

Fault Diagnosis and experimental analysis of 4-stroke, 4-cylinder petrol engine using Fault Tree Analysis

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Abstract - Internal combustion engine plays vital role in any automotive application and mechanical systems. These engines are worldwide used as device transforming one form of energy into another form and their cost is high so; maintenance of such engines is an essential thing. In this project the focus is on the fault detection and experimental analysis of the engine. The available literature was thoroughly reviewed and many methods about fault detection were studied. Review of research study concluded that fault tree analysis which uses logic gates and Boolean algebra. It is a graphically design technique that provide reliability block diagram and the tree developed will identify the root causes. By the use of this method it is an easy way to identify failure parts of system. After identifying the failure parts of the engine these parts will be either repaired or replaced and carried various experimental tests such as load, Speed and Morse test on the engine. To compare performance of test setup with and without fault tree analysis approaches are used. The results obtained using fault tree analysis is effective in manner. The performance of engine is increased after maintenance and fault tree analysis method facilitates successfully optimizing of maintenance effort.

Keywords: Fault Tree Analysis (FTA), 4-Stroke 4-Cylinder Petrol Engine Test Rig.

I. Introduction

Internal combustion (IC) engine is a power generating machines and used widely in automotive industry. The study of internal combustion engines has become a very important part of a mechanical engineer's education Hence it is appropriate that we have worked on 4-stroke 4-cylinder petrol engine test rig'. The test rig consists of Premier Padmini petrol engine which is a division of the Walchand Group, under license from Fiat. The performance of engine is highly depends on components efficient working; if these parts failed, the performance is partially or completely decreased. The failure of a system depends on the time, with varying over the life cycle of the system conditions. Engine failures result from a conditions, effects, and situations. To understand why engines fails and remedies to those failures, one must understand how engine components are designed and manufactured, how they interact with

other engine components. In case of this petrol engine; insufficient compression, improper combustion are the two main causes of reduction in efficiencies. Also there is insufficient spark occur, Failure of Ignition coil, Intake manifold & Carburetor which highly reduce the performance of the engine. The attempt made by earlier researchers for use of fault tree analysis for different case studies. DobrivojeCatic et.al, did work on the analysis of the fault tree of solar concentrator .The analysis of the operation mode of this device led to the conclusion that the failure of any subsystem leads to system failure. [1]

RafalLaskowski applied fault tree analysis as a tool for modeling the marine main engine reliability structure. In case of small fault tree the minimal cut sets are searched by tree inspection while for large and complex trees appropriately selected procedures and algorithms were used. [2] H.E.Lambert discussed the use of fault tree analysis for automotive reliability and safety analysis He concluded that the value of the fault tree it shows logical progression of events and ties all the events together to show important system interactions that are not displayed in an FMEA. [3] Jana Glisovic et.al, presented fault tree analysis of hydraulic power steering system. the potential modes of failure of the components can be recorded, which can be, inter alia, used as one of the best failure modes and effects analysis models for analyses of causes and consequences of faults. [4]

While going through various research papers for Fault tree Analysis, it is understood that failure of any subsystem leads to the failure of whole system. Also it is observed that the fault tree analyst must understand how the system works as well as the specific failure modes that cause the top event to occur. The use of fault tree may be used for the experimental analysis of 4stroke petrol engine.

From the review it can be observed that researchers have used the fault tree analysis for different systems. Unfortunately no one has used fault tree analysis for 4-stroke 4-cylinder petrol engine. Thus, there is need of working on fault tree analysis of 4-stroke 4-cylinder petrol engine.

