A Feasibility Study on Waste Heat Recovery in Six Stroke IC Engine

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Abstract - **Considering the climate change and the shortage of nonrenewable energy resources, the interests in waste heat recovery has been growing remarkably, especially during the past decade[1,2]. Waste heat recovery from internal combustion engines (ICE) is one of the opportunities for economizing of energy consumption. In an ICE, a great amount of fuel energy is wasted in the form of heat due to thermal limitations. Roughly one-third of fuel energy is converted to mechanical power and the rest is released to the ambience in the form of heat [3].**

To recover the waste heat, various methods are being adopted. Major modifications of conventional internal combustion engine must be done. In this paper the modification of the conventional four stoke internal combustion engine is illustrated to convert it into six stroke engine.

Keywords - Internal Combustion Engine, Six Stroke, Waste Heat Recovery, Water Injection

I. INTRODUCTION

Internal combustion engines efficiency is less than 40%. Most of the energy generated by burning the fuel in the combustion chamber is lost in water cooling and exhaust [4].

During every cycle in a typical four stroke engine, piston moves up and down twice in the chamber, resulting in four total strokes and one of which is the power stroke that provides the torque to move the vehicle. But in a six stroke engine there are six strokes and out of these, there are two power strokes. The automotive industry may soon be revolutionized by a new six-stroke design which adds a second power stroke, resulting in much more efficiency with less amount of pollution.

In 2006, Bruce Crower managed to develop the first six stroke engine. Using a modified single-cylinder diesel engine Crower converted it to use gasoline, and then machined the necessary parts to create the world's only six-stroke engine. The engine works through harnessing wasted heat energy created by the fuel combustion to add other two-strokes to the engine cycle. After the combustion stage water is injected into the super-heated cylinder and a steam form forcing the piston back down and in turn cools the engine. The result is normal levels of power using much less fuel and no need for an external cooling system [5].

According to Crower's design, during the operation of a six stroke engine, water is injected only after the exhaust stoke is completely finished.

In order to recover the waste heat, a second method has been adopted in this paper. See Figure 1.

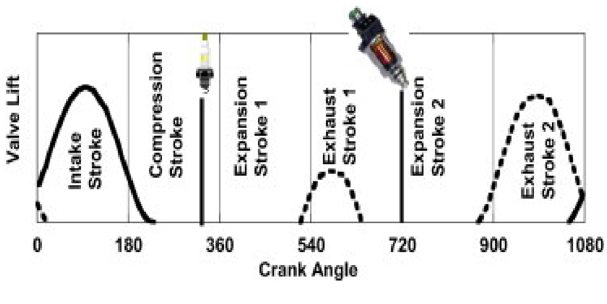

Fig. 1: Six Stroke Engine Cycle [5]

The idea is to trap & recompress the exhaust gas from the fourth piston stoke, followed by a water injection and expansion of the resulting steam/exhaust mixture

II. ENGINE MODIFICATION

To make six-stroke engine from conventional four-stroke engine, a few modifications must be done to specific parts on the conventional engine to be sure that the new engine with six-stroke will run successfully [5]. These modifications are:

A. *Crankshaft to Camshaft Ratio Modification*

In conventional four stroke engine, the gear at crankshaft must rotate 720^o while the camshaft rotates 360^o to complete one cycle. For six-stroke engine, the gear at the crankshaft must rotate 1080^o to rotate the camshaft 360^o and complete one cycle. Hence their corresponding gear ratio is 3:1, i.e. for every three revolution of crankshaft; the camshaft rotates once [5].

Therefore the camshaft design for a six stroke engine should be such that the exhaust valve cam should be 60^o ahead of intake valve cam. Water injection should also be cam operated.

B. *Modification of Sprocket*

For a four stroke engine, ratio of timing chain is 1:2, i.e. 14 teeth in crankshaft and 28 teeth in camshaft.

For a six stroke engine, ratio of timing chain is 1:3, hence 28 teeth in camshaft is converted to 42 teeth sprocket.

C. *Camshaft Modification*

The angle between the two lobes of the camshaft in a four stroke engine is 90^0, i.e. exhaust cam valve is 90^0 ahead of intake valve cam.

