Design of Six-Stroke Internal Combustion Spark Ignition Engine

A.B. Hassan & M.A. Olabiyi

Federal University of Technology

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The rate at which energy is lost by human activities is enormous. There is need to work on how to generate more energy and minimize the usage of the generated energy. In an internal combustion engine, there is a need to focus on gaining energy usage by using generated heat during the combustion process. To reduce the energy usage, emission rate and improve the efficiency of four-stroke internal combustion spark ignition engine, the four-stroke internal combustion spark ignition engine is modified into a six-stroke internal combustion spark ignition engine. The heat generated from a four-stroke cycle is used in a six-stroke cycle for additional power stroke and exhaust stroke of the piston in the same cylinder. There is an injection of water which forms steam with the help of generated heat from a four-stroke cycle which forces down the piston for additional power stroke and the piston comes up to expel the exhaust gases out of the cylinder. With the injection of water into the cylinder, there is no need for a cooling system as in a four-stroke Otto cycle which makes the engine become lighter and 25% fuel and power efficiency over the normal Otto cycle.

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ABSTRACT

The rate at which energy is lost by human activities is enormous. There is need to work on how to generate more energy and minimize the usage of the generated energy. In an internal combustion engine, there is a need to focus on gaining energy usage by using generated heat during the combustion process. To reduce the energy usage, emission rate and improve the efficiency of four-stroke internal combustion spark ignition engine, the four-stroke internal combustion spark ignition engine is modified into a six-stroke internal combustion spark ignition engine. The heat generated from a four-stroke cycle is used in a six-stroke cycle for additional power stroke and exhaust stroke of the piston in the same cylinder. There is an injection of water which forms steam with the help of generated heat from a four-stroke cycle which forces down the piston for additional power stroke and the piston comes up to expel the exhaust gases out of the cylinder. With the injection of water into the cylinder, there is no need for a cooling system as in a four-stroke Otto cycle which makes the engine become lighter and 25% fuel and power efficiency over the normal Otto cycle.

Keywords: six-stroke, spark ignition, internal combustion, cam shaft, crankshaft, sprocket.

Author α σ : Department of Mechanical Engineering, Federal University of Technology, P.M.B.65, Minna, Niger State, Nigeria.

I. INTRODUCTION

The six-stroke internal combustion spark ignition engine principle is based on the conventional four-stroke internal combustion spark ignition engine but with additional features for energy saving (fuel consumption), maximum power optimization, and cooling rate e.t.c. The additional features includes the addition of other two strokes in which the engine uses the waste heat from the four-stroke internal combustion spark ignition engine (Otto cycle or Diesel cycle) for additional power stroke and exhaust stroke of the piston in the cylinder. The design uses steam as working fluid for the additional power stroke.

1.1 Background of the Study

In an internal combustion engine, most of the fuels energy is lost as heat and as pollutant. The heat is aired out by the radiator. There is need to concentrate on the rate of energy loss as the world is working on how to generate more energy and minimize the usage of already generated energy. The consequence of energy cannot be overemphasized in the view of human technology; every aspect of human endeavor requires a consistent and viable source of energy and how to maintain it. There is need to focus on gaining of energy by the usage of this heat generated in the internal combustion engine. The six-stroke engine was developed since the 1990s, describes two different approaches in the internal combustion engine, to improve its efficiency and reduce emissions. The engine entrances the waste heat from the four-stroke of an internal combustion engine being Otto cycle or Diesel cycle and uses it to get an additional power and exhaust stroke of the piston in the same cylinder. Designs either use steam or air as the working fluid for the additional power stroke. The additional stroke cools the engine and removes the need for a cooling system making the engine lighter and giving 40% increased efficiency over the normal Otto cycle or

Diesel Cycle (Ahmad, 2012). The pistons in this six-stroke engine go up and down six times for each injection of fuel. These six-stroke engines have two power strokes: one by fuel, one by steam or air. The currently notable six-stroke engine designs in this class are the Crower's six-stroke engine, invented by Bruce Crower of the U.S.A; the Bajulaz engine by the Bajulaz S A Company, of Switzerland; and the Velozeta's Six-stroke spark ignition engine built by the College of Engineering, at Trivandrum in India.

The second approach to the six-stroke internal combustion spark ignition engine uses a second opposed piston in each cylinder which moves at half the cyclical rate of the main piston, thus giving six piston movements per cycle. Functionally, the second piston replaces the valve mechanism of a conventional engine and also it increases the compression ratio. The currently notable six-stroke spark ignition engine designs in this class include two designs developed independently: The Beare Head engine, invented by Australian farmer Malcolm Beare, and the German Charge pump, invented by Helmut Kottmann.

1.2 Strokes of Four-Stroke Spark Ignition Engine

The working principle of the four-stroke spark ignition engine:

- *First Stroke:* Here, the inlet valve opens for the air-fuel mixture from the carburetor which is sucked into the cylinder through the inlet manifold.
- *Second stroke:* The second stroke of the internal combustion engine which is the compression stroke, the piston moves from Bottom Dead Centre (BDC) to the Top Dead Centre (TDC) to compress the air-fuel mixture in which both the inlet and outlet valve were closed.
- *Third stroke:* This is the power stroke on an internal combustion engine in which the compressed air-fuel mixture is ignited by the spark plug. The two valves remain closed and the piston is forced down from Top Dead Centre (TDC) to Bottom Dead Centre (BDC).
- *Fourth stroke:* The fourth stroke of an internal combustion engine is the exhaust stroke where the exhaust (outlet) valve opens to allow the exhaust (burned gases) out of the engine cylinder. Here, the piston moves from the Bottom Dead Centre (BDC) to the Top Dead Centre (TDC) and the inlet valve remain closed.