II. Problem Statement

I.C. Engine is a unique event in twentieth century. These engines considered to be heat engine as they convert thermal energy into mechanical energy. In an internal combustion engine the products of combustion are directly the motive fluid. But overall performance of engine depends on full functioning of components. As if these parts failed e.g. carburetor, ignition coil, spark plug, starter etc there is possibility of engine gets totally failed or partially economy will be given less. FTA is a very effective risk assessment tool. Using FTA the failure component of engine will be identified and effects of component failure are discussed. By general observation in case of this petrol engine insufficient compression & improper combustion are the two main causes of reduction in efficiencies. Implementation of FTA method diagnosed the affected parts and will be replaced or repaired if they influenced on engine performance. The FTA method is very useful method for detecting the failure parts of the system. In this study fault tree analysis method will be helpful to diagnose the failure of components and to improve overall efficiency of 4-Stroke 4-Cylinder Petrol Engine setup.

III. Methodology

A. Fault Tree Analysis

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. A useful tool in performing a system safety analysis is fault tree analysis. A fault tree analysis is a graphical design technique that provides an alternative to reliability block diagrams. It is a top-down Deductive analysis structured in terms of events rather than components.

B. Objectives:

An FTA is conducted to satisfy any of the following objectives:

- 1) Improve understanding of system characteristics by diagrammatically representing the system architecture.
- 2) Facilitates the optimizing of maintenance effort (as fault diagnostics should benefit from the logic of the FTA).
- 3) Allows for quantitative evaluation of a probability for the undesirable outcome, so evaluating the ability of a chosen architecture to meet its safety/reliability requirements. [6]

C. Fault Tree Analysis Of 4-stroke, 4-cylinder petrol engine test rig:

As per fault tree diagram of petrol engine test rig, there are some systems and subsystems which reduces the brake thermal efficiency & volumetric

efficiency of the petrol engine. The above fault tree diagram is based on problems which are actually arise. These problems are illustrated below.

In case of these petrol engine insufficient compression & improper combustion are the two main causes of reduction in efficiencies.



Fig. 1 Fault tree analysis of I. C engine

Efficiencies are not going to reduce if & only if compression should be sufficient combustion should be proper. There will be sufficient compression if & only if there is no wear & tear of pistons & cylinders. Combustion is proper only if spark should be sufficient & A/F ratio should be proper.

1) Causes of insufficient spark

i. Spark plug failure:

Causes of spark plug failure are given below.

(a) Insufficient voltage:

As the electrons flow from the coil, a voltage difference is developed between the center electrode and side electrode. No current can flow because of the fuel and air in the gap is an insulator, but as the voltage rises further, it begins to change the structure of the gases between the electrodes. Once the voltage exceeds the dielectric strength of the gases, the gases become ionized. The ionized gas becomes a conductor and allows electrons to flow across the gap. Spark plugs usually require voltage in excess of 20,000 volts to 'fire' properly. Because the spark plug is inside the engine and is the only easily removable part it can be used as an

indicator to the Faults in Spark Plug. So voltage should be proper in order to eliminate spark plug failure.

(b) Fuel deposition:

Spark plug is inappropriate because of rough materials that accumulate on the side electrode may melt to bridge the gap when the engine is suddenly put under a heavy load. The voltage required to fire the plug is getting low so brown colour flame is not getting. The damage in spark plug mainly occurs due to fouling and the overheating of spark plugs. [6]



Fig.2 Fouling of spark plug

Deposits accumulated on the firing end may induce abnormal combustion (pre-ignition), causing problems that include melting of the electrodes. If the edges of electrodes are worn and rounded, sparks will not easily occur. Remedies for stopping of fuel deposition are replacement of worn or damaged valve guides or valve guide seals, allow rich fuel mixture, replacement of d guide seals, allow rich fuel mixture, replacement of damaged spark plug.

