World Journal of Advanced Engineering Technology and Sciences
eISSN: 2582-8266
Cross Ref DOI: 10.30574/wjaets
Journal homepage: https://wjaets.com/

(Research Article)

Failure Mode and Effect Analysis (FMEA) of a Taurus 60 Gas Turbine Power Plant System (GTPPS), in Mowe, Nigeria

Olufemi Oluseun Sanyaolu [1, *], Ayodele Samuel Onawumi [2], Abiola Olufemi Ajayeoba [2] and Nathaniel Abidemi Akinrinade [2]

[1] *Department of Mechanical Engineering, Redeemer's University, Ede, Nigeria.*
[2] *Department of Mechanical Engineering, Ladoke Akintola University, Ogbomoso, Nigeria.*

World Journal of Advanced Engineering Technology and Sciences, 2023, 08(02), 175–182

Publication history: Received on 02 Februay 2023; revised on 21 March 2023; accepted on 23 March 2023

Article DOI: https://doi.org/10.30574/wjaets.2023.8.2.0082

Abstract

Failure Mode and Effect Analysis (FMEA) is an approach used for maintenance system reliability analysis. FMEA is applied to the Taurus 60 Gas Turbine Power Plant System (GTPPS). The unexpected failures with the associated maintenance costs are major problems in most power plants. In this study, critical components of the Taurus 60 gas turbine power plant were identified. Twenty-five sub-assemblies were identified and the probable failure modes of the main sub-assemblies. Failure analysis and the Risk Priority Numbers (RPN) of the critical sub-assemblies were determined using failure modes and effect analysis method. Failure analysis and the Risk Priority Numbers (RPN) of the critical sub-assemblies were determined using failure modes and effect analysis method. Based on criticality analysis, six (6) critical sub-assemblies were identified. These are fuel gas supply, air filter package, air trap package, gearbox, compressor rotor assembly and fuel injector with criticality numbers 12.5, 20.83, 20.83, 20.83, 16.67 and 20.83 respectively. The failure analysis for these critical sub-assemblies specified the failure modes, failure effects, maintenance tasks, frequency of inspection and strategies. The ranges of the Risk Priority Number (RPN) for the components of fuel gas supply, air filter package, air trap package, gearbox, compressor rotor assembly and fuel injector were 54-126, 60-90, 75-90, 72-84, 36-112 and 90-120 respectively. The critical sub-assemblies should be given close attention in terms of monitoring, routine checks which can be monitored using prepared checklists. The semi- critical and non- critical assemblies should not be neglected either.

Keywords: Criticality; Failure Mode; Gas turbine; Maintenance; Risk Priority Number

---

1. Introduction

Each year around the world, a lot of money is spent on equipment maintenance, and since the industrial revolution, maintenance of engineering equipment has been a challenging issue. Over the years remarkable progress has been made in maintaining engineering equipment in the field, but it has remained a challenge due to factors such as complexity, size, competition, cost, and safety.Maintenance to an acceptable standard refers to the standard set by an organisation. It varies from one organisation to another and depends upon the machinery of the industry or the infrastructure, and it is commensurate with the value placed on the need for a high standard. Maintenance is a science since its execution relies, sooner or later, on most or all the sciences. It is an art because similar problems regularly demand and receive varying approaches and actions and because some people display a greater aptitude for it than others. Moreover, maintenance is a philosophy because it must be carefully fitted to the operation or organisation it serves [1]. Over the past decades, maintenance has changed dramatically and perhaps more than any other management disciplines. In the industries, maintenance expectations have shifted with the realisation of the impact of equipment or infrastructure failures have on safety or product quality. Maintenanceorganisations are now coming under increasing pressure to