1.3 Strokes of a Six-stroke Spark Ignition Engine

- *Fifth stroke:* In the fifth stroke of an internal combustion engine the piston is force down by the heat generated at the exhaust stroke and the steam formed by the injection of water under pressure and temperature through the water injection nozzles into the cylinder. The piston is forced down from the Top Dead Centre (TDC) to the Bottom Dead Centre (BDC) for the second power stroke.
- *Sixth stroke:* This is the second exhaust cycle where the piston moves from the Bottom Dead Centre (BDC) to the Top Dead Centre (TDC). The exhaust valve opens for the passage of gases out of the cylinder.

II. RESEARCH METHODOLOGY

2.1 Six-Stroke Engine

This Design uses steam as a working fluid for the additional power stroke as well as extracting power; the additional stroke cools the engine and removes the cooling system of the engine making the engine lighter and increased efficiency over the Otto cycle.

2.2 Additional Strokes Introduce

- *Fifth stroke:* At the fifth stroke which is the first additional stroke out of the two strokes added to the four-stroke of an internal combustion engine, the heat evolved at the exhaust of the forth cycle were use directly. There is intake of water by water injection into the super-heated cylinder, the water explodes into steam then forces the piston down for the second power stroke. This also cools the engine. The water injection consist of three main components; injector, water pressurizing system and electronic control system.

- *Sixth stroke:* All the vapors at the top of the piston inside the cylinder and gases are thrown out from the combustion chamber through the exhaust valve and water vapor can be collected by a condenser which is attached to the exhaust port so that the water can be reused. The processes are explained in the figure 2.1 below:

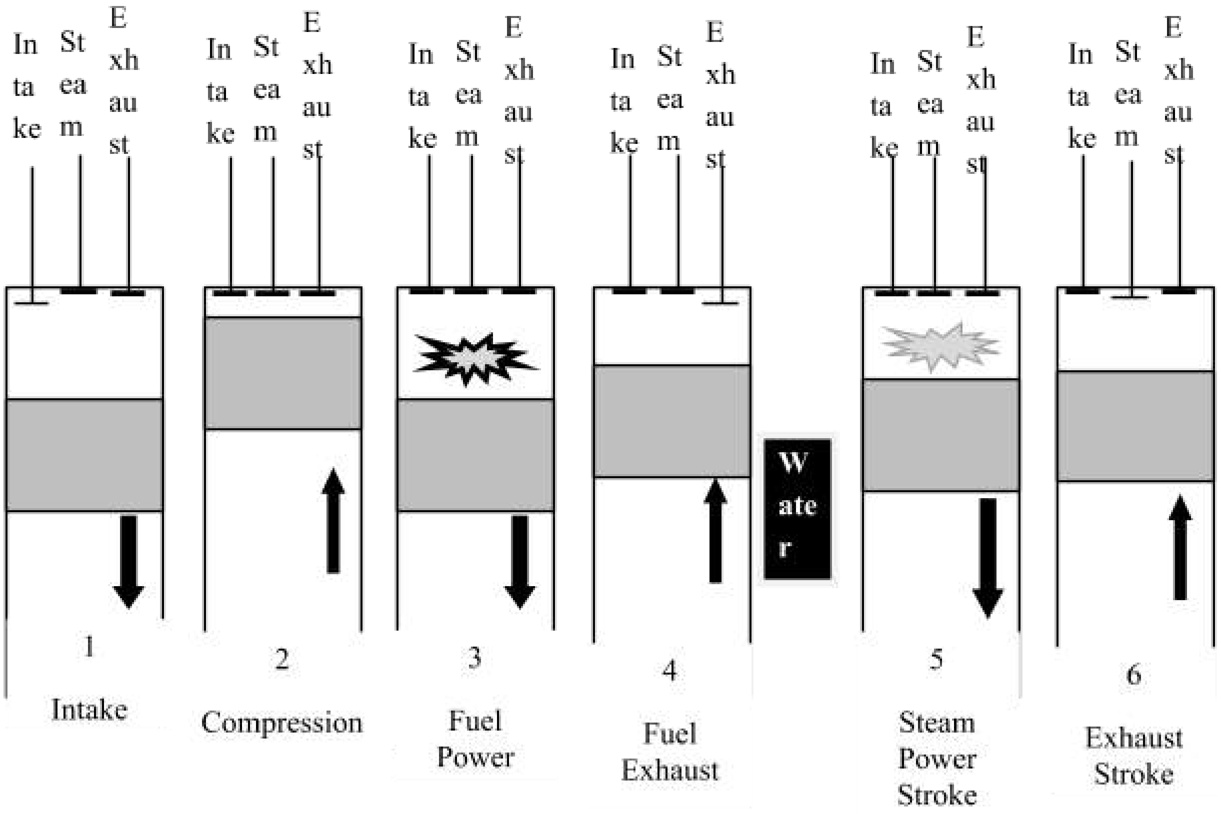

Figure 2.1: Analysis of Strokes in Six-Stroke Internal Combustion Engine

2.3 Engine Modification of Four-Stroke Spark Ignition Engine

The conventional four-stroke engine was modified by working on some specific part for the addition of two more strokes for additional power to the four-stroke engine. These modifications are:

