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# Fault Tree Analysis of Single Cylinder Vertical Diesel Engine

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**Abstract -** *Fault tree analysis is a top –down failure analyzing method which uses logic gates and Boolean algebra. By the use of this method it is easy to identify the critical part of the system, causes of its failure and potential countermeasures. It is used for reliability and safety analysis and risk evaluation in complicated system. FTA has various applications in critical areas such as aerospace, automotive industry and nuclear power plant. In thus paper fault tree analysis of single cylinder vertical diesel engine is done for finding out the main causes of engine failure and maintenance of engine is done and engine brought into the operating condition.*

***Key Words*: FTA, logic gates.**

## 1. INTRODUCTION

FTA is a top down analysis having a series of steps through which the causes of an event are established. It provides a visual representation of how an equipment failure, human error and other factors have lead to accident or event. It consists of logical gates and small events that depict the path of an accident through different stages and finally a fault tree is constructed for the particular event. The technical failures are shown as basic event and human errors as intermediate events that can lead to the technical failure [1]. The construction of FTA is shown in figure 1.

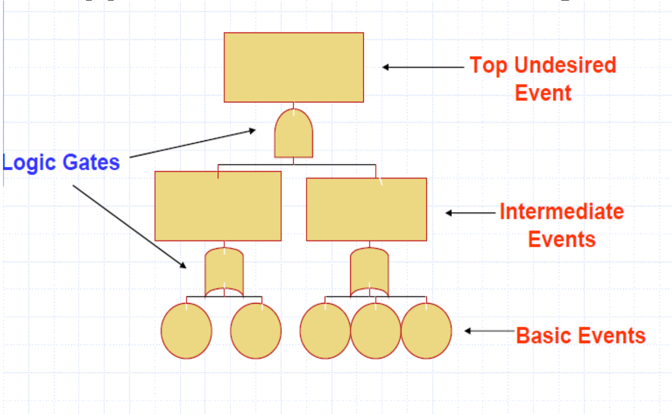



**Fig -1**: Construction of Fault Tree Diagram [2]

Fault Tree Analysis (FTA) is one of the mostly used techniques for reliability and safety analysis, and risk evaluation in large and complicated systems, by making use of logics and probabilities. FTA provides an effective method for evaluating risk at the system level [3] by making use of various tools like Probabilistic Risk Assessment (PRA), System Reliability Assessment and Safety engineering which helps for the quantitative determination of probability of a safety hazard. Many people and corporations around the globe are using this method on a regular basis to ensure the safety and reliability [4].

### 1.1 Fault Tree Analysis

The probability for a complete or partial success is more than the probability of a complete failure or partial failure, so making a success tree can turn out to be very time consuming. There may be very less number of ways in which non-failures can occur. And for a entire system, the complexity makes assembling a FTA a costly and bulky experience, so it is sensible to divide subsystems and start analysis from them. In this way, dealing with systems in smaller scale can reduce error work probability and system analysis [5].

### 1.2 History

FTA was introduced in the early 1960s by H. A. Watson of Bell Laboratories in connection with the U. S. Air Force contract to study the Minuteman Launch Control System [3]. Then it was applied to the entire Minuteman Missile System for the anticipation of random failure probability of missile launch by a team led by Dave Haasl from Boeing Company. Later, Boeing started to practice FTA during the design of commercial aircraft [3]. It has been widely applied in safety critical areas such as aerospace, automotive industry and nuclear power plant etc.

## 2. FEATURES OF FTA

### 2.1 Benefits

a) FTA is a very effective risk assessment tool [7].
b) The biggest advantage of using FTA is that it starts from a top event that is selected by the user for a

specific interest and the tree developed will identify the root cause [7].

c) The FTA can be used with help of a computer and generate results using its applications for improved analysis [7].
d) FTA directly focuses on the failure modes, which is more effectual method than system reliability block diagram [2].
e) Symbols of FTA are easy to understand [2].
f) Allows easy conversion to probability measures [7].

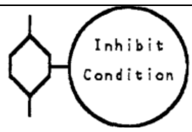
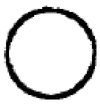
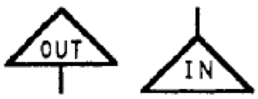
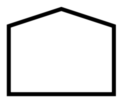
### 2.2 Limitations

a) In complex system, that includes a large number of equipment and process variables, the fault tree becomes complicated and takes fairly large time to be completed.
b) It may take years to complete without the guarantee of weather all the failure possibilities are taken into consideration or not.
c) There is no concept of partial failure in a fault tree.
d) If the equipment is partially operational, it is considered as fully unavailable or in failure mode. This partial failure will affects the reliability of a system but the FTA has no effect of such condition in its results.
e) Development of a fault tree will depend on the different nature of safety professional. This makes the fault tree a non-specific or vague in nature.
f) The probability calculation for a top event requires the failure data of all the events in the fault tree that are usually not known or not accurately known that decreases the reliability of the analysis.

