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Risk assessment of failure modes of gas diffuser liner of V94.2 siemens gas turbine by FMEA method

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Abstract. Failure of welding connection of gas diffuser liner and exhaust casing is one of the failure modes of V94.2 gas turbines which are happened in some power plants. This defect is one of the uncertainties of customers when they want to accept the final commissioning of this product. According to this, the risk priority of this failure evaluated by failure modes and effect analysis (FMEA) method to find out whether this failure is catastrophic for turbine performance and is harmful for humans. By using history of 110 gas turbines of this model which are used in some power plants, the severity number, occurrence number and detection number of failure determined and consequently the Risk Priority Number (RPN) of failure determined. Finally, critically matrix of potential failures is created and illustrated that failure modes are located in safe zone.

1. Introduction

The significance of power plant maintenance has dramatically surged in the recent years as the pivotal role of electrical devices in everyday life has become more evident. This is the rationale behind power plant managers employing maintenance programs – such as condition monitoring – to avoid unpredicted shutdowns.

One of the measures useful for the power plant maintenance systems is utilizing risk assessment methods to ascertain the hazard of unpredictable failures. FMEA is one of the risk assessments methods used during the design process of gas turbine through helping the executive personnel of power plants.

The crack on V94.2 gas diffuser liner is one of the failures transpiring in turbines utilized in certain power plants. This defect is one of the uncertainties of customers when they want to approve of the final commissioning of the product. Based on the request of costumers, the consequences of this failure are studied. A database has been developed in accordance with the history of failures in the power plants in Iran. By using the FMEA method and the provided database, the severity number, occurrence number and detection number of failure can be determined.

In this paper, first, the fundamentals of risk analysis and FMEA method are expounded and then the pertinent terms concerning the evaluation of failure risk are elaborated according to IEC standard: Code 60812. Afterwards, the potential failure modes have been assessed based upon IEC standard: Code 60812. Eventually, "Risk Priority Number" and critical matrix of potential failures are produced.

2. Risk Analysis and Risk Management

Risk management is an activity identifying existing and threatening risks, estimating their impacts and taking appropriate measures to reduce or hedge the risks [1]. The risk management process can be divided into five steps as listed below. First, risks are identified and evaluated, which is often referred to as risk analysis [2]:

1- Risk identification
2- Risk evaluation (probability & consequence)
3- Development and evaluation of risk management methods
4- Risk management decisions
5- Evaluation of implanted risk management solutions

The purpose of the first step is to identify all relevant risks of the situation under study. There are several techniques available to aid the process. In this paper, the failure mode and effect analysis (FMEA) is used to identify risks. When a tentative list of potential risk is gathered, the risks are screened in order to decide which ones may be neglected and which should be further analyzed. In the second step of the risk management process, risk evaluation, the probability of occurrence and consequences of the relevant risks are assessed. This involves usually utilization of models describing the dependencies of the uncertainties and analysis methods such as simulation.

3. FMEA method

A failure modes and effects analysis (FMEA) is a procedure in product development and operation management for analysis of potential failure modes within a system for classification by the severity and likelihood of the failures. A successful FMEA activity helps a team to identify potential failure modes based on the past experience with similar products or processes, enabling the team to design those failures out of the system with the minimum of effort and resource expenditure, thereby reducing development time and costs. It is widely used in manufacturing industries in various phases of the product life cycle and is now increasingly finding use in the service industry [3], [4].

In FMEA, failures are prioritized according to how serious their consequences are, how frequently they occur and how easily they can be detected. A FMEA also documents current knowledge and actions about the risks of failures for use in continuous improvement. The outcomes of an FMEA development are actions to prevent or reduce the severity or likelihood of failures, starting with the highest-priority ones. It may be used to evaluate risk management priorities for mitigating known threat vulnerabilities. FMEA helps select remedial actions that reduce cumulative impacts of life-cycle consequences (risks) from a systems failure (fault).

FMEA is intended to provide an analytical approach, when dealing with potential failure modes and their associated causes. FMEA is a recognized tool to help to assess which risks has the greatest concern, and therefore which risks addressing in order to prevent problems before it arises. The development of these specifications helps to ensure the product will meet the defined requirements and customer needs [5].

