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Implementation of Failure Mode and Effect Analysis to Enhance the Productivity of CNC Machines in a Valve Manufacturing Industry

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Abstract
The Failure Mode and Effects Analysis (FMEA) serves as a proactive quality assessment tool aimed at identifying potential failure modes and their underlying causes. Its purpose is to prioritize these failure modes and devise corrective measures to prevent catastrophic failures and enhance overall quality. This study endeavors to implement machinery FMEA within the valves manufacturing unit of Sirus Engineering Private Limited, located in Coimbatore, Tamil Nadu, India. The analysis involves identifying failure modes and their causes across all CNC machines, reassessing three critical indices—Severity (S), Occurrence (O), and Detection (D)—and conducting statistical analyses of failures using the Machinery Failure Mode and Effects Analysis (MFMEA) worksheet. Subsequently, recommended corrective actions are provided based on the findings.

***Keywords*: CNC machine failures, MFMEA, RPN, severity, occurrence, detection**

INTRODUCTION

The failure mode and effect analysis is employed to systematically identify and analyze: (a) the various failure modes occurring in different parts of the system, (b) the impacts of these failure modes on the system, and (c) strategies for preventing or mitigating the effects of system failures.

FMEA is a systematic approach used to identify all possible failures within a process through a step-by-step methodology. The term "Effect Analysis" refers to assessing the repercussions or outcomes of these failures.[7] The primary goal of conducting a Process FMEA is to consistently enhance products and processes, thus leading to increased customer satisfaction.[8]

FMEA is an invaluable methodology crucial for implementation in companies and manufacturing sectors, particularly in engineering design, production processes, and the introduction of new products throughout the product life cycle. Its primary objective lies in establishing connections between the causes and consequences of failures, while also identifying, addressing,
and implementing optimal solutions through the application of relevant actions.

Advantages ofFMEA as given below:

- Detect and avert safety risks.
- Reduce the impact on product performance or mitigate performance deterioration.
- Enhance testing and validation strategies.
- Enhance protocols for process control.
- Explore modifications to product design or manufacturing procedures.
- Recognize critical product or process attributes.
- Establish maintenance schedules for machinery and equipment in use.
- Implement online diagnostic methods.

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LITERATURE REVIEW

The literature survey involves a concise examination of the works of respected researchers and scholars who have contributed to the field under study. Its aim is to convey the established ideas and knowledge pertaining to the topic, highlighting both strengths and weaknesses. Defined by the guiding principle, the literature review encompasses various sources such as research reports and paper introductions.

Ambekar conducted research on Failure Mode and Effects Analysis (FMEA), a method utilized in product development and operations management to scrutinize potential failure modes within a system, categorizing them based on severity and likelihood. Effective implementation of FMEA facilitates the identification of potential failure modes, drawing from past experiences with analogous products or processes. This enables teams to proactively design out these failures from the system with minimal effort and resource allocation, ultimately reducing development time and costs.

Degu and Moorthy conducted a study where they identified failure modes and their causes for each machine, reassessed the three key indices (Severity, Occurrence, and Detection), and conducted an analysis using the Machine Failure Mode and Effect Analysis (MFMEA) Worksheet. The research findings revealed significant machine downtime, leading to disruptions in the continuous production of pipes.

Yang utilized evidence theory to consolidate risk evaluation data from multiple experts. However, the model assumed that all individual and interval assessment grades were clear-cut and independent of each other. It overlooked scenarios in FMEA where an assessment grade might signify a vague concept or standard, and there could be ambiguity between the meanings of two adjacent grades.

Braglia devised a method where the traditional scores for Occurrence (O), Severity (S), and Detection (D) were standardized as the local priorities of the causes concerning O, S, and D respectively. The weight composition technique within the Analytic Hierarchy Process (AHP) was employed to merge these local priorities into a global priority. This global priority was then used to rank the potential causes of failure.

Zammori and Gabbrielli conducted their research based on the ANP/RPN model. They divided Occurrence (O), Severity (S), and Detection (D) into sub-criteria and organized them into a hybrid decision structure, which included a hierarchy/network. Within this structure, the causes of failure were situated at the lowest level. Using this decision structure as a foundation, they computed the Risk Priority Number (RPN) by conducting pair-wise comparisons.

Liu utilized the VIKOR method, originally designed for multi-criteria optimization in intricate systems, to determine the prioritized ranking of failure modes based on risk factors in FMEA. Within the methodology, linguistic variables, represented by trapezoidal or triangular fuzzy numbers, were employed to evaluate ratings and weights for the risk factors O, S, and D.

METHODOLOGY

The CNC machines' specifications utilized within the SIRUS Valves industry are detailed in Table 1, serving as the reference for data collection.

In this study, failure data pertaining to CNC machines has been gathered from the SIRUS Valves industry, and an analysis of the data has been conducted using the conventional FMEA approach. The collection of CNC machine failure data has been carried out at regular intervals.

Failure date and time, Failure phenomenon, Cause analysis, repairing process of failure, Repairing time of failure, Downtime of machine, Model, sizeand numbers of the breakdown component.

