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Failure Mode and Effect Analysis for CNC Machines Used In GG Valves Industry

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Abstract

The Failure Mode and Effect Analysis (FMEA) is widely used technique due to enhance reliability and safety of complex system to identify and eliminate known or potential failure modes. In the present work, the FMEA were performed with two approaches. (1) Conventional FMEA approach and (2) Grey Relational Analysis approach. The rankings of the failure modes are both determined by conventional FMEA and the Grey Relational Analysis. The CNC machine failure is provided, the failure data have been collected and analysed, and the results show that the evaluation of failure modes by both conventional FMEA and Grey Relational Analysis. These theories are proposed in this paper helps to enhance the reliability of the prediction, and the predicted ranking of CNC machines failure can be used for better decision-making concerning inspection and maintenance.

Keywords: grey relational analysis, CNC machine failures, FMEA, RPN

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INTRODUCTION

A CNC machine is a complex mechanical system with high level automation and complicated structure which employs mechanics, electronics and hydraulics mechanism. Now-a-days almost all the industries are depended on CNC machines for their manufacturing processes. A single CNC machine is fails, when results in halting in the production process and requires time for repairing of the machine. The breakdown in CNC machine in any manufacturing plant may hamper normal production rate, which results in loss of the resources and manufacturing cost. Therefore, it is unavoidable to ensure the reliability of the machine operation during the process. A lot of work has been carried out to reduce the failure rate in the machine but it requires timely maintenance of the machine. The breakdowns in the CNC machines are not beneficial for manufacturing industries.

The present work is based on the CNC machine failures of CNC machines in GG (Gerhard Gabriel) Valves industry and its analysis to reduce the failure rate. To reduce the failure rate of CNC machines different approaches have been carried out by many researchers. The efforts to optimize the failure of CNC machines increase the efficiency of production. This work would help to concern the industries which rely majorly on CNC machines for their manufacturing process.

The Failure Mode and Effect Analysis (FMEA) approach helps in identification of occasions of malfunction of equipments. FMEA shows the causes and effects of potential failure modes. It also helps to identify the occurrence of failures in CNC machines. This technique was firstly used by NASA in 1960s. The first applications in automotive industry were held by Ford Motor Company. This method enables the manufacturing process to increase its efficiency. The FMEA identifies the corrective measures and possible failure modes by prioritization of possible failure modes with the help of a template.

The present work will be based on a collection of failure data of CNC machines and analysis of the failure data based on theoretical calculations by using conventional Failure Mode and Effect Analysis (FMEA). The use of conventional FMEA gives a support and advancement in approach towards failure analysis and an area to work for improving high speed technology. The result of conventional FMEA is further verified by using Grey Relational Analysis (GRA) approach. [1]

LITERATURE REVIEW

The purpose of FMEA for prioritizing failure modes is presented by Sofyalioglu and Ozturk for three different methods. These methods are traditional approach, Grey Relational Analysis and Fuzzy Analytic Hierarchy Process (FAHP) to estimate weights for the risk factors.

The study of breakdown maintenance for the machinery failure was performed by Degu and Moorthy. The failure modes and their causes were identified for each machine, the three key indices (Severity, Occurrence and Detection) reassessed and the analysis was carried out with the help of Machine Failure Mode and Effect Analysis (MFMEA) Worksheet. The research work results in a considerable machine downtime and disrupting the continuous production of pipes. The study to identify and eliminate potential problems from a system, subsystem, component or a process by Filip studied on CNC machines. So, the potential risks are identified, current controls evaluated and risk reducing actions defined in advanced to avoid that the potential risks become reality. It is a structured approach to the analysis, definition, estimation and evaluation of risks (product and process risks). [2]

Kulkarni and Shrivastava attempted to work on Failure Mode Effect Analysis (FMEA) to adapt the innovative technologies integrated with the operational aspects in order to enhance the process capability. The main objective of the study is to improve machinery system reliability and to enhance operational safety concept of CNC grinding machine. FMEA tend to give importance to the prevention efforts to prevent or decrease the probability of affecting machine performance.

Mhetre and Dhake worked to the identification and elimination of current and potential problems from a bending process of a company. They using Failure mode and Effect Analysis approach and Ishikawa Diagram aimed to reduce errors and shorten the development duration and increase product reliability. So that the prioritization of the potential failures according to their risk.

