in reliability engineering which shows the trend of failure rates of a system or equipment obtained throughout its life period. The trend looks like the cross-sectional shape of a bathtub so it is termed as bath tub curve. An ideal bathtub curve is shown in the figure-1.It mainly comprises of three parts:

- The first part represents the failure rate of early life period which is decreasing in nature.
- The second part represents the failure rate of useful life period which is more or less constant in nature.
- The third part represents failure rate of wear out period which is increasing in nature.

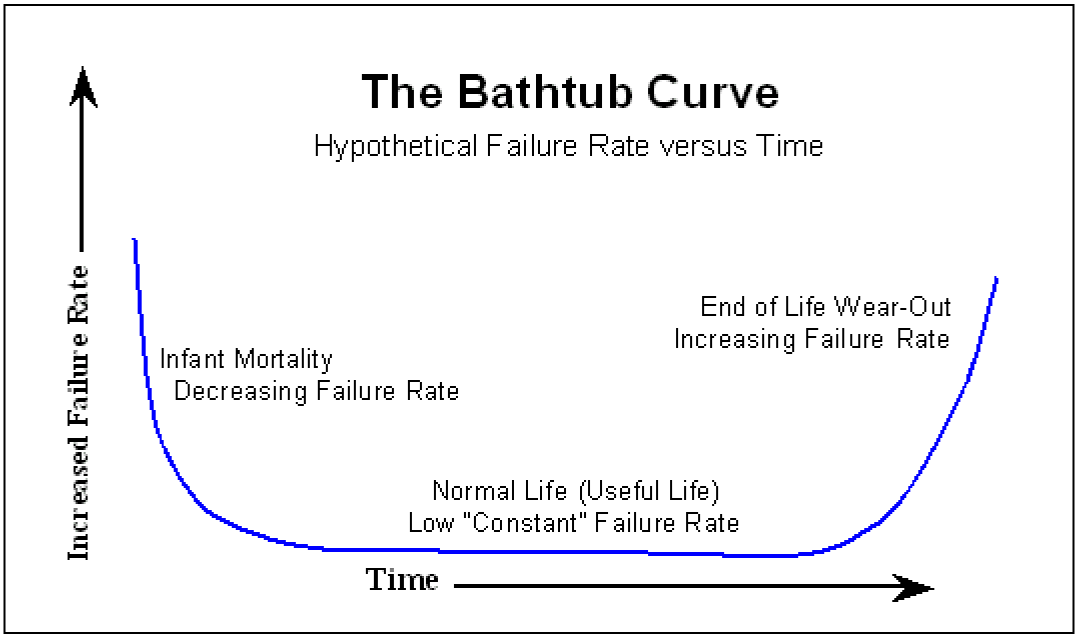

Figure - 1. Ideal Bathtub Curve [2]

The bathtub curve, does not depict the failure rate of a single item, but describes the relative failure rate of an entire population of products over time. The bathtub curve is generated by tracing the rate of failures of equipment throughout its life period. As explained earlier a set of data has been collected for the industrial process fans, which is shown in the Table-1.Now we can check the validity of bath tub curve by using these data with the help of MINITAB software.

The failure rate (Total number of failures per year) from the Table-1 has been plotted against all the years and the curve found from the graph is shown in figure - 2.Now we can see the curve obtained from the study looks like a Bath Tub. If we follow the curve we can observe there are mainly three parts as mentioned in the curve which is already discussed above.

