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Implementation of FMECA on Industrial Tool Room Cooling System

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Abstract

Failure analysis method with the application of FMECA on industrial cooling system has been proposed in this study. The objective of FMECA application is to classify critical and non critical failure modes with the help of criticality matrix and criticality graph and prepare a maintenance strategy to improve the performance and life of the components. Effective utilization is the major point of interest of many companies. This paper focuses on selection of suitable maintenance techniques with the help of FMECA which helps to reduce down time.

Keywords: Failure Analysis; FMEA; FMECA; Criticality Number; Criticality Matrix

1. Introduction

The natural process of the failure of a mechanical component/assembly associates to its age, mainly the wear and tear effects. In many cases it has been noticed that component performance is directly proportional to the aging of the components. The consequences of failure are many and varied, but the economic impact of the failures can't be ignored. Generally there are two types of failure: Functional and potential. Functional failure occurs when a component exhibits the incompetency to perform under a specified standards, whereas potential failure is a detectable physical condition suggesting a forthcoming functional failure [2].

In manufacturing industries, production machine failures bother the whole system in many ways. It may cause machine downtime, increased dissatisfaction in terms of customers, lack of availability, production cost may get affected due to increased maintenance time, quality degradation and delay in supply of the desired products. In case of chemical or nuclear plants, it is not only costlier but sometimes it is not admissible in keeping the view of safety issues. In fact, complete avoidance of failure is not possible, the risks and effects associated with it can be optimize and controlled by practicing efficient maintenance techniques.

The failure analysis must be the point of concern in the decision-making process towards the enhancement of the performance of a component/system. In the operating stage of a component system, data based on field failure analysis play an important role to identify, classify to quantify the criticality of physical and function failure. For identifying these failures, the application of semi-qualitative failure analysis tool, failure mode and effect analysis (FMEA) and/ or Failure Mode Effect and Criticality Analysis (FMECA) are the most eminent tools. Failure Modes and Effects Analysis (FMEA) and Failure Modes, Effects and Criticality Analysis (FMECA) are tried and tested tools or methods to identify potential failure mode to process the risk. Even though FMEA/FMECA is used as a problem prevention tool to increase the trust factor of a system/component, early designing stage to functional stage. The FMEA/FMECA applies to estimate comprehensively the effects of each failure mode of every component on a system.

The FMECA will: highlight single point failures demanding corrective measures; assistant in evolving test methods and troubleshooting techniques; provide a foundation for qualitative reliability, maintainability, safety and logistics analyses; provide approximation about system critical failure rates; provide a quantitative ranking of system and/or subsystem failure modes relative to mission importance; and identify parts & systems most likely to fail.

2. Literature Review

The literature presents the related research of FMEA/ FMECA and its application and extended works. Ahmad et al. (2012) proposed a failure analysis method by integrating the Failure Mode Effect and Criticality Analysis (FMECA) and Failure Time Modeling (FTM) based on Proportional Hazard Model (PHM) [2].Liu et al. (2012) assessed the ratings and weights for the risk factors O, S, and D using linguistic variables, expressed in trapezoidal or triangular fuzzy numbers. Wang et al. (2012) proposed risk-based maintenance (RBM) strategy is a useful tool to design a cost-effective maintenance schedule. In this paper, to quantify the severity of personnel injury and environmental pollution, a failure modes and effects analysis (FMEA) method is developed using subjective information derived from domain experts [3]. Sarkar et al. (2011) proposed a methodology to study the criticality

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analysis of components of Gas Turbine Power Plant Systems (GTPPS) and the failures occurring in the plant. FMECA is carried out to estimate the criticality number for different components and failure modes [7].Li et al. (2010) proposed Radical Maintenance (RM) which takes the root causes of failures as executive objects to make maintenance decisions [9]. Aymen Mili et al (2008) proposed a method using FMECA as an operational tool which unveils productivity improvement areas. It demonstrates that it is possible to use FMECA method in a more dynamic environment, continuously updated by operational events [12]. Puthillath et al. (2008) was proposed how to select suitable maintenance techniques that helps to reduce downtime and increase productivity. To demonstrate the selection process a chemical industry is used as a case study. Failure Mode and Effect Analysis (FMEA) is used for selection of maintenance technique [13].

The current paper deals with the failure analysis of an industrial cooling system with the help of FMECA.