(c) Spark plug polarity:

An important point relating to the misfire tendency which is not always appreciated is the spark plug polarity. The center electrode must be of negative polarity because it is hotter than the earth electrode and less voltage will be required to spark from the center electrode to the ground electrode. Suppose the manufacturer connects the coils to give a negative polarity to the central electrode but the mechanic, while installing a new coil reverses the connection. This will result in failure of spark plug. Remedies are installation of spark plug should be proper.

i. Ignition coil failure:

Ignition coil failures are caused by worn out spark plugs that fail to transmit electronic signals in a functional and fluid manner. This creates a disruption in the regular flow of power across the ignition coil and makes the engine lose power. It is less common but still possible that the rotor the ignition coil rests on wears on and reduces the function of the power circuit. Remedies are replacement of damaged ignition coil.

ii. Distributor failure:

Distributor fails when high resistance is occurred because most of the times only voltage is getting checked & not the resistance. Also any wear of cam shaft

causes misbehaving of contact breaker points resulting in distributor failure. Remedies are there should be no wear of camshaft, working of contact breakers should be proper.

● Causes of improper A/F ratio:

i. Intake manifold failure:

Possible modes of valve failure are wear failure, valve face recession, fatigue failure, thermal fatigue, erosion corrosion of valves, overheating of valves, carbon deposits on valves etc. The valve is subjected to various loads at any point of time, such as reverse loading at a high temperature, stress concentration at the keeper groove area and under carbon deposits at exhaust valves. The valves generally fail by fatigue.

Exhaust valves operate at very high temperatures and are subjected to cyclic loading, the failure of the conical surface of valve is mainly caused by the elastic and plastic deformation, and fatigue. Exhaust valve stems generally fail by overheating because the temperature of the exhaust valve is about 720 °C [7]

ii. Carburetor failure:

Engine backfiring and overheating are the common symptoms of a potential problem with the carburetor. A carburetor uses intake vacuum to supply fuel to the engine. As air is pulled down through the throat of the carburetor by intake vacuum, fuel is siphoned from the carburetor's fuel bowl and mixed with the incoming air to form a combustible mixture. If any problem arises in the above operation will affect air-fuel ratio. Remedies are overcoming of above problems.

iii. Air filter failure:

Most of the times filter is clogged with dust and grime so it affects fresh air & results in pollutants. Leakage in pipes affects volumetric efficiency. Remedies are replacement or cleaning of filter.

All the above discussed failures result in reduction of brake thermal efficiency & volumetric efficiency, Mechanical efficiency of these 4-stroke, 4-cylinder petrol engine test rig. After analyzing fault tree diagram we have done changes accordingly in present test rig & perform the same tests to check whether the efficiencies are improved or not.

● Experimental Analysis

An experimental analysis is carried out on a 4-stroke, 4-cylinder Petrol engine setup as shown in figure.

In this present work fault tree analysis is introduced to evaluate performance of 4-stroke 4-cylinder petrol engine test rig. In this work using fault tree analysis corrective maintenance is carried out for improvement of overall efficiency of engine. So in this

study both approaches are used to compare the results and it was found that fault tree analysis is useful tool to diagnose the problems and to improve the overall efficiency of engine. To evaluate performance of test setup various tests like Load test, Speed test & Morse test are performed.



Fig.3:- 4-Stroke, 4-Cylinder Petrol Engine Setup before FTA

I] Experimentation without fault tree analysis:

1.Load test - Load test is performed to check the fuel consumption for the same speed at different loads.

2 Observation Table –

Observation of load test are mentioned in following table 1.

Table 1: Observations of load test before FTA

S.N	Speed(rpm)	Load(kg)	Time(sec.)	Δ h(m)
1	1300	0	34.03	0.004
2	1300	1	31.09	0.004
3	1300	2	30.12	0.004
4	1300	3	25.84	0.005
5	1300	4	18.97	0.004
6	1300	5	18.25	0.005

3 Sample Calculation: -

Sample calculation for reading no. 2 is shown below.

i. For Mass Flow Rate :

$$\text{Head Of Air}(h_{\text{air}}) = \Delta h \times \frac{\rho_{\text{water}}}{\rho_{\text{air}}} - 1$$

$$= 0.004 \times \frac{1000}{1.16} - 1$$

$$= 0.4849 \times \frac{60000}{2\pi \times 1300}$$

$$= 3.44 \text{ m}$$

$$\text{Volume Flow Rate} = C_d \times A_{\text{orifice}} \times \sqrt{2gh_{\text{air}}}$$

$$= 0.64 \times 0.0005$$

$$= 0.00309 \frac{\text{m}^3}{\text{sec}}$$

Mass flow Rate of Air [M_{air}]