YEAR	No. of failures, FAN-1	No. of failures, FAN-2	No. of failures, FAN-3	No. of failures, FAN-4	No. of failures, FAN-5	No. of failures, FAN-6	No. of failures, FAN-7	No. of failures, FAN-8	No. of failures, FAN-9	No. of failures, FAN-10	TOTAL No. of Failures per year	AVG. Rate of failure (Nos. per year)
1st	1	1	2	3	1	0	1	1	2	1	13	1.3
2nd	1	2	0	2	1	0	2	2	1	1	12	1.2
3rd	1	0	2	0	1	0	0	1	0	1	6	0.6
4th	1	0	1	1	1	0	0	1	2	0	7	0.7
5th	1	1	1	0	0	1	0	1	2	1	8	0.8
6th	1	0	2	0	0	0	0	1	1	2	7	0.7
7th	1	1	0	1	0	1	1	0	1	1	7	0.7
8th	1	1	1	1	2	1	0	1	0	0	8	0.8
9th	2	1	2	2	2	3	1	1	1	0	15	1.5
10th	2	2	2	1	2	0	3	0	2	2	16	1.6

Table - 1. Failure Rate of Fans

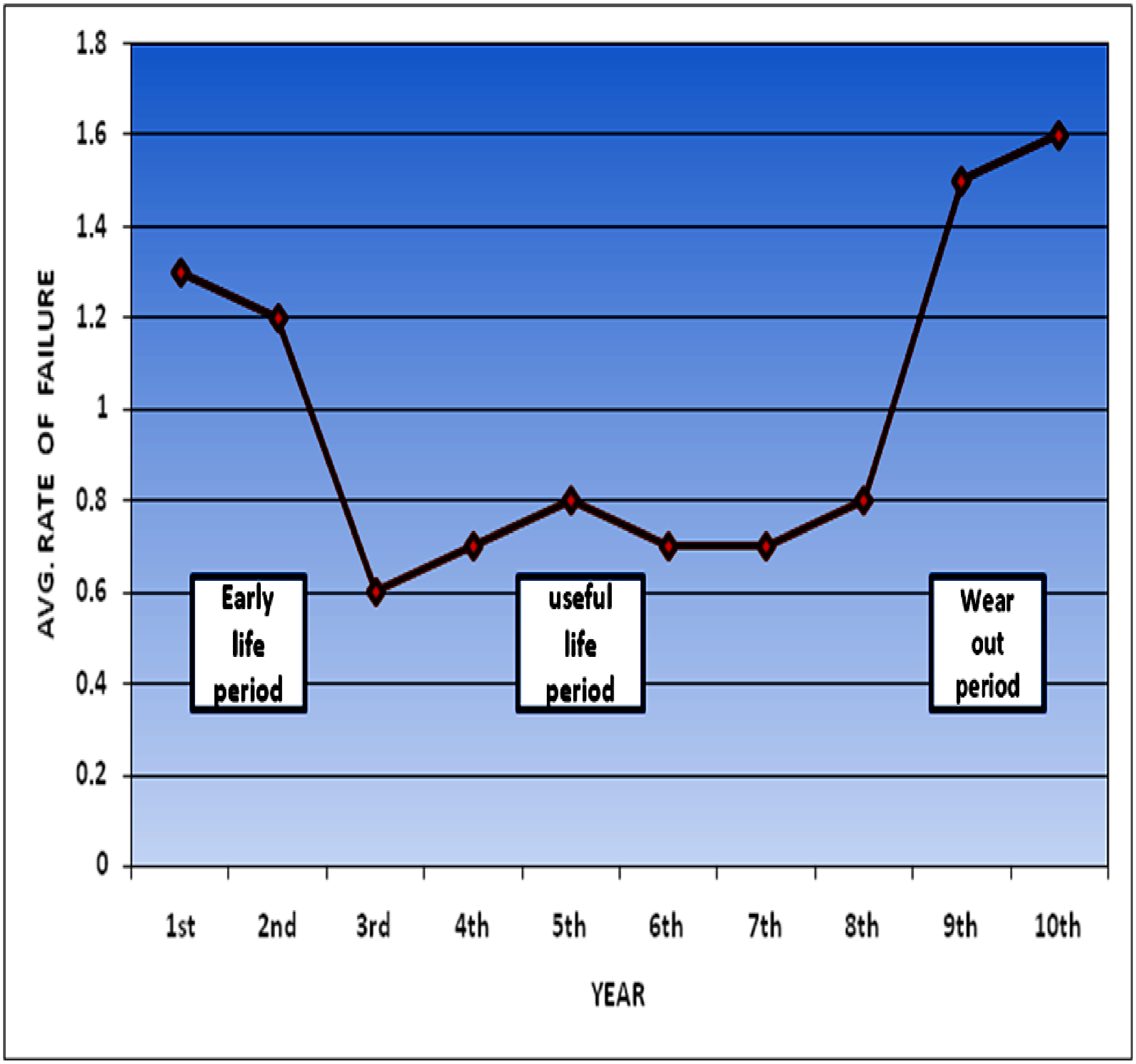

Figure - 2. Failure trend,Bath Tub curve

2.2. Concept of Madhab's Hat curve of Reliability

By using the above data, Mean Time Between Failures and the Reliability for each year has been calculated as shown in the Table 2. As explained earlier the reliability has been calculated by using failure data method. Like Bath Tub curve we can put the data of Reliability for all the years in MINITAB software and after putting the data we got a curve which is shown in the figure - 3. If we observe closely we can mark the curve looks lika a Hat. So it could be known as Madhab's Hat curve of

