RISK ANALYSIS OF INTERNAL COMBUSTION ENGINE VALVE PRODUCTION USING FMEA METHOD

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ABSTRACT

In this article, FMEA method usage for the production of the poppet valves is considered. The definition of valves, ICE, and FMEA method for risk analysis is going to be remembered to the reader. When we produce poppet valves, there may be numerous kinds of problems that we meet. These problems should be handled with care and while doing this we need an approach with FMEA method. To avoid these problems' recurrence, FMEA method seems the best for us. In this article, we will focus on the summary of our work and FMEA usage. The details of production steps, FMEA steps will be introduced in another article.

Keywords: ICE, Poppet, Valve, P-FMEA, Production.

1. Introduction

An internal combustion engine (ICE) is a heat engine where the combustion of a fuel occurs with an oxidizer (usually air) in a combustion chamber that is an integral part of the working fluid flow circuit. In an internal combustion engine the expansion of the high-temperature and high-pressure gases produced by combustion apply direct force to some component of the engine. The force is applied typically to pistons, turbine blades, or a nozzle. This force moves the component over a distance, transforming chemical energy into useful mechanical energy. The first commercially successful internal combustion engine was created by Étienne Lenoir around 1859 and the first modern internal combustion engine was created in 1864 by Siegfried Marcus.

Failure mode and effects analysis (FMEA) was one of the first systematic techniques for failure analysis. It was developed by reliability engineers in the late 1950s to study problems that might arise from malfunctions of military systems. A FMEA is often the first step of a system reliability study. It involves reviewing as many components, assemblies, and subsystems as possible to identify failure modes, and their causes and effects. For each component, the failure modes and their resulting effects on the rest of the system are recorded in a specific FMEA worksheet.

2. Internal Combustion Engine

The term internal combustion engine usually refers to an engine in which combustion is intermittent, such as the more familiar four-stroke and two-stroke piston engines, along with variants, such as the six-stroke piston engine and the Wankel rotary engine. A second class of internal combustion engines use continuous combustion: gas turbines, jet engines and most

rocket engines, each of which are internal combustion engines on the same principle as previously described. Firearms are also a form of internal combustion engine. [1][2]
Internal combustion engines are quite different from external combustion engines, such as steam or Stirling engines, in which the energy is delivered to a working fluid not consisting of, mixed with, or contaminated by combustion products. Working fluids can be air, hot water, pressurized water or even liquid sodium, heated in a boiler. ICEs are usually powered by energy-dense fuels such as gasoline or diesel, liquids derived from fossil fuels. While there are many stationary applications, most ICEs are used in mobile applications and are the dominant power supply for vehicles such as cars, aircraft, and boats.

Typically an ICE is fed with fossil fuels like natural gas or petroleum products such as gasoline, diesel fuel or fuel oil. There's a growing usage of renewable fuels like biodiesel for compression ignition engines and bioethanol or methanol for spark ignition engines. Hydrogen is sometimes used, and can be made from either fossil fuels or renewable energy.

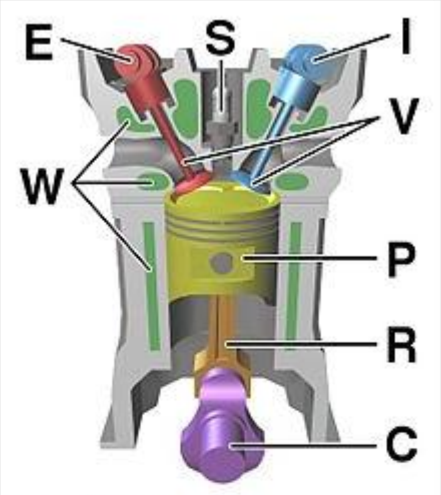

Diagram of a cylinder as found in 4-stroke gasoline engines.:
C – crankshaft.
E – exhaust camshaft.
I – inlet camshaft.
P – piston.
R – connecting rod.
S – spark plug.
V – valves. red: exhaust, blue: intake.
W – cooling water jacket.
gray structure – engine block.

Figure 1. Diagram of a cylinder as found in 4-stroke gasoline engines.

