Failure Mode and Effects Analysis

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Abstract – Failure mode and effects analysis (FMEA) is a term-based methodology for identifying potential problems with new or existing design. It is one of the most frequently used hazard analysis tools. FMEA identifies the mode of failure of every component in a system and determines the effect on the system of each potential failure. By failure we mean inability to meet a customer's requirements as opposed to actual catastrophic material breakage or failure. Thus, a failure mode is any way that a part could fail to perform its required function. For example, a cable used to lift I-beams could fray from wear, kink from misuse, or actually fracture from excessive load. Note that either fraying or kinking could lead to fracture, but fracture might occur without these events if a design error incorrectly estimated either the strength of the cable or the load it needed to support. There are many variations in detailed FMEA methodology, but they are all aimed to accomplishing three things: Predicting what failures could occur, Predicting the effect of the failure on the functioning of the system and establishing steps that might be taken to prevent the failure, or its effect on the function. FMEA is useful in identifying critical areas of the design that need redundant components and improved reliability. FMEA is a bottom-up process that starts with the required functions, identifies the components to provide the functions, and for each component, lists all possible modes of failure.

Index Terms – Failure modes, failure probability, failure rating

1. INTRODUCTION

The failure of engineering components frequently leads to disruption in services to the public at large. To avoid reoccurrence of the failure of engineering component during service, it is important that whenever failure occurs, the same is thoroughly investigated to establish primary factor and other important factors that led to failure so that suitable recommendations can be made to avoid similar failure in future. Failure analysis and its prevention needs a systematic approach of investigation for establish the important causes of the failure(1-2). Therefore, it is worth to familiarize with fundamental causes of failure of mechanical, general approach to be used for the failure analysis and failure analysis of welded joints.

In general, an engineering component or assembly is considered to have failed under any of the following three conditions when the component is a) inoperable, b) operates but doesn't perform the intended function and c) operates but safety and reliability is very poor. However, metallurgical failure of a mechanical component can occurs in many ways a) elastic deformation is beyond acceptable limit, b) excessive and unacceptable level of plastic deformation, c) complete fracture has taken place and d) loss of dimension due to wear and tear besides variety of reasons. In two chapters, failure analysis shall be oriented mainly towards the metallurgical failure of mechanical components(3-5).Elastic deformation occurs when stiffness of the component is less and the same is primarily determined by modulus of elasticity and cross section. Elastic deformation can lead to the failure of mechanical components especially in high precision assemblies and machinery where even small elastic deformation under operating conditions is not acceptable.Excessive plastic deformation of the mechanical components can lead to the failure in two conditions a) externally applied stress is beyond the yield strength limit and b) component is subjected to applied stress lower than yield stress but exposed to high temperature conditions enough to cause creep(6). Both the cases should be handled using different approaches. To avoid the failure by plastic deformation owing to externally applied stress more than yield strength, the cross section should be designed after taking proper factor of safety and considering the yield strength of materials of which component is to be made. For mechanical components that are expected to be exposed in high temperature creep resistant materials should be selected so that under identical load condition, low steady state creep rate of creep resistant materials can allow desired longer creep life.

Fracture of mechanical components is usually caused by a) overloading, b) fatigue and c) stress rupture. Failure due to overloading can occur in many ways such as accidental loading, gradual reduction in load resisting cross sectional area of component due to wear and tear, deterioration in mechanical properties of component due to unfavorable metallurgical transformations during service(7-8). To avoid failure due to overloading well thought out design should be developed in light prevailing technological understanding and stress calculations while regular monitoring the condition of component during the service should also be done using suitable techniques and proper inspection and testing schedules.

2. METHODOLOGY

Three factors are considered in developing a FMEA.

1.The severity of a failure. Table 1 gives the scale for rating severity. Many organizations require that potential failures with a 9 or 10 rating require immediate redesign.

2.The probability of occurance of the failure. Table 2 gives a scale for probability of occurrence. The probabilities given are very approximate and depend on the nature of the failure, the failure ,the robustness of the design, and the level of quality developed in manufacturing.

3.The likelihood of directing the failure in either design or manufacturing, before the product is used by the customer. Table 3 gives the scale for direction. Clearly, the rating for this factor depends on the quality review system in place in the organisation.