= Volume Flow Rate Of air × density of air

$$= 0.00309 \times$$

1.16

=

0.00359 kg/sec. **ii.For**

Mass Flow Rate of Fuel:

$$M_{\text{fuel}} = \frac{10 \times 10^{-6}}{\text{Time For 10cc Consumption}} \times \text{Density of air}$$

$$= \frac{10 \times 10^{-6}}{31.09} \times 760$$

$$= 0.000241 \text{ kg/sec.}$$

iii.Air fuel Ratio:

$$\text{Air fuel Ratio} = \frac{M_{\text{air}}}{M_{\text{fuel}}} = \frac{0.00359}{0.000241}$$

= 14.91 **iv.For Brake Power:**

$$\text{B.P} = \frac{W \times N}{2000} \times 0.746 = \frac{1 \times 1300}{2000} \times 0.746$$

$$= 0.4849 \text{ Kw}$$

v. For Brake Thermal Efficiency

$$\eta_{\text{brakethermal}} = \frac{\text{BP}}{\text{Heat Supplied}}$$

$$= \frac{\text{BP}}{M_{\text{fuel}} \times \text{colorific Value of fuel}}$$

$$= \frac{0.4849}{0.000241 \times 48000}$$

$$= 0.0419 \text{ or } 4.19 \%$$

vi. For Volumetric Efficiency :

Theoretical Volume = $V_{\text{theoretical}}$

$$= \frac{\pi}{4} \times D_{\text{bore}}^2 \times L_{\text{stroke}} \times k \times \text{Number of Cylinders}$$

$$= \frac{\pi}{4} \times (0.068)^2 \times 0.075 \times 1300 \times \frac{4}{2 \times 60}$$

$$= 0.0118 \frac{\text{m}^3}{\text{s}}$$

vii. For Brake Torque :

$$\begin{aligned} \text{Brake Torque} &= \text{B.P} \times \frac{60000}{2\pi N} \\ &= 3.56 \text{ Nm} \end{aligned}$$

viii. For Brake Thermal Efficiency

$$\begin{aligned} \eta_{\text{brakethermal}} &= \frac{\text{BP}}{\text{Heat Supplied}} \\ &= \frac{\text{BP}}{\text{M}_{\text{fuel}} \times \text{colorific Value of fuel}} \\ &= \frac{0.4849}{0.000241 \times 48000} \\ &= 0.0419 \text{ or } 4.19 \% \end{aligned}$$

ix. For Volumetric Efficiency :

$$\begin{aligned} \text{Theoretical Volume} &= V_{\text{theoretical}} \\ &= \frac{\pi}{4} \times D_{\text{bore}}^2 \times L_{\text{stroke}} \times k \times \text{Number of Cylinders} \\ &= \frac{\pi}{4} \times (0.068)^2 \times 0.075 \times 1300 \times \frac{4}{2 \times 60} \\ &= 0.0118 \frac{\text{m}^3}{\text{s}} \end{aligned}$$

$$\text{Actual Volume} = V_{\text{Actual}}$$

$$\begin{aligned} \text{Density of air} &= \frac{M_{\text{air}}}{1.16} = \frac{0.00359}{1.16} \\ &= 0.0039 \frac{\text{m}^3}{\text{s}} \\ \eta_{\text{volumetric theoretical}} &= \frac{V_{\text{actual}}}{V} \times 100 = \frac{0.00309}{0.0118} \times 100 \\ &= 0.2618 \text{ or } 26.28 \% \end{aligned}$$

● Graphs –

From the graphs below it is observed that thermal efficiency is not varying significantly & volumetric efficiency doesn't remain constant.