Before starting with an FMEA, a worksheet needs to be created which contains the important information about the system. On this worksheet all the items or functions of the subject should be listed in a logical manner. This worksheet will be completed in 3 steps which are described as followed [5].

3.1. Sensitivity

In this step, all failure modes will be determined based on the functional requirements and their effects. A failure mode in one component can lead to a failure mode in another component; therefore each failure mode should be listed in technical terms and their function.

Hereafter the ultimate effect of each failure mode needs to be considered. In this way it is appropriate to write these effects down in terms of what the user might see or experience. Each effect is given a sensitivity number (S) from 1 (no danger) to 10 (critical) (Table 1). These numbers help an engineer to prioritize the failure modes and their effects. A sensitivity rating of 9 or 10 is generally reserved for those effects which would cause injury to a user or otherwise result in litigation.

Table 1. Failure mode severity [5].

Severity	Criteria	Ranking
None	No discernible effect.	1
Very minor	Fit and finish/squeak and rattle item do not conform. Defect noticed by discriminating customers (less than 25 %).	2
Minor	Fit and finish/squeak and rattle item do not conform. Defect noticed by 50 % of customers.	3
Very low	Fit and finish/squeak and rattle item do not conform. Defect noticed by most customers (greater than 75%)	4
Low	Vehicle/item operable but conform/convenience item(s) operable at a reduced level of performance. Customer somewhat dissatisfied	5
Moderate	Vehicle/item operable but conform/convenience item(s) inoperable. Customer dissatisfied	6
High	Vehicle/item operable but at a reduced level of performance. Customer very dissatisfied	7
Very high	Vehicle/item inoperable (loss of primary function)	8
Hazardous with warning	Very high severity ranking when a potential failure mode affects safe vehicle operation and/or involves non-compliance with government regulation with warning	9
Hazardous without warning	Very high severity ranking when a potential failure mode affects safe vehicle operation and/or involves non-compliance with government regulation without warning	10

3.2. Occurrence

In this step it is necessary to look at the cause of a failure mode and the frequency of occurrence. This can be done by looking at the similar products or processes and the failure modes that have been documented for them. All the potential causes for a failure mode should be identified and documented. A failure mode is given an *occurrence ranking (O)*, again 1–10. Occurrence ranking (O) is shown in table 2.

Table 2. Failure mode occurrence [5].

Failure mode occurrence	Rating	Frequency	Probability
Remote: Failure is unlikely	1	≤0.010 per thousand vehicles/items	$\leq 1\times10^{-5}$
Low: Relatively few failures	2	0.1 per thousand vehicles/items	1×10^{-4}
	3	0.5 per thousand vehicles/items	5×10^{-4}
Moderate: occasional failures	4	1 per thousand vehicles/items	1×10^{-3}
	5	2 per thousand vehicles/items	2×10^{-3}
	6	5 per thousand vehicles/items	5×10^{-3}
High: repeated failures	7	10 per thousand vehicles/items	1×10^{-2}
	8	20 per thousand vehicles/items	2×10^{-2}
Very high: Failure is almost inevitable	9	50 per thousand vehicles/items	5×10^{-2}
	10	≥100 in thousand vehicles/items	$\geq 1\times10^{-1}$

3.3. *Detection*

First, an engineer should look at the current controls of the system, that prevent failure modes from occurring or which detect the failure before it reaches the customer. Hereafter one should identify testing, analysis, monitoring and other techniques that can be or have been used on similar systems to detect failures. From these controls an engineer can learn how likely it is for a failure to be identified or detected.

Each combination from the previous 2 steps receives a detection number (D). This ranks the ability of planned tests and inspections to remove defects or detect failure modes in time. The assigned detection number measures the risk that the failure will escape detection. A high detection number indicates that the chances are high that the failure will escape detection, or in other words, that the chances of detection are low. The ranking of this parameter is shown in table 3.

Table 3. Failure mode detection evaluation criteria [5].