Waghmare worked on the goal of quality and reliability systems to achieve customer satisfaction. A system cannot be reliable if it does not have high quality. Likewise, a system cannot be of high quality if it is not reliable. FMEA provides an easy tool to determine which risk has the greatest concern and therefore an action to prevent a problem before it arises. The development of these specifications will ensure the product will meet the defined requirements. [3–10]

FMEA serves as a better way to maintain the equipment as defect free through integrated approach. Aravinth found that most important parts with higher risks are compressed cylinders and grounded. The causes, effects and preventive measures of all the possible failures are given along with the priorities

Mahto and Kumar worked on conventional root cause method that was implemented to optimize the efficiency of these machines. Thus, provide the platform of human event in problem solving. This work gave the stock holder a clear idea to promote the effective solution for long time. Peng gave more attention towards the core of manufacturing and its reliability of CNC systems.

They stated that soft fault of CNC system occupies a large proportion in failure, but it is hard to diagnose. The criteria to distinguish soft fault data from abnormal data of multi-sample CNC systems, uses Failure Mode. At the concluded that end, the weak module, main reason and fault effect of CNC system have great significance for the reliability growth technology of CNC system.

Wang analysed the computerized numerical control lathe which is a part of CNC machines. They also collected the failure data over a period of two years on approximately eighty CNC lathes. They also analysed the collected data using Weibull distribution method which provided them the suitable vehicles for the analysing the failure patterns of those CNC lathes. Thus, results that the Weibull distribution provides the best fit suggestion to describe how to reduce the failure of CNC lathes.

The study on CNC machines is done to eliminate the early failures and improve the reliability. During the course of work a database was constructed based on the collection of field early failure data by codification of data. The work finalized that the reliability screening and quality control may improve the reliability of machining centres in the burn-in phase conditions by Wang.[11]

METHODOLOGY

The specification of CNC machines used in GG Valves industry, for the data collection is as given in Table 1.

Table 1. *Types of CNC Machines.*

Machine no.	Name of CNC Lathe	Specification				
		Max. turning length (mm)	**Max. turning Diameter (mm)**	**Length between centres (mm)**	**No. of tools on Turret**	**Turning speed (RPM)**
L-01	Daewoo Puma 10-HC	525.8	370.8	525.8	10	35-3500
L-02	LMW-P20T.L3	250	320	350	8	45-4300
L-03	LMW- P20T.L5	440	380	550	8	35-3500

In the present work, the failure data of CNC machines have been collected from GG Valves industry and analysis of data has been performed by conventional FMEA approach and GRA approach. The data of CNC machine failures at the regular interval of time has been collected.

The following parameters are used for the data collection of failures of the CNC machines:

- Failure date and time
- Failure phenomenon
- Cause analysis
- Repair process
- Repair time
- Downtime
- Model, size and numbers of the breakdown component
- Number of service engineers or repair

engineers

Analysis Approach

The Failure Mode and Effect Analysis (FMEA) is widely used for engineering technique in many industries, which can be used to identify and eliminate known or potential failure modes to enhance reliability and safety of complex system.

In the present work, the Failure Mode and Effect Analysis are used with mainly two approaches:

(1) Conventional FMEA approach

(2) Grey Relational Analysis approach

A brief description of both approaches is given below.

Conventional FMEA Approach

The conventional Failure Mode and Effect Analysis (FMEA) approach is a pro-active quality tool for evaluating potential failure modes and their causes. It helps in prioritizing the failure modes and recommends corrective measures for the avoidance of catastrophic failures and improvement of the quality of product.

A process of conventional FMEA is as follows [12, 13]:

Step 1: Identification of components and associated functions

The process is to identify the main components of the process and determines the functions of the components. It describe technical terms i.e. cracked, deformed, loosened, short circuited, fractured, leaking, sticking, oxidized, etc.

Step 2: Identification of failure modes

The identify failure mode must be carried out under the mechanical system, electrical system, hydraulic system or electronic system etc. For examples erratic operation, poor appearance, noise, impaired functions, deterioration, etc.

Step 3: Identification of effects of the failure modes (Severity, S)

The effect of failure mode can be obtained on the CNC machines. Severity is the assessment of the seriousness of the effect of the potential failure mode. In this process, all failure modes based on the functional requirements and their effects are determined.

The severity of the failure estimated using an evaluation scales from 1-10 for machine downtime in hours shown in Table 2. The low rank indicates a low control limits, whereas a high rank indicates high severity of failure (Figure 1).