---

[*] Corresponding author: Sanyaolu OO

achieve high equipment availability while striving to reduce costs. This increasing pressure calls for a radical reform of maintenance by ensuring best practices in order to compete on cost with similar industries.The primary objective of infrastructure maintenance is reducing the adverse effect of breakdowns and maximising facility availability for the lowest cost possible [2]. Under most circumstances, the operability of the infrastructure is closely related to the resources extended. A higher level of operability requires more resources while lower expenditure of resources usually results in a diminished level of operability [3]. Fortunately, there are ways for maintenance personnel to apply their resources to attain higher levels of operability. Preventive maintenance is one of such methods. Preventive maintenance is defined as scheduled maintenance actions that are based on average failure rates of the components of an asset [2]. Maintenance actions can take many forms which may include inspections, adjustments, calibrations, cleaning, lubrications, replacements, and rebuilds. Maintenanceprogramme development will extend the expected life of equipment and ensures the equipment runs more efficiently, thereby reducing the chance and number of catastrophic failures, and results in maintenance and capital cost savings [3].The gas turbine power plant is a plant that produces large amounts of energy based on their capacity and weight [4]. The gas turbine is driven by hot gas from combustion. The simplest gas turbine system consists of three main components: compressor, combustor and turbine. [5]. A gas turbine does not require a large place because the number of components in a gas turbine is less compared to a steam turbine. The cost of purchasing and installing a gas turbine is lower than a steam turbine [6]. However, the gas turbine is very low in efficiency, from 25% - 30%. This is due to the fact that most of the work done by the turbine is used to drive the compressor. Ideally, the work of turbine used to drive compressor is up to 50% [7]. Effective maintenance, can eliminate failures and heavy damage to machinery, facilities and systems and can save 40% - 60% of expenses [8]. It is necessary to conduct in-depth studies and analysis so that preventive maintenance is carried out effectively and on target [9]. All products or processes have modes of failure. Analyzing potential failures helps to focus and understand the impact of possible process or product risks and failures.It is important to identify and analyze the probability, causes, and consequences of failures. It involves a logical and systematic investigation of various reasons for failure [10].Failure analysis is performed to prevent product malfunctions, ensure increased product life of the infrastructure, and prevent safety hazards while using the equipment, achieve process reliability and prevent safety or environmental hazards. Failure analysis methods include Fault Tree Analysis (FTA), Event Tree Analysis (ETA), Root Cause Analysis (RCA), Failure Mode and Effect Analysis (FMEA) and Finite Element Analysis (FEA). Failure Mode and Effects Analysis (FMEA) of equipment is an adequate scientific tool used to identify the assemblies, sub-assemblies, and components critical for equipment's satisfactory and successful performance [11]. It uses the bottom-up approach, where tabulation of equipment/components and their associated single point failure modes, consequences, and safeguards are done. Identification and assessment of risk are derived from looking at each element (or machine in the case of multi-unit manufacturing). The purpose of carrying out an FMEAof equipment is to identify its critical systems from failure data, identification of assemblies and components, or the significant maintenance items which contribute the most to the failure of the equipment and assigning maintenance tasks to these essential maintenance items. The Risk Priority Number (RPN) is a numeric assessment of risks assigned to a process or steps in a procedure as part of Failure Modes and Effects Analysis (FMEA), in which a team gives each failure mode numeric values which quantify the likelihood of occurrence, probability of detection, and severity of impact. An FMEA identifies the opportunities for failure in each step of the process [12]. Each failure mode is assigned a numeric score that quantifies the likelihood of the failure occurring, the likelihood that it will not be detected, and the harm or damage the failure mode may cause to a person or the equipment [12]. The product of these scores is the Risk Priority Number (RPN) for that failure mode. The sum of the various RPNs for the failure modes is the overall RPN for the process. The RPN is a measure for comparing within one process only; it is not a measure for comparing risk between processes or organizations [13].

2. Material and methods

A questionnaire was administered to the operators and engineers of the selected gas turbine. The target population was forty people to be distributed based on the four-shift system operated on the gas turbine. Each shift has a minimum of twelve people per shift and a stratified sample size of at least seven people per shift was taken.