Detection	Criteria	Ranking
Almost certain	Design control will almost certainly detect a potential cause/mechanism and subsequent failure mode.	1
Very high	Very high chance the design control will detect a potential cause/mechanism and subsequent failure mode	2
High	High chance the design control will detect a potential cause/mechanism and subsequent failure mode	3
Moderately high	Moderately high chance the design control will detect a potential cause/mechanism and subsequent failure mode	4
Moderate	Moderate chance the design control will detect a potential cause/mechanism and subsequent failure mode	5
Low	Low chance the design control will detect a potential cause/mechanism and subsequent failure mode	6
Very low	Very low chance the design control will detect a potential cause/mechanism and subsequent failure mode	7
Remote	Remote chance the design control will detect a potential cause/mechanism and subsequent failure mode	8
Very remote	Very remote chance the design control will detect a potential cause/mechanism and subsequent failure mode	9
Absolutely uncertain	Design control will not and/or cannot detect a potential cause/mechanism and subsequent failure mode: or there is no design control	10

After estimating these parameters, the Risk Priority Number (RPN) must be calculated.

3.4. *Risk Priority Number (RPN)*

RPN play an important part in the choice of an action against failure modes. They are threshold values in the evaluation of these actions. After ranking the severity, occurrence and detection the RPN can be easily calculated by multiplying these three numbers:

$$RPN=S*O*D \tag{1}$$

Once this is done, it is easy to determine the areas of the greatest concern. The failure modes that have the highest RPN should be given the highest priority for corrective action. This means it is not always the failure modes with the highest severity numbers that should be treated first. There could be less severe failures, but which occur more often and are less detectable.

4. Gas diffuser liner failure

Gas turbine exhaust has an elevated temperature and it passes through the gas diffuser, leading to diffuser expansion, and consequently, two compensators are designed in the gas diffuser and two smooth liners are located under each compensator (figure 1). The temperature of turbine exhaust is approximately 540°C, and this must be tolerated by both liners. As mentioned above, a crack on the liner weld bead of the gas diffuser has been reported as a defect of the gas turbine and this result in uncertainty of customers (figure 2). According to this matter, the FMEA method is used to evaluate the threat of this failure and to check the consequences of failure. In the first step, all the potential failures which could occur are listed, and by using the FMEA, the severity number, occurrence number and detection number of each failure mode are evaluated in the following sections.