Table 2. *Criteria for Ranking Severity (S) in FMEA*

Effect	**Severity criteria**	**Ranking**
Hazardous without warning	Very High severity ranking (downtime of more than 8 hours), affects operator, plant or maintenance personnel	10
Hazardous with warning	High severity ranking (downtime of more than 8 hours), affects operator, plant or maintenance personnel	9
Very high downtime	Downtime of more than 8 hours.	8
High downtime	Downtime of more than 4–7 hours.	7
Moderate downtime	Downtime of more than 1–3 hours.	6
Low downtime	Downtime of 30 minutes to 1 hour.	5
Very low	Downtime up to 30 minutes and no defective parts	4
Minor effect	The process parameters variability exceeds upper/lower control limits	3
Very minor effect	The process parameters variability within upper/lower control limits	2
No effect	The process parameters variability within upper/lower control limits	1

(Source: Yonas M. Degu and R. S. Moorthy, 2014).

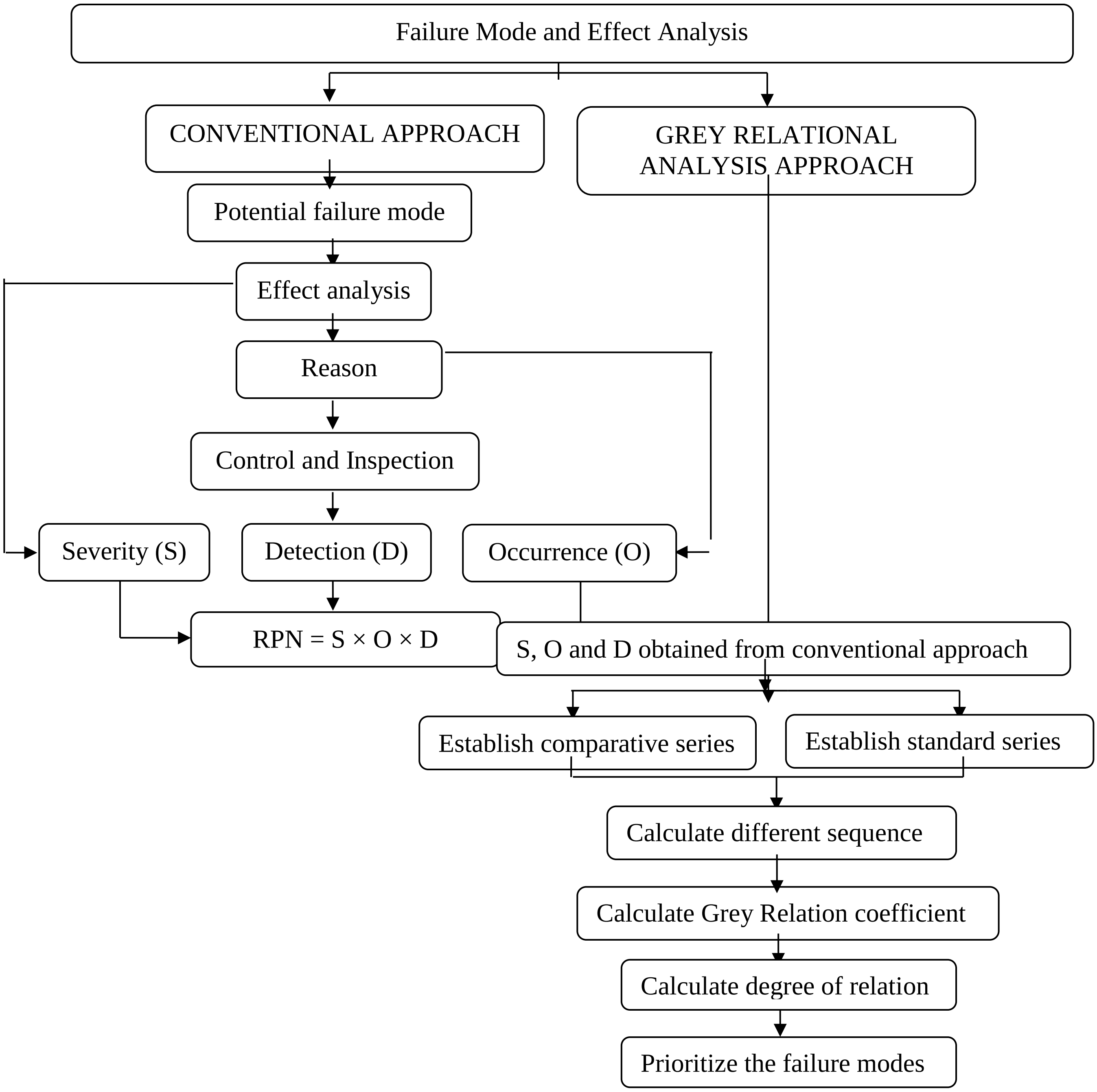

Fig. 1. *Flowchart of FMEA and Grey Relational Analysis.*

Step 4: Identification of cause of the failure mode (Occurrence, O)