2. 1. Four Stroke Engines

A four-stroke engine (also known as four cycle) is an internal combustion engine in which the piston completes four separate strokes while turning a crankshaft. A stroke refers to the full travel of the piston along the cylinder, in either direction. [4][5]The four separate strokes are termed:

Intake: This stroke of the piston begins at top dead center (T.D.C.) and ends at bottom dead center (B.D.C.). In this stroke the intake valve must be in the open position while the piston pulls an air-fuel mixture into the cylinder by producing vacuum pressure into the cylinder through its downward motion.

Compression: This stroke begins at B.D.C, or just at the end of the suction stroke, and ends at T.D.C. In this stroke the piston compresses the air-fuel mixture in preparation for ignition during the power stroke (below). Both the intake and exhaust valves are closed during this stage.

Power: This is the start of the second revolution of the four stroke cycle. At this point the crankshaft has completed a full 360 degree revolution. While the piston is at T.D.C. (the end of the compression stroke) the compressed air-fuel mixture is ignited by a spark plug (in a gasoline engine) or by heat generated by high compression (diesel engines), forcefully returning the piston to B.D.C. This stroke produces mechanical work from the engine to turn the crankshaft.

Exhaust: During the exhaust stroke, the piston once again returns from B.D.C. to T.D.C. while the exhaust valve is open. This action expels the spent air-fuel mixture through the exhaust valve.

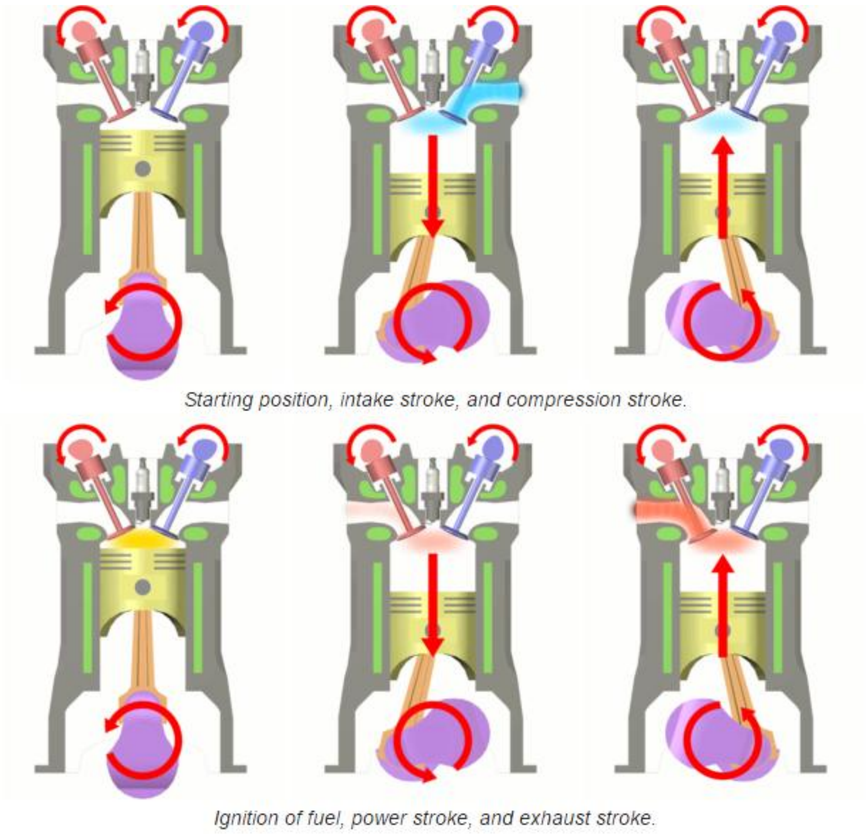

Figure 2. Strokes and positions

3. Valve

A valve is typically used to control the timing and quantity of gas or vapor flow into an engine. It consists of a hole, usually round or oval, and a tapered plug, usually a disk shape on the end of a shaft also called a valve stem. The portion of the hole where the plug meets with it is referred to as the 'seat' or 'valve seat'. The shaft guides the plug portion by sliding through a valve guide. In exhaust applications a pressure differential helps to seal the valve and in intake valves a pressure differential helps open it. Poppet valves date from at least the 1770s, when James Watt used them on his steam engines. [3][6]

Figure 3. Valve and components.

