

A Review on Brown Crower's Six Stroke Internal Combustion Engine

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Abstract- Due to higher power to weight ratio, four stroke internal combustion engine are employed at very large number. But major drawback of four stroke engine is that it's not much efficient. Diesel engines are more efficient than petrol engines. But their thermal efficiency is maximum up to 50% so there is much loss of power. So development of six stroke internal combustion engine increases overall thermal efficiency of the engine. In the six stroke engine, first four strokes are same as four stroke engine, and later two strokes are employed to increase the overall power output. These later two strokes don't take power from fuel, but take it from the high temperature exhaust gases as well as the superheated cylinder walls. Due to this reason, six stroke engine has higher brake thermal efficiency and there is reduction in the emission of exhaust gases.

Keywords- Internal combustion engine; four stroke engine modification; six stroke engine; efficiency; water injection; waste heat recovery

1. INTRODUCTION

With continuous increase in the population, number of vehicles as well as machines operated by internal combustion engines are increasing very fast. We have a limited stock of conventional sources of energy. In 2006, Bruce Crower was able to develop this engine with modification made in the modified diesel engine which he maintained to run by gasoline and machined the engine to add extra features of the six stroke engine [3]. In this engine there is no need of the cooling system as the cooling of the engine occurs due to transfer of heat from superheated cylinder walls to the water to vaporize it.

In this type of engine, water is injected in the superheated cylinder only after complete exhaust of the burnt gases from the cylinder.

which is also degrading very fast. Due to this reason, optimum utilization of fuels are required.

In the conventional two and four stroke internal combustion engines, there are huge losses in these due to high temperature exhaust, leakage of energy through cylinder walls and friction. To increase the brake thermal efficiency of the engine, six stroke engine is developed. It is an advancement on the two and four stroke engines. It gives more power output from same heat given to the engine by waste heat recovery method. In the six stroke engine, there are two power stroke engine for once supply of fuel in the engine cylinder, once through burning of fuel and another through vaporization of injected water in the cylinder.

In four stroke engine, for every two revolution of the crank shaft one power stroke is available and high temperature exhaust gases leave the engine taking a much amount of available heat. In six stroke engine, first four strokes are same as conventional four stroke engine and in fifth stroke water is injected in the superheated cylinder which on sudden evaporation provides secondary power stroke in the engine and in the sixth stroke the water vapors are ejected out of the engine cylinder [1-2].

The six strokes of this engine are:

- Charge suction stroke
- Charge compression stroke
- Ignition stroke (1st power stroke)
- Exhaust stroke
- Vapor expansion stroke (2nd power stroke)
- Vapor exhaust stroke

Due to implication of two power strokes instead of one for same amount of fuel supplied, the brake thermal efficiency of the six stroke engines are increased by more than 30% [4]. On increasing the engine head complexity, weight of the engine reduces

by more than 50%. Along with this, it also increases the torque applied by engine on crankshaft by more than 35% than a four stroke engine for same amount of fuel consumption[5].

2. TYPES OF SIX STROKE ENGINE

A. SINGLE PISTON DESIGNS

In this type of six stroke engine designs, only one piston is employed as like the conventional two stroke and four stroke engines. In this type of engine, first power stroke is obtained by the burning of fuels and second power stroke is obtained by the expansion of the secondary fuel (air or water).

A.1 GRIFFIN'S SIX STROKE ENGINE

It was the first six stroke engine developed in 1883 by Engineer Samuel Griffin. The principle of this engine was spraying the fuels into the heated exhaust-jacketed external vaporizer.

A.2 BAZULAZ SIX STROKE ENGINE

It is similar in design to a regular internal combustion chamber, however there is some modification in the cylinder head. There are two supplementary chambers above the main cylinder. These are: a combustion chamber and an air pre-heating chamber.

A.3 VELOZETA SIX STROKE ENGINE

In this engine, fresh air is injected inside the superheated cylinder chamber in which it expands by rising of temperature by gaining heat from the cylinder walls pushing piston away and providing additional power stroke and cooling engine. So necessity of the cooling system also vanishes.

A.4 NIKYADO SIX STROKE ENGINE

This engine was designed and developed in the Nikyado Motors. It was designed and developed by the ChanayilCleetus Anil belonging from India. He holds Indian patent number IN252642, granted by IPIndia on May 25, 2012 [6]. It was claimed that this engine was 23% more fuel efficient than a four stroke engine and very low on pollution.

A.5 BROWN CROWER SIX STROKE ENGINE

This engine was developed and invented by the Brown Crower, a race car mechanic with own workshop in California, USA in 2004. In this engine, water is injected in the superheated cylinder which on vaporization provides additional power stroke other than the power stroke obtained by combustion of the fuel.

