American Journal of Engineering Research (AJER)
e-ISSN : 2320-0847 p-ISSN : 2320-0936
Volume-03, Issue-01, pp-57-63
www.ajer.org

Research Paper Open Access

Implementation of Machinery Failure Mode and Effect Analysis in Amhara Pipe Factory P.L.C., Bahir Dar, Ethiopia

Yonas Mitiku Degu[1], R. Srinivasa Moorthy[2]
[1, 2]: School of Mechanical and Industrial Engineering, BiT, Bahir Dar University, Bahir Dar, Ethiopia.

Abstract: - Failure Mode and Effect Analysis (FMEA) 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 quality. In this work, an attempt has been made to implement Machinery FMEA in UPVC pipe production unit of Amhara Pipe Factory, P.L.C., Bahir Dar, Ethiopia.
The failure modes and their causes were identified for each machine, the three key indices (Severity, Occurrence and Detection) we reassessed and the analysis was carried out with the help of MFMEA Worksheet. Finally, the necessary corrective actions were recommended.

Keywords: **-** Detection, MFMEA, Occurrence, RPN, Severity.

I. INTRODUCTION

Amhara Pipe Factory P.L.C., Bahir Dar, Ethiopia specializes in the production of UPVC, HDPE and threaded casting pipes of various diameters and geo-membrane sheets for domestic, construction and industrial needs. They currently follow breakdown maintenance for the machinery which results in a considerable machine downtime, disrupting the continuous production of pipes. The identification and elimination or reduction of the problems inherent in the UPVC pipe production unit using a continuous process improvement tool will be substantially beneficial in the grounds of reduced MDT (machine down time), minimized scrap, lessened cost of replacing spare parts and higher productivity.

Failure Mode and Effect Analysis (FMEA) is one such quality tool which gives a clear description of the failure modes so that the catastrophic failure possibilities can be readily identified and eliminated or minimized through corrective actions in design or operating procedure.

Among the different types of FMEA, Machinery FMEA has been chosen for implementation in UPVC production unit of Amhara Pipe Factory P.L.C. The methodology, the results of MFMEA analysis and the recommended corrective actions for quality improvement were detailed in this work.

II. FAILURE MODE AND EFFECT ANALYSIS (FMEA)

Murphy's Law states, "Everything that can fail shall fail". FMEA addresses the elimination of premature failure due to faulty design or process.

Failure Mode and Effect Analysis (FMEA) is defined as a systematic process for identifying potential design and process failures before they occur, with the intent to eliminate them or minimize the risk associated with them. FMEA procedures are based on standards in the reliability engineering industry, both military and commercial [1]. FMEA provides an organized critical analysis of potential failure modes of the system being defined and identifies the associated causes. It uses occurrence and detection probabilities in conjunction with severity criteria to develop a risk priority number (RPN) for ranking corrective action considerations [2].

FMEA can also be defined as a group of activities intended to "recognize and evaluate the potential failure of a product or process and its effects and identify actions that could eliminate or reduce the chance of potential failures" [3].

2.1 Objectives of FMEA

The main objectives of FMEA are to:

- identify the equipment or subsystem and mode of operation

- recognize potential failure modes and their causes
- evaluate the effects of each failure mode on the system and
- identify measures for eliminating or reducing the risks associated with each failure mode [1].

2.2 Major types of FMEA

The following major types of FMEA are commonly used, based on the application:

- Design FMEA (DFMEA) – focuses on potential failure modes of products caused by design deficiencies.
- Process FMEA (PFMEA) - focuses on potential failure modes of products caused by manufacturing or assembly process deficiencies.
- Machinery or Equipment FMEA (MFMEA) – focuses on designs that improve the reliability and maintainability of the machinery for long-term plant usage [4].

2.3 Key parameters of FMEA

Any type of FMEA involves the following key parameters for prioritizing the corrective action:

2.1.1 Severity

It is an assessment of seriousness of the effect of a failure mode on the customers.

2.1.2 Occurrence

Occurrence is an assessment of the likelihood that a particular cause will happen and result in a failure mode.

2.1.3 Detection

It is an assessment of the likelihood that the current controls will detect the cause of the failure mode thus preventing it from reaching the customer.

2.1.4 Risk Priority Number (RPN)

It is a mathematical product of Severity (S), Occurrence (O) and Detection (D). It serves in fixing the priority for the process / item to focus for corrective action. It is computed as:

$$\boldsymbol{RPN = S \times O \times D} \quad \textbf{(1)}$$

The three indices (Severity, Occurrence and Detection) are individually assessed on a 1 to 10 scale basis for each failure mode, using the standard guidelines specifically tailored for Design, Process and Machinery FMEA's, to address the objectives and requirements of the selected type of FMEA. Then RPN is calculated using **(1)** for each process/system/sub-system to rank and prioritize the corrective action plan.