The analyst will search out the cause of the failure. The failure could be temporary or permanent. Every cause may dependent on inadequate design, incorrect material composition, inaccurate life assumption, poor environmental protection, over stressing, insufficient lubrication etc. Failure Mechanisms are fatigue, wear, corrosion, yield, creep etc.

The occurrence is based on knowledge of the failure mode and prioritizes for an evaluation scale as 1–10 for Mean Time between Failure (MTBF) in hours shown in Table 3. The scale 1 indicates a low probability of occurrence whereas scale 10 indicates very high probability to the occurrence of failure.

Table 3. *Criteria for Ranking Occurrence (O) in FMEA.*

Probability of failure occurrence	**Possible failure rates criteria**	**Ranking**
Very high: Failure is almost inevitable	Intermittent operation resulting in 1 failure in 100 production piece or MTBF of less than 1 hour.	10
	Intermittent operation resulting in 1 failure in 100 production pieces or MTBF of less than 2 to 10 hours.	9
High: Repeated failures	Intermittent operation resulting in 1 failure in 1000 production pieces or MTBF of 11 to 100 hours.	8
	Intermittent operation resulting in 1 failure in 10,000 production pieces or MTBF of 101 to 400 hours.	7
Moderate: Occasional failures	MTBF of 401 to 1000 hours.	6
	MTBF of 1001 to 2000 hours.	5
	MTBF of 2001 to 3000 hours.	4
Low: Relatively few failures	MTBF of 3001 to 6000 hours.	3
	MTBF of 6001 to 10,000 hours.	2
Remote: Failure unlikely	MTBF greater than 10,000 hours.	1

(Source: Yonas M. Degu and R. S. Moorthy, 2014).

Step 5: Current design control (Detection, D)

The chance of detection of the potential failure before it reaches to the customer. The detection is the term that defines the failure related to the manufacturing of CNC machine. The CNC machine manufacturing is based on the design, assembly, material, complexity of parts etc. The detection is the failure which occurs due to problem in any one of the parameter discussed. The use of evaluation scale shown in Table 4, shows the scale 1 as low probability of failure detection and scale 10 indicates as a very high probability of failure detection.

Table 4. *Criteria for Ranking Detection (D) in FMEA.*

Detection	**Detection by design controls**	**Ranking**
Absolute uncertainty	Very high remote chance a machine controls will not or cannot detect potential cause of failure mode.	10
Very remote	Very remote chance a machinery/design control will detect a potential cause/mechanism and subsequent failure mode.	9
Remote	Remote chance a machinery/design control will detect a potential cause/mechanism and subsequent failure mode.	8
Very low	Very low chance a machinery/design control will detect a potential cause/mechanism and subsequent failure mode.	7
Low	Low chance a machinery/design control will detect a potential cause/mechanism and subsequent failure mode. Machinery control will prevent an imminent failure.	6
Moderate	Moderate chance a machinery/design control will detect a potential cause/mechanism and subsequent failure mode.	5
Moderately high	Moderately high chance a machinery/design control will detect a potential cause/mechanism and subsequent failure mode.	4
High	High chance a machinery/design control will detect a potential cause/mechanism and subsequent failure mode.	3
Very high	Very high chance a machinery/design control will detect a potential cause/mechanism and subsequent failure mode. Machinery controls not necessary.	2
Almost certain	Design control will almost certainly detect a potential cause/mechanism and subsequent failure mode. Machinery controls not necessary.	1

(Source: Yonas M. Degu and R. S. Moorthy, 2014).

Step 6: Calculate Risk Priority Number (RPN)

After deciding the Severity, Occurrence and Detection numbers, the RPN was calculated by multiplying of Severity (S), Occurrence (E) and Detection (D).

$$R\ P\ N = S \times O \times D \qquad \text{Eq. (1)}$$

The small RPN is always better than the high RPN. According to the values of RPN, the failure modes can be categorized and then proper remedial actions can be taken on the CNC machine failures with high level of risks.

