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FMEA for Stage Sealing in Multistage Submersible Pump

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Abstract--- *The study has attempted to present an effective tool for solving the problem of manufacturing process quality by executing process FMEA with proposed process control pratices this project aims to identify and eliminate current and potential problemsin the leakage of submersible pump by failure mode and effective analysis for improving the performance of pump in order to ensure the quality of the industry. Thus the various possible causes of the failure and the effects along with the prevention are discussed in the work. Severity values, occurance number, detection and RPN are some parameters which need to be determined. Futher more, some actions atre proposed which require to be taken as quickly as possible to void potential risk which aid to improve the performance of the pump and customer satisfaction. The prevention suggested in this paper can considerably decrease loss to the industry in terms of money, time and quality.*

Keywords—*FMEA, Failures, Identifying risk, Priority level, RPN Analysis.*

I. Introduction

The FMEA was developed and implemented for the first time in 1949 by U.S. Army and later executed in Apollo space programme to temperate the risk FMEA is a very significant method which should be engaged in companies for an engineering design, production process and new product in planning and production sphere in product life cycle. Purpose of FMEA is founding links between causes and effects of defects, as well as searching, solving and drawing the best decisions regarding solicitation of applicable action.

II. Literature Review

In 1950s the increasing attention paid to safety and the need to prevent predictable accidents in aerospace industry led to the development of the FMEA methodology. Later, it was introduced as key tool for increasing quality and efficiency in manufacturing processes In 1977, Ford Motors introduced FMEA to address the potential problems in the Research and Development (R&D) in the early stage of production and published the Potential Failure Mode and Effects Analysis Handbook in 1984 to promote the method. Later on the automobile manufacturers in America also introduced the FMEA into the management of suppliers, and took it as a key check issue Find out reasons behind the failure of some subjects of mechanical engineering course and after analysed the system through FMEA and they suggested recommend to solve the problem Execute FMEA to develop an effective quality system and to improve the current production processor the better quality of the products Applied FMEA model in salmon processing and packing industry in joint with ISO 22000 and they got the valuable result from implementation The FMEA has the potential to improve the reliability of Wind turbine systems especially for the offshore environment and made system cost effective Modified failure mode and effects analysis (MFMEA) method to select new suppliers in term the supply chain risk's perspective and applies the analytic hierarchy process method and found excellent result Applied FMEA technique on two products flywheel and flywheel housing and prevent different failure mode and suggestions were successfully implemented and the industry gained considerably in terms of both money and time. Used FMEA to optimize the decision making process in new product development in automobile industry Implemented FMEA at the design stage As such, they could be compared with Failure Reporting, Analysis and Corrective Action System results once actual failures are observed during test, production and operation. They recommended taking appropriate actions to avoid possibility. Christo Ananth et al.[3] discussed about E-plane and H-plane patterns which forms the basis of Microwave Engineering principles.

III. Concept of FMEA

Failure mode and effect analysis is an analytical technique (a paper test) that combines technology and experience of people in identifying probable failure mode of product or process and planning for its abolition. FMEA is a “before-the-event” action requiring a team effort to easily and inexpensively alleviate changes in design and production.

FMEA can be explained as a group of events projected to

- Recognize and evaluate the potential failure of a product or process and its effects.
- Identify actions that could eliminate or reduce the chance of potential failures.
- Document the process.

FMEA can be used as an individual project tool. However, it is strongly recommended that use to generate corrective action in a process improvement project. An FMEA is not a trivial tool rather it requires significant effort from a diverse team.

FMEA method use at:

- Formation of the product concept, for checking whether all prospects of the customer are included in this concept.
- Define the product, in order to check whether projects, service, supplies are appropriate and controlled in the right time.
- Process of production, in order to check whether documentation primed by engineers is fully carried out.
- Assembly, for checking whether the process of the assembly is compatible with documentation.
- Organization of the service, in order to check whether the product or the service is pleasant with recognized criteria.

IV. Documentation Procedure for FMEA

A. *Item and its Functions*

Specify all the functions of an item, including the environment in which it has to operate.

B. *Potential Failure Mode*

- Considering past failures, present reports, brainstorming.
- Describe in technical terms and not as customers will see.
- For e.g. cracked, deformed, loosened, short circuited, fractured, leaking, sticking, oxidized etc.