2.3.1 Camshaft/Crankshaft sprocket

Camshaft is a rod or shaft to which cams are attached. Cams are non-circular wheels, which operate the cylinder valves of an internal combustion engine and are also used to operate other gear-driven engine components. Camshaft design can determine whether the camshaft can help the engine to produce heavy torque. The cams on the camshaft operate the intake and exhaust valves of the engine. The original angular speed of the camshaft is one-half that of the crankshaft, such that the camshaft rotates once for every two revolutions (four-stroke) of the crankshaft. The six-stroke camshaft has been designed to turn one revolution every three revolutions (six-stroke) of the crankshaft.

In an internal combustion engine, camshaft is a cylindrical rod running at the length of the cylinder bank with a number of a long lobes protruding from it, one for each valve. The cam lobes force the valve open by pressing on the valve as they rotate. The main function of camshaft is to operate poppet valve

In 2-stroke engine,
If there is two stroke of the piston and one revolution (360^o) of the camshaft, the revolution of the crankshaft of the two stroke of the piston in degree will be:

$$\frac{2\times360}{2} = \frac{720}{2} = 360^o \text{ revolution of crankshaft}$$

For 2 –stroke, power stroke occurs once in every 360^o revolution of crankshaft
For 4-stroke engine,
If firing takes place once after every 4-stroke

$$\frac{4\times360}{2} = \frac{144}{2} = 720^o \text{ revolution of crankshaft}$$

For 6 – stroke engine,
If power will occur once in every

$$\frac{6\times720}{4} = \frac{4320}{4} = 1080^o \text{ revolution of crankshaft}$$

Therefore the corresponding sprocket of four strokes to six-stroke having teeth ratio 720^o: 1080^o

This gives ratio 1:3
This makes it necessary to keep the camshaft pulley three times bigger than crank shaft pulley for the 6- stroke engine.

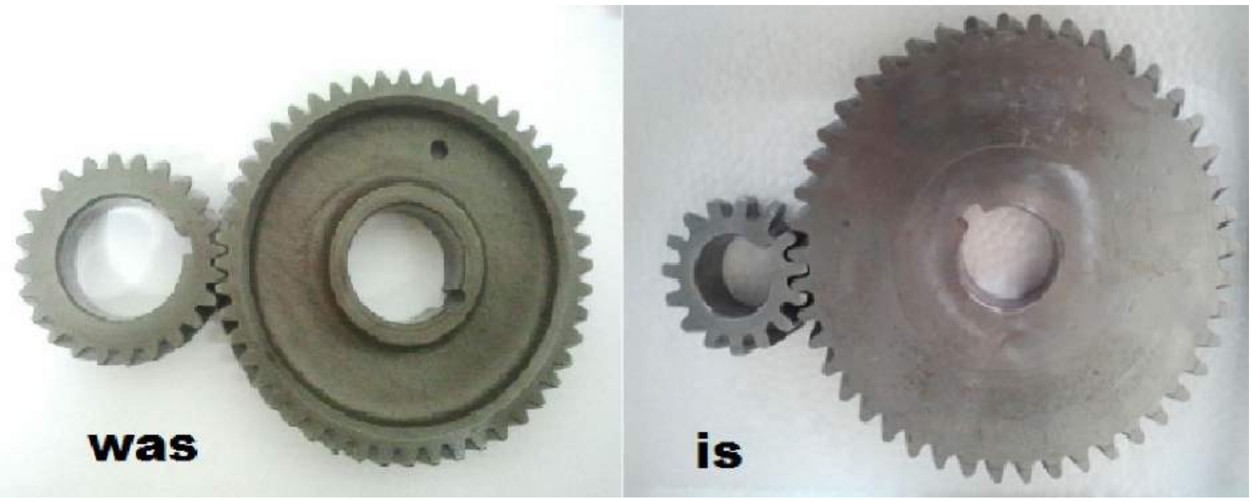

Figure 2.2: The unmodified and modified crank and cam shaft gear teeth (Shubham, 2016)

2.3.2 Camshaft Modification

In a six stroke internal combustion engine, the 360^o cam was divided into six, the exhaust has two (2) lobes, one to open the exhaust valve at the forth stroke and at the sixth stroke to push out the steam.

2.3.3 Timing Gear

The gear train (sprocket) with two to one reduction through which the crankshaft drives the camshaft and controls valve timing in an internal combustion spark ignition engine. The timing gear of a four-stroke internal combustion spark ignition engine consists of 32 teeth with a cam revolution ratio of 1:2.

If for every two rotations of a crank, the timing gear rotates a single rotation. The timing gear of a six-stroke internal combustion spark ignition engine will consists of

$\frac{1}{2} \times 32 = 16$

$16 \times 3 = 48$

.48 teeth with a cam revolution ratio of 1:3. Here for every three rotations of a crank the timing gear rotates a single rotation.