3. Objective of the Work

The main objective of this work is to analyze the various failure modes of an industrial cooling system and priorities of each failure modes based on the criticality and also mark some recommendations to improve the maintenance strategy of the industrial cooling system. The main objectives are given below:

- Determination of criticality number for failure modes of industrial cooling system.
- Preparation of Criticality Matrix with the help of Criticality Number.
- Selection of critical components with the help of criticality matrix.
- Preparing maintenance strategy to improve the performance as well as longevity of the components.

4. Proposed Methodology

Fig 1 shows the block diagram of proposed methodology. While conducting FMECA, the set order of the tests must be followed. The CA should be conducted after the FMEA. The FMEA will work as the fundamental tool of the Criticality Analysis. The FMEA will help the users to recognize systems and/or components and failure modes associated with it. This segment of the test makes us available an assessment indicating the reason of failure mode and its consequences.

The main steps of FMECA are identification of failure modes, failure effect cause analysis, assigning of severity ranking and criticality analysis. The first step of analysis is to construct the functional block diagram of the system. Next step is to identify the all possible failure modes of the system. Next step is to analyse causes of failure of each failure mode. Then, assign severity ranking for each failure modes. Final step of the FMECA is criticality analysis.

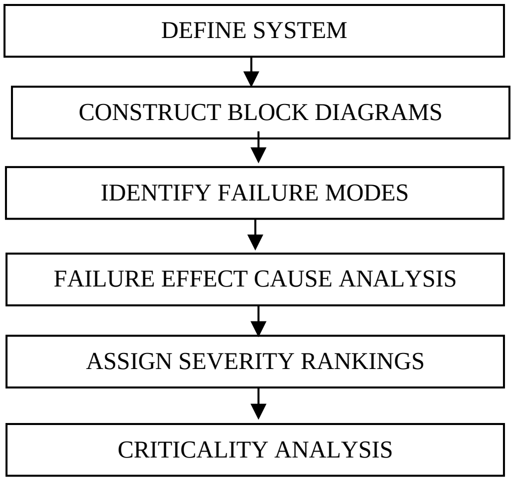

Fig 1 FMECA flow diagram [26]

During FMECA analysis failure mode identification must be performed first, which is a qualitative action of the investigation. Failure modes of a machine/component recognized and categorized either on the basis of its functionality or physical point of view. The next step is failure effect cause analysis, which is recognized as a qualitative type analysis. Generally, the objective of failure cause identification step is to point out the possible cause or causes that contribute to each failure mode. After completing the documentation of all failure modes and their effects on the system in the FMEA, we should provide the ranking of the effect on the mission for each failure mode. While doing criticality analysis ranging of the failure modes will play a vital role to quantify the relative severity ranking of each major failure modes. A severity classification is carried out to each pre recognized failure mode and each item is subjected for analysis according to the categories shown below;

1. Category I - Minor: A failure with very low severity. The probability of property damage or system damage is very low, but unscheduled maintenance or repair might be taken place.
2. Category II - Marginal**:** A failure with relatively high risk of damage which may cause minor injury, minor property damage, or minor system damage consequently delay or loss of availability or mission degradation might be appeared.
3. Category III - Critical**:** A failure with high severity and causes severe injury or major system damage consequently mission loss might be taken place. Restoring of functioning may exhibits the significant delay to the system will occur.
4. Category IV - Catastrophic**:** A failure which may cause death or lack of ability to carry out mission without warning [2].

4.1 Criticality analysis

Final step of the proposed methodology is criticality analysis. Finally it interprets the importance of the effects of a failure mode, as well as the significance of an entire equipment or system, on safe, successful working and mission requirements. This tool plays an important role to set the priorities and to minimize the impact of the critical failures in the design earlier. The main steps of criticality analysis are calculation of criticality number, creation of criticality matrix, determination of critical items and provide recommendations based on analysis.

1) Failure Mode Criticality Number (Cm)

The failure mode criticality number is a relative measure of the frequency of a failure mode. In essence it is a mathematical means to provide a number in order to rank importance based on its failure rate. The equation used to calculate this number is as follows:

$$C_m = ß.\alpha.\lambda_p.t \text{ [2]}$$

Where Cm is the failure mode criticality number, β is the conditional probability of the current failure mode's failure effect, α is the failure mode ratio, λp is item failure rate and t is the duration of applicable mission phase (expressed in hours).