C. *Potential Effects of Failure*

- As perceived by the customer (internal/end user).
- For e.g. erratic operation, poor appearance, noise, impaired functions, deterioration etc.

D. *Severity*

Severity is the assessment of the seriousness of the effect of the potential failure mode. In this we have to determine all failure modes based on the functional requirements and their effects. An example table of severity is given below.

Table 1: Table of Severity

Code	Classification	Example
10	Hazardous Without Warning	Very High Ranking – Affecting safe operation.
9	Hazardous With Warning	Regulatory non compliance
8	Very High	Product becomes inoperable, with loss of function – Customer Very Much Dissatisfied
7	High	Product remain operable but loss of performance – Customer Dissatisfied
6	Moderate	Product remain operable but loss of comfort/convenience - Customer Discomfort
5	Low	Product remain operable but loss of comfort/convenience - Customer Slightly Dissatisfied
4	Very Low	Non-conformance by certain items – Noticed by most customers
3	Minor	Non-conformance by certain items – Noticed by average customers
2	Very Minor	Non-conformance by certain items – Noticed by selective customers
1	None	No Effect

E. *Class*

Classification of any special product characteristics requiring additional process control

F. *Potential Cause /Mechanism of Failure*

Every cause/mechanism must be listed concisely

- E.g. of Failure Causes are inadequate design, incorrect material, inaccurate life assumption, poor environmental protection, over stressing, insufficient lubrication etc.
- E.g. of Failure Mechanisms are fatigue, wear, corrosion, yield, creep etc.

G. *Occurrence*

Occurrence is the chance that one of the specific cause/mechanism will occur. In this step, it is necessary to look at the cause of a failure and how many times it occurs. Looking at similar products or processes and the failures that have been documented for them can do this. A failure cause is looked upon as a design weakness. An example for occurrence rating is given in following table.

Table 2: Table of Occurrence

Code	Classification	Example
10 and 9	Very High	Inevitable Failure
8 and 7	High	Repeated Failures
6 and 5	Moderate	Occasional Failures
4, 3 and 2	Low	Few Failures
1	Remote	Failure Unlikely

H. *Current Design Control*

The control activities generally include Prevention Measures, Design Validation, and Design Verification Supported by physical tests, mathematical modeling, prototype testing, and feasibility reviews etc.

I. *Detection*

- Relative measures of the ability of design control to detect wither a potential cause/mechanism or the subsequent failure mode before production.
- Supported by physical tests, mathematical modeling, prototype testing, feasibility reviews etc.

Table 3: Table of Detection

Detection	Rank	Criteria
Extremely Likely	1	Can be corrected prior to prototype/ Controls will almost certainly detect
Very High Likelihood	2	Can be corrected prior to design release/Very High probability of detection
High Likelihood	3	Likely to be corrected/High probability of detection
Moderately High Likelihood	4	Design controls are moderately effective
Medium Likelihood	5	Design controls have an even chance of working
Moderately Low Likelihood	6	Design controls may miss the problem
Low Likelihood	7	Design controls are likely to miss the problem
Very Low Likelihood	8	Design controls have a poor chance of detection
Very Low Likelihood	9	Unproven, unreliable design/poor chance for detection
Extremely Unlikely	10	No design technique available/Controls will not detect

J. *Risk Priority Numbers (RPN)*

RPN is the indicator for the determining proper corrective action on the failure modes. It is calculated by multiplying the severity, occurrence and detection ranking levels resulting in a scale from 1 to 1000.After deciding the severity, occurrence and detection numbers, the RPN can be easily calculated by multiplying these 3 numbers: $RPN = Severity \times Occurrence \times Detection$. The small RPN is always better than the high RPN. The RPN can be computed for the entire process and/or for the design process only. Once it is calculated, it is easy to determine the areas of greatest concern. The engineering team generates the RPN and focused to the solution of failure modes.

K. *Recommended Actions*

Beginning with high RPN and working in descending order

- The objective is to reduce one or more of the criteria that make up the RPN.
- Typical actions are design of experiments, revised test plans, revised material specifications, revised design etc.
- Important to mark "None" in case of no recommendation for future use of FMEA document.