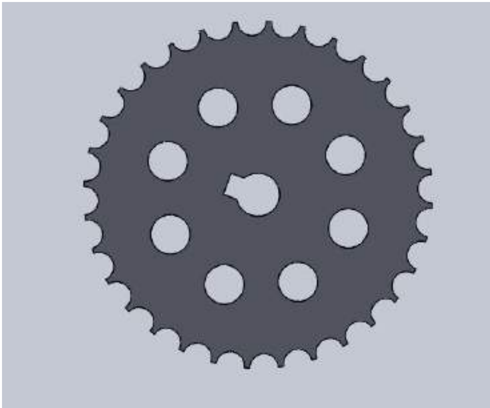

Figure 2.3: Sprocket of Four-Stroke Engine. (Arul, 2017)

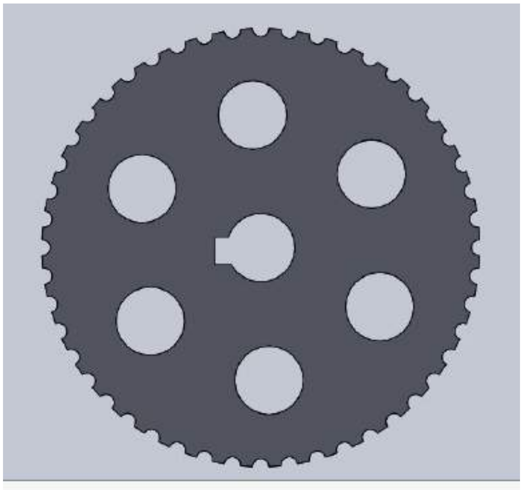

Figure 2.4: Sprocket of a Six-Stroke Engine.

2.3.4 Cam Profile Design

2.3.5 The design of the cam profile is very vital and it will be design on the basis of the following

- The distance that the valve will move toward the piston
- The time for the valve to remain open for exhaust gases
- The time it will take for the closing of the valve which is the same as that of opening time

The four-stroke camshaft profile: the four-stroke camshaft has a 90^{o} of design in angle; the circle was divided into four.
The camshaft has two lobes, one for intake valve and one for exhaust valve

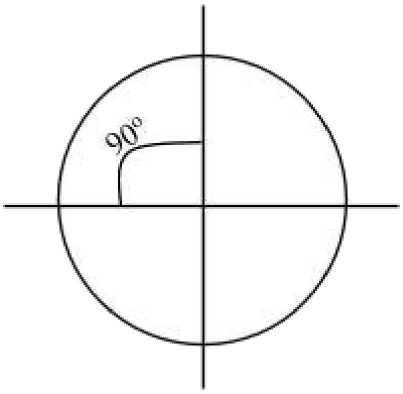

Figure 2.4: Cam Lobe of Four-Stroke Engine (Mohd, 2012)

2.3.5.1 Six-stroke Camshaft Profile

The six-stroke camshaft profile has a 60° design of an angle; the circle was divided into six. The camshaft has four lobes, two for the intakes valve (for the intake of air-fuel mixture), two to allow injection of water at the fifth stroke and two for the exhaust valve (for the first exhaust after the combustion and for the second exhaust of the steam after the fifth stroke)

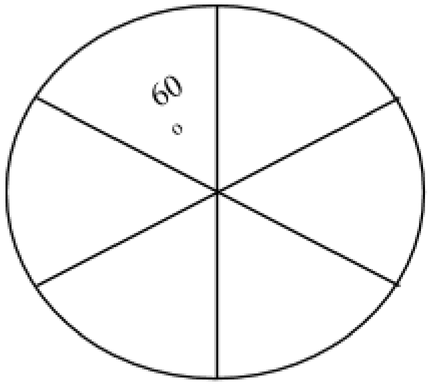

Figure 2.5: Cam lobe shape of six-stroke engine

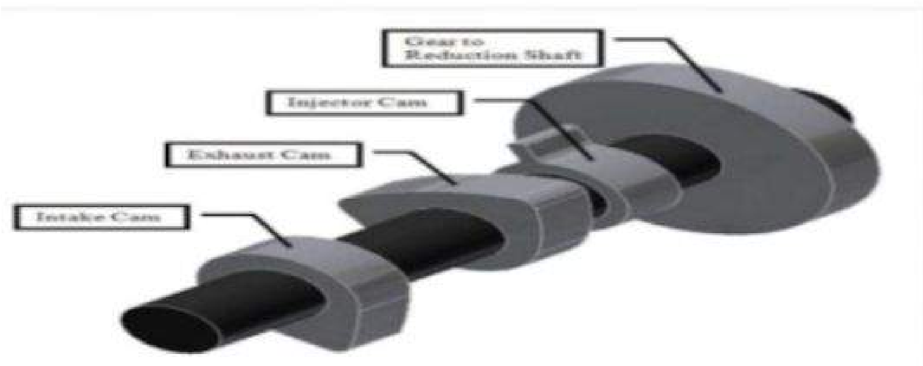

Figure 2.6: Six-stroke Flat and Spherical Camshaft Follower (Saurabh, 2015)

2.4 Fuel Tank

The fuel tank of four-stroke internal combustion spark ignition engine has to be divided into two for the six-stroke internal combustion spark ignition engine as one side is for fuel and the other will be for water and the water has to be distill and pure.