5. Research Work

The applicability of methodology presented in section 3 is validated in an industrial case study was undertaken on an industrial cooling system which is used to maintain a certain temperature to the tool room at CLASSIC ENGINEERING WORKS, KOCHIN.

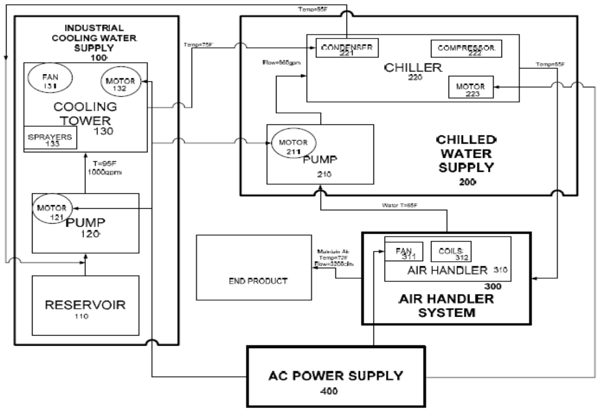

Fig. 2. Functional block diagram of Industrial Cooling System [27]

They provide the schematic and operational details of the system. The mission of the facility is to maintain a temperature of 720F to the tool room. Mission of the system must be identified prior to analysis. The system indenture level must be identified. Fig 2 shows the functional block diagram of the industrial cooling system.

The block diagrams provide the ability to trace the failure mode effects through each level of indenture. With the help block diagram, identify possible failure modes and the effects of failure. The data which identified are added to the FMECA work sheet.

This method works when failure rates, failure modes, failure mode ratios, and failure effects probabilities are given. These variables are useful to quantify a "criticality number" which is used to prioritize items of concern. This comes into play on the completion of design when confident data on the system can be collected. After completing the calculation of criticality numbers of each item, those values are also added in to the FMECA work sheet. Table 1 shows the completed FMECA work sheet of industrial cooling system.

Table 1. Completed FMECA worksheet

Failure Mode Effect And Criticality Analysis

SYSTEM: Mechanical System
PART NAME: Industrial Cooling System
REFERENCE DRAWING:
MISSION: Provide Temperature Control To Tool Room

DATE:01-02-2013
SHEET: 1 0f 4
COMPILED BY:
APPROVED BY:

ITEM NUMBER	ITEM OR FUNCTIONAL ID	POTENTIOL FAILURE MODE	SEVERITY	FAILURE RATE λ_P	FAILURE EFFECT PROBILITY (β)	FAILURE MODE RATIO (α)	OPERATING TIME (t)	FAILURE MODE CRITICALITY NUMBER C_M
110.0	Reservoir contain 6000 gallon of water	Leak	4	1.500×10^{-6}	1	1	61320	9.198×10^{-2}
120.0	Pump / transport industrial water at 1000 GPM	Transport water at a rate above 1000 GPM	3	12.058×10^{-6}	1	.35	61320	2.587×10^{-1}
120.1		Restricted/no water flow	3	12.058×10^{-6}	1	.65	61320	4.806×10^{-1}
130.0	Cooling tower / maintain a water temp of 75^0F	Scaling (deposits) on media	4	10.0518×10^{-6}	1	.36	61320	2.218×10^{-1}
130.1		Clogged sprayers	4	10.0518×10^{-6}	1	.36	61320	2.71×10^{-1}
130.2		Fan failure	3	10.0518×10^{-6}	1	.2	61320	1.232×10^{-1}
210.0	Pump transport chilled water supply 960 GPM	Degraded operation produce water less than 960 GPM	3	12.058×10^{-6}	1	.35	61320	2.587×10^{-1}
210.1		Produce no water flow	3	12.058×10^{-6}	1	.65	61320	4.806×10^{-1}
220.0	Chiller remove heat from(10^0F) chilled water	Degraded operation remove less than 10^0F	3	9.279×10^{-6}	1	.72	61320	4.096×10^{-1}
220.1		Remove no heat	4	9.279×10^{-6}	1	.08	61320	4.551×10^{-2}
220.2		Remove more than 10^0F	3	9.279×10^{-6}	1	.2	61320	1.137×10^{-1}
310.0	Air handler/ maintain room temperature of 72^0F, 3200cfm	Maintain air temperature higher than 72^0F	3	1.765×10-6	1	.25	61320	2.698×10^{-2}
310.1		Provide air flow at a rate less than 3200cfm	3	1.765×10-6	1	.30	61320	3.237×10^{-2}
310.2		Maintain air temperature less than 72^0F	3	1.765×10-6	1	.2	61320	2.158×10^{-2}
310.3		Provide no air flow	4	1.765×10-6	1	.25	61320	2.698×10^{-2}

