Analysis of Failure and Reliability of Spark Plug using Failure Mode and Effect Analysis (FMEA) Process

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Abstract

A Spark Plug is used for initiation of combustion(Ignition) by passing a high temperature fire into the combustion chamber containing a mixture of air and fuel. The most commonly used fuels are petrol, compressed natural gas, liquefied petroleum gas, ethanol and kerosene.

There are many different types of spark plug designs available on the market today. Understanding the difference between them can help your engine run smoothly and efficiently. Failure Mode and Effect Analysis is a tool that can be used to identify the effects or consequences of product or process failure and eliminate or reduce the failure. This article introduces the use of FMEA to improve the reliability of the spark plug to ensure smooth operation of the machine and thus increase profits in the automotive industry. Severity rating, Occurrence rating, Detection rating and Risk Priority Number (RPN) are some considerations. Here FMEA is applied to ensure the operation of spark plug and defects are detected. This function ensures efficient operation of the vehicle by acting as a guide to both prevent failure and increase the reliability of the spark plug.

***Key Words*: FMEA, Spark plug, Mode Failure, Reliability, Severity rating, Occurrence rating, Detection rating, Risk Priority Number.**

1.INTRODUCTION

There are many types of spark plug designs on the market today. Understanding the difference between them can help your engine run correctly and efficiently. [1] The high pressure cylinder directly supplies the working material in the combustion chamber and thus provides an important insight into the management and control of engine.[2] A spark plug (sometimes known as sparking plug in British English and also known as a plug) is a device that delivers electrical current from an ignition system into the combustion chamber of a spark ignition engine to ignite the compressed air/fuel mixture by means of an electric spark while maintaing the combustion pressure in the engine.

The spark plug has a wire housing that is electrically isolated from a central electrode by a porcelain insulator. The central electrode may have a resistor connected to the output terminal of an ignition coil or magneto by highly insulated wire. The metal housing of the spark plug is screwed into the engine cylinder head and thus grounded. The central electrode is connected to the combustion chamber through a porcelain insulator, and one or more gaps are formed between the inner end of the central electrode and one or more laterally selected protrusions or structures, usually connected to the inner end of the threaded shell and designated the side, or ground electrode.

Spark plugs may also be used for other purposes in Saab Direct Ignition when they are unable to fire. The spark is used to measure ionization in the cylinder. The existing ionic current measurement is used for replacing the cam level sensor, knock sensor, and misfire measurement function.

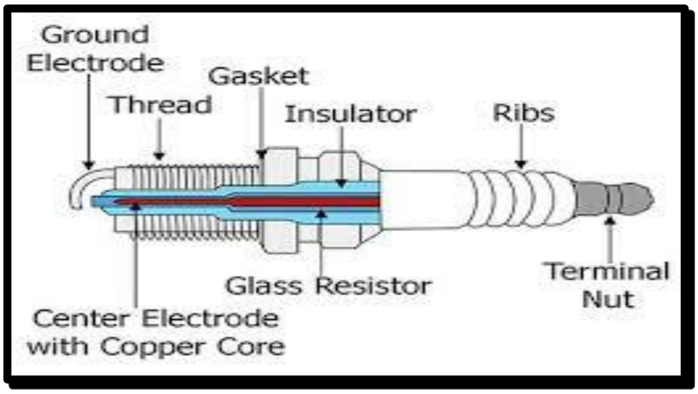

Fig 1: Spark plug design

Spark plugs can also be used in other applications, such as furnaces where a hot air/fuel mixture must be ignited. In this case they are sometimes called flame igniters. Spark plugs are constantly exposed to chemical, thermal, physical and electrical attack by corrosive gases at temperatures of 4,500 degrees Fahrenheit, crushing pressures of 2,000 pounds per square inch (PSI) and output voltages of up to 18,000 volts. This incredible attack on the hood of the car occurs twelve times per second and more than a million times in a day during driving.

1.1 History of the Spark Plug:

The spark plug evolved with the development of internal combustion engine technology, but earliest in 1777 the use of electrical spark plug to ignite a fuel-air mixture was demonstrated. That year, Alessandro Volta filled the toy piston with marsh gas and air, plugged its head with a cork, and ignited the charge with a spark from the Ley Den jar. French engineer Jean Lenoir in 1860 created what most closely resembles the spark plug of today.

1.2 Failure Mode and Effects Analysis

Failure Mode and Effects Analysis (FMEA) was first developed as a formal design method for reliability and safety by the aerospace industry in the 1960s. The purpose of FMEA is to identify possible failure modes in the system, evaluate their effects on system behavior, and recommend appropriate measures to prevent these effects. FMEA increases the improvisation of the design and manufacturing process in the future because it works based on the information of the current design process [3]. It reduces costs by identifying system, product and process improvements early in the development cycle. It performs the most important action of reducing the risk of failure.