Reliability.Like bath tub curve it has mainly three regions.

- The first region is early life period or infant stage where the reliabilty is in increasing trend just opposite to the bath tub curve.
- The second region is useful life period where the reliabilty is more or less consatnt in nature just like in bath tub curve.
- The third region is wear out period where the reliability is in decreasing trend just opposite to the bath tub curve.

The hat curve of Relibility will be helpful for comparison with the actual reliability cycle of any equipment.It will also work as a guideline for equipment lifecycle performance analysis.

Table – 2. Reliability of Fans.

YEAR	UP TIME IN HOURS (T)	AVG.NO. OF FAILURES (N)	MTBF (T/N)	TIME/MTBF (T/M)	RELIABILITY ($e^{-T/M}$)
1st	**8450**	1.3	**6500.00**	1.3	0.272
2nd	**8360**	1.2	**6966.67**	1.2	0.301
3rd	**8500**	0.6	**14166.67**	0.6	0.548
4th	**8456**	0.7	**12080.00**	0.7	0.496
5th	**8366**	0.8	**10457.5**	0.8	0.449
6th	**8499**	0.7	**12141.43**	0.7	0.496
7th	**8632**	0.7	**12331.43**	0.7	0.496
8th	**8392**	0.8	**10490.00**	0.8	0.449
9th	**8546**	1.5	**5697.33**	1.5	0.223
10th	**8593**	1.6	**5370.62**	1.6	0.201