● Result-

Result of load test are mentioned in following table 2 and 3.

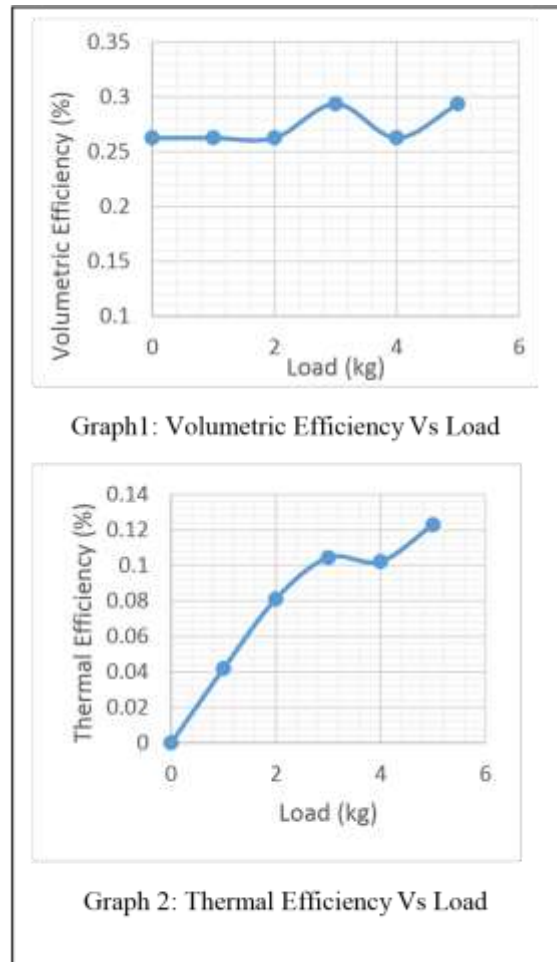


Table 2: Result of load test before FTA

S.N	Load (kg)	Speed (rpm)	Air fuel Ratio	BP (KW)	$\eta_{\text{Vol.}}$
1	0	1300	16.328	0	0.262
2	1	1300	14.918	0.4849	0.262
3	2	1300	14.452	0.9698	0.262
4	3	1300	13.862	1.4547	0.293
5	4	1300	9.102	1.9396	0.262
6	5	1300	9.790	2.4245	0.293

Table 3: Result of load test before FTA

S.N	BMEP	BSAC	BSFC	$\eta_{\text{brake thermal}}$	Brake Torque (T)
1	0	0	0	0	0
2	2.738	26.718	1.790	0.0418	3.5618
3	5.477	13.359	0.924	0.0811	7.1237
4	8.216	9.9573	0.718	0.1044	10.6856
5	10.95	6.679	0.733	0.1022	14.2475
6	13.69	5.974	0.610	0.1229	17.8094

2.Morse Test –

Morse test is performed to check the mechanical efficiency of the petrol engine.

Observation Table:

Observation of load test are mentioned in following table 4.

Table 4: Observation of Morse test before FTA

S.N	Rated Speed in (RPM)	Cylinder firing order	Load on Dynamometer (kg)
1	1615	1234	4.5
	1615	234	2.3
	1615	134	2.5
	1615	124	2.25
	1615	123	2.3
2	1500	1234	5.2
	1500	234	2.7
	1500	134	2.9
	1500	124	2.7
	1500	123	2.65

● **Sample Calculation:-**

Sample calculation for reading no. 1 is shown below.

