A Case Study: A Process FMEA Tool to Enhance Quality and Efficiency of Manufacturing Industry

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Abstract--- *The study has attempted to present an effective tool for solving the problem of manufacturing process quality by executing process FMEA with proposed process control practices. This paper aims to identify and eliminate current and potential problems from a manufacturing process of cylinder head in the company through the application of Failure Mode and Effects Analysis (FMEA) for improving the reliability of sub systems in order to ensure the quality which in turn enhances the bottom line of a manufacturing industry. Thus the various possible causes of failure and their effects along with the prevention are discussed in this work. Severity values, Occurrence number, Detection and Risk Priority Number (RPN) are some parameters, which need to be determined. Furthermore, some actions are proposed which require to be taken as quickly as possible to avoid potential risks which aid to improve efficiency and effectiveness of cylinder head manufacturing processes and increase the customer satisfaction. The prevention suggested in this paper can considerably decrease the loss to the industry in term of both money time and quality.*

Keywords--- *Cylinder Head, Failure Mode Effect Analysis, Potential Effect of Failure, Potential Failure Mode, Risk Priority Number*

I. INTRODUCTION

THE failure mode and effect analysis is used to identify and analyzed: (1) all failure mode of different parts of the system, (2) effects of these failure mode on the system and (3) how to circumvent the failure and/or moderate the effect of the failure system. FMEA is a step by step tactic to identifying all possible failure throughout the processes. "Effect Analysis" denotes to studying the consequences of those failures [12]. The motivation for undertaking a Process FMEA is to continually develop products and process consistency thereby increasing customer satisfaction [8].

The FMEA was developed and implemented for the first time in 1949 by U.S. Army and later executed in Apollo space programme to temperate the risk [5]. FMEA is a very significant method which should be engaged in companies for

an engineering design, production process and new product in planning and production sphere in product life cycle. Purpose of FMEA is founding links between causes and effects of defects, as well as searching, solving and drawing the best decisions regarding solicitation of applicable action.

II. LITERATURE REVIEW

In 1950s the increasing attention paid to safety and the need to prevent predictable accidents in aerospace industry led to the development of the FMEA methodology. Later, it was introduced as key tool for increasing quality and efficiency in manufacturing processes [10]. In 1977, Ford Motors introduced FMEA to address the potential problems in the Research and Development (R&D) in the early stage of production and published the Potential Failure Mode and Effects Analysis Handbook in 1984 to promote the method. Later on the automobile manufacturers in America also introduced the FMEA into the management of suppliers, and took it as a key check issue [13]. Find out reasons behind the failure of some subjects of mechanical engineering course and after analyzed the system through FMEA and they suggested recommend to solve the problem [15]. Execute FMEA to develop an effective quality system and to improve the current production process for the better quality of the products [14]. Applied FMEA model in salmon processing and packing industry in joint with ISO 22000 and they got the valuable result from implementation [7]. The FMEA has the potential to improve the reliability of Wind turbine systems especially for the offshore environment and made system cost effective [3]. Modified failure mode and effects analysis (MFMEA) method to select new suppliers in term the supply chain risk's perspective and applies the analytic hierarchy process method and found excellent result [11]. Applied FMEA technique on two products flywheel and flywheel housing and prevent different failure mode and suggestions were successfully implemented and the industry gained considerably in terms of both money and time [4]. Used FMEA to optimize the decision making process in new product development in automobile industry [2]. Implemented FMEA at the design stage As such, they could be compared with Failure Reporting, Analysis and Corrective Action System results once actual failures are observed during test, production and operation. They recommended taking appropriate actions to avoid possibility [1].

III. CONCEPT OF FMEA

Failure mode and effect analysis is an analytical technique (a paper test) that combines technology and experience of people in identifying probable failure mode of product or

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process and planning for its abolition. FMEA is a “before-the-event” action requiring a team effort to easily and inexpensively alleviate changes in design and production.

FMEA can be explained as a group of events projected to

- Recognize and evaluate the potential failure of a product or process and its effects.
- Identify actions that could eliminate or reduce the chance of potential failures.
- Document the process.