B. OPPOSED PISTON DESIGNS

In these designs of the six stroke engine, there are two pistons in each cylinder operating at different speeds with combustion of fuel occurring between them.

B.1 BEARE HEAD SIX STROKE ENGINE

This engine was developed by an Australian wheat farmer Malcolm Beare. Actually, the name 'six stroke' was coined by the Malcolm Beare himself. In this type of engine, two pistons working together at different speeds which are working opposite to each other. In other words, it is a hybridization of the two stroke in the top end together with a four stroke.

B.2 M4+2

This engine is an advancement of the Beare Head Engine. In this engine, one piston moves at double the speed than the other. But main function of the second piston is to remove the valve mechanisms of the conventional four stroke engines.

B.3 PISTON-CHARGER ENGINE

It is designed similar to the Beare Head Engine. In this engine, piston charger replaces the valve mechanism employed in Beare Head. It properly charges the cylinder as well as it also regulates the inlet and outlet openings which reduces the air and fuel losses. The construction of the compact design of the combustion cylinder with very low losses of the air and fuel gives the engine more torque, more efficiency and better exhaust quality [6].

3. WORKING OF SIX STROKE ENGINE

In the six stroke engine, there are six stroke or the three complete revolution of the crank for one cycle. The following stroke details are as given:-

A. FIRST STROKE (SUCTION OF CHARGE)

In the suction stroke, piston moves from Top Dead Centre to Bottom Dead Centre sucking charge inside the cylinder. During this stroke, inlet valve opens and the exhaust valve remains closed.

B. SECOND STROKE (COMPRESSION OF CHARGE)

In this stroke, piston moves from Bottom Dead Centre to Top Dead Centre compressing the sucked charge. During this process, both inlet as well as exhaust valves remain closed.

C. THIRD STROKE (1ST POWER STROKE)

In this stroke, piston moves from Top Dead Centre to Bottom Dead Centre. In this process, compressed charge is ignited which provides the 1st power stroke in the engine. During this process, both inlet as well as exhaust valves remain closed.

D. FOURTH STROKE (1ST EXHAUST)

In this stroke, piston moves from Bottom Dead Centre to Top Dead Centre. During this process, inlet valve remains closed while exhaust valve opens to allow the burnt gases to flow out of the combustion chamber.

E. FIFTH STROKE (2ND POWER STROKE)

In this stroke, piston moves from Top Dead Centre to Bottom Dead Centre. In this process, water is injected in the superheated cylinder chamber. Liquid water suddenly vaporizes into vapor by taking heat from the cylinder walls. This provides an extra power stroke. In this process, inlet as well as exhaust valves remain closed.

F. SIXTH STROKE (2ND EXHAUST)

In this stroke, piston moves from Bottom Dead Centre to Top Dead Centre. In this process, water vapors are exhausted from the cylinder chamber. During this process, inlet valve remain closed while exhaust valve opens.