$$\begin{aligned}
 \text{i. } \text{BP}[1234] &= \frac{W \times N}{2000} \times 0.746 \\
 &= \frac{4.5 \times 1615}{2000} \times 0.746 \\
 &= 2.71 \text{ Kw}
 \end{aligned}$$

$$\begin{aligned}
 \text{ii. } \text{BP}[234] &= \frac{W \times N}{2000} \times 0.746 \\
 &= \frac{2.3 \times 1615}{2000} \times 0.746 \\
 &= 1.38 \text{ Kw}
 \end{aligned}$$

$$\begin{aligned}
 \text{iii. } \text{BP}[134] &= \frac{W \times N}{2000} \times 0.746 \\
 &= \frac{2.5 \times 1615}{2000}
 \end{aligned}$$

$$\begin{aligned}
 \text{iv. } \text{BP}[124] &= \frac{W \times N}{2000} \times 0.746 \\
 &= \frac{2.25 \times 1615}{2000} \\
 &= 1.35 \text{ Kw}
 \end{aligned}$$

$$\begin{aligned}
 \text{v. } \text{BP}[123] &= \frac{W \times N}{2000} \times 0.746 \\
 &= \frac{2.3 \times 1615}{2000} \\
 &= 1.38 \text{ Kw}
 \end{aligned}$$

$$\begin{aligned}
 \text{vi. } \text{IP}[1] &= \text{BP}[1234] - \text{BP}[234] = 2.71 - 1.38 \\
 &= 1.33 \text{ Kw}
 \end{aligned}$$

$$\begin{aligned}
 \text{vii. } \text{IP}[2] &= \text{BP}[1234] - \text{BP}[134] = 2.71 - 1.50 \\
 &= 1.21 \text{ Kw}
 \end{aligned}$$

$$\begin{aligned}
 \text{viii. } \text{IP}[3] &= \text{BP}[1234] - \text{BP}[124] = 2.71 - 1.35 \\
 &= 1.36 \text{ Kw}
 \end{aligned}$$

$$\begin{aligned}
 \text{ix. } \text{IP}[4] &= \text{BP}[1234] - \text{BP}[123] = 2.71 - 1.38 \\
 &= 1.33 \text{ Kw}
 \end{aligned}$$

$$\begin{aligned}
 \text{x. } \text{Indicated Power of Engine xi.} &= \text{IP}[1] + \text{IP}[2] + \text{IP}[3] + \text{IP}[4] \\
 &= 1.33 + 1.21 + 1.36 + 1.33 \\
 &= 5.23 \text{ kW}
 \end{aligned}$$

$$\begin{aligned}
 \text{xii. Mechanical Efficiency} &= \frac{\text{BP}[1234]}{\text{IP}[1234]} = \frac{2.71}{5.23} \\
 &= 0.51 \text{ or } 51.81 \%
 \end{aligned}$$

● **Result: –**

Following result were obtained for Morse test on petrol engine

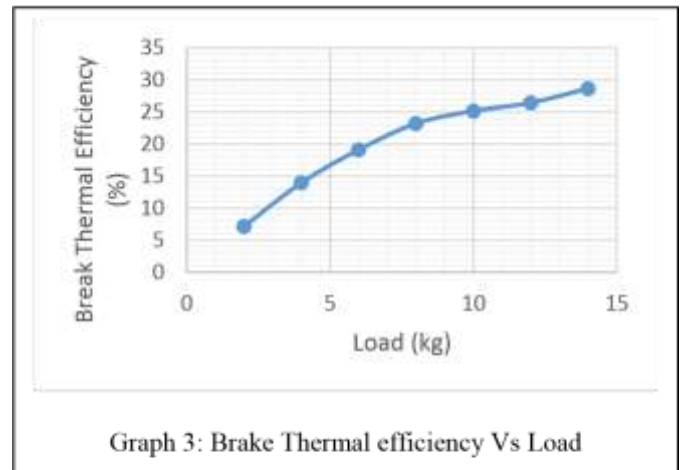
S. N	Rated Speed in RPM	Cylinders Working	Load on Dynamometer in kg	IP	Mechanical Efficiency in %
1	1615	1234	4.5	5.23	51.81
	1615	234	2.3		
	1615	134	2.5		
	1615	124	2.25		
	1615	123	2.3		
2	1500	1234	5.2	5.48	52.91
	1500	234	2.7		
	1500	134	2.9		
	1500	124	2.7		
	1500	123	2.65		