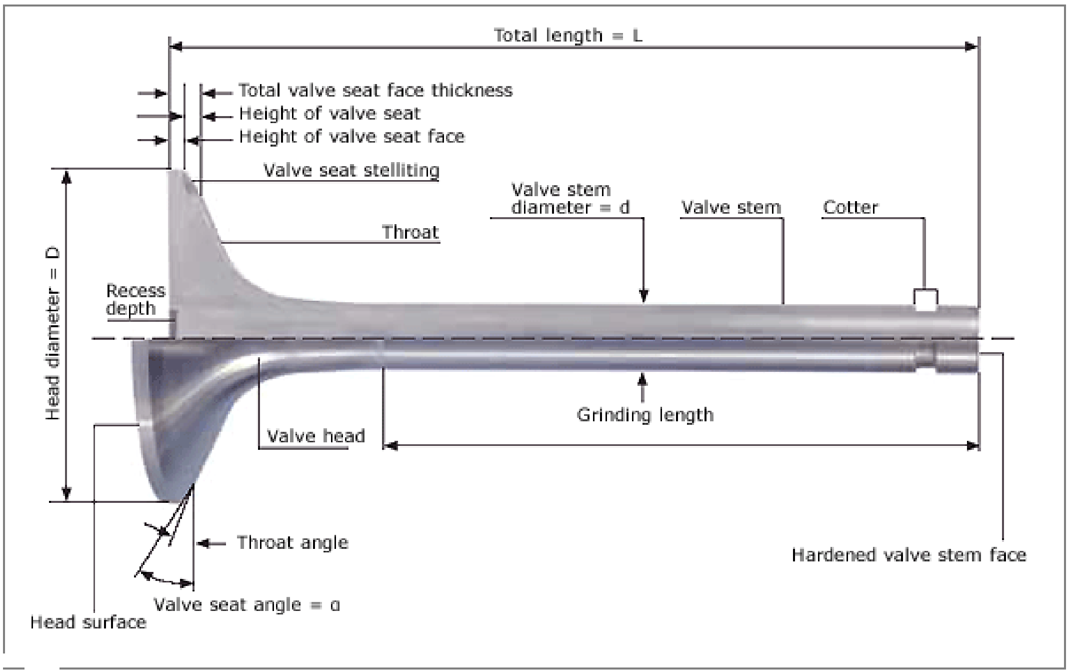

Figure 4. Valve terminology

3. 1. Basic Valve Characteristics

There are some main specifications for valves we need to know while doing our P-FMEA for them. If we subgroup them briefly;

- One-piece valves: They are made from one piece as whole, from martensitic/austenitic or nimonic materials.
- Two-piece valves: They are made from two pieces differently, one part (stem) is from martensitic material always, and the other half is made from austenitic or nimonic material.
- Seat-hardened valve: For only martensitic valves, seat part may be hardened with high temperatures.
- Stellite-welded valves: In order to hardening, seat part may be welded with a material called stellite.

These are some main characteristics that we shall keep in mind while making our FMEA sheet.

Also we can keep in mind that the working temperatures for a valve in an engine, changes like the figure below:

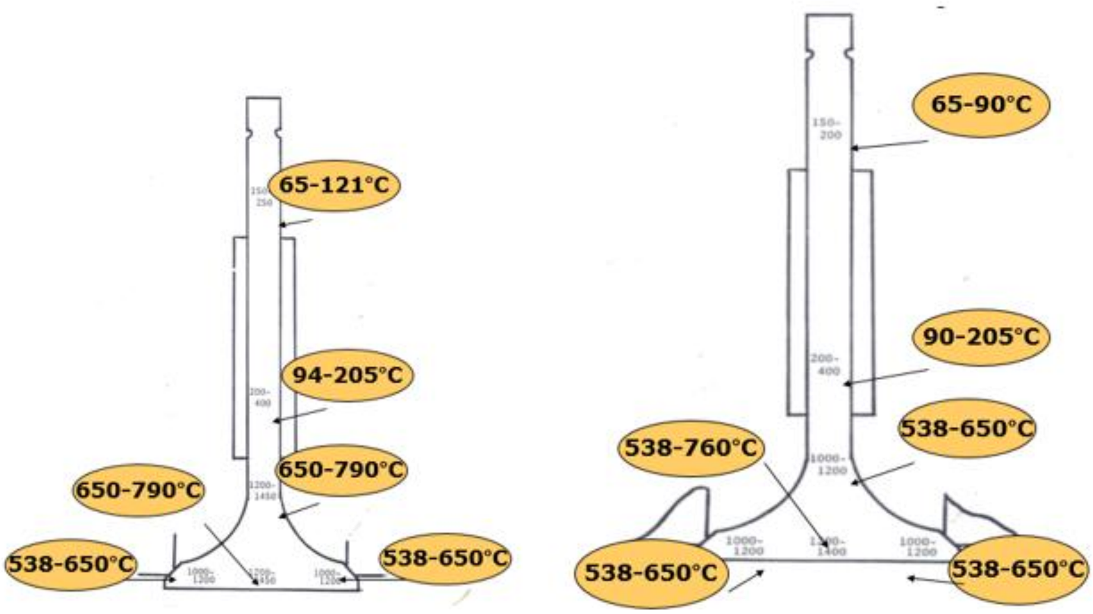

Figure 5. Working temperatures for exhaust (left-side) and intake (right-side) valves.

4. FMEA

As we defined FMEA at the introduction section above; there are numerous variations of such worksheets. A FMEA can be a qualitative analysis, [7] but may be put on a quantitative basis when mathematical failure rate models are combined with a statistical failure mode ratio database.

A few different types of FMEA analyses exist, such as

- Functional
- Design, and
- Process FMEA.

Sometimes FMEA is extended to FMECA to indicate that criticality analysis is performed too.

FMEA is an inductive reasoning (forward logic) single point of failure analysis and is a core task in reliability engineering, safety engineering and quality engineering. Quality engineering is especially concerned with the "Process" (Manufacturing and Assembly) type of FMEA.

A successful FMEA activity helps to identify potential failure modes based on experience with similar products and processes - or based on common physics of failure logic. It is widely used in development and manufacturing industries in various phases of the product life cycle. Effects analysis refers to studying the consequences of those failures on different system levels.

4. 1. Main Rules of FMEA

The ground rules of each FMEA include a set of project selected procedures; the assumptions on which the analysis is based; the hardware that has been included and excluded from the analysis and the rationale for the exclusions. The ground rules also describe the indenture level of the analysis, the basic hardware status, and the criteria for system and mission success. Every effort should be made to define all ground rules before the FMEA begins; however, the ground rules may be expanded and clarified as the analysis proceeds. A typical set of ground rules (assumptions) follows:

- Only one failure mode exists at a time.
- All inputs (including software commands) to the item being analyzed are present and at nominal values.
- All consumables are present in sufficient quantities.
- Nominal power is available

4. 2. Advantages of FMEA

Major benefits derived from a properly implemented FMEA effort are as follows:

- It provides a documented method for selecting a design with a high probability of successful operation and safety.
- A documented uniform method of assessing potential failure mechanisms, failure modes and their impact on system operation, resulting in a list of failure modes ranked according to the seriousness of their system impact and likelihood of occurrence.
- Early identification of single failure points (SFPS) and system interface problems, which may be critical to mission success and/or safety. They also provide a method of verifying that switching between redundant elements is not jeopardized by postulated single failures.
- An effective method for evaluating the effect of proposed changes to the design and/or operational procedures on mission success and safety.

- A basis for in-flight troubleshooting procedures and for locating performance monitoring and fault-detection devices.
- Criteria for early planning of tests.

From the above list, early identifications of SFPS, input to the troubleshooting procedure and locating of performance monitoring / fault detection devices are probably the most important benefits of the FMEA. In addition, the FMEA procedures are straightforward and allow orderly evaluation of the design.