2.4 General benefits of FMEA

- Prevention planning
- Identifying change requirements
- Cost reduction
- Increased through-put
- Decreased waste
- Decreased warranty costs
- Reduced non-value added operations

III. MACHINERY FMEA

MFMEA is a standardized technique for evaluating equipment and tooling during its design phase to improve the operator safety, reliability and robustness of the machinery. MFMEA provides an opportunity to prioritize the design improvement actions through identification of corrective actions to prevent or mitigate possible failures.

Machinery FMEA should be started early in the design process (best practice) when the equipment and tooling is able to take advantage of design revisions. Normally MFMEA's are targeted for long-term, repetitive cycles, where wear-out is a prime consideration. The specifically tailored criteria for ranking MFMEA parameters of Severity, Occurrence and Detection are given in TABLES I, II and III [4].

The key benefits of MFMEA are to:

- improve safety, reliability and robustness of equipment / tooling
- allow design changes to be incorporated early, to minimize machinery cost and delivery delays and
- reduce overall life-cycle costs.

Owing to the fact that Amhara Pipe Factory P.L.C. is continuous pipe production industry and that the current problems in UPVC pipe production unit are more machine-centric, MFMEA was selected among the three major types of FMEA for implementation.

IV. PROFILE OF AMHARA PIPE FACTORY P.L.C., BAHIR DAR, ETHIOPIA

Amhara Pipe Factory P.L.C., Bahir Dar, Ethiopia is the biggest producer of plastic products in Ethiopia. The major products of the factory are Un-plasticized Polyvinyl Chloride (UPVC) pipes, High Density Poly Ethylene (HDPE) pipes, Geo-membrane sheets and Threaded casing pipes.

UPVC pipe unit has the capacity to produce pipes of diameters ranging from 16 mm to 630 mm for various nominal pressures from 3 bar to 16 bar, as per the Ethiopian standards identical to ISO standards. UPVC pipes are used for water sewerage system, potable water transportation, industrial waste disposal system, irrigation and for making electric conduits.

HDPE unit has two lines – one for producing pipes of outer diameter in 16 mm – 63 mm range which can be coiled in lengths from 100 m to 300 m as rolls; the other line produces pipes in 75 mm - 250 mm diameter range for 12 m length or as per the customer requirements. HDPE pipes, made to withstand four different nominal pressure capacities from 6 bar to 25 bar, are used for industries, marine mining, potable water transport, waste water disposal, slurry/chemical and compressed gas transport.

Geo-membrane sheets are produced in the range of thickness 0.5 mm to 2.0 mm, width 6.2 m to 6.3 m, and lengths up to 140 m. They are used for land fill project sites, banking dam, channel irrigation, tunnel, highway and railway construction, river way, etc.

Threaded casing pipes are produced for standard diameters from 75 mm to 315 mm for two nominal pressures (10 bar and 16 bar), confirming to international standards.

V. PRODUCTION OF UPVC PIPES

The UPVC pipe production is carried out in eight distinct stages, right from raw materials to finished pipe of required dimensions.

5.1 Mixing Unit

This unit comprises of Hot and Cold chambers. The raw materials are thoroughly mixed in the Hot chamber first and are automatically transferred to the Cold chamber. The output of the Cold chamber is a homogenous mixture of the raw materials in proper proportion.

5.2 Helical Spring Conveyor Unit

The output of Mixing unit is conveyed to Extruder unit through a helical spring conveyor enclosed in a flexible PVC pipe.

5.3 Extruder Unit

A threaded feeder thrusts the mixture into a die set with a concentric mandrel and sleeve of required size to extrude the pipe. The mandrel and sleeve heaters impart the required temperature, thus giving uniform temperature distribution in the pipe cross-section.

5.4 Vacuum Pass

The extruded pipe is made to pass through a vacuum unit. This facilitates the extruded pipe to sustain the dimensions without any wrinkling and improves cleanliness and hardness of the pipe surface.

5.5 Cooling Pass

In this unit water is used for spray cooling to ensure the pipe quality and high speed stable extruding.

5.6 Haul-off Unit

The chain drive with an endless wooden gripper belt is used to provide traction to pull the extruded pipe.

5.7 Planetary Cutter Unit

A motor-driven circular saw cutter enables high-speed cutting operation of the pipes. A chamfer tool is also incorporated along with the cutter.

5.8 Belling Unit

This unit performs the bulging operation on one end of the cut pipes to facilitate joining of pipes.