Table 2. Failure Modes and its Criticality Number

Item	Failure Mode	Criticality Number
110.0	Leak	9.198×10^{-2}
120.0	Transport water at a rate above 1000 GPM	2.587×10^{-1}
120.1	Restricted/no water flow	4.806×10^{-1}
130.0	Scaling (deposits) on media	2.218×10^{-1}
130.1	Clogged sprayers	2.71×10^{-1}
130.2	Fan failure	1.232×10^{-1}
210.0	Degraded operation produce water less than 960 GPM	2.587×10^{-1}
210.1	Produce no water flow	4.806×10^{-1}
220.0	Degraded operation remove less than 10^{0}F	4.096×10^{-1}
220.1	Remove no heat	4.551×10^{-2}
220.2	Remove more than 10^{0}F	1.137×10^{-1}
310.0	Maintain air temperature higher than 72^{0}F	2.698×10^{-2}
310.1	Provide air flow at a rate less than 3200cfm	3.237×10^{-2}
310.2	Maintain air temperature less than 72^{0}F	2.158×10^{-2}
310.3	Provide no air flow	2.698×10^{-2}

Table 2 shows the failure modes of industrial cooling system and criticality number of each failure. It is used to create the criticality matrix.

5.1 Criticality matrix

The Criticality Matrix is a graphical or visual means of identifying and comparing failure modes for all components within a given system or subsystem and their probability of occurring with respect to severity. The matrix can be used in order to prioritize components.

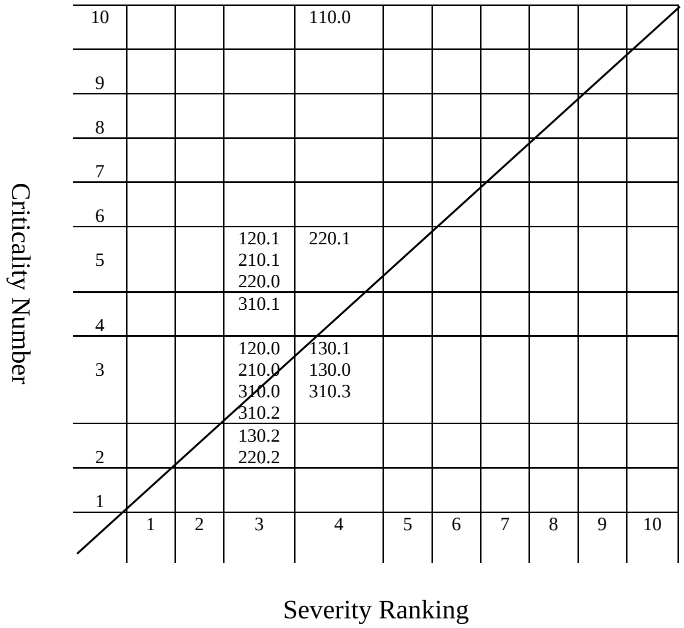

Fig. 3. Criticality Matrix

6. Result and Discussion

Table 2 summarizes the FMEAC work sheet. Based on the table, generate a criticality matrix which is help full for sort out critical and non critical failure modes. Utilizing the Criticality Matrix, items in the upper most right hand quadrant will receive attention first.

Fig 4 shows the failure mode criticality graph of industrial tool room cooling system. Based on the graph, we can find out the critical and non-critical item. In the above graph, items shows in red color are more critical components and items shows in blue color are less critical component. Based on the graph we can differentiate the critical and non critical component. Below table shows the critical and non critical failure modes.

