Failure Mode and Effect Criticality Analysis of locomotive Reciprocating Air Compressor

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Abstract— In present epoch of automation and modernization, setting up of production plants involves huge capital investment especially for the process industry. The deterioration and failure of these systems might incur high costs due to production losses and delays, unplanned intervention on the system and safety hazards. The causes of failure may be human error, poor maintenance, inadequate testing, inspection or improper use and the resulting effects vary from minor in convenience to lost service time and sometimes to loss of material, equipment and even life. Several techniques have been used to determine the causes for the failure modes and what could be done to eliminate or reduce the chance of failure. The most notable methodology dealing with this issue is the Failure mode effects and critique analysis (FMECA). Failure modes, effects and critique analysis (FMECA) is an integral part of the technical design of maintenance and it represents a strong tool to evaluate and improve Reciprocating Air Compressor reliability and therefore reduces costs associated with maintenance that is used in a wide range of industry. This allows to optimized the components while identifying the most critical elements and helping decision makers to define maintenance service with appropriate maintenance policy.

Key words: failure, intervention, Failure mode effects and critique analysis, Reciprocating Air Compressor and reliability

I. INTRODUCTION

Failure Mode and Effect Criticality Analysis (FMECA) is a methodology designed to identify potential failure modes for a product or process, to assess the risk associated with those failure modes, to rank the issues in terms of importance and to identify and carry out corrective actions to address the most serious concerns. Failure Modes, Effects and Criticality Analysis (FMECA) requires the identification of the following basic information namely Item, Failure, Effect of Failure, Cause of Failure and recommended action. A typical failure modes and effects analysis incorporates some methods to evaluate the risk associated with the potential problems identified through the analysis.

The most common method of evaluation of risk is Risk Priority Number. To use the (RPN) Risk Priority Number method to assess risk, the analysis team must rate severity of each effect of the failure; rate the likelihood of occurrence for each cause of failure, rate the likelihood of prior detection for each cause of failure calculate the RPN by obtaining the product of the three ratings.

RPN= Severity*Occurrence*Detection

The RPN can then be used to compare issues within the analysis and to priorities problems for corrective action. This risk assessment method is commonly associated with Failure Mode and Effects Analysis (FMEA).

The severity and probability indices are added together to yield the criticality index. It represents a measure of the overall risk associated with each combination of severity and probability. This probability is used for failure prediction for a particular frequency and diagnoses them with optimum maintenance strategies like as condition based maintenance (CBM), time based maintenance (TBM) etc.

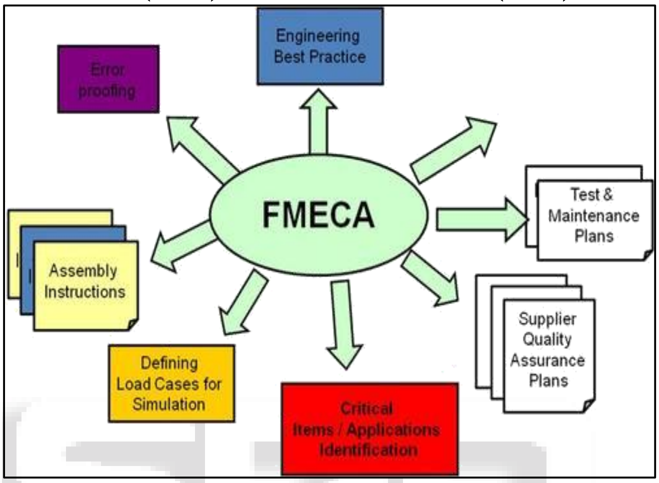

Fig. 1: Basics of applied Failure Modes Effects and Criticality Analysis [3]

A. Advantages of FMECA

- FMECA is one of the most important and most widely used tools of reliability analysis.
- The FMECA facilitates identification of potential design reliability problems.
- It can help removing causes for failures or developing systems that can mitigate the effects of failures.
- Help engineers prioritize and focus on high-risk components failures.
- It provides detailed insight into the systems interrelationships and potentials for failure.
- Information and knowledge gained by performing the FMECA can also be used as a basis for trouble shooting activities, maintenance manual development and design of effective built-in test techniques.
- Systematically identifies cause and effect relationships
- Indicates critical failure modes.
- Identifies outcomes from causes.
- Framework for identifying mitigating actions.
- Output may be large even for simple systems.
- Prioritizing may become difficult with competing failure modes
- May not easily deal with time sequences, environmental conditions and maintenance aspects