The sample size met the following specific criteria, that is, the workers should have

- worked on the gas turbine for at least two years
- been involved in the operation and maintenance activities of the gas turbine with the existing maintenance system.
- A requisite technical and theoretical experience of the gas turbine.

The objective of this questionnaire was to determine critical components of the gas turbine based on the number of failures spanning a period of 24 months and thus being able to perform the criticality analysis which was used in performing the Failure Mode and Effect Analysis (FMEA). The failure investigation determined the number of failures on each sub-assembly in the period under review. The degree of maintenance carried out on equipment depends on the criticality of the equipment [14]. The criticality analysis, therefore, was done based on the components identified in the product analysis. Criticality analysis is the quantitative analysis of events and effects and the ranking of these in order of the seriousness of their consequences. The criticality of the components identified is determined by how the failure affects the availability of the gas turbine. Criticality is directly proportional to the ratio of the number of failures and the unit time.

$$\text{Criticality} = \frac{\text{Number of Failures}}{\text{Unit Time}} \quad \ldots\ldots\ldots\ldots\ldots\ldots 1 \quad \text{(Source: 14)}$$

The RPN values range from 1 to 1000, indicating absolute best and absolute worst, respectively.

$$Risk\ Priority\ Number = Severity(S) \times Occurence(O) \times Detection(D) \quad \ldots\ldots\ldots\ldots\ldots.\ 2$$

$$Criticality\ Number = Severity \times Occurence \quad \ldots\ldots\ldots\ldots\ldots\ldots.\ 3$$

Therefore,

$$Risk\ Priority\ Number(RPN) = Criticality \times Detection \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.4$$

Table 1 Generic five-point severity scale

Rating	Description	Criteria
1	Very Low or None	Minor Nuisance
2	Low or Minor	Product operable at reduced performance
3	Moderate or Significant	Gradual performance degradation
4	High	Loss of function
5	Very high or catastrophic	Safety-related catastrophic failures.

Source: (15)

Table 2 Qualitative Scale for Occurrence Index (O)

Effect	Level	Criteria
Almost never	1	Failure is unlikely; History shows no failure.
Remote	2	Rare number of failures likely.
Very slight	3	Very few failures are likely.
Slight	4	Few failures likely
Low	5	Occasional number of failures
Medium	6	Medium number of failures likely
Moderately high	7	Moderate high number of failures likely
High	8	High number of failures likely
Very high	9	Very high number of failures likely
Almost certain	10	Failures are almost inevitable; a history of failures exists from previous or similar designs.

Source: (15)

Rating scales usually range from 1 to 5 or from 1 to 10, with the higher number indicating a higher risk. The generic five-point Severity scale (S), the Qualitative Scale for Occurrence Index (O), and the Qualitative Scale for Detectability Index (D) are represented in Tables 1, 2, and 3, respectively.

The criticality rating is given below.

Critical – 10 and above
Semi-Critical – 5.1 to 9.99
Non-Critical – 0 to 5

Table 3 Qualitative Scale for Detectability Index (D)

Effect	Level	Criteria
Almost certain	1	Proven detection method available in the concept stage
Very high	2	Proven computer analysis available in early stage
High	3	Simulation and modeling in early stage
Moderately high	4	Tests on early prototype system elements
Medium	5	Tests preproduction system components.
Low	6	Tests on similar system components.
Slight	7	Tests on the product with a prototype with system component installed
Very slight	8	Proving durability test on the product with system component installed.
Remote	9	Only unproven or unreliable techniques are available.
Almost Impossible	10	No known technique(s) are available.