Table 1. Specification of CNC Machines.

Machineno.	Name of CNC lathe	Specification				
		Max. turning diameter (mm)	Max. turning length (mm)	No. of tools on turret	Length between centers (mm)	Turning speed (RPM)
L-01	Daewoo Puma 10-HC	370.8	525.8	10	525.8	35-3500
L-02	LMW-P20T.L3	320	250	8	350	45-4300
L-03	LMW-P20T.L5	380	440	8	550	35-3500

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The conventional Failure Mode and Effect Analysis (FMEA) method serves as a proactive quality assessment tool, aimed at assessing potential failure modes and their underlying causes. It aids in prioritizing these failure modes and suggesting corrective actions to prevent catastrophic failures, thus enhancing product quality.

Step 1: Involves identifying components and their associated functions.

Step 2: Failure modes are identified.

Step 3: Focuses on assessing the severity of failure, rated on a scale from 1 to 10 based on machine downtime hours as detailed in Table 2.

Step 4: Entails identifying the causes of failure modes, with occurrence rated on a scale of 1 to 10 representing Mean Time Between Failures (MTBF) hours, as outlined in Table 3.

Step 5: The current design control's detection capability is assessed, employing the evaluation scale provided in Table 4.

Step 6: Involves the computation of the Risk Priority Number (RPN).

The Risk Priority Number (RPN) serves as a key indicator for determining appropriate corrective actions for failure modes. Severity, Occurrence, and Detection are ranked on a scale from 1 to 10. Once the Severity, Occurrence, and Detection levels are determined, the RPN is calculated by multiplying the Severity (S), Occurrence (O), and Detection (D) values.

$$RPN = S \times O \times D$$

A lower RPN value is consistently preferable to a higher one. Based on the RPN values, failure modes are categorized, and appropriate corrective actions are then implemented for CNC machine failures with higher risk level.

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

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

Table3. Criteria for Ranking Occurrence (O)in FMEA.

Probability of occurrence	**Possible failure rates criteria**	**Ranking**
Very high: Failure is almostinevitable	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

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

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

RESULTS AND DISCUSSION

The findings presented in Table 5 outline the calculation of the Risk Priority Number (RPN) for various failure modes. The analysis conducted in the MFMEA worksheet highlights that the highest RPN value (RPN=225) corresponds to the (MTBF), and the challenges associated with its detection. Following this, significant attention should be directed towards addressing the alignment disorder of the turret head issue of play in coupling for the turret head. This primarily stems from the severity of its potential failure in halting production, its extended Mean Time Between Failures

(RPN=216), given its critical impact on subsequent processing stages.

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Table 5. MFMEA Worksheet for CNC Machine Failures of SIRUS Valves Industry.

Failure mode	**Subsystem**	**Part name**	**Potential effects**	**S**	**Potential cause**	**O**	**Current controls**	**D**	**Rank**	**RPN**
Alignment disorder	Mechanical system	Turret head dismantling	Gun metal bush damage	9	Improper fitment	6	Replacing the gun-metal bush	4	II	216
Play in coupling	Mechanicalsystem	Turret head dismantling	Coupling bearing damage andloose fasteners	9	Jerk/accident, lubrication oil	5	Replacing the all damaged bearing	5	I	225
Indexing time mismatch	Electronicsystem	Turret head dismantling	I/O parameter and sensor setting disorder	9	High input currents and sensor in fault	5	Reset the I/O parameter	3	IV	135
Low pressure of coolant	Coolantsystem	Coolant Tank	Low viscosity lubricant changed	7	Blockage the coolant flowline	5	Remove chips present in lubricant	3	V	105
Improper work	Coolantsystem	Coolantpump	Damage/ burn motorwinding andcontactor relay	7	Faulty supply	5	Rewinding the motor coil	4	III	140
Parameter disorder	Electronicsystem	Feed servo system	PLC unit reorder and I/O parameter change	7	Faulty supply, contactor relay burn	6	Replacing the contactor relay	1	IX	42
Overload/power fluctuated	Electricalsystem	Feed servo system	Connections and supplyunit checked	7	Faulty supply, stabilizer card burn	5	Replacing the stabilizer card	2	VII	70
Changing tableturns slowly	Hydraulicsystem	Hydraulictable	Damaged oil seals replaced	6	Damage the oil seal, leakage in hydraulic flow line	5	Ensure the proper checking of hydraulic flow line	2	VIII	60
Oil leaks from cylinder	Hydraulicsystem	Hydraulic function	Oil pipes cleaned, damaged oil seals replaced	6	Leakage in hydraulic cylinder	5	Ensure the proper checking of hydraulic flow line	3	VI	90

This study holds significant implications for the relevant industry and those heavily reliant on CNC machines for manufacturing processes. While numerous endeavors focus on failure analysis, some prove intricate and challenging to thoroughly investigate, often relying on numerous assumptions to achieve conclusive results. The established ranking system offers valuable insights for decision-making managers, aiding in the strategic scheduling of inspections and maintenance activities for equipment. This approach optimizes maintenance resources and mitigates potential risks effectively.

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