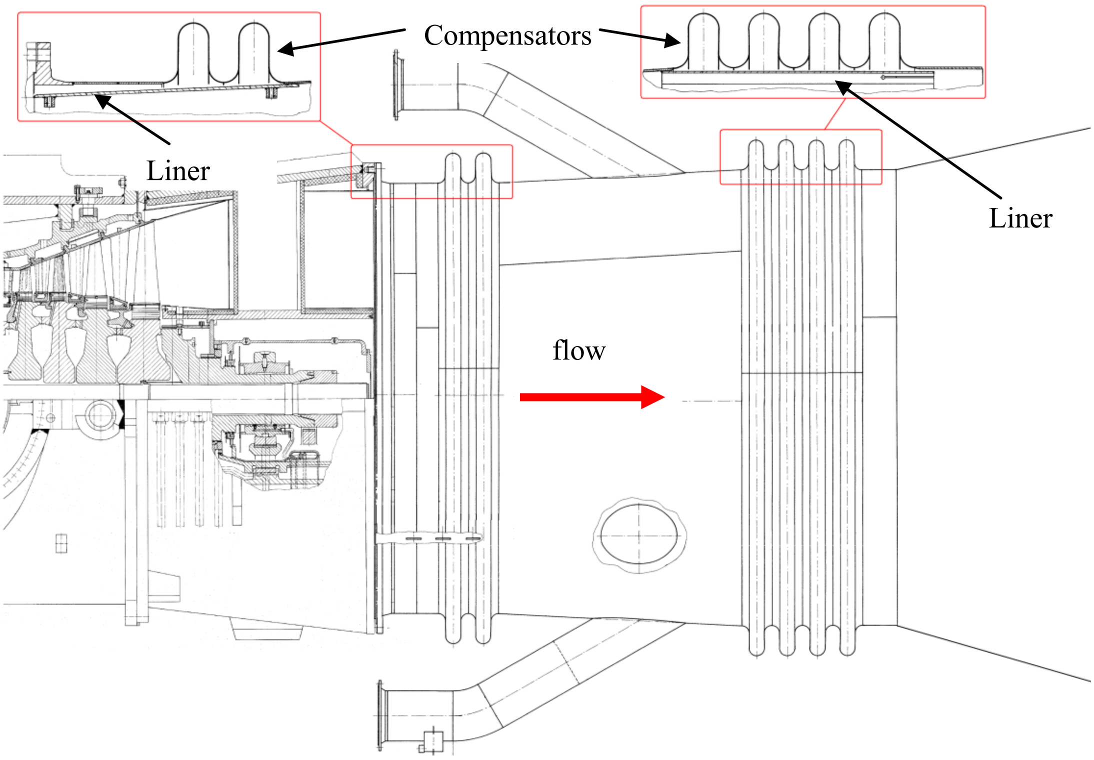

Figure 1. Exhaust diffuser configuration.

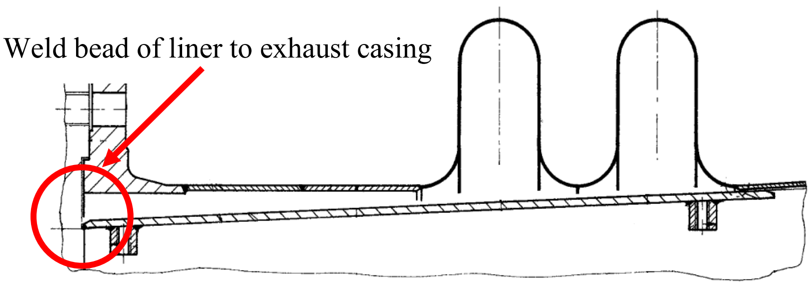

Figure 2. Weld bead of first liner.

5. Evaluation of liner failure risk by FMEA method

In this step, the failure modes of gas diffuser liner of V94.2 will be evaluated. For this, first, the worksheet is prepared - illustrated in table 4 and table 5. The worksheet mainly incorporates the potentials to cause the liner failure.

Table 4. Potential failure modes of gas diffuser liner failure.

Potential failure mode	Potential cause(s)	Potential effects of failure	Failure mode number
Circumferential Cracking on the weld seam connecting the diffuser liner and casing liner	Changing the clearance between diffuser liner and diffuser outer casing	Increasing the liner clearance (6+2 clearance) and consequently gas escapes to space between liner and expansion joint and finally reduction of expansion joint life	FM 1
		Increasing the liner clearance (6+2 clearance) and consequently gas escape to space between liner and expansion joint and finally increasing the exhaust casing temperature	FM 2
		Increment of turbine absolute vibration due to contact of diffuser liner and diffuser outer casing	FM 3
		Contact of diffuser liner and diffuser cone and increment of vibration and consequently reduction of life of welding joints of diffuser outer casing	FM 4
	Exhaust gas leaks from the crack of weld joint into space between diffuser liner and diffuser outer casing	Exhaust gas escape in space between diffuser liner and diffuser outer casing and consequently reduction of expansion joint life	FM 5
		Exhaust gas escape in space between diffuser liner and diffuser cone and consequently increment of the exhaust casing temperature	FM 6
	Increasing the diffuser liner vibration and consequently increase of diffuser outer casing vibration	Increase of absolute vibration of Turbine	FM 7
Detachment of first liner of diffuser	Collision of liner with thermocouples which are measuring the temperature of exhaust gas	Thermocouples are damaged and consequently the control and monitoring system is failed	FM 8
	Emerging turbulence in turbine outlet flow	Reduction of turbine performance	FM 9
	Hot turbine exhaust flow is directed towards the gas diffuser outer casing	Reduction of expansion joint life	FM 10
		The temperature of exhaust casing increases and it is deformed due to temperature increase	FM 11
	Liner vibrations are transmitted to the stationary turbine parts	Increment of absolute vibration of Turbine	FM 12

Table 5. FMEA worksheet for risk analysis of gas diffuser liner failure.