FMEA can be used as an individual project tool. However, it is strongly recommended that use to generate corrective action in a process improvement project. An FMEA is not a trivial tool rather it requires significant effort from a diverse team.

FMEA method use at [9]:

- Formation of the product concept, for checking whether all prospects of the customer are included in this concept.
- Define the product, in order to check whether projects, service, supplies are appropriate and controlled in the right time.
- Process of production, in order to check whether documentation primed by engineers is fully carried out.
- Assembly, for checking whether the process of the assembly is compatible with documentation.
- Organization of the service, in order to check whether the product or the service is pleasant with recognized criteria.

IV. DOCUMENTATION PROCEDURE FOR FMEA

A. Item and its Functions

Specify all the functions of an item, including the environment in which it has to operate.

B. Potential Failure Mode

- Considering past failures, present reports, brainstorming.
- Describe in technical terms and not as customers will see.
- For e.g. cracked, deformed, loosened, short circuited, fractured, leaking, sticking, oxidized etc.

C. Potential Effects of Failure

- As perceived by the customer (internal/end user).
- For e.g. erratic operation, poor appearance, noise, impaired functions, deterioration etc.

D. Severity

Severity is the assessment of the seriousness of the effect of the potential failure mode. In this we have to determine all failure modes based on the functional requirements and their effects. An example table of severity is given below.

Table 1: Table of Severity

Code	Classification	Example
10	Hazardous Without Warning	Very High Ranking – Affecting safe operation.
9	Hazardous With Warning	Regulatory non compliance
8	Very High	Product becomes inoperable, with loss of function – Customer Very Much Dissatisfied
7	High	Product remain operable but loss of performance – Customer Dissatisfied
6	Moderate	Product remain operable but loss of comfort/convenience - Customer Discomfort
5	Low	Product remain operable but loss of comfort/convenience - Customer Slightly Dissatisfied
4	Very Low	Nonconformance by certain items – Noticed by most customers
3	Minor	Nonconformance by certain items – Noticed by average customers
2	Very Minor	Nonconformance by certain items – Noticed by selective customers
1	None	No Effect

E. Class

Classification of any special product characteristics requiring additional process control

F. Potential Cause /Mechanism of Failure

Every cause/mechanism must be listed concisely

- E.g. of Failure Causes are inadequate design, incorrect material, inaccurate life assumption, poor environmental protection, over stressing, insufficient lubrication etc.
- E.g. of Failure Mechanisms are fatigue, wear, corrosion, yield, creep etc.

G. Occurrence

Occurrence is the chance that one of the specific cause/mechanism will occur. In this step, it is necessary to look at the cause of a failure and how many times it occurs. Looking at similar products or processes and the failures that have been documented for them can do this. A failure cause is looked upon as a design weakness. An example for occurrence rating is given in following table.

Table 2: Table of Occurrence

Code	Classification	Example
10 and 9	Very High	Inevitable Failure
8 and 7	High	Repeated Failures
6 and 5	Moderate	Occasional Failures
4, 3 and 2	Low	Few Failures
1	Remote	Failure Unlikely

H. Current Design Control

The control activities generally include Prevention Measures, Design Validation, and Design Verification Supported by physical tests, mathematical modeling, prototype testing, and feasibility reviews etc.

I. Detection

- Relative measures of the ability of design control to detect wither a potential cause/mechanism or the subsequent failure mode before production.
- Supported by physical tests, mathematical modeling, prototype testing, feasibility reviews etc.