2.5 Cam Follower Modification

The four-stroke internal combustion spark ignition engine has its bottom shape follower in flat pattern. For the six-stroke internal combu- stion spark ignition engine, the follower has to be in roller or spherical shape has its contact area is lesser.

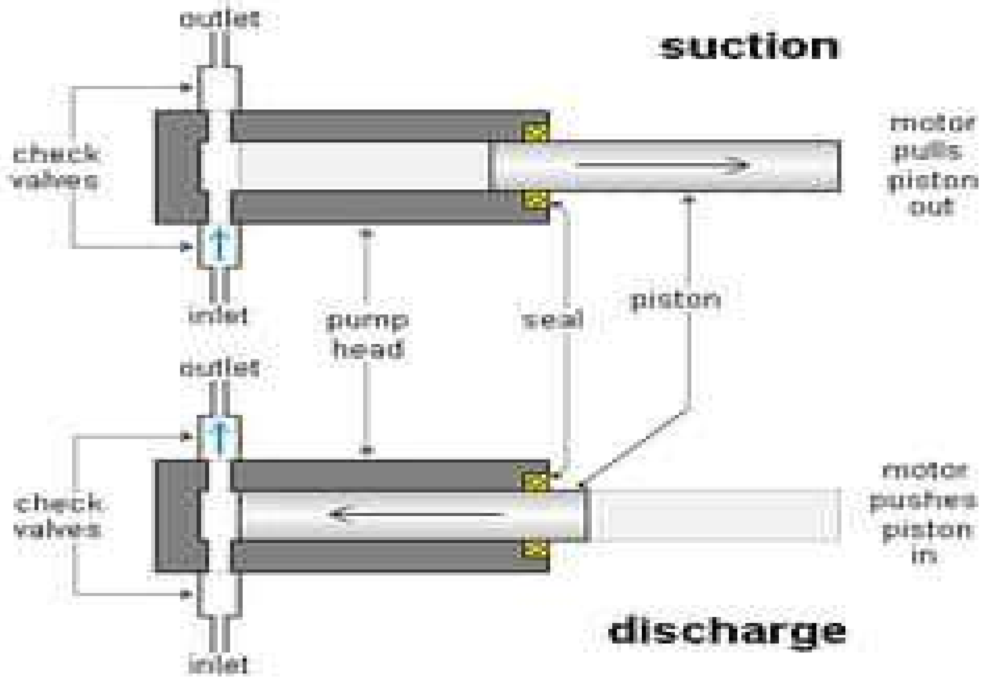

Figure 2.7: Water Metering Pump

2.6 Injection of Water System

The injection of the water system is done with the help of a water injector operated by the cam. This can be achieved with the use of a water metering pump. The water metering pump is a positive displacement pump capable of driving a fixed quantity of water into the cylinder at regular intervals independent of the back pressure applied.

2.7 Analysis of Internal Combustion Spark Ignition Engine

2.7.1 Indicated Power

The indicated power can be defined as the power remaining to drive the piston after some are loss to the coolant, radiation and exhaust

For four-stroke engine n: the indicated power is thus.

$$Ip = \frac{P_m \times L \times A \times N}{60 \times 1000} \quad (2.1)$$

Where:

ip = indicated power (kW)

P_m = indicated mean effective pressure

n = is the number of power stroke

N = $\frac{N}{2}$ and N = speed of the engine (r.p.m)

L = length of the stroke (m)

A = cross – sectional area of the piston (m^2)

For four-stroke engine, since N = N/2

Therefore substitute for the value of n

$$Ip = \frac{i_{mep} \times L \times A \times N/2}{60 \times 1000} \quad (2.2)$$

$$= 8.333\times10^{-6}\, i_{mep}LAN \quad (2.3)$$

For six-stroke engine n: the indicated power is as follows:

$$Ip = \frac{i_{mep} \times L \times A \times N}{60 \times 1000} \quad (2.4)$$

Where N = $\frac{2N}{3}$

$$Ip = \frac{i_{mep} \times L \times A \times 2 \times N}{60 \times 1000 \times 3}$$

$$= 1.111\times10^{-5}\, i_{mep}LAN \quad (2.5)$$

2.7.2 Percentage Difference in Indicated Power

The percentage difference in the indicated power of four-stroke internal combustion spark ignition engine and the six-stroke internal combustion spark ignition engine may be calculated as:

$$\% = \frac{ip\ of\ six\text{-}stroke - ip\ of\ four\text{-}stroke}{ip\ of\ six\text{-}stroke} \times \frac{100}{1} \qquad (2.6)$$

From equation (3.3) and equation (3.5)

$$\% = \frac{1.111\times 10^{-5}\ i_{mep}LAN - 8.333\times 10{-6}\ i_{mep}LAN}{1.111\times 10{-5}\ i_{mep}LAN} \times \frac{100}{1}$$

$$= 25\%$$

2.7.3 Break Power

Is the useful power trans mitted by the piston to the crankshaft

$$B.P = \frac{2\pi NT}{60\times 10^3} \qquad (2.7)$$

Where BP = Break Power

T = Torque (Nm)

N = $\frac{N}{2}$ for 4 stroke engine

N = speed of the engine (r.p.m)