B. Applications of FMECA

- To identify failures which, alone or in combination, have undesirable or significant effects; to determine the failure modes which may seriously affect the expected or required quality.
- To identify safety hazard and liability problem areas, or non-compliance with regulations.
- To focus development testing on areas of greatest need.
- To assist the design of Built-in-Test and failure indications.
- To assist the preparation of diagnostic flow charts or fault-finding tables.
- To assist maintenance planning.
- To identify key areas in which to concentrate quality control, inspection and manufacturing controls. To provide a systematic and rigorous study of the process and its environment.
- To support the need for standby or alternative processes or improvements to current processes. To identify deficiencies in operator and supervisor training and practices.

II. LITERATURE REVIEW

Carl S. Carlson et.al [1] focus on problem of prevention, anticipating that lead to failure and ensuring designs are robust. Failure Mode and Effects Analysis (FMEA) can anticipate and prevent problems, reduce costs, shorten product development times, and achieve safe and highly reliable products and processes. The plain truth is FMEA has the potential to be a very powerful tool to achieve high reliability in products and processes; and when done well, it is remarkably effective. Yet in practice, FMEA does not always achieve the expected results. It has to be done correctly: performed on the correct parts, by the correct team, during the correct timeframe, with the correct procedure. The purpose of this tutorial is to share the fundamental concepts and procedures for effective FMEAs and highlight the FMEA success factors.

Deeptesh Singh et.al [2] represents the generic process of FMECA for centrifugal pump failures and a case study on centrifugal pump failure cost estimation actual and after implementation of optimum strategies of maintenance. FMECA focused on critical components and reduce them their priority level and frequency with exact analysis of maintenance requirement of centrifugal pump. Profitability is a new parameter based on costs and potential profit to reduce the losses caused by failure occurrence, has been used in order to consider economic aspects.

Dobrivoje Catic et.al [3] gives the basic concepts of Failure Modes, Effects and Criticality Analysis - FMECA. Features of elements of mechanical systems regarding failure intensity demand a special approach of quantitative FMECA. The paper presents this approach, applied to the elements of mechanical systems and used for the design of a software package. Criticality analysis of failure modes of light commercial vehicle's steering tie-rod joint elements was conducted based on the exploitation results and with the use of the previously mentioned method and program. In conclusion, the possibilities of application of the obtained results are presented.

J Lair et.al [4] describe two steps lead to the behavior modelling of the product.

1) Finally, an FMEA in order to identify failure modes (exhaustive search for the behaviors, degradations and failures of elements), their causes and effects, taking into account the potential problems and errors which could occur during the process.
2) This step leads to the identification of degradation and failure. We thus can build the failure modes (or failure scenarios). The methodology proposed simplifies each step of the approach, and provides us with a graphical representation of the product behavior.

Jerome Lair et.al [5] explain two main parts:

1) The use of Failure Modes and Effects Analysis within IEA T27 – Project C2 is firstly presented. This part includes a description of the methodology (and the needed adaptations to take into account the building products specificities), as well as some applications to window and solar components.
2) The "An Insulating Glass Knowledge Base" project led by Aspen Research Corporation and supported by The US Department of Energy is then presented. It includes the joint use of FMEA and Event Tree methodologies on Insulated Glazing, and deeply presents an expert approach for criticality analysis.

Lefayet Sultan Lipol et.al [6] present report on the FMEA/FMECA risk analysis method in industries. We have visited at Parker Hannifin, Boras to know their techniques to implement it and found that the company is familiar with Design and Process FMEA only and organization's FMEA software is based on MS Excel sheet to put all of the data's of FMEA team's risk analysis investigation. The company follows a limit of RPN's 200 and any value beyond this limit and equal to this is marked red. The software presents a graph of RPN's of before action taken and after action taken. The industry is not so familiar with FMECA but using qualitative part of criticality analysis (criticality matrix of severity on Y-axis and occurrence on X axis). We tried to find some differences of FMEA and FMECA. The company is making risk analysis if they are asked to do so by the top management. It is helping the company to avoid accident, re-design and making a reliable design or process.