Table 3: Table of Detection

Detection	Rank	Criteria
Extremely Likely	1	Can be corrected prior to prototype/ Controls will almost certainly detect
Very High Likelihood	2	Can be corrected prior to design release/Very High probability of detection
High Likelihood	3	Likely to be corrected/High probability of detection
Moderately High Likelihood	4	Design controls are moderately effective
Medium Likelihood	5	Design controls have an even chance of working
Moderately Low Likelihood	6	Design controls may miss the problem
Low Likelihood	7	Design controls are likely to miss the problem
Very Low Likelihood	8	Design controls have a poor chance of detection
Very Low Likelihood	9	Unproven, unreliable design/poor chance for detection
Extremely Unlikely	10	No design technique available/Controls will not detect

J. Risk Priority Numbers (RPN)

RPN is the indicator for the determining proper corrective action on the failure modes. It is calculated by multiplying the severity, occurrence and detection ranking levels resulting in a scale from 1 to 1000. After deciding the severity, occurrence and detection numbers, the RPN can be easily calculated by multiplying these 3 numbers: $RPN = Severity \times Occurrence \times Detection$. The small RPN is always better than the high RPN. The RPN can be computed for the entire process and/or for the design process only. Once it is calculated, it is easy to determine the areas of greatest concern. The engineering team generates the RPN and focused to the solution of failure modes.

K. Recommended Actions

Beginning with high RPN and working in descending order

- The objective is to reduce one or more of the criteria that make up the RPN.

- Typical actions are design of experiments, revised test plans, revised material specifications, revised design etc.
- Important to mark “None” in case of no recommendation for future use of FMEA document.

L. Responsibilities and Completion Dates

Individual or group responsible for the recommended actions and target completion date to be entered.

M. Actions Taken

Brief descriptions of the action taken to be entered after actual actions are taken by the team.

N. Revised RPN

Recalculation of Severity, Occurrence and Detection rankings after implementation of recommended actions and thus calculation of revised RPN.

Revised RPN=revised ($Severity \times Occurrence \times Detection$)

V. FMEA PROCEDURE [6]

The process for conducting FMEA can be divided into following steps. These steps are briefly explained as follows.

- Step 1: Collect the functions of system and build a hierarchical structure. Divide the system into several subsystems, having number of components.
- Step 2: Determine the failure modes of each component and its effects. Assign the severity rating (S) of each failure mode according to the respective effects on the system.
- Step 3: Determine the causes of failure modes and estimate the likelihood of each failure occurring. Assign the occurrence rating (O) of each failure mode according to its likelihood of occurrence.
- Step 4: List the approaches to detect the failures and evaluate the ability of system to detect the failures prior to the failures occurring. Assign the detection rating (D) of each failure mode.
- Step 5: Calculate the risk priority number (RPN) and establish the priorities for attention.
- Step 6: Take recommended actions to enrich the performance of system.
- Step 7: Conduct FMEA report in a tabular form.

VI. CASE STUDY AND FMEA ANALYSIS

A cylinder head is the closed, and often detachable, end of a cylinder located in an internal combustion engine. It is typically found on the top portion of the engine block as shown in Figure 1.

Figure 1: Cylinder Head

The cylinder head is an integral component of internal combustion engines. It conveys air and gasoline to the combustion chamber and serves as a cover for the cylinders. The main function of the cylinder head is to help the head gasket seal the cylinders properly so that they are able to build enough compression for engine operation.

In the vast majority of four stroke engines, the cylinder head mounts the entire valve gear and provides the basic framework for housing the valves as well as the spark plugs and injectors.

Case study is conducted and FMEA technique is applied to the cylinder head manufacturing process industry. There are various operation and processes carried out by various machine for manufacturing cylinder head. Facing, drilling and tapping are the main manufacturing operations of the cylinder head. Following manufacturing operations are carried out on the cylinder head:

- Bottom Face Finish
- Top Face Finish
- Inlet & Exhaust face finish

- Front & rear side face finish
- Top Side
- Bottom Side
- Inlet & Exhaust face Drilling
- Water Outlet Face Drilling
- Core Plug Drilling
- Injector Bore etc.

Criteria for ranking of severity occurrence and detection are selected suitably by analyzing the past failure records of the machine. Firstly, the basic requirements of the manufacturing processes are studied and then the potential failure mode of the specific process is found out. After that the potential effects of the failure mode are noted with their severity value. The occurrence value for the potential causes and their prevention is also calculated. The Detection value is assigned to the failure mode and finally the R.P.N value is calculated. The sample calculations are if $S = 4$, $O = 3$, & $D = 4$

Then, $R.P.N = S \times O \times D = 4 \times 3 \times 4 = 48$

FMEA Chart of Cylinder head is shown in Table 4.