Assuming the Torque to be 58Nm, N to be 900 r.p.m

For four-stroke internal combustion spark ignition engine

$$B.P_4 = \frac{2\pi NT}{60\times 10^3}$$

$$B.P_4 = 2.73\ W$$

For six-stroke internal combustion spark ignition engine where N = $\frac{2N}{3}$

$$B.P_6 = \frac{2\pi NT}{60\times 10^3} \qquad (2.9)$$

$$B.P_6 = 3.64\ W$$

2.7.4 Percentage Difference in Break Power

The percentage difference in the break power of four-stroke internal combustion spark ignition engine and the six-stroke internal combustion spark ignition engine may be calculated as:

$$\% = \frac{bp\ of\ six\text{-}stroke - bp\ of\ four\ stroke}{ip\ of\ six\ stroke} \times \frac{100}{1} \qquad (2.10)$$

From the result of equation 3.7 and equation 3.8, the percentage difference can be calculated as:

$$\% = \frac{3.64 - 2.73}{3.64} \times \frac{100}{1} = 25\%$$

2.7.5 Mechanical Efficiency

The mechanical efficiency can be defined as the ratio of the brake thermal efficiency to indicated thermal efficiency.

$$\eta_{th} = \frac{bp}{ip} \qquad (2.11)$$

2.7.6 Thermal Efficiency

The thermal efficiency can be defined as the ratio of the power produced to the energy in the fuel burned to produce this power. It can be expressed as follows:

$$\eta_{th} = \frac{P}{\dot{m}_f Q_f} \qquad (2.12)$$

Where $\dot{m}_f$ = fuel mass flow rate

Q_f = caloric value of fuel

And $Q_f = \frac{Heat\ Produced\ (kJ)}{Amount\ of\ fuel\ used\ (kg)}$

Where P can be either break power or indicated power, therefore

$$\eta_{bth} = \frac{bp}{\dot{m}_f Q_f}; \qquad (2.13)$$

Fuel Consumption $\dot{m}_f = \frac{v_f}{t_f} \times \rho_f$ (2.14)

v_f = Volume of fuel (m^3)

t_f = Fuel consumption time (sec)

ρ_f = Density of fuel kg/m^3

Let Q_f of gasoline = 46400kJ/kg

ρ_f of gasoline = 737kg/m^3 and

take Torque to be 58Nm

η_{bth} = Break Thermal Efficiency

2.8 Percentage Useful Power Stroke

In four-stroke internal combustion spark ignition engine there is only one useful power stroke and other three strokes idle, the percentage useful power stroke may be calculated as

$$\% \text{ useful power stroke} = \frac{\textit{number of power stroke}}{\textit{number of stroke}}$$

Where number of useful power stroke = 2
Number of stroke = 4

$$= 0.25 \times 100$$
$$= 25\%$$

While:

In six-stroke internal combustion spark ignition engine, there is two useful power stroke and four stroke being idle, the percentage useful may be calculated as % useful power stroke =

$$\frac{\textit{number of power stroke}}{\textit{number of stroke}}$$

Where number of useful power stroke = 2
Number of stroke = 6

$$= \frac{2}{6} \times \frac{100}{1}$$
$$= 0.333 \times 100$$
$$= 33.3\%$$

2.8.1 Percentage Difference of Useful Power Stroke

The percentage difference of the useful power stroke of four-stroke internal combustion spark ignition engine and the six-stroke internal combustion spark ignition engine may be calculated as:

$$\% = \frac{\%\text{ useful stroke of six–stroke} - \%\text{ useful stroke of four stroke}}{\%\text{ useful stroke of six stroke}} \times \frac{100}{1} \qquad (2.15)$$

From the result of equation 3.7 and equation 3.8, the percentage difference can be calculated as:

$$\% = \frac{33.3 - 25}{33.3} \times \frac{100}{1}$$
$$= 24.9\%$$
$$\approx 25\%$$

2.9 Piston Movement of Six-Stroke Engine

For six-stroke engine, the movement of the piston continues at the fourth stage of the four-stroke engine. The piston moves from the Top Dead Centre to Bottom Dead Centre for another expansion which occurs between the top and Bottom Dead Centre at 450° of the camshaft 900° crankshaft.

The last movement of the piston for six-stroke engine is from Bottom Dead Centre to Top Dead Centre for the second exhaust of gas at 540° of the camshaft 1080° crankshaft.

