Fuller Engineering Design

Design Methods

FMEA - Failure Mode And Effect Analysis

Introduction

Failure Mode and Effect Analysis (FMEA) is a technique which aims to identify potential weaknesses in design, manufacture and operation of a system or product and provide a methodology of improving the design and operation to reduce the effect of the weakness to an acceptable level. Traditionally, two types of FMEA are recognised, they are the ***DESIGN FMEA*** and the ***PROCESS FMEA***. Essentially they are similar, the differences being that the FMEA is applied with different objectives with different emphasis and at different times in the product or system development life cycle.

> A Design FMEA is carried out during the design process and has the specific aim of allowing the design to be tested and if necessary changed to remove or reduce the risk of failure. The analysis may be concentrated on the engineering design aspects of components, sub-systems and systems; alternatively the analysis may be directed towards how the design effects the operation of the completed system.
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> A Process FMEA is usually carried out after the design has been finalised. The analysis may be directed towards the process of manufacture and introduction into service, or it may concentrate on the long term operation of the system taking into account the likely utilisation, maintenance and repair.

Objectives.

FMEAs are directed towards preventing defects before they occur, enhancing safety and increasing customer satisfaction. The objectives of an FMEA are to:-

- Recognise and evaluate potential defects in a component or process and determine its effects
- Examine actions that could eliminate or reduce the chance of a potential failure occurring
- Improve the design or operating process to provide greater assurance of continued safe and useful service

Hierarchical Structure.

In an FMEA each individual component failure is examined as an independent event with no relation to other failures in the system except for subsequent failures that the original failure may cause. It is necessary to identify each component and process and understand the behavioural relationships between them. This requires the product or system to have a well-ordered hierarchical structure of systems and sub-systems (which may be presented as a bill of materials). The logical combinations of events can then be considered to arrive at the final consequence.

Method of Analysis of Failure Modes.

For each component or process it is necessary to consider and assess all potential causes of failure, each of these failure modes then needs to be assessed for the following criteria:-

- The potential effect of the failure followed by the allocation of a severity rating (S) on a 0 to 10 scale
- The likely occurrence of the failure occurring followed by the allocation of an occurrence rating (O) on a 0 to 10 scale
- Assess the likelihood of detecting the potential failure followed by allocating a detection rating (D) on a 0 to 10 scale
- Calculate a Risk Priority Number (RPN) given by the product of the severity rating, the occurrence rating and the detection rating, often converted to a percentage

$$RPN = \frac{S \times O \times D}{10} \ \%$$

- Starting with the highest RPN recommend actions to reduce the severity rating S, reduce the occurrence rating O and increase the likelihood of early detection of the failure to reduce the detection rating D
- After the actions have been taken reassess the risk by evaluating new values of S, O, D and RPN

Severity Rating (S).

The severity rating S represents the seriousness of the effects in the event of a failure. The rating is determined on a scale of 01 to 10, note that the ideal lowest rating is one, not zero. In the following table the criteria to be

assessed has been sub-divided into human, equipment and environmental aspects; descriptive phrases have been provided to assist in arriving at the correct rating.

Severity Rating	Criteria		Class
10	Human Equipment Environment	Life threatening, or permanent loss of bodily function Total loss of equipment Very severe environmental damage	Extremely Hazardous
9	Human Equipment Environment	Major injury, hospitalisation required Partial loss of equipment Severe pollution., some permanent environmental damage	Hazardous
8	Human Equipment Environment	Minor injury, first aid required Breakdown of equipment. Equipment inoperative or operation cannot be continued Severe pollution, temporary environmental damage	Very High
7	Human Equipment Environment	Very severe discomfort, probable long-term accumulative medical problem Loss of major function. Operator or customer will abort process Severe pollution, does not satisfy legislation	High
6	Human Equipment Environment	Severe discomfort, possible long-term accumulative medical problem. Very high noise or vibration levels Loss of minor function but equipment continues to operate. Some operators or customers may abort process Pollution, does not satisfy legislation	Above average
5	Human Equipment Environment	Unacceptable comfort levels. High noise or vibration levels Major reduction in performance, defect causes operators or customers to have concern and to complain Pollution, does not satisfy legislation	Average
4	Human Equipment Environment	Uncomfortable to operate, noisy, vibration. High strength needed to operate equipment. Operator becomes very tired Noticeable reduction in performance, most operators or customers will notice the defect. Defect will probably be reported Some pollution, only just satisfies legislation	Below average
3	Human Equipment Environment	Not really comfortable to operate, operator becomes tired after a period of operation. Minor reduction in performance or minor difficulty causes small disruption to production, average operator or customer will notice the defect, will require some rework Some pollution	Fairly low
2	Human Equipment Environment	Little effect Minor reduction in performance, only discriminating operators or customers will notice the effect Minor difficulty but does not stop production, may require some rework Little effect	Low
1	Human Equipment Environment	No effect No effect No effect	None

Occurrence Rating (O).