Table 5: Result of Morse test before FTA

Table 8: Result of load test after FTA

S.N	BMEP	BSAC	BSFC	$\eta_{\text{brake thermal}}$	Brake Torque (T)
1	5.477	18.892	1.045	7.171	7.123
2	10.955	8.836	0.536	13.970	14.247
3	16.433	5.453	0.392	19.113	21.371
4	21.911	4.418	0.323	23.210	28.495
5	27.389	3.272	0.298	25.160	35.618
6	32.867	2.945	0.283	26.443	42.742
7	38.345	2.698	0.261	28.662	49.866

• Graph :-



Graph 3: Brake Thermal efficiency Vs Load

II] Experimentation with Fault Tree

1 Load Test

Observation Table: –

Observation of load test are mentioned in following table6

S.N	Speed(rpm)	Load(kg)	Time(sec.)	del H(m)
1	1291	4	25.53	0.007
2	1312	6	23.65	0.006
3	1322	8	21.54	0.007
4	1330	10	18.68	0.006
5	1312	12	16.36	0.007
6	1285	14	15.2	0.008

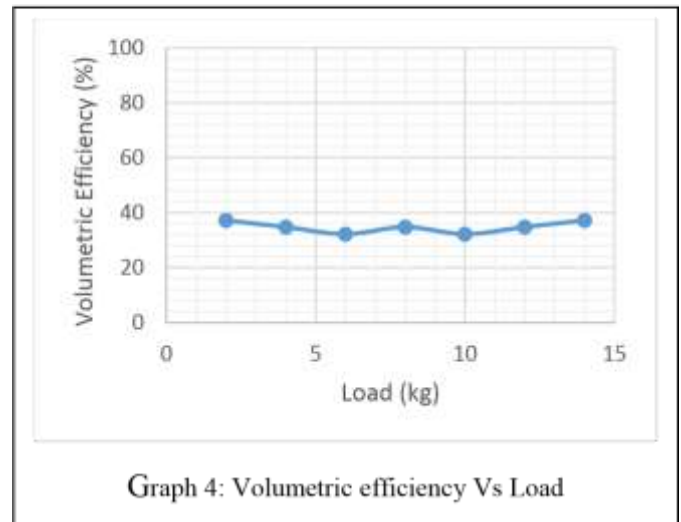
Table 6: Observations of load test after FTA

Results –

Following result were obtained for Load test on petrol engine without fault tree analysis mentioned in table 7 and table 8

Table 7: Result of load test after FTA

S.N	Load (kg)	Speed (rpm)	Air fuel Ratio	BP (KW)	$\eta_{\text{Vol.}}$
1	2	1280	18.064	0.969	37.175
2	4	1291	16.459	1.939	34.774
3	6	1312	13.898	2.909	32.195
4	8	1322	13.672	3.879	34.774
5	10	1330	10.977	4.849	32.195
6	12	1312	10.384	5.818	34.774
7	14	1285	10.314	6.7886	37.175



Graph 4: Volumetric efficiency Vs Load

From the graphs above it is observed that thermal efficiency is varying significantly & volumetric efficiency remains constant.

2) Morse Test:

● Observation table:

Observation of load test are mentioned in following table 9.

Table 9: Observations of Morse test after FTA

S.N	Rated Speed (RPM)	Cylinder firing order	Load on Dynamometer (kg)
1	1560	1234	10
	1560	234	7.1
	1560	134	7.2
	1560	124	7.15
	1560	123	7.15
2	1184	1234	12
	1184	234	8.5
	1184	134	8.6
	1184	124	8.55
	1184	123	8.5

● Results:-

Following results were obtained for Morse test on petrol engine without fault tree analysis.