Source: (15)

3. Results and discussion

A total of forty questionnaires were sent out to the gas turbine power plant (both operational and maintenance staff) across the four shifts and those on day duty. Twenty-nine (29) were returned and used for this analysis. It indicated that 79.31 % of the respondents are maintenance staff while the rest are operational staff. 10.34 % of the respondents have their ages in the range of 50 years and above, while the others are within the range of 20 years and 49 years old. 26 out of 29 respondents have at least two years of working experience in the gas turbine. This means 89.63 % of the respondents have adequate maintenance experience needed for this study. A total of 27 out of 29 respondents have a minimum of a Diploma and a maximum of M.Sc. This indicates that 93.11 % have had specializedtraining which guides their activities on the gas turbine. The sub-assemblies are arranged in a tabular form with their corresponding aggregate number of failures in the period of 24 months. The criticality number was calculated using equation 3 and the criticality rating.

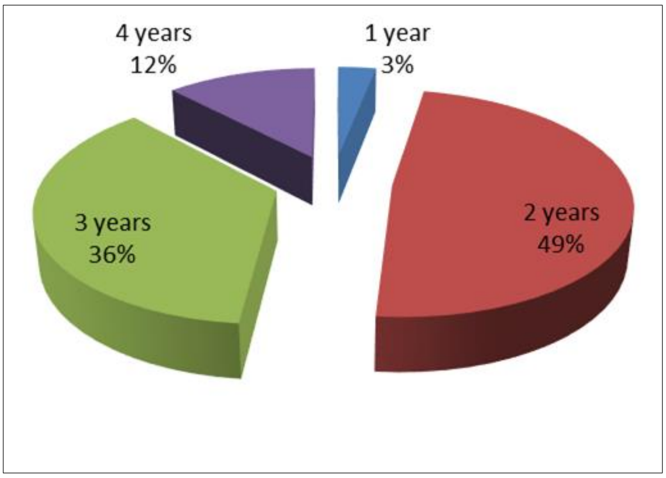

Figure 1 Years of Working on the Gas Turbine

The criticality analysis is represented in Table 4, indicating the nomenclature of the sub-assemblies, the number of failures based on the aggregate of the responses from the questionnaires, the time frame (24 months), and the criticality ratings. From the criticality analysis in Table 4, the fuel gas supply, air filter package, air trap package, gearbox, compressor rotor assembly and fuel injector were identified as the critical sub-assemblies, hence, the failure mode and effects analysis (FMEA) was done on the components of these critical sub-assemblies.

Table 4 Criticality analysis of the sub-assemblies

Nomenclature of Component	Number of Failures	Time (Months)	Criticality Number	Criticality Rating
Air Inlet	0	24	0	Non-Critical
Accessory Drive Assembly	0	24	0	Non-Critical
Compressor Rotor Assembly	4	24	16.67	Critical
Gas Generator Rotor Assembly	2	24	8.33	Semi- Critical
Power Turbine Rotor Assembly	1	24	4.17	Non-Critical
Fuel Gas Supply	3	24	12.5	Critical
Combustor	2	24	8.33	Semi-Critical
Exhaust Collector	1	24	4.17	Non-Critical
Generator	2	24	8.33	Semi- Critical
Base Control Frame	0	24	0	Non- Critical
Compressor Housing	0	24	0	Non- Critical
Enclosure Doors	0	24	0	Non- Critical
Enclosure Locks	0	24	0	Non- Critical
Cooling Fan	0	24	0	Non- Critical
Air Filter Package	5	24	20.83	Critical
Combustion Air Treatment Package	1	24	4.17	Non-Critical
Fuel Injector	5	24	20.83	Critical
Output Drive Shaft	2	24	8.33	Semi- Critical
Gas Fuel Manifold	0	24	0	Non- Critical
Bleed Air Valve	0	24	0	Non- Critical
Bleed Air Pipe	0	24	0	Non- Critical
Exhaust Manifold	3	24	12.5	Critical
Gearbox	5	24	20.83	Critical
Air Trap Package	1	24	4.17	Non-Critical
Lubrication System	1	24	4.17	Non-Critical

Table 5 Failure Modes and Effects Analysis (FMEA) and Risk Priority Number (RPN) Calculations for Air Trap Package

Components	Failure modes	Failure effects	Severity	Occurrence	Detection	RPN
Fuel Modules	Clogging / blocked surfaces	Reduced airflow rate	3	5	6	90
Pre Filter	Clogging /blocked surfaces	Reduced airflow rate	3	5	6	90
Weather Hoods	Blockage in the hood	Reduced airflow rate	3	5	5	75

The Risk Priority Number (RPN) for the critical sub-assemblies are were calculated for each of the components using Equation 4. The Failure Modes and Effects Analysis (FMEA) of the components of the critical sub-assemblies and their respective risk priority number (RPN) is presented in Tables 5, 6, 7, 8, 9 and 10.