Table 1. Rating for severity of Failure

Rating	Severity description
1	The effect is not noticed by the customer
2	Very slight effect noticed by customer; does not annoy or inconvenience customer
3	Slight effect that causes customers annoyance, but they do not seek service
4	Slight effect, customer may return product for service
5	Moderate effect, customer requires immediate service
6	Significant effect,causes customer dissatisfaction ; may violate a regulation or design code
7	Major effect system may not be operable;elicits customer complaint;may cause injury
8	Extreme effect, system is inoperable and a safety problem. May cause severe injury
9	Critical effect, complte system shutdown;safety risk
10	Hazardous; failure occurs without warning; like: threatining

Table 2. Rating for Occurrence of Failure

Rating	Description of occurrence
1	Extremely remote
2	Remote,very unlikely
3	Very slight chance of occurrence
4	slight chance of occurrence
5	Occasional occurrence
6	Moderate occurrence
7	Frequent occurrence
8	High occurrence
9	Very high occurrence
10	Extremely high occurrence

Table 3. Rating for Detection of Failure

Rating	Description of Detection
1	Almost certain detect
2	Very high chance of detection
3	High chance of detection
4	Moderately high chance of detection
5	Medium chance of detection
6	Low chance of detection
7	Slight chance of detection
8	Remote chance of detection
9	Very remote chance of detection
10	No chance of detection ; no inspection

3. RESULTS AND DISUSSION

Usual practice is to combine the rating for the three factors into a risk priority number (RPN).

RPN = Severity of failure x Occurrence of failure x detection rating

The values of RPN can vary from a maximum of 1000, the greatest risk, to minimum 1. Numbers derived from above equation are often used to select the vital few problems to work on. This can be done by setting a threshold limit, for example, RPN = 200, and working on all potential failures above this limit. Another approach is to arrange the RPN values in a Pareto plot and give attention to those potential failures with the higher ratings. The an alternate approach suggests as decision on how to use the information provided from the FMEA should not be blindly based on the RPN values,. Consider the results of a FMEA analysis shown in Table 4.

Table 4. Results of a FMEA Analysis

Failure mode	Severity	Occurrence	Detection	RPN
A	3	4	10	120
B	9	4	1	36
C	3	9	3	81

Compare the failure modes A and B. A has nearly four times the RPN of B, yet B has a severity of failure that would cause safety risk and complete system shutdown. Failure by A would cause only a slight effect on product performance. It achieves its high RPN value because it is not possible to detect the defect that is causing the failure. certainly failure B is more critical than A and should be given prompt attention for design of the product. Failure mode C has over 2 times the RPN of B, but because the severity of the failure is low it should be given lower priority than B even though the occurrance of failure is high. A rational way to interpret the results of FMEA analysis has been shown Fig.1 Often product specifications include a requirement that action should be taken if the RPN value exceeds some number like 100 or 200. It may not be rational to require a design change if the reason for the high RPN is due to a very hard to detect defect or if detectability scores high because no inspection process is in use. Using a plot such as Fig.1 gives better guidance on which design details (failure modes) require remedial action than simply basing all decisions on the RPN value.

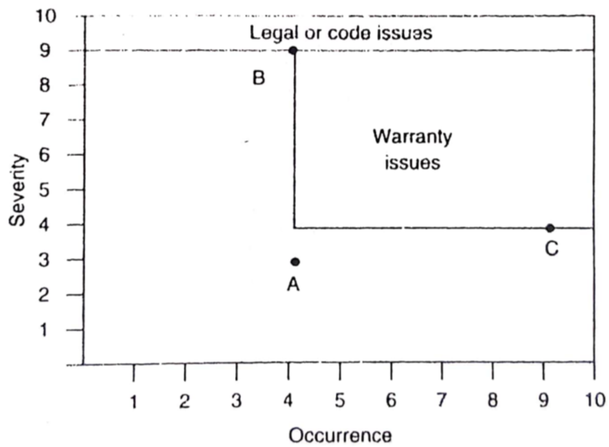

Fig.1 A rational way to interpret FMEA results

4. CONCLUSIONS

The design details determine the level of defects. Fairly estimation of potential failure mades by FMEA lead to more reliable designs. Other methods to increase the reliability of the design are use of highly durable materials and components, derating of components, reduction in part count and simplicity of the design, and adoption of a damage tolerant design coupled with ready inspection. Extensive testing of preproduction prototypes to work the bugs out is a method that works well. Methods for carrying out a root cause analysis of the reasons for a failure are an important means of improving the reliability of designs. FMEA applications in various fields as classify the failures by its effects on the system operation and mission, determine the failure probability of occurrence and identify how the failure mode can be detected.

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