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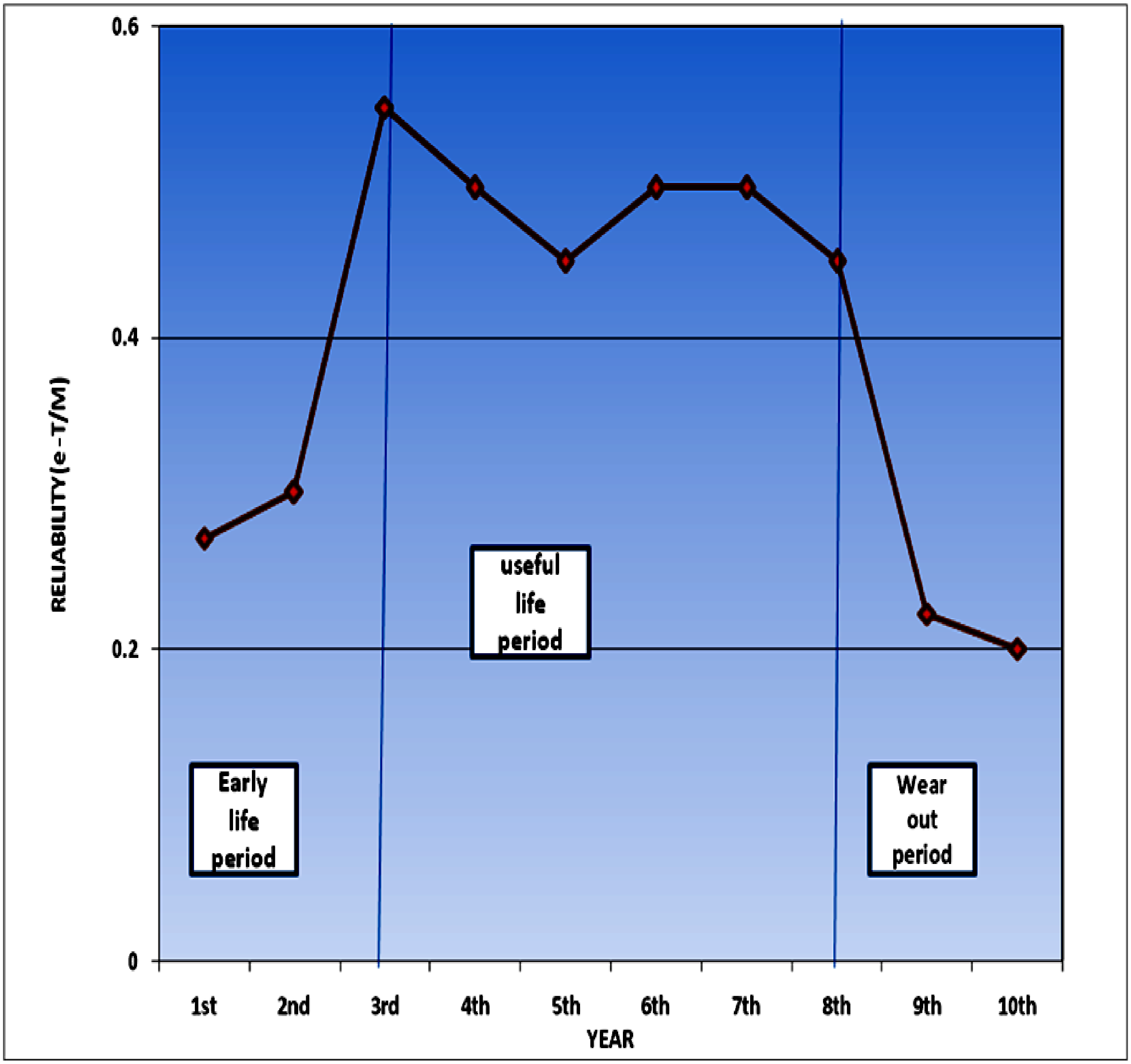

Figure - 3. Madhab's Hat curve of Reliability

2.3.Failure prevention and reliability improvement[3][4]

Failure can be described in many different ways. One of the definitions may be as follows-
"The failure is a deviation from the designed and assured performance level of any equipment which creates dissatisfaction to its user".

We can find out some individual units fails relatively early, others will last until wear-out, and some will fail during the relatively long period typically called normal life. Failures during infant mortality are highly undesirable and are always caused by defects and mistakes like: material defects, design mistakes, manufacturing defects, etc. Normal life failures

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are normally considered to be random cases of "stress exceeding designed strength" due to abnormal operating conditions. Wear-out is a fact of life due to fatigue or depreciation of materials. After useful life period most of the equipments fails which is normal and acceptable for both the manufacturer and customer. A product's useful life is limited by its endurance design. A product manufacturer must assure that all specified materials are adequately designed to function through the intended product life cycle. There are mainly two types of premature failures observed in any equipment, those are:

- Instantaneous or sudden failure – This type of failure mainly occurs when stress exceeds the strength of material.
- Progressive/fatigue failure – This type of failure occurs mainly due to improper or lack of maintenance of equipments.