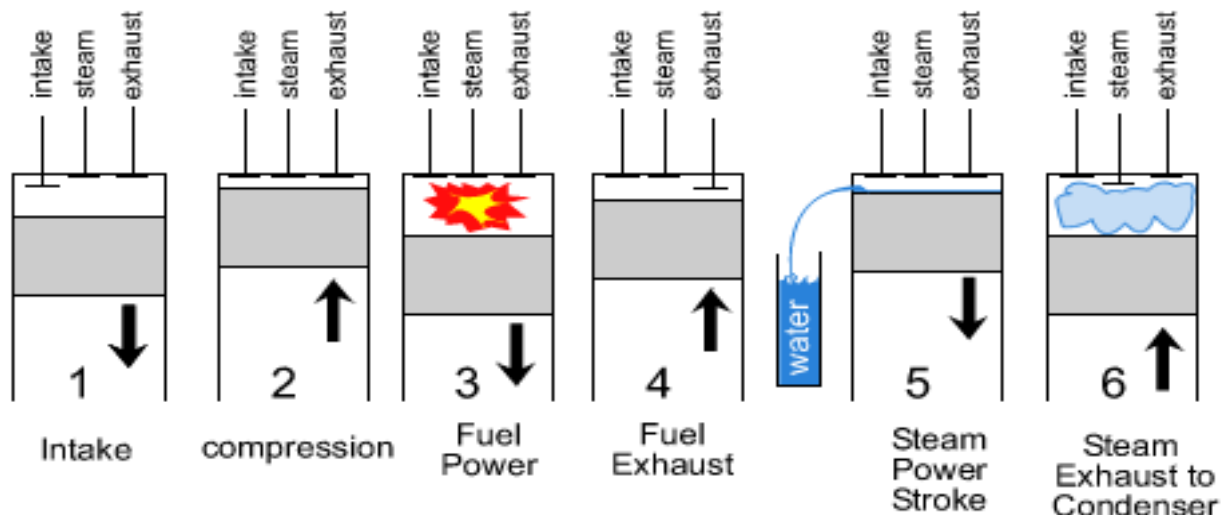


Fig. 1 Working of six stroke engine

4. WATER AS SECONDARY FUEL

Water is available on the earth in abundance. It has a specific heat of 4.18 kJ/kg-K. The vaporization of the water takes place by absorption of the energy equivalent to latent heat of vaporization. In vaporization, water changes its phase from liquid to gas. In the six stroke engine, water is injected in the

fifth stroke which on vaporization provides an extra power stroke. The following properties of water made it possible for used as a secondary fuel in the engine:-

1. Water has a specific heat of 4.18 kJ/kg-K.
2. It vaporizes at 100⁰C at 1 bar pressure.
3. It prevents the detonation in the engine.

4. it has higher heat absorption capacity than air as it has higher specific heat capacity value.
5. It on vaporization, expands nearly 1600 times the volume it has in liquid phase.
6. It prevents the need of the cooling system in the engine.[7]

5. MODIFICATION REQUIRED IN THE ENGINE COMPONENTS

The following components in the four stroke engine require modification for its conversion into six stroke engine:-

A. TIMING GEAR MODIFICATION

In the conventional six stroke engine, the crankshaft must rotate two complete rotation while camshaft rotates once. It means the gear ratio used in this is 2:1. While in the six stroke engine, the crankshaft must rotate three complete rotation for one complete rotation of camshaft. So gear ratio should be changed to 3:1 instead of 2:1.



Fig.2Timing Gear Modification

B. CAM MODIFICATION

In the conventional four stroke engine, the cam has one lobe which opens the exhaust valve in the 4th stroke (exhaust stroke). In the six stroke engine, there are two exhaust strokes i.e. in the fourth stroke and six stroke. So there is need of two lobes for the opening of the exhaust valve. Both lobes are separated by the 60°.



Fig.3 Cam Modification

C. CAM FOLLOWER MODIFICATION

In the conventional four stroke engine, the bottom of shape of regular follower has flat pattern as it more reliable for one lobe. But as the number of lobes increases from one to two, separated by the 60°, the shape of the follower changes from the flat shaped to roller or spherical shaped [8].

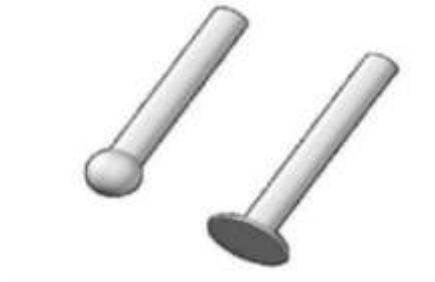


Fig.4 Cam follower modification

6. THERMODYNAMIC ANALYSIS OF SIX STROKE ENGINE

A. PRESSURE-CRANK ANGLE DIAGRAM

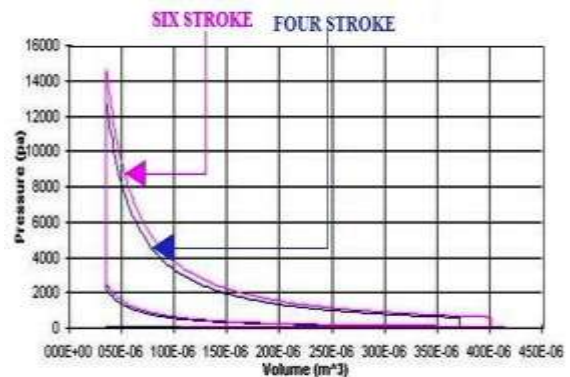


Fig.5 Comparison of pressure-volume diagram

This comparison shows that the area covered by the six stroke cycle is greater than the four stroke cycle. Both engine works on the Otto Cycle and greater area of six stroke shows that the extra work obtained from the same amount of the fuel supplied.