Table 4: Process FMEA

PROCESS FAILURE MODE AND EFFECT ANALYSIS										
Part / Product No. : X-Cylinder Head					Key Contact Person :***			Doc. No. : X/FMEA/**		
Part / Product Description : Engine Cylinder Head					Key Contact : ****			Rev. No. :		
Customer Name (If any) : ***					Core Team : ****			Revision Date :		
Customer Drawing No. (If any) : ***										
Other Details (if any) :										
Operation No.	Process Description	Potential Failure Mode	Potential Effect of Failure	SEV.	Potential Causes	OCC.	Current Control Prevention	Current Control Detection	DET.	RPN
1	Bottom Face Finish	Height $\pm$ then specification	Smoke problem, Fuel problem	6	Improper Setting, Improper material removal	2	Process drawing, work instruction, first piece inspection	Inprocess inspection (inspect 1 after 5)	3	36
		Flatness out of specification	Fitment problem & functional problem	6	Improper setting, Improper tool select	2		100 % inspection	1	12
2	Top Face Finish	Height $\pm$ then specification	Oil leakage problem, Function problem at customer end	6	Improper Setting, Improper material removal	2	Process drawing, work instruction, first piece inspection	Inprocess inspection (inspect 1 after 5)	3	36
		Flatness out of specification	Fitment problem & functional problem		Improper setting, Improper tool select	2		100 % inspection	1	12

3	Dowel hole semi finish, bottom side	Drill Dia. And depth $\pm$ then specification	Fitment problem & functional problem at later stage(internal)	6	Improper setting, Improper tool select	2	Process drawing, work instruction, first piece inspection	100% inspection	1	12
4	Inlet & Exhaust face finish	Height $\pm$ then specification	Subsequent operation problem, functional problem at customer end	6	Improper Setting, Improper material removal	2	Process drawing, work instruction, first piece inspection	Inprocess inspection (inspect 1 after 5)	3	36
		Flatness out of specification	Fitment problem & functional problem at later stage(internal)	6	Improper setting, Improper tool select	2		100 % inspection	1	12
5	Front & rear side face finish	Height $\pm$ then specification	Subsequent operation problem, functional problem at customer end	6	Improper Setting, Improper material removal	2	Process drawing, work instruction, first piece inspection	Inprocess inspection (inspect 1 after 5)	3	36
		Flatness out of specification	Fitment problem & functional problem at later stage(internal)	6	Improper setting, Improper tool select	2		100 % inspection	1	12
6 (Top Side)	Top side dowel hole finish	Drill Dia. And depth $\pm$ then specification	Fitment problem & functional problem at customer end	6	Improper setting, tool wear, improper process parameters	2	Setup VMC program, process drawing, work instruction, first piece inspection	Inprocess inspection	3	36
	Top side bolt hole finish	Drill Dia. And depth $\pm$ then specification	Fitment problem & functional problem at customer end							
	Rocker mounting hole	Drill Dia. And depth $\pm$ then specification	Functional problem at customer end							
	Spot face	Drill Dia. And depth $\pm$ then specification	Functional problem at customer end							
7 (Bottom Side)	Bolt Hole finish	Drill Dia. And depth $\pm$ then specification	Fitment problem & functional problem at customer end	6	Improper setting, tool wear, improper process parameters	2	Setup VMC program, process drawing, work instruction, first piece inspection	Inprocess Inspection	3	36
	Dowel finish	Drill Dia. And depth $\pm$ then specification		6		2			3	36
	Push rod Hole	Drill Dia. And depth $\pm$ then specification		2		2			3	12
	Valve guide Hole	Drill Dia. And depth $\pm$ then specification	Fitment problem & functional problem at	6	Improper setting, tool wear, improper	2		In process inspection (100%)	3	36