The occurrence rating O represents the probability of both the failure mode and the subsequent effect occurring. The rating is determined on a scale of 01 to 10 with the lowest rating being one not zero. The failure rates shown should be used with caution as the size of the production run or the number of hours of acceptable life time have to be considered.

Occurrence Rating	Criteria	Failure Rates	Class
10	Extremely high – Failure is inevitable	> 1 in 2 or > 50% (	Extremely serious
9	Very high – Failure is almost inevitable	1 in 3 or 33·3%	Very High
8	High – Frequent premature failures	1 in 8 or 12·5%	High
7	High – Repeated failures	1 in 20 or 5%	High
6	Moderate to high – Premature failures are common	1 in 80 or 1·25%	Above average
5	Moderate – Occasional premature failures	1 in 400 or 0·25%	Average
4	Low to moderate – Relatively few failures	1 in 2000 or 0.·05%	Below average
3	Low – Very few failures.	1 in 15,000 or 0·0067%	Fairly low
2	Very low – Occasional premature failure	1 in 150,000 or 0·00067%	Low
1	Remote - Failure is unlikely	< 1 in 1,500,000 or <0·000067%	None

For a Process FMEA in manufacturing a six-sigma process of ±3σ with a non-shifted normal distribution has defects of 2,700 per million or 0·27% equivalent to a FMEA occurrence rating just over 5. If the normal distribution is shifted ±1·5σ from the required central value then the defect rate rises to 66,810 per million or 6·681% equivalent to a FMEA occurrence rating between 7 and 8. A FMEA occurrence rating of 3 is approximately ±4σ and a FMEA occurrence rating of 1 is approximately equivalent to ±5σ.

Detection Rating (D).

The detection rating D represents the likelihood of early discovery of the failure before the failure occurs or before the consequences of the failure occur. For a design FMEA this assumes that a system of design monitoring is being used and the rating is a measure of how well the design monitoring process can detect or predict the possible failure. For a process FMEA the assumption is that a process monitoring system is being used which can detect the failure. The rating is determined on a scale of 01 to 10 as follows:-

Detection Rating	Criteria	Class
10	No monitoring system in place. Or monitoring system can not detect this cause of failure or subsequent failure mode.	Absolute uncertainty
9	Monitoring system is ineffective, very remote chance that the monitoring system can detect this cause of failure or subsequent failure mode.	Very remote
8	Monitoring system is ineffective, remote chance that the monitoring system can detect this cause of failure or subsequent failure mode.	Remote
7	Monitoring system is not very effective, very low chance that the monitoring system can detect this cause of failure or subsequent failure mode.	Very low
6	Monitoring system is not very effective, low chance that the monitoring system can detect this cause of failure or subsequent failure mode.	Low
5	Monitoring system is effective, moderate probability that the monitoring system can detect this cause of failure or subsequent failure mode.	Moderate
4	Monitoring system is effective, moderately high probability that the monitoring system can detect this cause of failure or subsequent failure mode.	Moderately high
3	Monitoring system is effective, high probability that the monitoring system can detect this cause of failure or subsequent failure mode.	High
2	Monitoring system is very effective, very high probability that the monitoring system can detect this cause of failure or subsequent failure mode.	Very high
1	Monitoring system is absolutely effective, certain that the monitoring system can detect this cause of failure or subsequent failure mode.	Almost certain

Design FMEA monitoring techniques should include:-

The application of recognised design codes,
The use of specialist design calculations such as stress analysis, flow calculation, mass and heat transfer analysis,
A formal checking and approval procedure of the design process,
A formal drawing release procedures, a formal design change control procedure.

Process FMEA monitoring techniques should include:-

Production inspection procedures.
Product and system test.
Instrumentation to monitor critical flows, pressures, currents etc.
Vibration measurement.

Risk Priority Number (RPN).

The calculated RPN, which is the product of the severity rating, the occurrence rating and the detection rating expressed as a percentage, is used an indication of the overall risk and the priority which should be applied to tackling the various risks. Those risks with the highest values of RPN should be tackled first, any RPN greater than 10% must be considered and any individual severity rating, occurrence rating or detection rating greater than 4 should be tackled.

Action Recommendations.

Action recommendations should be made that will reduce the severity rating and occurrence rating to acceptable values. Methods should be introduced to increase the possibility of detection and hence reduce the detection rating.

Post Action or Final Risk Assessment.

After the recommended actions have been completed a post action or final FREA should be carried out to check that the risk has been reduced to an acceptable level.