FMEA analysis

- Possible failure modes of a product or machine,
- Possible effects of the failure,
- Possible causes of the failure (such as product defects, design defects, processing and manufacturing defects, and service condition)
- Evaluate the current process controls, and
- Determine the significance of the risk

Importance of FMEA in Spark Plug

The spark plug is an important element in the production of an effective spark ignition engine. A spark plug is a device to deliver electrical current from the engine to the combustion chamber of a spark ignition engine to ignite the compressed air/fuel mixture of electric spark while maintaining high pressure in the engine. A wide variety of materials increases the accuracy and reliability of the product. Damage to these parts may cause product failure. These may lead to undesirable consequences such as product/system failure and production of inaccurate product. Therefore, it is necessary to conduct FMEA of these products to avoid or reduce failure.

2. Literature Review

Ford Motors introduced FMEA in 1977 to address potential problems in the R&D and early stage of production, and published the "Potential Failure Modes and Effects Analysis Handbook" in 1984 to support this method. Later, American automobile manufacturers also incorporated FMEA into supplier management and made it an important audit issue. Previous researchers have done some research on FMEA, but many of the studies used in the above study are still needed to explore the success of FMEA technology in design and area of manufacturing. Failure Mode and Effects Analysis (FMEA) is a method designed to identify the failure modes of a product or process, examine the risks associated with those failure modes, fix the problems first, and identify and implement corrective actions to resolve the most serious problems. In FMEA, failures are prioritized according to their severity, frequency of occurrence and ease of detection. Ideally, FMEA begins at the initial conceptual stage of design and continues throughout the lifecycle of the product or service. The results can be used to identify weak points and guide the allocation of resources to achieve better results. Starting from the initial design, FMEA can be done at any time in the system lifetime. The various steps in the process failure and effect analysis process are as follows

- Review process
- List effects and failure modes
- Assign a severity rating
- Provide occurrence rating
- Assign detection rating
- Calculate Risk Priority Number (RPN) for each failure mode
- Perform steps to eliminate or reduce the high-risk failure
- Calculate the final RPN when the failure mode is reduced or eliminated [3].

3. FMEA Process Flow

3.1 Spark Plug System

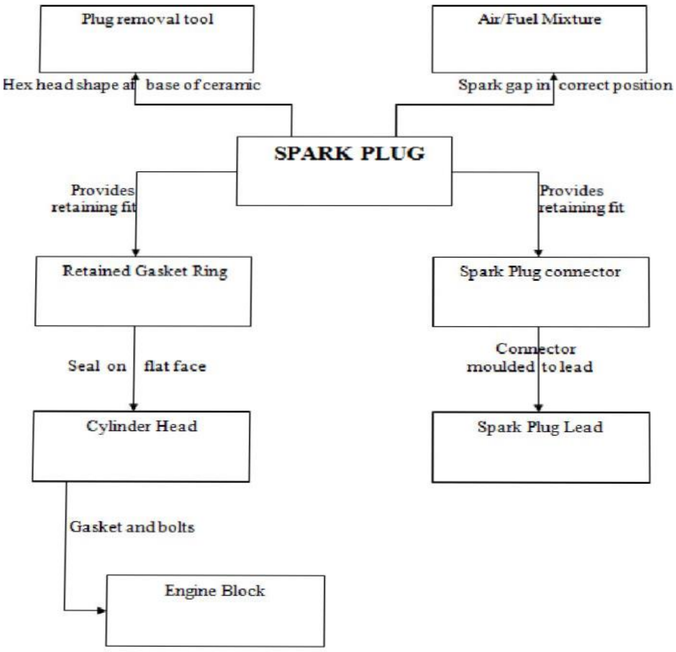

Fig 2: Spark plug block diagram

The recommended way to analyze a system is to break it down into different levels (e.g., system, subsystems, subcomponents, and field-replaceable units). By examining the schematics and other technical drawings of the system, it is seen how different subsystems, components or parts interact with one another through their support systems to understand the normal functional flow requirements. Figure 2 shows how the different parts interact with each other to verify the critical path. It is easy to understand the relationship between parts , so the block diagram provides an important point for analysis.

Causes of Failure Of Spark Plug

- Dirty air filter
- Excessive driving at low speeds
- Too rich of a fuel/air mixture
- Dirty fuel injectors
- Idling your vehicle for too long
- Soft, black, sooty dry deposits on plug

Prevention for spark plug fouling

- Regular Maintenance: Performing regular maintenance, including changing the oil, air filter, and fuel filter, can help prevent fouling.
- Use the Correct Spark Plug: Ensure that the spark plugs used in the engine are the correct type and heat range recommended by the vehicle manufacturer.
- Clean plug and socket connectors with a socket brush and water.
- Apply di-electric grease to all pins on both the plugs and sockets to prevent corrosion by keeping moisture out and increasing the flow of energy through the connection.