Failure Mode Number	Severity	Occurrence	Detection	RPN
FM 1	2	1	7	14
FM 2	3	3	6	54
FM 3	5	6	2	60
FM 4	3	3	8	72
FM 5	2	2	7	28
FM 6	3	1	7	21
FM 7	5	2	4	40
FM 8	9	1	2	18
FM 9	7	2	3	42
FM 10	6	1	4	24
FM 11	4	1	7	28
FM 12	7	1	3	21

6. Critical matrix

Based on the data presented in table 5, the critical matrix has been completed and depicted in figure 3. The variables of critical matrix are severity number and occurrence number. In figure 3, the LR, FM and HR are the abbreviations of low risk, failure mode and high risk. As stated in figure 3, six failure modes are located in the negligible risk zone. Moreover, five failure modes are situated in the minor risk zone and only one failure mode (FM 3) is in the moderate risk zone. Ergo, there is no failure mode in serious or critical zones and all the noticed failure modes are in acceptable zones.

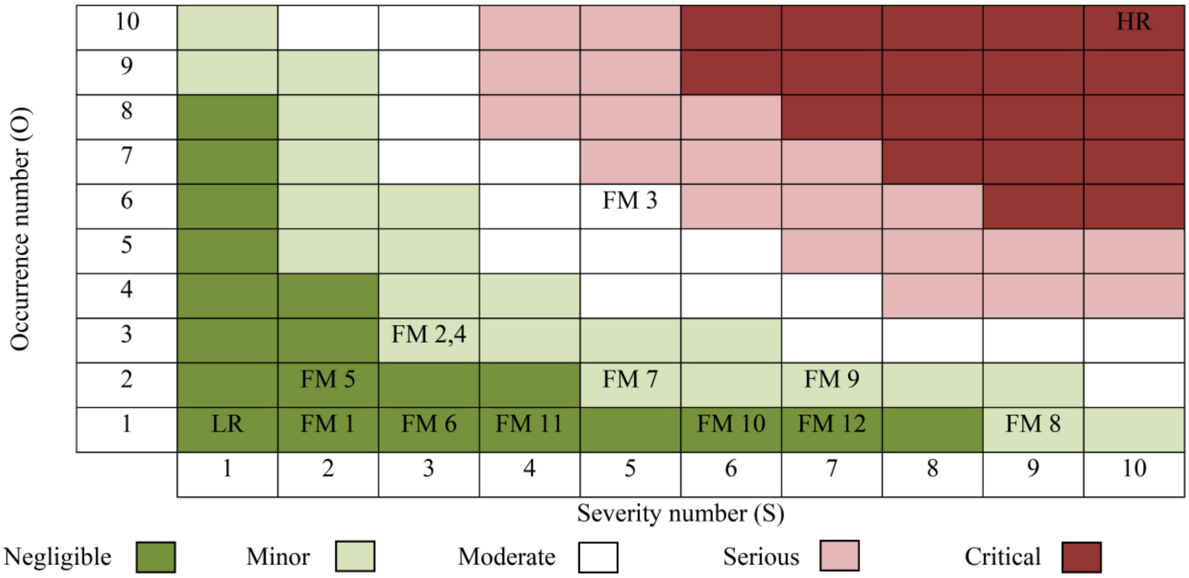

Figure 3. Critical matrix.

7. Summary

In this paper, the risk of failure modes of the gas diffuser liner of V94.2 Siemens Gas Turbine has been estimated via the FMEA procedure. For this reason, the potential failure modes and their consequences have been elucidated and listed. In the next step, in accordance with the database of failures, the severity number, occurrence number and detection number of each failure mode has bee evaluated and risk priority number has been calculated. Finally, the critical matrix has been extracted and based on the critically matrix, the failure modes are located in the safe zones and there is no serious failure modes for the turbine.

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References

[1] Pausenberger E and Nassauer F 2000 *Risk Management, Challenge and Opportunity* ed F Michael , H Ulrich and R Markus (Berlin: Springer) pp263-276
[2] Porthin M 2004 *Advanced Case Studies in Risk Management* (Master thesis, Helsinki University of Technology) p 11
[3] Dill Robert et. Al. 1963 *State of Art Reliability Estimate of Saturn V Propulsion Systems* (General electric company, RM 63TMP-22)
[4] 2010 *Failure Modes, Effects and Critically Analysis (FMECA)* (National Aeronautics and Space Administration JPL. PD-AD-1307)
[5] IEC standard: Code 60812.