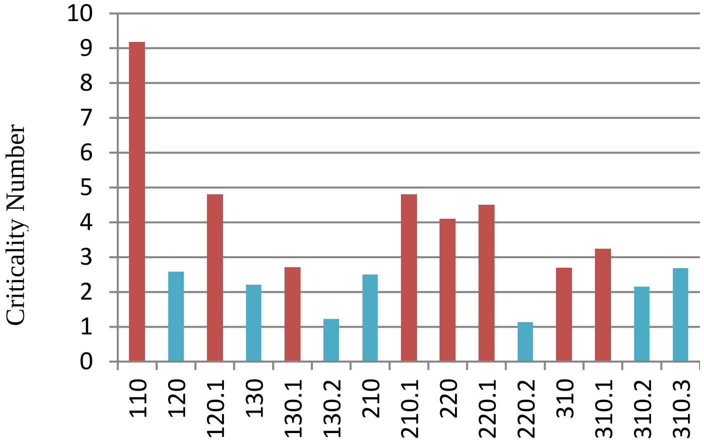

Fig. 4. Failure Mode Criticality Graph

Table 3 shows the critical and non critical failure modes of industrial cooling system. Item number 110, 120.1, 210.1, 220.1, 220, 310.1, 310 and 130.1 are critical components and item number 310.3, 120.0, 210, 130, 310.2, 220.2 and 130.2 are non critical components based on the graph

Table 3. Critical and Non-critical Failure Modes.

CRITICAL	NON CRITICAL
110.0	310.3
120.1	120.0
210.1	210.0
220.1	130.0
220.0	310.2
310.1	220.2
130.1	130.2
310.0	

6.1 Recommendations based on criticality matrix

1. First the items should be assigned in their respective "squares" in the criticality matrix, It gives the information about the components which needs further review. This helps in fast judgement of items. If the matrix has many items with the same or roughly same criticality number the team has the right to make the priority list of item as per the need of time. . Below shows the recommendations made based on criticality matrix.
2. Item #110.0 indicates the reservoir with high failure rate. Therefore possibility of another reservoir which has lower failure rate with the condition of annual evaluation/inspection should more appropriate option for the same.
3. Item #220.1 indicates the incompetency of the chiller to extract the heat from the chilled water supply. This shows the high failure rate and may cause an accidental phenomenon. To prevent any accidental event it should be inspected in regular interval of time and eddy current testing should be done annually to check the damage of the tubes. Motor must be inspected annually to monitor the windings. Fatal breakdown of the chiller can be prevented by continuous monitoring of temperature along with the present sensors. Same should be practiced with item 220.0 too.
4. Item numbers 310.0, 310.1, 310.2 & 310.3 all are about the air handler system. Among them item no 310.0 and 310.1 have the highest failure rate. Therefore preventive actions for the proper monitoring and maintenance

should be deployed initially on manufacturer's demand. Interval of monitoring the system can be adjusted according to evaluation report from the maintenance action. Single belt driven fan should not be used instead the use sheave with three belt system should be suggested to use for a safe action or to diminish the chance of failure. One extra motor for instantaneous replacement in case of failure is the add on precautionary action. Quarterly greasing of bearings and replacing the air filters twice in a year will decrease the chance of failure.

5. Item numbers 130.0, 130.1, and 130.2 possess comparatively high severities and average failure rates. They all are associated with cooling towers. Contamination of the water is the responsible factor for the failure of these items. To prevent these failures regular monitoring of the water through appropriate analysis technique and chemical treatment as desired must be taken place. Water filtering and changing the filtering devices should be done on the regular basis. Sprayers and fan motors must be ready to use it quickly in case of immediate failure. Annual maintenance is also desirable to avoid or decrease the chance of failure.
6. The final four failure modes are related with the pumps of chilled water supply and the industrial cooling water supply. Chilled water supply pump should be on first priority because absence of chilled water supply withheld the heat removal which may cause an accidental failure of whole system. Otherwise both the pumps should be inspected in regular interval of time and suitable corrective measures should be taken to insure the proper working.

7. Conclusion

The FMECA is a very useful tool to manage the system of a machine effectively. It becomes more efficient if is implemented from designing stage to functional use of a system. Early initiation of this tool by providing the systematic information with the prioritized list of identified areas helps to minimize the cost of maintenance

The results reflected from above study, clearly indicates that FMECA can be an effective tool which facilitates the maintenance manager to enable to criticality of the components in a particular department/section. Hence this tool can be effectively utilized in present industrial scenario.

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