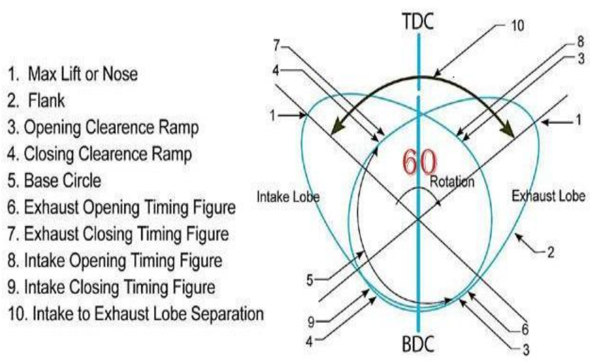

Fig. 2: Modified Camshaft

Whereas in a six stroke engine, the exhaust valve should be 60^0 ahead of intake valve cam. So the angle between the two lobes of the cam shaft in a six stroke engine should be 60^0. See Figure 2.

D. *Temperature Sensor Unit*

A step down transformer is used to convert the 230 Volt AC to 12 Volt AC. The full wave rectifier circuit is used to rectify the AC sin wave.

In this design, heat sensor is used as a sensor unit. The resistance of the heat sensor varies depending upon the temperature and will mostly linear to it. The OP-AMP 324 IC is used as a comparator. The comparator is giving the output voltages depending upon the two input voltage values. One of the input voltage (Reference Voltage) is given to the PIN number 2 (negative pin) of 324 IC from the variable resistor (10 K Ohm). The heat sensor output is given to the OP-AMP PIN number 3 (positive pin).

During the normal condition, the resistance of heat sensor shoots up to Mega ohm range. When heat sensor is heated by means of the heating coil the external temperature rises, the resistance of heat sensor suddenly decreases (below 10 Kilo ohm).

D.1 Normal Condition

In normal condition, the resistance of the heat sensor is high. The voltage applied to the non-inverting terminal (positive) is low when compared to the inverting terminal voltages (negative). At that time, the OP-AMP output is -Vsat, i.e. -12 Volts. The transistor and relay are in “OFF” condition.

D.2 Heating Condition

In normal condition, the resistance of the heat sensor is low due to the intensity of light or fire. The voltage applied to the non-inverting terminal (positive) is high when compared to the inverting terminal voltages (negative). At that time, the OP-AMP output is +Vsat, i.e. -12 Volts. The transistor and relay are in “ON” condition.

E. *Proximity Sensor Unit*

Proximity sensors are the most common and affordable solution for no-touch object detection. The most commonly used proximity sensors are the inductive type which generate an electromagnetic field to sense metal objects passing close to the face [6].

A metal piece is connected to cam or crank side of the timing chain, so that at the end of the fourth stroke metered amount of water is injected via a pump to the cylinder. The proximity sensor comes to “ON” condition when this metal connected to timing chain came near to proximity sensor.

F. Pump

The oil pump in an internal combustion engine circulates engine oil under pressure to the rotating bearings, the sliding pistons and the camshaft of the engine. This lubricates the bearings, allows the use of higher-capacity fluid bearings and also assists in cooling the engine.

When the two sensors i.e. the Temperature sensor unit and the proximity unit are in “ON” condition, the pump works and will inject metered amount of water.

III. WORKING OF THE ENGINE

In a six stroke engine, when the combustion chamber temperature reaches approx. 400 ^{o} F (200^{o} C), just before the fifth stroke fresh water is injected directly into the hot combustion chamber through the engine’s fuel injector pump, which is quickly turned into a superheated steam, which causes the water to expand to 1600 times its volume and forces the piston down for an additional power stroke [7].

The working of the six stroke engine is described as follows:

First Stroke: During the first stroke, the inlet valve opens and air-fuel mixture from carburetor is sucked into the cylinder through the inlet manifold.

Second Stroke: During the second stroke, piston moves from Bottom Dead Center to Top Dead Center, both the inlet valve and exhaust valves are closed and air-fuel mixture is compressed.

Third Stroke (Fuel Power Stroke): During the third stroke, power is obtained from the engine by igniting the air-fuel mixture using a spark plug. Both valves remain closed. Piston moves from Top Dead Center to Bottom Dead Center.

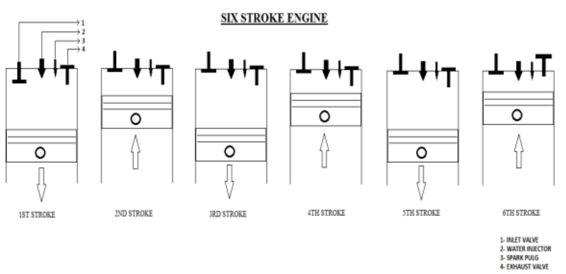

Fig. 2: Working of Six Stroke Engine

Fourth Stroke (Re-Compression Stroke): During the third stroke, piston moves from Bottom Dead Center to Top Dead Center. Both the inlet and the exhaust valves are closed. By the time piston reaches Top Dead Center, water injector injects water which is then converted to steam.