### 2.3 Symbols And Meaning

As shown in Table 1, the logic gates can explain the different ways in which the human- machine interface may have resulted into an accident. For e.g. AND gate means that both the initial events should occur for the occurrence of intermediate event while OR gate implies that only one of the initial event should occur for the occurrence of intermediate event [1], [6]. The top and intermediate events are shown by a rectangle in which top event is the accident and the intermediate events are the occurrences that contributed to the top event to occur. Basic events are the lowest level of importance in the fault tree, which are depicted by a circle and there are undeveloped events, shown by a diamond, about which insufficient information is available. An Inhibitor gate is a special case of an AND gate in which output is obtained only if there is an input.

**Table -1**: FTA Symbols and Description [8]

| **Symbol** | **Meaning and Description** |
|---|---|
|  | AND gate:<br><br>Requires all input events for an output event to occur. |
|  | OR gate:<br><br>Requires any single input event for the resulting output event. |
|  | Inhibit Event:<br><br>The output event will occur only if the entire input events occur and an inhibit (conditional) event occurs. |
|  | Basic Event:<br><br>The last finding event which cannot further be defined. |
|  | Intermediate Event:<br><br>It is the resulting event of many different sub events. |
|  | Undeveloped Event:<br><br>When the required information is unavailable the event cannot further be developed. |
|  | Transfer Symbols:<br><br>Used to transfer the fault tree to other location on sheet. |
|  | An event that is normally expected to occur or not. (i.e., they have a fixed probability of 0 or 1). |

## 3. SINGLE CYLINDER VERTICAL DIESEL ENGINE

A Kirloskar single cylinder vertical diesel engine was in Breakdown condition (shown in figure 2). The specifications of the engine are given in table-2. The causes of the engine failure are found out which will be discussed further.

**Table -2**: Engine Specifications [9]

| | |
|---|---|
| Cylinder position | Vertical |
| Cylinder | single |
| Fuel | Diesel |
| Compression Ratio | 17.5:1 |
| Rated Output kW(hp) | 5.9(8) |
| Rated Speed (rpm) | 1800 |
| Overall Dimensions (L x W x H) (mm) | 617 x 504 x 877 |
| Bore X Stroke (mm) | 87.5 X 110 |
| Cubic Capacity (L) | 0.661 |
| Fuel tank Capacity (L) | 11.5 |
| Lubricating Oil | SAE 30 / SAE 40 |
| Cooling | Water cooling |

## 4. METHODOLOGY OF ENGINE MAINTENANCE

The methodology of the maintenance of single cylinder vertical diesel engine comprises basic functions of maintenance as overall inspection of engine, finding out the causes of the engine breakdown accordingly take corrective actions and then bring the engine into the operating condition.

### 4.1 Causes Of The Engine Breakdown

Technical Causes:

- Fuel filter was damaged
- Air cleaner was absent
- Originally it was a diesel engine but was running in petrol in past.
- Change in Compression ratio
- No Cooling arrangement
- Cylinder Head partially damaged
- Valves were not in proper position
- Spark Plug used in place of fuel injector
- Carburetor used in place of fuel pump

Human factors:

- Diesel Engine modified to run with Petrol
- Some additional holes were made
- Some holes which were necessary for cooling were made closed
- No Cleaning and Servicing done for long time.

Operation beyond limits:

- No such factors have been found.

**Fig -2**: Single cylinder vertical diesel engine

Now engine brought into operating condition by disassembling the Cylinder Head, Engine Block, Fuel Filter, Inlet and Exhaust manifold, water supply pipe line and then Cleaning of dust, dirt and oil deposits on the engine parts done. Grinding of Cylinder Head and valves is done for finishing the surface from carbon deposits, corrosion and dirt. Some parts which were in damaged condition or absent, replaced or added respectively, such as Fuel filter with filter pipe, Gaskets, Inlet water pipeline, Fuel pipe line from fuel tank and bolts and washers. The parts which added were Fuel Injector with injector line, Fuel pump, Air Cleaner with air bend and Silencer. The modifications in the engine were the cooling of the engine made functional and engine again converted to run in diesel.

A fault tree analysis is done to identify the faults in the engine and accordingly corrective actions can be taken to prevent similar failures in future.

## 4.2. Critical Components Regarding Maintenance

In the failure analysis of engine we have taken Engine block as our system of interest and studied causes of their failure. The engine block has two main parts as cylinder head and valves.