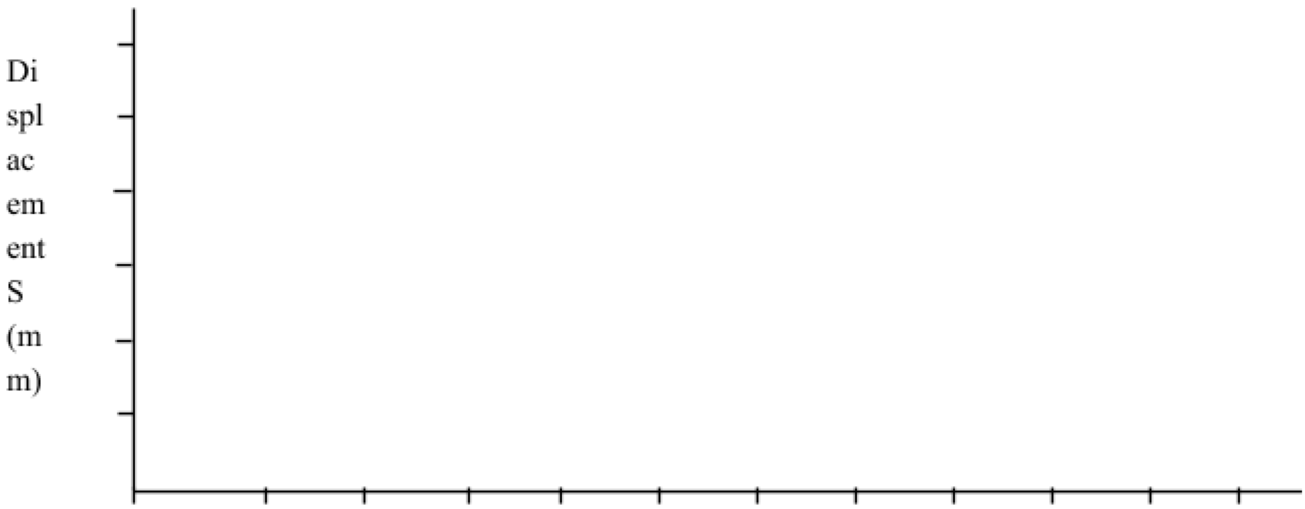

Figure 2.8: Angle of crankshaft of Six- Stroke Engine

III. RESULTS

3.1 Thermal Efficiency

The thermal efficiency can be defined as the ratio of the power produced to the energy in the fuel burned to produce this power. Using equation (2.13) and (2.14) the result of break thermal efficiency for four-stroke engine and six-stroke engine are shown in the table 3.1 and 3.2

Table 3.1: Result of Raw Data for Break Thermal Efficiency of Four-Stroke Engine Calculation

S/No	Assumption	1	2	3	4	5
1	Load W (kg)	0	0	0	0	0
2	Speed N (r.p.m.)	900	1200	1500	1800	2000
3	Volume of fuel (m^3)	0.00001	0.00001	0.00001	0.00001	0.00001
4	Fuel consumption time (sec)	42	34	30	26	24
	N for 4 stroke	0.5	0.5	0.5	0.5	0.5
	Torque = 58Nm	58	58	58	58	58
	caloric value of fuel = 46400kJ/kg	46400	46400	46400	46400	46400
	Density of fuel kg/m^3 = *737kh/m³*	737	737	737	737	737
	Break Power	2.73354	3.64472	4.5559	5.46708	6.074533
	fuel mass flow rate	0.000175	0.000217	0.000246	0.000283	0.000307
	Break Thermal Efficiency %	33.57293	36.23745	39.96777	41.56649	42.63229

Table 3.2: Result of Raw Data for Break Thermal Efficiency of Six-Stroke Engine Calculation

S/No	Assumption	1	2	3	4	5
1	Load W (kg)	0	0	0	0	0
2	Speed N (r.p.m)	900	1200	1500	1800	2000
3	Volume of fuel (m^3)	0.00001	0.00001	0.00001	0.00001	0.00001
4	Fuel consumption time (sec)	42	34	30	26	24
	N for 6 stroke	0.666667	0.666667	0.666667	0.666667	0.666667
	Torque = 58Nm	58	58	58	58	58
	caloric value of fuel = 46400kJ/kg	46400	46400	46400	46400	46400
	Density of fuel kg/m^3 = *737kh/m³*	737	737	737	737	737
	Break Power	3.64472	4.859627	6.074533	7.28944	8.099378
	fuel mass flow rate	0.000175	0.000217	0.000246	0.000283	0.000307
	Break Thermal Efficiency %	44.76391	48.3166	53.29037	55.42198	56.84306

Table 3.3: Six-Stroke and Four-Stroke Data for Break Efficiency

Brake Thermal Efficiency		
Speed N (r.p.m)	4-stroke %	6-stroke %
900	33.57	44.76
1200	36.24	48.32
1500	39.97	53.29
1800	41.57	55.42
2000	42.63	56.84