L. *Responsibilities and Completion Dates*

Individual or group responsible for the recommended actions and target completion date to be entered.

M. *Actions Taken*

Brief descriptions of the action taken to be entered after actual actions are taken by the team.

N. *Revised RPN*

Recalculation of Severity, Occurrence and Detection rankings after implementation of recommended actions and thus calculation of revised RPN.

Revised RPN=revised ($Severity \times Occurrence \times Detection$)

V. FMEA PROCEDURE

The process for conducting FMEA can be divided into following steps. These steps are briefly explained as follows.

- Step 1: Collect the functions of system and build a hierarchical structure. Divide the system into several subsystems, having number of components.
- Step 2: Determine the failure modes of each component and its effects. Assign the severity rating (S) of each failure mode according to the respective effects on the system.
- Step 3: Determine the causes of failure modes and estimate the likelihood of each failure occurring. Assign the occurrence rating (O) of each failure mode according to its likelihood of occurrence.
- Step 4: List the approaches to detect the failures and evaluate the ability of system to detect the failures prior to the failures occurring. Assign the detection rating (D) of each failure mode.
- Step 5: Calculate the risk priority number (RPN) and establish the priorities for attention.
- Step 6: Take recommended actions to enrich the performance of system.
- Step 7: Conduct FMEA report in a tabular form.

VI. SUBMERSIBLE PUMP

A submersible pump is a device which has a hermetically sealed motor close coupled to pump body. The whole assembly is submerged in the fluid to be pumped. The main advantage of this type of pump is that it prevents pump caviation, a problem associated with a high elevation difference between pump and fluid surface

This is used in installation in vertical position but the construction and the working process are same. Produced liquids, after being subjected to centrifugal force caused by high rotational speed of the impeller. It loses their kinetic energy and converted to pressure energy

When fluid enters the pump through an intake screen and are lifted by pump stages. Other parts include the radial bearings distributed along the length of the shaft providing radial support to the pump shaft rotating with high rotational speed.

V. Problem Identification

The main failure that has been analysed in this project is Leakage.

Leakage has been classified based on two aspects they are

- Design Aspects
- Process Aspects

a. Design Aspects

The failures that occur due to the design aspects are

- Contact Area
- Fits and Tolerance
- Tie Bolt Strength
- Inter stage Pressure

b. Process Aspects

The failures that occur due to process aspects are

- Misalignment
- Tightness of the tie bolt
- Surface Cleaning
- Improper application of the sealant

VI Causes Of Failure Based On Design

a. Contact Area

The main cause of the failure is caused due to the gap that is caused while applying the sealant in between the housing

b. Fits and Tolerance

The main cause is due to the improper mounting of impeller in the shaft and also due to the misalignment in the whole assembly

c. Tie bolt strength

This failure is caused due to the aging of tie rod and also the material and threading of the tie rod are under rated and not machined properly

d. Inter stage Pressure

When the number of stages increased the pressure in between the stages will increase.

VII Causes Of Failure Based On Process

a. Misalignment

- It is occurred when the surface of the shaft is forced to deviate from its desired shape
- Excessive force and moment can lead to misalignment

they are as follows.

- Proper alignment of mating bodies
- Proper maintenance
- Proper application of sealant
- Clean installation of housing.
- Closed coupling method is preferred

a. Improper or without application of sealant :

- Proper applying of sealant
- The one who is working in that sector is recommended to follow the working manual

b. surface cleaning

- In the Quality Control sector the surface cleaning procedure should be added
- Fresh candidates appointed for working should be instructed about surface cleaning.

c. Tightness of the tie bolt

It can be controlled by proper tightness of the bolt

- Many threads can be added to the tie bolt for strong fit
- It can be inspected properly while the rod is completely fixed.