			customer end		process parameters					
	Valve seat Bore	Drill Dia. And depth $\pm$ then specification	Fitment problem & functional problem at customer end	4	Improper setting, improper Tool select	2		Inprocess Inspection	3	24
	Water Direction Hole	Drill Dia. And depth $\pm$ then specification	Leakage Problem	6	Improper setting, improper Tool select	2		Inprocess Inspection	3	36
8	Inlet & Exhaust face Drilling	Drill Dia. And depth $\pm$ then specification	Functional Problem In Tapping	6	Improper setting, tool wear, improper process parameters	2	Process drawing, work instruction, first piece inspection	In process inspection (100%)	1	12
9	Water Outlet Face Drilling	Drill Dia. And depth $\pm$ then specification	Functional Problem In Tapping	6	Improper setting, tool wear, improper process parameters	2	Process drawing, work instruction, first piece inspection	In process inspection (100%)	1	12
10	Core Plug Drilling	Drill Dia. And depth $\pm$ then specification	Fitment Problem & Leakage Problem	6	Improper setting, improper Tool select	2	Process drawing, work instruction, first piece inspection	Inprocess Inspection	2	24
11	Injector Bore	Nozzle Bore Plus	loose Fitment	6	Manual Boring Control On Reading	2	Process drawing, work instruction, first piece inspection	Inprocess Inspection	3	36
		Nozzle Bore Minus	No Fitment	6		2			3	36
		Nozzle Step Bore Plus	loose Fitment	6	Manual Boring Control On Reading	2	Process drawing, work instruction, first piece inspection	Inprocess Inspection	2	24
		Nozzle Step Bore Minus	No Fitment	6		2			2	24
		Nozzle Bore Depth Plus	Injection Point/Position Changes Can Lead High Fuel Consumption	6	Stopper Resting Face Is Uneven Or Containment In Between Control Face	3	Process drawing, work instruction, Master piece of Correct Depth is Provide For Setting,	In process inspection (100%)	3	54
		Nozzle Bore Depth Minus	Knocking Effect & Effect On Fuel Consumption	6	Excess Wear out of Valve Guide Locking Pins	3			2	36
		Concentricity of Both Bores Not Ok	No Fitment	6	Inpositioning Boring	2	Process drawing, work instruction	In process inspection (100%)	2	24
12	Hole Chamfering	Burr Inside	Handling & Fitment Problem	8	Improper Tool, File Selected	2	Process drawing, work instruction, first piece inspection	Inprocess Inspection	1	16
13	Tapping	Tapping depth $\pm$ then	Functional problem at	6	Improper setting, tool	2	Process drawing,	100% inspection	1	12

		specification	customer end		wear, Jig bush Wear out		work instruction, first piece inspection			
14	Core Plug Fitting	Improper Fitting	Leakage Problem at customer End	8	in positioning fitting	2	Process drawing, work instruction, first piece inspection	100% inspection	1	16
15	Air Testing	Air Pressure & Leakage Test	Leakage Problem at customer End	8	Improper Leakage Testing	2	work Instruction	100% Inspection	1	16
16	Valve seat Cutting Inlet	Depth $\pm$ then specification	Leakage Problem at customer End	6	Depth Control On Reading	2	Process drawing, work instruction, first piece inspection	Inprocess inspection	3	36
17	Valve seat Cutting Exhaust	Depth $\pm$ then specification	Leakage Problem at customer End	6		2			3	36
18	Deburring, Cleaning, Inspection, Oiling, Packing	Dust & Rust Inside	Functional problem at customer end	6	Improper Cleaning	2	work Instruction	Inprocess inspection & pre- dispatch inspection	3	36

VII. CONCLUSION

FMEA provides a discipline/methodology for documenting this analysis for future use and continuous process improvement. It is a systematic approach to the analysis, definition, estimation, and evaluation of risks. Following a standard setup procedure will reduce setup time and improve part accuracy thereby increasing the quality and efficiency of processes. Many measures like standard operating procedures, Master piece of Correct Depth is Provide for Setting, Inprocess inspection, process drawing, and first piece inspection. FMEA analysis may easily help in improving the efficiency of the manufacturing process and quality of product thus decreasing the number of defective products and saving of rework cost and time. For each specific process the preventions suggested in the table can considerably decrease the loss to the manufacturing industry in terms of both money and time.

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