The Conventional FMEA approach will verify the analysis to include equal weight factors for Severity (S), Occurrence (O) and Detection (D) using Grey Relational Analysis approach.

Grey Relational Analysis (GRA) Approach

Grey theory was first proposed by Julong Deng (1982), aiming to make decisions under incomplete information. The information which is either incomplete or undetermined is called Grey.

A system having incomplete information is called the Grey system. The Grey number in the Grey system represents a number with less complete information. The qualification and quantification of influences of various factors and their relations is called the whitening of factor relation in the Grey Relational Analysis.

The steps used in the approach are as the follows:

- Identification of Comparative Series

An information series includes value of Severity (X_i (1)), Occurrence (X_i (2)) and Detection (X_i(3)) as the comparative series. The comparative series applied to FMEA is given as:

$X_i(k) = [X_i(1) \quad X_i(2) \qquad X_i(3)]$

where k = 1, 2 or 3(number of risk factors)
i = 1, 2, 3 ………n (n is the number of failure modes)

If all series are comparative series, the n information series can be defined as following matrix in which n is the number of failure modes;

$$X_i(k) = \begin{bmatrix} X_1(k) \\ X_2(k) \\ . \\ . \\ X_n(k) \end{bmatrix} = \begin{bmatrix} X_1(1) X_1(2) X_1(3) \\ X_2(1) X_2(2) X_2(3) \\ . \\ . \\ . \\ X_n(1) X_n(2) X_n(3) \end{bmatrix} \qquad \text{Eq. (2)}$$

- Identification of Standard Series

An objective series called as the standard series can be expressed as the following:

Series notation $\quad X_0(k) = \{X_0(1), X_0(2), X_0(3)\}$
Matrix notation as: $X_0(k) = [X_0(1)\ X_0(2)\ X_0(3)]$

In FMEA, the smallest score represents the smallest risk.

Thus, the standard series should be the lowest score of likelihood of Severity (X_0 (1)), Occurrence (X_0 (2)) and Detectability (X_0 (3)) factors which is shown below:

Matrix notation is:
$X_0(k) = \{X_0(1), X_0(2), X_0(3)\} = \{1, 1, 1\}$ Eq. (3)
$X_0(k) = [1 \quad 1 \quad 1]$
(Sofyalioglu and Ozturk, 2012)

The purpose of defining standard series is to estimate the relationship between standard series and comparative series. The magnitude of this relationship is called as a "degree of relation". As the degree of relation goes higher the score comes closer to the desired value.

- Estimating the Difference between Comparative and Standard Series

To find the degree of Grey Relationship, the difference between the scores of risk factors and scores of standard series must be calculated.

The result of this calculation is expressed as the follows:

$$\Delta_i(k) = \begin{bmatrix}\Delta_{01}(k)\\ \Delta_{02}(k)\\ .\\ .\\ \Delta_{0n}(k)\end{bmatrix} = \begin{bmatrix}\Delta_{01}(1)\Delta_{01}(2)\Delta_{01}(3)\\ \Delta_{02}(1)\Delta_{02}(2)\Delta_{02}(3)\\ .\\ .\\ .\\ \Delta_{0n}(1)\Delta_{0n}(2)\Delta_{0n}(3)\end{bmatrix} \quad \text{Eq. (4)}$$

where i= 1, 2, 3 ……..
n = number of failure modes)
$\Delta_{i(k)}$ is calculated as the following:

$$\Delta_{0i}(k) = |X_0(k) - X_i(k)| \quad \text{Eq. (5)}$$

- Estimation of Grey Relationship Coefficient

To estimate the grey relationship coefficient, three risk factors of the failure modes are compared with the standard series. The correlation coefficient is calculated as the following:

$$\gamma[X_0(k), X_i(k)] = \frac{\Delta_{\min} + \zeta\Delta_{max}}{\Delta_{i(k)} + \zeta\Delta_{max}} \quad \text{Eq. (6)}$$

where $X_0(k)$; standard series
$X_i(k)$ = comparative series
i = 1, 2, 3…..
n = number of failure modes
k = 1, 2 or 3 (number of risk factor)
$\Delta_{\min}$ = minimum value of all $\Delta_i(k)$
$\Delta_{\max}$ = maximum value of all $\Delta_i(k)$
ζ (0,1) dentifies coefficient and if affects the relative value of the risk without changing its priority. The value of ζ is 0.5.