***d.* Fits and tolerance**

There are two methods in which this fits and tolerance defect can be reduced they are

- Discoloration.
- Scoring.

a. Tightness of the tie bolt

- It is caused due to the improper tightness of the bolt at both top and bottom of the tie rod
- Improper alignment of the tie rod

c. Surface Cleaning

This error may occur when the working manual is not followed properly

b. Improper application of the sealant

- This failure may cause due to the carelessness of the one who is applying the sealant
- This error may also occur when the working manual is not followed properly

VIII Effect Of Failure Based On Design

a. Contact Area

- Damage the housing
- The shaft may disengage
- Vibration

b. Fits and Tolerance

- Misalignment
- Vibration

c. Tie bolt strength

- Improper alignment of the shaft
- Fretting of mating surfaces.

d. Inter stage Pressure

- High noise
- Breakage of impeller
- Life span of shaft and impeller will decrease

IX Effect Of Failure Based On Process

a. ***Misalignment***

- Pump can't be able to rotate in its own direction
- The pump loses its performance
- vibration

b. ***Tightness of the tie bolt***

- It makes housing get misaligned
- It creates more vibration

c. ***Surface Cleaning***

Due to improper cleaning of the surface there is a chance of presence of forigen materials which damage the pump housing

d. ***Improper application of the sealant***

- Vibration
- Noise

XI Recommend Actions Failure Based On Process

e. Misalignment

In the Quality some of the actions can be taken to reduce the effect caused by misalignment they are as follows.

- Proper alignment of mating bodies
- Proper maintenance
- Proper application of sealant
- Clean installation of housing.
- Closed coupling method is preferred

f. ***Improper or without application of sealant :***

- Proper applying of sealant
- The one who is working in that sector is recommended to follow the working manual

g. ***surface cleaning***

- In the Quality Control sector the surface cleaning procedure should be added
- Fresh candidates appointed for working should be instructed about surface cleaning.

h. ***Tightness of the tie bolt***

It can be controlled by proper tightness of the bolt

- Many threads can be added to the tie bolt for strong fit
- It can be inspected properly while the rod is completely fixed.

i. **Fits and tolerance**

There are two methods in which this fits and tolerance defect can be reduced they are

- Discoloration.
- Scoring.

X Calculation

a. *Contact area*

Diameter = 134 mm

Thickness = 1mm

Radius = d/2

= 134/2

= 67mm

Circumference = $2\times \pi \times r \times t$

= $2\times \pi \times 67 \times 1$

Contact area = $420 mm^2$

P = F/A

F = P×A

= (224×10^5) 420

($1 bar = 0.1 N/mm^2$)

= 22.4 × 420

Load P = $9408 N/mm^2$

b. *Inter stage pressure*

Pressure = 1.6 bar/stage

Number of stages = 25

Inter stage pressure = { Number of stages * Pressure }

= 25 * 1.6

= 38.6 bar

Inter stage pressure = 38.6 bar

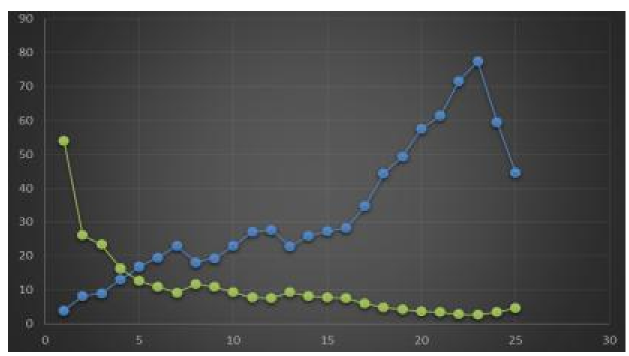
XII Analysis

a. ***Material Properties***

Table. 5 Material Properties

AISI { STAINLESS STEEL }	
Yield stress	215 Mpa
Ultimate Stress	505 Mpa
Density	8 g/cc
Modulus of elasticity	197000 Mpa
Poisson's ratio	0.29

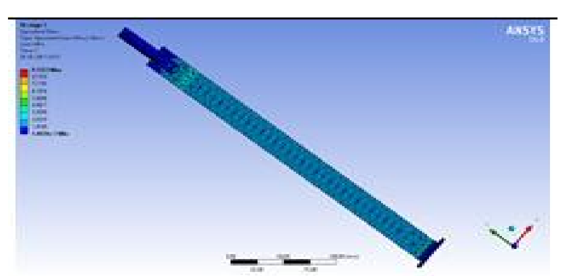
b. ***Stress vs Factor of Safety Graph:***