B. TORQUE- CRANK ANGLE DIAGRAM

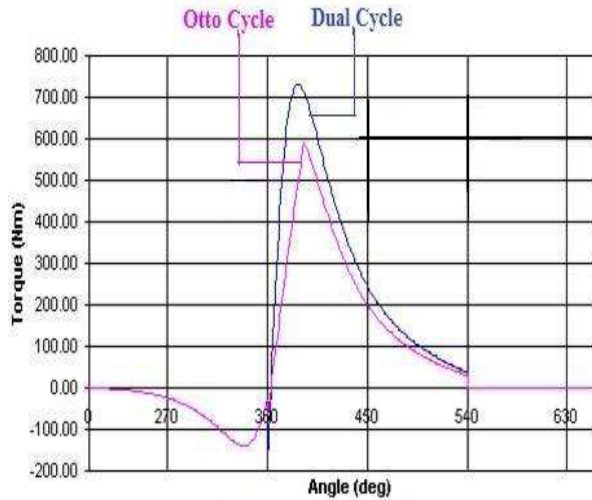


Fig.6 Torque-crank angle diagram for six stroke engine



Fig.7 Torque-crank angle diagram for four stroke engine

As from the above graphs, it is clear that torque produced by the six stroke engine working on either Otto or Dual cycles is much more than what it is obtained from the four stroke engine working on these cycles. [9]

C. MEAN EFFECTIVE PRESSURE-EXHAUST VALVE CLOSING DIAGRAM

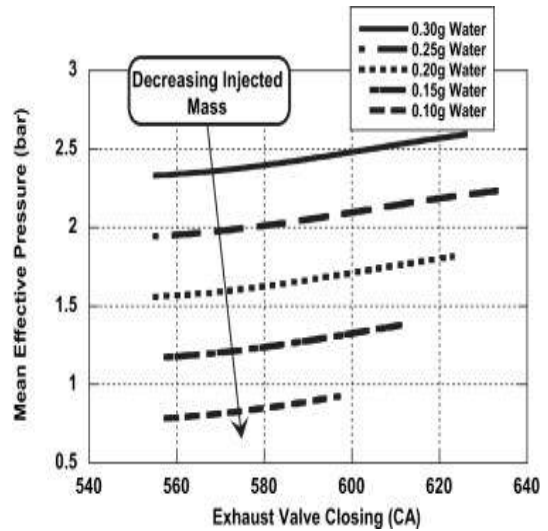


Fig.8 Mean effective pressure-exhaust closing valve diagram for different amount of water injected inside the cylinder [10]

The above diagram shows the variation of the mean effective pressure with exhaust valve closing for different amount of water injected inside the combustion chamber. It shows that for higher amount of water injection, there is generation of higher mean effective pressure due to vaporization of water.

7. ADVANTAGES OF SIX STROKE ENGINE [11]

- A. *Reduction in fuel consumption:-* As the power output per unit fuel consumption is reduced for the six stroke engine, so it leads to the lesser consumption of the fuel.
- B. *Increased efficiency:-* As the power output for same fuel consumption increases in the six stroke engine, it increases the overall efficiency of the engine.
- C. *Extreme reduction in the pollution:-* Due to proper utilization of the energy generated in engine and some engine’s own characteristics leads to lower the emission of the engine. Emission gases are mixture of HC, NO_x, CO and SO_x. Due to lower emission from the engine, there is reduction in the environment pollution.
- D. *Flexibility to use multi fuel:-* This engine gives us flexibility to use multi fuels. Due to this

ability of the engine alternative fuels can also be used instead of conventional fuel.

- E. *Increased power to weight ratio:-* Due to extra power available in the six stroke engine for nearly same weight four stroke engine, so its power to weight ratio is higher than the four stroke engine.
- F. *No need of cooling arrangement:-* This is one of the biggest advantage of this engine. In this engine, the requirement of the cooling arrangement is vanished as the secondary power stroke is obtained through the remaining heat of the superheated cylinder left out after exhaust process.

8. DISADVANTAGES OF SIX STROKE

ENGINE [12]

- A. *Complex head design:-*Due to presence of many components and many manifolds, this engine has complex design leading to higher manufacturing cost.
- B. *Complex cam design:-*Due to two exhaust strokes for six stroke engine, the cam should have two lobes to open exhaust valves twice and due to two lobes of the cams, its manufacturing becomes quite difficult.

9. CONCLUSIONS

The six stroke engine modification may lead to the optimum utilization of the fuels. It also leads to the greater torque transmission than the four stroke engines.

By the utilization of the heat which lost to environment in four stroke engine provides greater thermal efficiency. The utilization of the alternative fuels are also possible.

In this paper, a method is employed to modify the conventional four stroke engine into a six stroke engine in which various components are needed to modify.

A comparison is made between six stroke engine and four stroke engine by the thermodynamic analysis of both engines.

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