Table 6 Failure Modes and Effects Analysis (FMEA) and Risk Priority Number (RPN) Calculations for Fuel Gas Supply

Components	Failure modes	Failure effects	Severity	Occurrence	Detection	RPN
Fuel Filter	Clogging/dirt in the orifice	Fuel flow is disturbed.	3	7	6	126
Pressure Transmitter	False reading on the pressure transmitter	Failure of the valve to open/close	3	6	6	108
Valves	Blocked orifice	Failure of valves to open/close	3	7	5	105
Pressure Regulator	External leakage of air/fails to vent	Failure of valves to open/close	3	3	5	45
Fuel Pump	Low pump pressure	Failure of valves to open/close	4	3	6	72
Fuel Strainer	Low Pump Pressure	Fuel Flow is disturbed	3	3	6	34

Table 7 Failure Modes and Effects Analysis (FMEA) and Risk Priority Number (RPN) Calculations for Air Filter Package

Components	Failure modes	Failure effects	Severity	Occurrence	Detection	RPN
Fuel Modules	Cloggings and blocked orifices	Reduced airflow rate	3	5	6	90
Pre Filter	Cloggings and blocked surfaces	Reduced airflow rate	3	5	5	75
Weather Hoods	Blockage in the hood orifice	Reduced airflow rate	3	5	6	90
Vane Separator	Blockage in the vane	Reduced airflow rate	3	5	5	75
Droplet Eliminator	Moist surface	Reduced airflow rate	2	5	6	60

Table 8 Failure Modes and Effects Analysis (FMEA) and Risk Priority Number (RPN) Calculations for Gearbox

Components	Failure modes	Failure effects	Severity	Occurrence	Detection	RPN
Sprocket	Wear/ Cracks	Stiffness of gearbox	4	3	7	84
Bearings	Damaged/failed bearings	Wobbling / Stiffness of gearbox	4	3	6	72
Motor	Winding Distortions	Gearbox Failure	4	3	7	84
Drive Shaft	Incorrect fixation/ keyway looseness	Gearbox failure/stoppage of equipment	4	3	6	72

Table 9 Failure Modes and Effects Analysis (FMEA) and Risk Priority Number (RPN) Calculations for Compressor Rotor Assembly

Components	Failure modes	Failure effects	Severity	Occurrence	Detection	RPN
Bearings	Worn/ stiff bearings	The shaft fails to rotate.	4	4	7	112
Housing	Cracks	Turbine shutdown	4	4	7	112
Stator Vanes	Winding distortions	Excessive current	3	4	6	72
Exhaust Diffuser	Fractures/Abrasions	Exhaust Failure	4	4	5	80
Shaft	Lubrication/ misalignment	Stiffness of shaft	3	4	5	60
Hubs	Wear and tear/ looseness from the shaft	Stiffness of shaft	3	4	5	60
Seals	Oil leaks	Bearing failures	3	4	3	36

Table 10 Failure Modes and Effects Analysis (FMEA) and Risk Priority Number (RPN) Calculations for Fuel Injector