Blue - Stress

Yellow - Factor Of Safety

XI STRESS ANALYSIS RESULT FROM ANSYS



Failure mode	Failure effects	Failure cause	Sev	Occ	Det	RPN	Recommended actions	Sev	Occ	Det	RPN
Fits and tolerance	Misalignment	Improper alignment of the shaft on the housing	7	4	8	224	Discoloration.	5	3	6	90
	vibration	Misalignment					Scoring.				
Contact area	Damage the housing	Gap caused while applying sealant in the housing	5	7	7	245	Increase the sealent curing time	3	6	6	108
Inter stage Pressure	High noise	Due to the increase in the number of stages the pressure stages	3	3	5	45	loctite 603 is suggested to increase the total presure	2	3	4	24
	Breakage of the impeller										
	Life span of the impeller reduces										
Fits and Tolerance	Misalignment	Improper mounting of the impeller	7	4	8	224	No recommended actions	6	4	5	120
	Vibration	Misalignment									
Tie bolt strength	Aging of the tie rod	shaft misalignment	8	7	3	168	Reduce the number of tie bolts from 4 to 3	5	7	3	105
	The material and threading of tie rod are under rated	fretting of mating surfaces									
Fits and tolerance	Misalignment	Improper alignment of the shaft on the housing	7	4	8	224	Discoloration.	5	3	6	90
	vibration	Misalignment					Scoring.				
Contact area	Damage the housing	Gap caused while applying sealant in the housing	5	7	7	245	Increase the sealent curing time	3	6	6	108
Inter stage Pressure	High noise	Due to the increase in the number of stages the pressure stages	3	3	5	45	loctite 603 is suggested to increase the total presure	2	3	4	24
	Breakage of the impeller										
	Life span of the impeller reduces										
Fits and Tolerance	Misalignment	Improper mounting of the impeller	7	4	8	224	No recommended actions	6	4	5	120
	Vibration	Misalignment									
Tie bolt strength	Aging of the tie rod	shaft misalignment	8	7	3	168	Reduce the number of tie bolts from 4 to 3	5	7	3	105

Table. 6 Tie bolt analysis

Tie Bolt Analysis			
stage	**Stress (Mpa)**	**displacement (mm)**	**FOS**
1	**3.9789**	**0.00083278**	**54.0350348**
2	**8.1967**	**0.0019498**	**26.2300682**
3	**9.1523**	**0.0033433**	**23.4913628**
4	**13.171**	**0.0050242**	**16.3237415**
5	**16.907**	**0.006981**	**12.7166262**
6	**19.524**	**0.0091743**	**11.0120876**
7	**22.987**	**0.011698**	**9.35311262**
8	**18.179**	**0.014492**	**11.8268331**
9	**19.343**	**0.017536**	**11.1151320**
10	**22.934**	**0.02093**	**9.37472747**
11	**27.048**	**0.026158**	**7.94883170**
12	**27.718**	**0.030229**	**7.75669240**
13	**22.893**	**0.034587**	**9.39151705**
14	**25.974**	**0.039206**	**8.27750827**
15	**27.322**	**0.044031**	**7.86911646**
16	**28.241**	**0.049276**	**7.61304486**
17	**34.72**	**0.054701**	**6.19239631**
18	**44.348**	**0.060342**	**4.84802020**
19	**49.379**	**0.066348**	**4.35407764**
20	**57.62**	**0.073066**	**3.73134328**
21	**61.447**	**0.082444**	**3.49895031**
22	**71.614**	**0.089205**	**3.00220627**
23	**77.349**	**0.096482**	**2.77960930**
24	**59.635**	**0.10467**	**3.60526536**
25	**44.549**	**0.11208**	**4.82614649**

XII. CONCLUSION

Thus the various modes of failures of submersible pumps is identified and it is classified based on process aspects and in design aspects. The Risk Priority Number is given separately to each failure and proper recommended actions are given. The Risk Priority Number and leakage has been reduced due to follow up of recommended actions The tie bolt plays a vital role in submersible pump to withstand the total fluid pressure induced inside the impeller assembly of submersible pump. The tie bolt strength also calculated analytically using design software

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