4. 3. Limitations of FMEA

While FMEA identifies important hazards in a system, its results may not be comprehensive and the approach has limitations.[8][9][10] In the healthcare context, FMEA and other risk assessment methods, including SWIFT (Structured What If Technique) and retrospective approaches, have been found to have limited validity when used in isolation. Challenges around scoping and organizational boundaries appear to be a major factor in this lack of validity.[9]

If used as a top-down tool, FMEA may only identify major failure modes in a system. Fault tree analysis (FTA) is better suited for "top-down" analysis. When used as a "bottom-up" tool FMEA can augment or complement FTA and identify many more causes and failure modes resulting in top-level symptoms.

Additionally, the multiplication of the severity, occurrence and detection rankings may result in rank reversals, where a less serious failure mode receives a higher RPN than a more serious failure mode. The reason for this is that the rankings are ordinal scale numbers, and multiplication is not defined for ordinal numbers. The ordinal rankings only say that one ranking is better or worse than another, but not by how much. For instance, a ranking of "2" may not be twice as severe as a ranking of "1," or an "8" may not be twice as severe as a "4," but multiplication treats them as though they are. See Level of measurement for further discussion.

4. 4. Some of the Risks and Results of Them for Manufacturing Valves

- Wrong material for stem/head
- Wrong dimensions
- Cracks on any step of production
- Visual defects
- Hardness value may not match the desired value
- Material structure may be wrong
- Welding stress relief can be incorrect
- Porosity or bonding on stellite surface

And results may be:

- Engine failure due to low mech. properties
- Wrong dimensions may lead low performance, premature failure of engine, also wrong dimensions may lead machine failures while valve is being produced
- Cracks may lead premature fracture on valves, can damage engine

- Visual defects can be only visual and not harmful, but also they can effect roughness and again performance/abrasion
- If hardness values won't match, it can cause malfunction of engine due to wrong timing of a valve with worn tip-end
- Wrong structure of material also may lead to failure of the valve and also failure of engine
- If welding stress relief is not suitable, it will cause welding to crack and eventually break

5. FMEA Sheet

Since the FMEA sheet for this manufacturing process is very long, because it contains way more risks, a little part for the FMEA sheet will be shared in this article as a screen, to give you an idea what it looks like to make one for this process.

POTENTIAL EFFECT(S) OF FAILURE	POTENTIAL CAUSE(S) OF FAILURE	CURRENT CONTROLS (Prevention)			CURRENT CONTROLS (Detection)			SEV	OCC	DET	RPN	RECOMMENDED ACTIONS
Possibility of a premature engine failure due to valve head cracks	Incorrect set up	Visual Control	5pcs	set up	Visual Control	5pcs	2 hours	8	2	4	64	N/R
		Crack Control	100pcs	set up	Crack Control	100pcs	day					
					Crack Control	100%	Final					
	Incorrrect blade	Visual Control	5pcs	set up	Visual Control	5pcs	2 hours	8	2	4	64	N/R
		Crack Control	100pcs	set up	Crack Control	100pcs	day					
					Crack Control	100%	Final Inspection					
Reduction of production rate	Incorrect set up	Dimensional Control	5pcs	set up	Dimensional Control	5pcs	2 hours	5	2	5	50	N/R
Scrapped valve due to length undersized.	Incorrect set up	Dimensional Control	5pcs	set up	Dimensional Control	5pcs	2 hours	7	2	5	70	N/R
Possibility of engine failure due	Incorrect upsetting speed-	Upsetting temp. check	100%	poke-yoke	Upsetting temp. check	100%	poke-yoke	8	2	3	48	N/R
		Ups. Temp Check by	1pcs	unit setup	Ups. Temp Check by hand	1pcs	every shift					

Figure 6. Screen sample from the FMEA sheet.

Acknowledgement

I would like to express my special thanks of gratitude to my teacher (Prof. Dr. Hakan Akyıldız) as well as our company (Supsan – Borusan Holding) who gave me the opportunity and knowledge to do this studies.

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