Fig 3: Spark plug failure

3.2 Severity ratings

The severity ranking is an estimation of how serious the effects would be if a given failure did occur. In some cases the nature of the failure is clear from experience. In other cases, it is necessary to estimate the severity based on the knowledge of the process. There may be other factors that need to be taken into consideration (factors that affect the overall severity of the failure being analyzed) [3]. Calculation of severity levels provides for a classification ranking that encompasses safety, continuous production, residual loss, etc. Each effect has a severity number (S) from 1 (not dangerous) to 10 (severe). A failure mode with the severity number of 10 can cause major customer dissatisfaction and even physical injury due to failure. While severity levels in the range of 4-6 may cause mild customer dissatisfaction and severity in the range of 13 are less and may not be noticed.[2], [3], [10]. Table 1 gives the guidelines based on which severity ratings were given.

Table 1: Severity ratings

Severity Rating	Description
1-2	Failure is of such minor nature that the customer (internal or external) will probably not detect the failure.
3-5	Failure will result in slight customer annoyance and slight deterioration of part or system performance
6-7	Failure will result in customer dissatisfaction and annoyance and/or deterioration of part or system performance.
8-9	Failure will result in high degree of customer dissatisfaction and cause non functionality of system
10	Failure will result in major customer dissatisfaction and cause non-system operation or non-compliance with regulations

3.3 Occurrence Ratings

The result shows how often this failures occurs. It is necessary to look at the number of times a failure occurs in this step. This can be done by looking at similar products or processes and failure modes that have been documented[3]. Failure mode is given an occurrence ranking (O) between 1-10. If the failure cannot be avoided or occurs frequently, then it is given a rating in the range of 8-10. Events with minor consequences are given a grade of 4-6, while events with low or eliminated failure are given a grade of 1-3. [2], [3], [10]. Table 2 gives the occurrence ratings based on which FMEA table is designed in this paper.

Table 2: Occurrence Ratings

Occurrence Rating	Description
1	Failure eliminated or no know occurrence
2,3	Low or very few
4,5,6	Moderate or few occasional
7,8	High or repeated failure occurrence
9,10	Very high rate of failure or inevitable failures.

3.4 Detection ratings

This section provides a ranking based on assessing the likelihood of identifying failure modes based on appropriate controls. An appropriate inspection method must be selected. The results of the detection are listed in reverse order. For example, "1" indicates a high probability that the failure will be detected before it reaches the customer; "10" indicates the least probability that the failure will be not detected [2], [3], [10]. Table 3 shows the guidelines based on which the detection ratings of a product are given.

Table 3: Detection Rating

Detection Rating	Description
1	Very certain that the failure will be detected
2-4	High probability that the defect will be detected
5-6	Moderate probability that the failure will be detected
7-8	Low probability that the defect will be detected
9	Very low probability that the defect will be detected
10	Fault will be passed to customer undetected

3.5 Risk Priority Number

The risk priority number (RPN) is simply calculated by multiplying the severity ranking times the occurrence ranking times the detection ranking for each item.

Risk Priority Number = Severity × Occurrence × Detection

The total risk priority number should be calculated by adding all of the risk priority numbers. This number alone is meaningless because each FMEA has a different number of failure modes and effects. The small RPN is always better than the high RPN. The RPN can be computed for the whole process and/or for the design process only. Once it is calculated, it is easy to determine the areas of greatest concern.

4. Result and Discussion

It is studies that spark plug damage is caused by carbon fouling and overheating of spark plug. The former has two types: dry deposition (due to exhaust) and wet deposition (due to lubricating oil). Carbon deposits can be controlled by regularly checking the engine and fuel filter and regularly servicing the A/F mixture.

The latter causes the electrodes to melt and engine efficiency to decrease, causing the spark plug overheating to be avoided. By regularly cleaning the air filter and regularly checking that the fuel passage is not blocked, the spark plug can be kept within the temperature range.

5. Conclusion

The present work includes FMEA process study of spark plug. Thus, the spark plug used in many vehicles is analyzed and the expected failure is evaluated and recorded. The potential effects of failures are evaluated according to its severity and then calculated its causes, prevention and consequences. The value of risk priority number is calculated by assigning a detection level to the failure mode. The risk priority number is given, which indicates that care is necessary for the reliability of the spark plug. This FMEA process will be an important tool in determining the occurrence of failure mode and ensuring efficient operation of the spark plug. This study provides a well documented method to choose the spark plug with the best performance and safety. The causes of spark contamination and preventive measures are also being investigated. The benefit of FMEA analysis is that it reduces vehicle downtime by increasing the reliability of the spark plug. This method is used for consumer products such as automobiles and their parts, home appliances, as well as other fields such as manufacturing, aerospace, instrumentation, medical, chemical processing, etc.

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