- Determining the Degree of Relation

In order to find the degree of relation, first the relative weight of the risk factors. The relative weight used in following formulation is given below:

$$\tau_i(k) = \beta_k \sum_{k=1}^{3} \Delta_i(k) \quad \text{Eq. (7)}$$

where i=1, 2, 3…….
n = number of failure modes
k = 1, 2 or 3(number of risk factors)
β_k = the weighting coefficient of the risk factors and $\sum_{k=1}^{3} \beta_k = 1$

If all factors are equally important, stated formula can be changed as follows:

$$\tau_i(k) = \frac{1}{3}\sum_{k=1}^{3} \Delta_i(k) \quad \text{Eq. (8)}$$

- Ranking the priority of risk

The relational series are established based on the degree of relation between comparative series and standard series. The degree of relation closer to 1 means the failure mode is closer to the optimal value. The failure mode which has the lowest degree of relation should be the first one to improve. Therefore the lower degree of relation represents the higher risk priority.

RESULTS AND DISCUSSION

The results show that the Risk Priority Number (RPN) of the failure modes is calculated in Table 5. [12, 13]

Table 5. *FMEA Worksheet for CNC Machine Failures of GG Valves Industry.*

S. no.	Subsystem	Item/part	Potential failure mode	Potential effects	S	Potential cause	O	Current controls	D	RPN
1	Mechanical system	Turret Head dismantling	Alignment disorder	Gun metal bush damage, Gear key and guide pin damage, O-ring damage	9	(1)Jerk/accident, I/O parameter disorder (2) Jerk/accident, I/O parameter disorder, faulty job piece (3) Improper fitment, poor quality	6	(1)Replacing the Gun-metal bush (2) Replacing gear key, Replacing guide pin and Cleaning the guide way (3) Replacing	4	216

								the damaged O-ring		
2	Mechanical system	Turret Head dismantling	Play in coupling	Coupling bearing damage and loose fasteners	9	Jerk /accident, lubrication oil	5	Tighten the all fasteners, cleaning the complete assembly and replacing the damaged bearing	5	225
3	Electronic system	Turret Head dismantling	Indexing time mismatch	I/O parameter and sensor setting disorder	9	High input currents and sensor in fault	5	Reset the I/O parameter and replacing the faulty sensor	3	135
4	Mechanical system	Turret Head dismantling	CAM setting disordered, Job centre disorder	CAM setting adjusted, Band/ rubbed guide pin	9	Accident due to defective job piece	5	Replacing the guide pin and readjustment of the CAM setting	4	180
5	Coolant system	Coolant Tank	Low pressure of coolant	Low viscosity lubricant changed, Filter cleaned	7	Blockage the coolant flow line	5	Remove chips present in lubricant, Coolant air flow line cleaned,	3	105
6	Coolant system	Coolant pump	Improper work	Damage/burn motor winding and contactor relay	7	Faulty supply	5	Replacing the contactor relay and rewinding the motor coil	4	140
7	Electronic system	Feed Servo System	Parameter disorder	PLC unit reorder and I/O parameter change	7	Faulty supply, stabilizer card and contactor relay burn	6	Replacing the stabilizer card, replacing the contactor relay and reset the I/O parameters	1	42
8	Electrical system	Feed Servo System	Overload/Power fluctuated	Connections and supply unit checked, Stabilizer card checked, Contactor relay changed	7	Faulty supply, stabilizer card burn	5	Ensure the proper power supply and Replacing the stabilizer card	2	70
9	Hydraulic system	Hydraulic table	Changing table turns slowly	Damaged oil seals replaced, Top-up oil and filter cleaned	6	Damage the oil seal, leakage in hydraulic flow line	5	Ensure the proper checking of hydraulic flow line	2	60
10	Hydraulic system	Hydraulic function	Oil leaks from cylinder	Oil pipes cleaned, damaged oil seals replaced	6	Leakage in hydraulic cylinder	5	Ensure the proper checking of hydraulic flow line	3	90