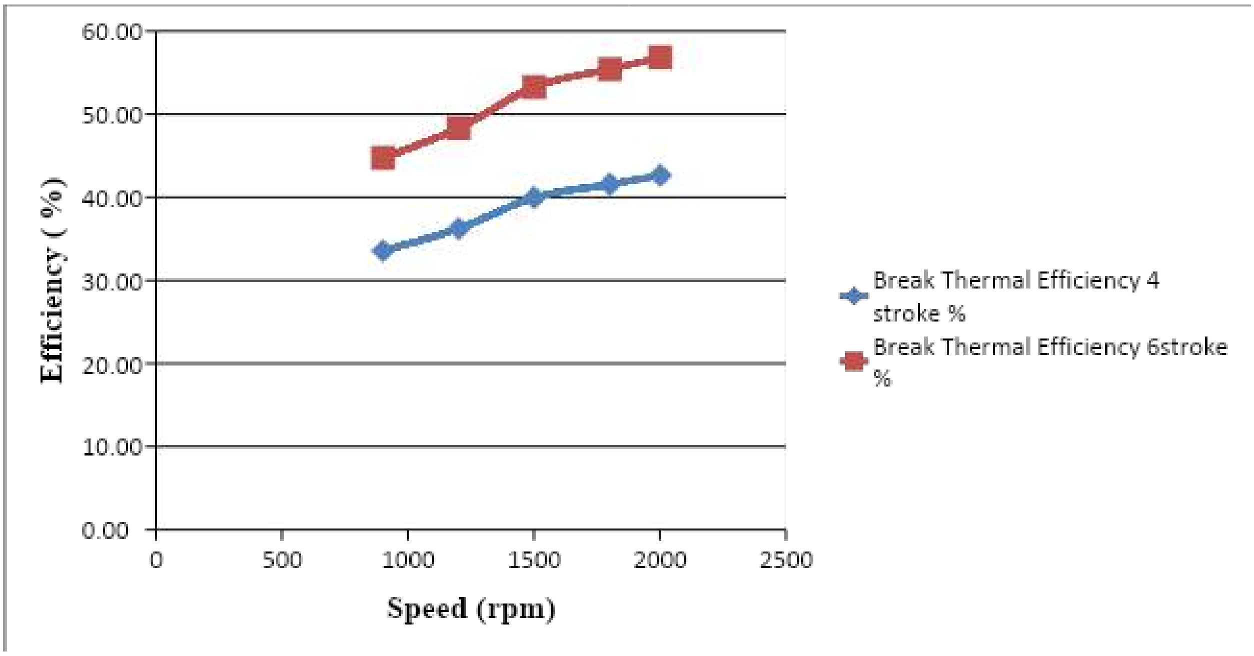

Figure 3.1: Efficiency (%) of Four-Stroke and Six-Stroke Engine

3.2 Pressure – Volume of Six-Stroke Engine

The constant volume cycle (Otto cycle) volume of six-stroke internal combustion spark ignition engine continue from the fourth stage of the normal convention of the four-stroke internal combustion spark ignition engine. The resulting presure -volume diagram for the six-stroke internal combustion spark ignition engine is shown in figure 3.2.

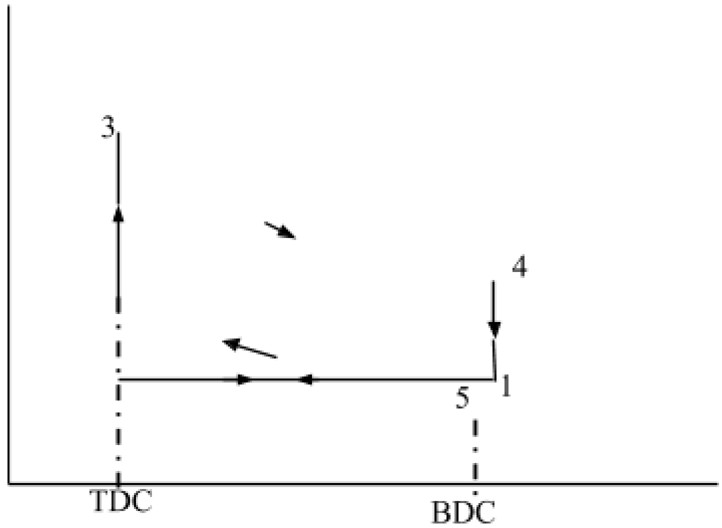

Figure 3.2: P-V diagram of six-stroke engine

3.3 Percentage Differences in Power

The output power percentage differences of four-stroke internal combustion spark ignition engine and the six-stroke internal combustion spark ignition engine using equation are shown in table 3.4 below:

Table 3.4: Six-Stroke and Four-Stroke Output Percentage Differences

S/NO	Power	Percentage Differences (%)
1	Indicated Power	25 %
2	Break Power	25%
3	Useful Power Stroke	25%

3.4 Discussion of Analysis of Internal Combustion Spark Ignition Engine

From equations (2.3) and (2.5), it shows that some of the power produced in the cylinder to drive the piston after combustion are loss to radiation and exhaust of the six-stroke internal combustion spark ignition engine is more than that of four-stroke internal combustion spark ignition engine as the six-stroke requires no cooling system. Also the results from equations (2.8) and (2.9) implies that the power transmitted from the piston to drive the crankshaft is greater than that of four-stroke internal combustion spark ignition engine which gives the six-stroke internal combustion spark ignition engine a greater output (speed) with the same energy (fuel) burned resulting in reduction of fuel burned with the same distance covered of about 25%.

Table 3.4 shows that the six-stroke internal combustion spark ignition engine is of 25% power efficiency than that of four-stroke internal combustion spark ignition engine.

IV. CONCLUSION AND RECOMMENDATION

4.1 Conclusion

The introduction of six-stroke internal combustion spark ignition engine has positive impact in the world economy as it reduces the rate of energy consumption, and reduces the rate of polluting the environment with exhaust flame. The temperature of the engine is lower due to the injection of water which improved the cooling system and increases its overall efficiency. With all the desired qualities and modification, the six-stroke internal combustion spark ignition engine is better than the four-stroke internal combustion spark ignition engine.

4.2 Recommendation

This project design should be recommended for further research base on the material properties that is of thermal resistant alloys as the components will be subjected to thermal stresses that will be developed due to water injection into the superheated cylinder in which the rapid temperature changes can cause fracture or micro cracking at low cost.

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