Mahdi Shaghaghi et.al [8] propose a FMEA which uses generalized mixture operators to determine and aggregate the risk priorities of failure modes. In a numerical example, a FMEA of the LGS gas type circuit breaker product in Zanjan Switch Industries in Iran is presented to further illustrate the proposed method. The results show that the suggested approach is simple and provides more accurate risk assessments than the traditional RPN.

Raja Yahmadi et.al [9] reviews the lead acid battery performance related to the manufacturing process problem. Chemical reactions occurring during the manufacturing process of leadacid batteries have a significant impact on their performance and lifetime. Understanding and control of these chemical and electrochemical processes will result in battery performance. In this context, the authors propose an approach to study the degradation of lead acid battery during the manufacturing process by adopting a quantitative analysis based on the Failure Mode and Effects and Criticality Analysis (FMECA). This analysis allows determining, classifying and analyzing common failures in lead acid battery manufacturing. As a result, an appropriate risk scoring of occurrence, detection and severity of failure modes and computing the Risk Priority Number (RPN) for detecting high potential failures is achieved.

Robyn Lutz et.al [10] presents several of the most widely used and useful techniques for failure assessment across the system lifecycle with an emphasis on the role of software. For each technique the paper describes its purpose and background, summarizes the process of performing the technique, and evaluates the technique's strengths and limitations. The discussion provides lessons learned from practice, examples from spacecraft applications, and pointers to additional work in the field. The paper describes some of the tools that are available to help the practitioner select and implement failure assessment techniques and identifies likely future directions in failure assessment.

Yonas Mitiku Degu et.al [11] explain that Failure Mode and Effect Analysis (FMEA) is a pro-active quality tool for evaluating potential failure modes and their causes. It helps in prioritizing the failure modes and recommends corrective measures for the avoidance of catastrophic failures and improvement of quality. In this work, an attempt has been made to implement Machinery FMEA in UPVC pipe production unit of Amhara Pipe Factory, P.L.C., Bahir Dar, Ethiopia. The failure modes and their causes were identified for each machine, the three key indices (Severity, Occurrence and Detection) we reassessed and the analysis was carried out with the help of MFMEA Worksheet. Finally, the necessary corrective actions were recommended.

III. Practical Method of FMECA

FMECA is a way to evaluate potential failure modes and their effects and causes in a systematic and structured manner. Failure modes mean the ways in which something could fail. Effects analysis refers to studying the consequences. The purpose of the FMECA is to take actions to eliminate or reduce failures, starting with the highest-priority ones. By itself, an FMECA is not a problem solver; it should be used in combination with other problem solving tools. The analysis can be done either in a qualitatively or quantitatively way.

The basic steps in performing a FMECA could be

1) Define the system to be analyzed. A complete system definition includes defining system boundaries, identifying internal and interface functions, expected performance, and failure definitions.
2) Identify failure modes associated with system failures. For each function, identify all the ways of failure could happen. These are potential failure modes.
3) Identify potential effects of failure modes, for each failure mode, i.e. identifying all the consequences on the system. Condition of happening when the failure occurs.
4) Determine and rank how serious each effect is. The most critical pieces of equipment, which affected the overall function of the system, need to be identified and determined.
5) For each failure mode, determine all the potential root causes.
6) For each cause, identify available detection methods.
7) Identify recommended actions for each reason that can reduce the severity of each failure.

Possible rate of occurrence	Criterion of Occurrence	Value
Once every 12 years	Failure near zero or no	1
Once every 10 years	Very low, failure isolation, rarely	2
Once every 8 years	Low, often fail	3
Once every 6 years	Low, often fail	4
Once every 4 years	Average, occasional failure	5
Once every 2 years	Average, occasional failure	6
Once every years	Average, occasional failure	7
Once every 6 months	High, frequent failure	8
Once every month	High, frequent failure	9
Once every week	Very high, very high failure	10

Table 1: Parameters FMECA (Occurrence)

Duration of service interruption	Criterion of Severity	Value
8h	Very catastrophic	8
7h	Catastrophic	7
6h	Very serious	6
5h	Serious	5
4h	Medium	4
3h	Significant	3
2h	Minor	2
1h	Very minor	1
30 min	Small	0.6
< 30 min	Very small	0.2

Table 2: Parameters FMECA (Severity)

Level of Detection	Criterion of Detection	Value
Not detectable	Impossible	10
Difficult to detect	Very difficult	9
Difficult to detect	Very difficult	8
Detecting random	Not sure	7
Detecting random	Occasional	6
Possible detection	Low	5
Possible detection	Late	4
Reliable detection	Easy	3
Reliable detection	Immediate	2
Detection at all times	Immediate corrective	1

Table 3: Parameters FMECA (Detection)

A. Major Findings of the Study

Equipments are ranked based on severity, detection and occurrence. The risk priority number RPN for these equipment's are found out. The reliability of all the equipments is calculated.