11	Hydraulic system	Hydraulic pressure	Oil pressure is not stable	Hydraulic pump cleaned, damaged oil seals replaced, Hydraulic hose changed	6	Damage the oil seals and hydraulic hose	5	Change all damaged or cracked hose and oil seal	4	120
12	Hydraulic system	Hydraulic pump	Improper work	Changing table turns slowly, Clamping accessory doesn't work, Oil pressure is not stable	7	Damage oil seals and hose, blockage hydraulic flow line and filter,	6	Replacing the oil filter, replacing the damaged oil-seals and hoses and cleaning the pump	3	126
13	Mechanical	Spindle system	Improper work	Poor precision and abnormal sound	7	Wear / jam of the bearing, blockage the oil flow line	6	Cleaning the complete assembly and replacing the damaged bearing	2	84
14	Mechanical system	Head stoke	Centre out	Poor precision and high RPM of spindle	8	Impact / jerk, tool break, damage bearing and I/O parameter disorder	6	Replacing the damaged bearing and reset the I/O parameters	3	144
15	Mechanical system	Tail stoke	Centre out	Nonlinear finishing	6	Revolving centre bearing jam/damage, play in bearing	5	Replacing the damaged bearing and reset the I/O parameters	5	150

The results of comparing Conventional FMEA and Grey Relational Analysis approach for the CNC machine failures are shown in Table 6. The ranking of the failure modes by both conventional FMEA approach and grey relational FMEA approach (under the assumption of the risk factors having equal weights) are similar priorities are obtained.

Table 6. *Comparison Between FMEA (Traditional Approach) and Grey Relational Method.*

S. no.	Part function	Potential failure mode	FMEA RPN (traditional approach)	Rank	Grey RPN (risk factor have equal weights)	Rank
1	Turret head	Alignment disorder	216	II	0.4467	II
2	Turret head	Play in coupling	225	I	0.4433	I
3	Turret head	Indexing time mismatch	135	VII	0.5000	VI
4	Turret head	CAM setting disordered	180	III	0.4667	III
5	Coolant tank	Low pressure of coolant	105	X	0.5233	VIII
6	Coolant pump	Improper work	140	VI	0.4900	V
7	Feed servo system	Parameter disorder	42	XV	0.6133	XIII

8	Feed servo system	Overload/power fluctuated	70	XIII	0.5667	XI
9	Hydraulic table	Changing table turns slowly	60	XIV	0.5800	XII
10	Hydraulic function	Oil leaks from cylinder	90	XI	0.5367	IX
11	Hydraulic pressure	Oil pressure is not stable	120	IX	0.5033	VII
12	Hydraulic pump	Improper work	126	VIII	0.5033	VII
13	Spindle system	Improper work	84	XII	0.5467	X
14	Head stoke	Centre out	144	V	0.4900	V
15	Tail stoke	Centre out	150	IV	0.4800	IV

The ranking can be used for the decision making managers, arranging the inspection and maintenance of the equipment properly, which can optimize the maintenance resources and avoid risk.

CONCLUSION

In the present work, the FMEA is a very important safety and reliability analysis tool which has been widely used in many areas and industries. FMEA provides an efficient tool for product design and process planning by detecting the potential product and process failures and by taking actions to prevent them in the early stages. In the conventional FMEA, the failure modes that have to be handled primarily are determined according to the RPN values which are estimated by multiplying values of three different risk factors.

In this study, the relative importance of risk factors O, S and D have been considered and evaluated in a linguistic manner rather than by precise numerical values, which makes the prioritization of failure modes more realistic and objective. For example, the historical data can be applied to the weight of risk factors, or a higher weight can be assigned to the factor that is more concerned about, which can make the results more aligned to the practical situation. In this connection, both conventional and Grey theory can be applied in FMEA, and the results are almost the same. Compared with the conventional FMEA, the Grey theory in FMEA can reflect the nature of relative ranking, because the ranking is based on the Grey Relational Coefficient which is determined by the comparison between comparative and standard series.

Finally, the results of the both approaches (Conventional and Grey theory) were compared and the differences were interpreted. The obtained results under the assumption of assigning equal weights to the risk factors differ from the conventional FMEA applications. Thus, this study a new perspective about prioritization of the failure modes is presented. This new perspective is a contribution to the literature, because it proposes a more efficient model for prioritization of the failure modes. Identifying the most severe failure modes is an important phenomenon for the quality focused firms.

Since Grey Relational Analysis approach to FMEA eliminates previously stated shortcomings of conventional approach, it is a useful tools to identification the failure modes that should be handled primarily. Thus, the limited resources of businesses can be effectively allocated to eliminate the most severe failure modes.

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