### 4.2.1 Failure Of Valves

By SEM and XRD, the microstructure and phases of the plates of the failed valves were investigated. The austenitic matrix disintegrates to form the lamellar structure which consists of $\gamma$ + $Cr_{23}C_6$ at the boundary and within the grains in service. The lamellar structure divides the matrix to decrease strength, toughness, the loading ability of the matrix, and resistance to gas corrosion. Formation of the lamellar structure is mainly responsible for the failure of the exhaust valves.
Also cracks, burning and carbon deposition are the main causes of valve failure [10].
Valve spring deteriorates and deform gradually with time and extensive use. A deformed spring results in a condition, known as valve float and valve bounce which will reduce engine efficiency and functioning due to improper valve closing and sealing. Deformed valve springs are difficult to identify and are usually misdiagnosed as fuel injection or ignition problems. A deformed spring may lead to spring failure, if not detected and properly repaired which in turn could result in disastrous failure of the engine. The engine's manufacturer state that a valve spring with 3 mm or more deformation should be replaced.
Valve clearance means clearance between the rocker and valve cap. Each engine has a normal valve clearance value designed to permit for thermal expansion [11].

### 4.2.2 Failure Of Cylinder Head

Cylinder head is a heavy loaded combustion chamber. The arrangement of head for engine is quite intricate in order to suit the structural and performances demands of the engine. Several components are assembled in the cylinder head such as valves, fuel injector, inlet- exhaust manifolds etc. The high temperature strongly affects the mechanical strength of the material of head.
The high pressure and temperature between cylinder and head causes fatigue failure which is initiated by the formation of cracks and high concentration of stress in the head also leads to failure. [12]

## 4.3 Implementation Of FTA

Ayyub, B. M describes the procedure for fault-tree is consisted of 8 steps [1]:

- Define the system of interest: With the conditions of the system the boundaries of importance are defined on which analysis is to be made.
- Define top event of the system: Identify the problem on which the analysis will be made.
- Define top Structure of the tree: Define the events and the conditions that lead to the top event.
- Explore each branch in details: To complete the fault tree, find out the events and conditions that lead to the intermediate event and repeat this process at different successive levels.
- Solve the fault tree for the combination of events contributing to the top event.
- Find vital dependent failure potentials and amend the model appropriately: Study the event and find out the interrelations among the event that can cause a single or multiple events and conditions to occur simultaneously.
- Execute quantitative analysis: Use the past statistical data to predict the future performance of the system.
- Use the outcomes in decision making: Find the conditions of the system which are most vulnerable and place suitable measure and recommendations to counteract with such risk.

With the help of above steps fault tree analysis of the engine is done and the fault tree diagram of engine is given below in figure 3

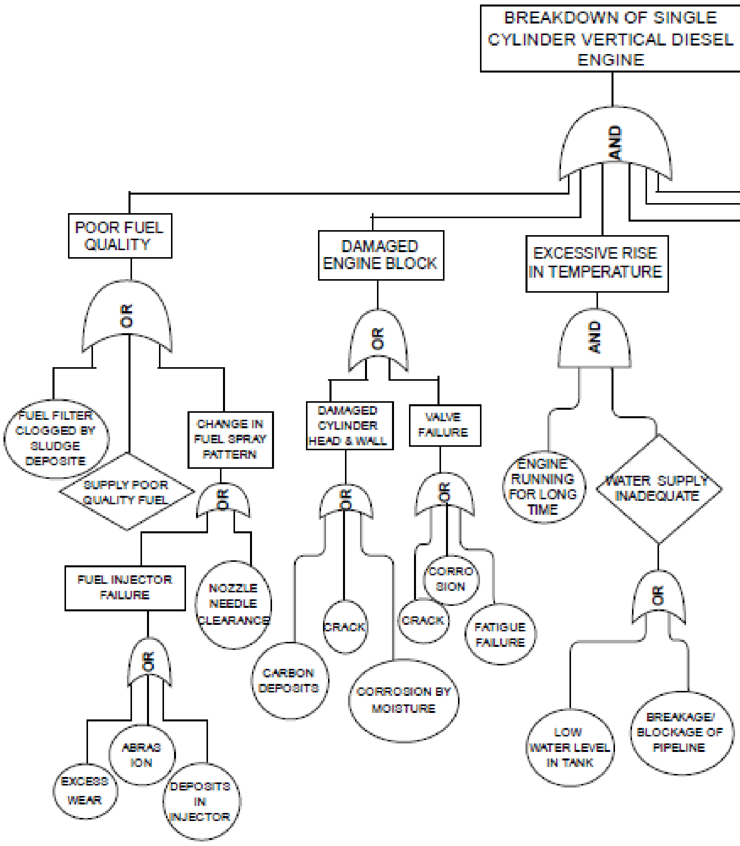



**Fig -3**: Fault Tree Analysis of Single cylinder vertical diesel engine

## 5. CONCLUSIONS

In this paper fault tree analysis, its applications, benefits and limitations of using FTA are discussed. A fault tree diagram is also made for single cylinder vertical diesel engine. In fault tree, failure of engine and its various components discussed. The causes of engine failure such as technical causes, human factors etc. discussed and accordingly necessary maintenance strategy can be adopted to prevent similar failures in future.

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