1) Components having RPN greater than 300 are critical and perform predictive maintenance.
2) Components having RPN between 200 and 300 and hence it is semi critical, so perform preventive maintenance or modify present maintenance schedule.

3) Components having RPN less than 200 perform corrective maintenance.

B. Selection Criteria for Maintenance Program

Selection is based on risk priority number RPN value to take a appropriate maintenance plan for reciprocating air compressor.

Rank	Maintenance Technique	Criteria
1		
	Predictive Maintenance	RPN> 300
2		
	Preventive Maintenance	200<RPN<300
3		
	Corrective Maintenance	RPN<200

Table 4: Selection of program

1) Predictive Maintenance

Unlike the condition based maintenance policy, in predictive maintenance the Acquired controlled parameters data are analyzed to find a possible temporal trend. This makes it possible to predict when the controlled quantity value will reach or exceed the threshold values. The maintenance staff will then be able to plan when, depending on the operating conditions, the component substitution or revision is really unavoidable

2) Preventive Maintenance

Preventive maintenance is based on component reliability ch1aracteristics. This data makes it possible to analyze the behavior of the element in question and allows the maintenance engineer to define a periodic maintenance program for the machine. The preventive maintenance policy tries to determine a series of checks, replacements and/or component revisions with a frequency related to the failure rate. In other words, preventive (periodic) maintenances are effective in overcoming the problems associated with the wearing of components. It is evident that, after a check, it is not always necessary to substitute the component: maintenance is often sufficient

3) Corrective Maintenance

the main feature of corrective maintenance is that actions are only Performed when a machine breakdown. There is no intervention until a failure has occurred.

IV. CONCLUSIONS AND RESULT ON THE BASIS OF FMECA

This work showed the feasibility of conducting an optimum method of maintenance. This approach is based on the analysis FMECA. The implementation of this approach shows its contribution in reducing maintenance costs. In deed it can:

1) FMECA provide the recommendation of critical parts in a precise manner.
2) Identify critical functions for the system and critical component of reciprocating air compressor.
3) Define the maintenance policy for the system and its components, maintenance policy is indicated in Table 4. For main parts of reciprocating air compressor.
4) To select the best mix of failures to be repaired and this type of problem is easily resolvable through priority of critical index of components and diagnose them appropriate maintenance strategies.

Here main components of a reciprocating compressor are analyzed to find the criticality. The risky components and failure modes are easily identified by incorporating the occurrence of failure mechanism. Thus as a result both the RPN and Criticality can be identified in one analysis. When such components are identified the plant manager can fix the maintenance strategies and design modifications for the improved performances

Component	Failure Cause	Effects	likelihood of Occurrence P	Consequence- C	Detection D	P*C*D= Criticality	Maintenance Plan
Frame	loose	Frame knocks	2	7	6	84	Corrective
							Action: If the fault is minor.
	low oil pressure	frame knocks	3	4	3	36	Corrective
	loose crank pin	frame knocks	3	6	7	126	Corrective
	Improper alignment	frame knocks	3	6	7	126	Corrective
	damaged coupling	frame knocks	2	7	4	56	Corrective

Cylinder	broken	knocking	8	7	6	336	Predictive
	ring	noise					
	loose/broken	knocking	7	6	8	336	Predictive
	valve	noise					
			6	7	8	336	Predictive
Valves	impurities in air	valve breakage					
	excessive lubrication		7	4	8	224	Predictive
		valve breakage					
	worn out	low oil pressure	6	7	4	168	Corrective
Main bearing							
	worn out	misaligned	5	8	8	280	Predictive
Piston rod not lined up with frame high run			6	8	4	192	Corrective
Intercooler fouling 7				6	4	16	Corrective

Table 4: Maintenance Plan on the basis of FMECA

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