VI. RESULTS AND DISCUSSION

MFMEA of the UPVC pipe production unit was done based on the MFMEA Severity, Occurrence and Detection criteria outlined in TABLES I, II and III respectively, by the MFMEA team comprising of the authors, Mr. Adem Dawud, Production and Technical Process Owner and the workers of each machine.

The results summarized in MFMEA Worksheet (TABLE IV) revealed that the Risk Priority Number was the highest (RPN = 168) for Mixer unit, mainly owing to the degree of severity of the failure in disrupting the entire production, excessive mean-time-between-failures (MTBF) and difficulties in detection. Hence, utmost priority should be given to the corrective measures for Mixer unit to eliminate the failure. The next priority should be given to the Extruder unit (RPN = 120), mainly because of its criticality in affecting further processing. For the Planetary cutter unit ranking three with an RPN of 42, the sole reason for failure was found to be the breakage of screw shaft in the minor diameter section.

The RPN values of the other units were found to be less critical and substantially low when compared to Mixer and Extruder units. Nevertheless, the required corrective actions were recommended for all the eight units in the MFMEA Worksheet.

VII. CONCLUSION

The failure problems in UPVC production unit of Amhara Pipe Factory P.L.C. was analyzed using MFMEA technique and corrective actions for quality improvement were documented and presented to the authorities of the factory. The vibration problem inherent in the Mixer unit was found to pose a major threat. Since MFMEA implementation involves preventive maintenance as a control to ensure reliability, the authorities were insisted to keenly follow the preventive maintenance guidelines for each machine, documented in the Maintenance Catalogue given by the suppliers of the machinery, in addition to the recommended corrective actions.

Once the recommended actions for reducing machine vibrations and other corrective measures mentioned in MFMEA Worksheet were implemented along with a strict adherence to the preventive maintenance schedule, then the RPN values can be recomputed, which are sure to show a marked decrease in its value, owing to reduced severity, occurrence and detection indices, thus improving the life of machines and the overall productivity of Amhara Pipe Factory P.L.C. The authorities were suggested to keep track of the MFMEA documents in future, since it is a continuous quality improvement tool.

Use of FTA (Fault Tree Analysis), a deductive top-down failure analysis technique, will compliment this attempt. The work can be extended by using FMECA (Failure Mode, Effect and Criticality Analysis) which additionally charts the probability of failure modes against the severity of their consequences.

VIII. ACKNOWLEDGEMENTS

The authors wish to register their heartfelt gratitude to Mr. Adem Dawud, Production and Technical Process Owner in particular and all the authorities, management staff and workers of Amhara Pipe Factory P.L.C., Bahir Dar, Ethiopia for supporting us with necessary technical information and giving feedback about the failure modes of each machinery of UPVC production unit.

IX. REFERENCES

[1] Guidance of Failures Modes and Effects Analysis, International Marine Contractors Association, April 2002.

[2] Failure Mode and Effects Analysis (FMEA): A Guide for Continuous Improvement for the Semi-conductor Equipment Industry, Sematech, September 30, 1992.

[3] Veeranna D. Kenchakkanavar and Co., Failure Mode and Effects Analysis: A Tool to Enhance Quality in Engineering Education, *International Journal of Engineering (IJE), Vol. 4: Issue 1.*

[4] Failure Mode and Effects Analysis, Cayman Business System (Rev: Q), May 31, 2011.

TABLES

TABLE I: Criteria for Ranking Severity (S) in MFMEA [4]

Effect	***Severity Criteria***	***Ranking***
Hazardous without warning	Very high severity ranking: Affects operator, plant or maintenance personnel; safety and/or effects non-compliant with government regulations.	10
Hazardous with warning	High severity ranking: Affects operator, plant or maintenance personnel; safety and/or effects non-compliant with government regulations.	9
Very high downtime or defective parts	Downtime of more than 8 hours .	8
High downtime or defective parts	Downtime of more than 4-7 hours.	7
Moderate downtime or defective parts	Downtime of more than 1-3 hours.	6
Low downtime or defective parts	Downtime of 30 minutes to 1 hour.	5
Very low	Downtime up to 30 minutes and no defective parts	4
Minor effect	Process parameters variability exceed upper/lower control limits; adjustments or process controls need to be taken. No defective parts.	3
Very minor effect	Process parameters variability within upper/lower control limits; adjustments or process controls need to be taken. No defective parts.	2
No effect	Process parameters variability within upper/lower control limits; adjustments or process controls not needed or can be taken between shifts or during normal maintenance visits. No defective parts.	1

TABLE II: Criteria for Ranking Occurrence (O) in MFMEA [4]