Components	Failure modes	Failure effects	Severity	Occurrence	Detection	RPN
Filters	Blocked filters	No/low fuel dosage	3	5	6	90
Swirlers	Low fuel pressure	Increased fuel consumption	3	5	6	90
Spray Tips	Low fuel pressure	Increased fuel consumption	3	5	6	90
Nozzles	Blocked nozzles	No/low dosage of fuel	3	5	6	90
Core Springs	Excessive current	Increased injector temperature	3	5	6	90
Guide Rings	Broken rings	Injector failure	3	5	7	105
Needle Valves	Valve failure to open/close	Low /excessive dosage of fuel	4	5	6	120

4. Conclusion

This study identified twenty- fivesub-assemblies of the Taurus 60 gas turbine and the six critical sub-assemblies of the gas turbine power plant were identified by the Risk Priority Number (RPN). The critical sub assemblies should be given close attention in terms of monitoring, routine checks which can be monitored using prepared checklists. The semi-critical and non- critical assemblies should not be neglected either. A wholesome and robust maintenance system or method can be developed to ensure the turbine or any other similar facility performs optimally. A similar study on the facility can be done at least every two years or as the years of operation increases and a further extension of the study can be done on other sub-assemblies especially the semi-critical sub-assemblies.

Compliance with ethical standards

Acknowledgments

We acknowledge the support of the management of the Gas Turbine Power Plant System in Mowe, Ogun State, Nigeria.

Disclosure of conflict of interest

All authors declare that they have no conflicts of interest.

References

[1] Lindley, R. and Keith-Mobley, R., (1995). Maintenance Engineering Handbook, Six Edition. Access Publishing Company: 28-37.

[2] Krajewski, L.J, and Sheut, C., (1994). "A Decision Model for Corrective Maintenance Management". International Journal of Production Research: 1365 -1382.

[3] Dotzlaf, R.E. (2009). Modernizing a Preventive Maintenance Strategy for Facility and Infrastructure Maintenance. Wright- Patterson Publishers, Ohio: 1- 47.

[4] Boyce, M. P. (2012). Combined cycle power plants. In Combined cycle systems for near-zero emission power generation (pp. 1-43). Woodhead Publishing.

[5] R. Sugiharto, (2009). "Perancangan Heat Recovery Steam Generator (HRSG) dengan Sistem Tekanan Uap Dua Tingkat Kapasitas Daya Pembangkitan 77 MW".," Universitas Sumatera Utara.

[6] Abdul Wahid, H. A. N. I. M. (2006). Integrated Solar Combined Cycle System (ISCCS).

[7] Ekstrom, T.E. (1995). "Reliability/availability guarantees of gas turbine and combined cycle generating units," IEEE Trans. Industrial. Application., 31(4). pp. 691–707.

[8] B. S. Dhillon, (2002). Engineering Maintenance: A Modern Approach. Boca Raton, Florida: CRC Press.

[9] Zuhdi, M.S. and Suef, M. (2019). Risk Analysis of Combustion Failure in Gas Turbine Start Process in PLTGU Unit. IPTEK Journal of Proceedings Series No. (5), ISSN (2354-6026) 245 The 1st International Conference on Business and Management of Technology.

[10] Khan, M.Y. (2013). Installation Testing and Maintenance. S.K. Kataria and Sons, New Delhi. 101-103.

[11] Mahendra, P. (2012). Applying Failure Mode, Effect and Criticality Analysis (FMECA) For Ensuring Mission Reliability of Equipment. Institute for Defense Studies and Analysis. Issue Brief.

[12] Okes, D. (2009). Root Cause Analysis: The Core of Problem Solving and Corrective Action. McGraw Hill Professionals, USA: 13-41.

[13] Barsalou, M.A. (2014). Root Cause Analysis: A Step by Step Guide to Using the Right Tool at the Right Time. Productivity Press: 65-122

[14] Namboothiri, V.N. and Joshy, P.J. (1999). An Approach for Identification of Critical Equipment for Preventive Maintenance of a Plant. First International Seminar, SAFE '99 on Safety and Fire Engineering, Cochin, India: 228-232.

[15] Stamatis.D.H. (1995). Failure Mode and Effect Analysis, Milwaukee, WI, ASQC Quality Press.