To prevent both the types of premature failures and to increase the reliability, for smooth operation of equipments, different failure prevention techniques are adopted. Those are discussed below.

TECHNIQUES TO PREVENT THE SUDDEN FAILURES ARE–

- Abnormal operating conditions to be considered at design stage.
- Proper stress analysis and metallurgy study of components to be done before using in the equipment at design stage.
- Redundancy – use of parallel components wherever possible.
- Always in design stage, Factor of Safety and endurance limit of components should be considered towards a safe side.
- Proper methods for manufacturing of equipments should be adopted in its manufacturing stage.
- Proper method of installation and start up/commissioning of equipments should be followed.

TECHNIQUES TO PREVENT THE PROGRESSIVE FAILURES ARE–

- Cleaning and lubrication of the equipments to be done at a regular basis.
- Lubricants should be used as per the recommendation of the OEM.
- Lubricant analysis to be done in a regular basis to check the oil contamination level, wear particle analysis, viscosity etc.
- Tightness of fasteners used in equipments must be checked in a regular interval.
- Follow the proper maintenance procedure and adopt the methods of Reliability Centered Maintenance (Predictive and Preventive maintenance) to increase the reliability of the equipments.
- The most important failure prevention technique is Condition monitoring of the equipments like vibration measurement and analysis, temperature measurement and analysis, wear pattern measurement and analysis, bearing clearance measurement and analysis, gear wear pattern measurement and analysis, electrical current of motor measurement and analysis etc. to be done in regular basis and preventive actions to be taken if required. Some important condition monitoring techniques are shown in the figure - 4.
- According to the result of the condition monitoring the appropriate preventive actions must be taken to prevent failures of equipments.
- Alignment and balancing of equipments must be checked in a regular interval and necessary actions to be taken against the abnormalities.
- Measurement of pressure, flow and velocity of fluids to be done regularly and the trend should be analyzed.
- Avoid running the equipments above the recommended temperature, pressure, vibration, noise etc.

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- Adopt proper operating procedure with recommended operating parameters.
- Analyze all the minor issues and also big failures using proper failure analysis techniques like FMEA, Fish bone diagram, root-cause failure analysis etc.
- Always learn the lessons from the past failures and follow the preventive mode to avoid those failures in future.
- Modifications and continuous improvement should be done depending on the requirements of operating conditions.

Bearing Vibration Measurement

Bearing Temperature Measurement

Motor Current Measurement

Bearing clearance Measurement

Figure- 4, Condition monitoring Techniques

2.4. Daily checklist for a fan:

A sample of daily checklist which is prepared through work experience is given below which will be very helpful for mateinance engineers to get a trend of different factors which plays a great role for failure of an industrial process fan. The trends can be analyzed in a regular basis to get the important information about the abnormalities. On the basis of this information the preventive actions can be taken to avoid failures and thus increasing the reliability of the systems.

ATTRIBUTE	**FAN**		**MOTOR**	
	DE SIDE BEARING	NDE SIDE BEARING	DE SIDE BEARING	NDE SIDE BEARING
VIBRATION IN MM/SEC				
BEARING TEMPERATURE				
LOOSENESS OF BOLTS				
OIL LEVEL/ LUBRICATION STATUS				
NOISE				
RPM				

ATTRIBUTE	**MOTOR**		
	R	Y	B
RPM			
CURRENT IN AMPERE			
POTENTIAL DIFFERENCE IN VOLT			

CONCLUSION

In the first phase of this study the Bath tub curve is validated. A new concept that is “Hat curve of Reliability” has been established, thus it is a simple clarification still it is important for the life cycle reliability study of any equipment. In the third phase some failure prevention methods has been discussed.

It is hoped that this study would be helpful for the maintenance engineers as well as the design engineers and Reliability engineers to achieve the excellence in their respective field.

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