Probability of Failure Occurrence	*Possible Failure Rates Criteria*	*Ranking*
Very high: Failure is almost inevitable	Intermittent operation resulting in 1 failure in 10 production pieces 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 III: Criteria for Ranking Detection (D) in MFMEA [4]

Detection	*Likelihood of Detection by Design Controls*	*Ranking*
Absolute uncertainty	Machine controls will not and/or cannot detect potential cause/mechanism and subsequent failure mode; or there is no design or machinery control.	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. Machinery control will prevent an imminent failure.	8
Very low	Very low chance a machinery/design control will detect a potential cause/mechanism and subsequent failure mode. Machinery control will prevent an imminent failure.	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. Machinery control will prevent an imminent failure and will isolate the cause. Machinery control may be required.	5
Moderately high	Moderately high chance a machinery/design control will detect a potential cause/mechanism and subsequent failure mode. Machinery control will prevent an imminent failure and will isolate the cause. Machinery control may be required.	4
High	High chance a machinery/design control will detect a potential cause/mechanism and subsequent failure mode. Machinery control will prevent an imminent failure and will isolate the cause. Machinery control may be required.	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

TABLE IV: MFMEA Worksheet for PVC Pipe Production Unit of Amhara Pipe Factory P.L.C.

Sub-system	***Function***	***Potential Failure Mode(s)***	***Potential Effect(s) of Failure***	***S***	***Potential Cause(s) of Failure***	***O***	***Current Design / Machine Control(s)***	***D***	***RPN / Rank***	***Recommended Action(s)***
Mixer	To mix the raw materials homogenously	Premature Bearing failure Crushing of key	The respective production line is disrupted	7	Undue vibration of the equipment	3	Replacing bearing Replacing key	8	168 / I	Providing vibration isolation with elastic pads; laying foundation beds
		Burning of motor coil			Overload due to coagulation		Rewinding motor coil			Monitoring of Hot chamber temperature
Helical Spring Conveyor	To transport Mixer unit output to Extruder unit	Breakage of spring	Disrupts further processing	5	High inertia torque	4	Welding the broken spring	1	20 / V	Limiting the radius of curvature
		Feed motor failure			Overload due to coagulation					Monitoring of Cold chamber temperature
Extruder	To get the reqd. pipe dimensions	Burning of mandrel and sleeve heaters	Prolonged uneven temperature distribution causing scrap	8	Improper handling of die sets	3	Replacing resistors	5	120 / II	Use of material handling equipment for die sets
Vacuum Pass	To prevent pipe wrinkling	Noisy operation	Reduced vacuum pressure causing pipe wrinkling	3	Accumulation of foreign particles	2	Cleaning of vacuum pump, when noisy	1	6 / VI	Supplying clean filtered water for recycling
Cooling Pass	To cool the pipe	Leakage of water	Reduces the cooling effect	2	Poor maintenance of pipe joints	2		1	4 / VII	Periodic maintenance of cooling pipes
Haul-off	To pull the extruded pipe	Accelerated wear and tear of rubber gripper	Disrupts further processing	6	Inadequate gripping and slippage	3	Replacing damaged grippers	2	36 / IV	Periodic grease lubrication of the chain sprocket
		Breakage of roller chain					Replacing broken pins			
Planetary Cutter	To cut and chamfer the pipe	Breakage of screw shaft	Necessitates manual cutting	6	Stress concentration in screw shaft shoulder	7	Replacing the screw shaft	1	42 / III	Avoiding abrupt change in screw diameter
Belling	To bulge the pipe	Burning of 0.5 A	Delivery affected till repair	1	Variation of supply voltage	6	Changing fuse	1	6 / VI	Using 1 A fuse

AUTHORS' BIBLIOGRAPHY

Yonas Mitiku Degu received his B.Sc. in Mechanical Engineering from Bahir Dar University, Bahir Dar, Ethiopia in 2005; pursued M.Sc. in Applied Mechanics (Mechanical Design) Addis Ababa University, Addis Ababa, Ethiopia graduated in 2008; currently working as Assistant Professor and Director of School of Mechanical and Industrial Engineering, Bahir Dar Institute of Technology, Bahir Dar University, Bahir Dar, Ethiopia.

R. Srinivasa Moorthy obtained his Masters Degree in Mechanical Engineering Design from Kongu Engineering College, Perundurai, Tamilnadu, India; has 17+ years of teaching experience; worked in Erode Sengunthar Engineering College, Erode, Tamilnadu, India, for 10 + years; worked in Eritrea Institute of Technology, Eritrea, North-East Africa, for 4 years; currently working as a Lecturer in School of Mechanical and Industrial Engineering, Bahir Dar Institute of Technology, Bahir Dar University, Bahir Dar, Ethiopia.