Table 10: Result of Morse test after FTA

S.N	Rated Speed in RPM	Working cylinders	Load on Dynamometer in kg	IP	Mechanical Efficiency in %
1	1560	1234	10	6.61	87.89
2	1560	234	7.1		
3	1560	134	7.2		
4	1560	124	7.15		
5	1560	123	7.15		
1	1184	1234	12	6.10	86.72
2	1184	234	8.5		
3	1184	134	8.6		
4	1184	124	8.55		
5	1184	123	8.5		

● Results and Conclusion:-

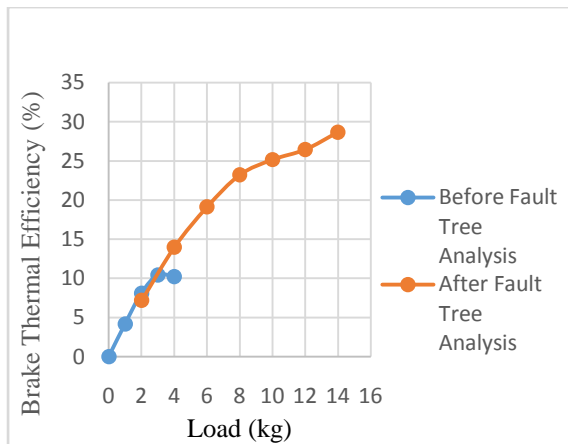
Table 11: Comparison of Results

S. N	η	Exp. Conditions	Before FTA	After FTA	Improvement
1	Load test				
	$\eta_{thermal}$	At 4 kg load, 1300 rpm	10.22 %	13.97 %	3.75 %
		At 6kg load, 1300 rpm	13.90 %	19.11 %	5.21 %
	$\eta_{volumetric}$	At 4 kg load, 1300 rpm	26.28 %	34.77 %	8.49 %
		At 6kg load, 1300 rpm	26.28 %	32.19 %	5.91 %
2	Morse test				
	$\eta_{mechanical}$	At 1500 rpm	52.91 %	87.89 %	34.98 %

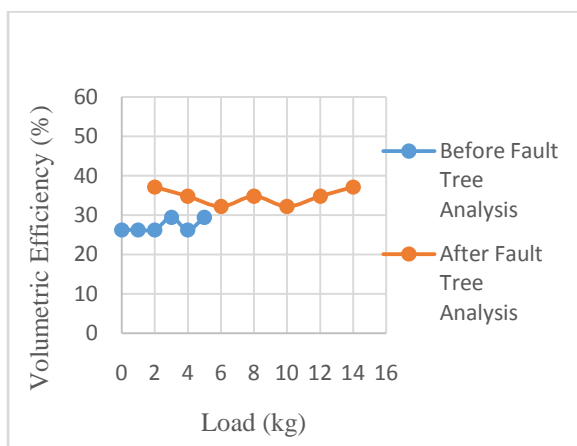
The results thus obtained without Fault Tree Analysis are directly compared with the results obtained with Fault Tree Analysis are mentioned in table 5.1. Hence using Fault Tree Analysis thermal efficiency and volumetric efficiency of 4stroke 4-cylinder petrol engine is improved by 15% and 8% respectively.

After identifying the defective parts of the engine they will be either repaired or replaced and various experimental tests are carried out such as load, Speed and Morse test on the engine to evaluate performance of the engine. In this current study with and without fault tree analysis approaches are used to compare performance of test setup. The results obtained using fault tree analysis is effective in manner.

The performance of engine is increased after maintenance and fault tree analysis method facilitates successfully optimizing of maintenance effort.



Graph 5: Brake Thermal Efficiency Vs Load



Graph 6: Volumetric Efficiency Vs Load

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● **Appendix:-**

FTA: Fault tree analysis.

BSFC: Break specificfuel consumption

BSAC: Break specific air consumption

BMEP: Break mean effective pressure

BP: Break power

BT: Break Torque

A/F Ratio: Air Fuel ratio

M_{fuel}:Mass of fuel

M_{air}: Mass of air