Fifth Stroke (Steam Power Stroke): During the fifth stroke, the steam initiates the second power stroke. Both valves remain closed. Piston moves from Top Dead Center to Bottom Dead Center.

Sixth Stroke (Exhaust Stroke): During the sixth stroke, piston moves from Bottom Dead Center to Top Dead Center. The inlet valve remains closed. The exhaust valve opens and the exhaust gases are released.

IV. ENGINE SPECIFICATIONS & CALCULATION

A. Engine Specifications

Engine type	4-Stroke single cylinder OHC
Displacement	97.2 cc
Maximum power	4.7 KW@5000rpm
Maximum torque	0.77kgm@6000rpm
Bore * Stroke	50 *49.5 mm
Compression Ratio	8.8:1
Idle speed	1400rpm
Ignition	CDI capacitor discharge Ignition
Break drum diameter	0.4 m
Chain Diameter	0.02 m

B. Calculations

Number of Power Stroke per minute	= 5000/2 =2500 rpm =2500 * 60 rph = 150000 rph
Calorific Value of petrol	=44000 KJ/Kg
Specific heat capacity of 1 Kg water, C_w	= 4.18 KJ/Kg
Specific heat capacity of 1 gm water	= 0.0418 KJ/kg
Fuel Consumption	=195g/KW/hr
Water Consumption, W_w	= 5.54 liter/KW/sec
Input Power (water), l_w	= $C_w * W_w$ = 4.18 * 1995 = 8.33 KW
Input Power (Fuel),	= 44000 * 0.195

l_f	= 8.58 KW
Total Input, P_i	= 8.33+8.58 = 16.91
Frictional Power, FP Therefore for six stroke	= 1.6 for 4 stroke = 1.6+1.6/2 = 2.24 KW
% FP	= (2.4/ 16.95) * 100 = 14.15 %

Heat Lost Through Cooling Air/Water

M_w = Mass of cooling water

T_{w1} = temperature of outlet water

T_{w2} = temperature of inlet water

$H_w = M_w C_w (T_{w1} - T_{w2}) / 1000$ KW

= 172.24 * 4.18 (36-29)/ 1000 KW

= 5.039 KW

$\%H_w = H_w / P_i$

= (5.039/16.96)/1000

= 29.71%

Heat Lost Through Exhaust Air

M_a = mass of air

T_{a1} = temperature of outlet air

T_{a2} = temperature of inlet air

$H_a = M_a C_a (T_{a1} - T_{a2}) / 1000$ KW

= 97.51 * 1.005 (70-30) / 1000 KW

= 3.91 KW

$\%H_a = H_a / P_i$

= (3.91/ 16.96) * 100

= 23.05%

Output (Thermal Efficiency) = 100 – (H_a + H_w+ FP)

= 100 – (23.05+29.71+ 14.15)

= 33.09%

Maximum Load

BP = (2.* 3.14 * N (D + d)/2 * 9.81* (w - s)) / 60000

4.4= (2 * 3.14 * 5000 (0.4 + 0.2) / 2* 9.81 * (w - s)) / 60000

w-s = 5.16 Kg (max load)

At No Load

BP = (2 * 3.14 * 5000 (0.4 +0.02) / 2 * 9.81) / 60000

= 1.08 KW

Heat Lost through Cooling water (4 Stroke)

$H_w = M_w C_w (T_{w2} - T_{w1})/1000$

= 75.75*4.18(32-29)/1000

= 0.9499 KW

$\%H_w$= 0.9499/16.91*100

= 27.24%

Heat Lost through Exhaust Air (4 Stroke)

$H_a = M_a C_a (T_{a2} - T_{a1})/1000$

= 6.74*1.005(100-31)/1000

= 0.467 KW

% Ha = 0.467/16.91*100

= 13.53%

V. PERFORMANCE ANALYSIS

- The heat that is evacuated during the cooling of a conventional engine's cylinder head is recovered in the six-stroke engine by the air-heating chamber surrounding the combustion chamber [8].
- After intake, air is compressed in the heating chamber and heated through 720 degrees of crankshaft angle, 360 degrees of which in closed chamber (external combustion) [8].
- The transfer of heat from the very thin walls of the combustion chamber to the air heating chambers lowers the temperature and pressure of the gases on expansion and exhaust (internal combustion) [8].
- Better combustion and expansion of gases that take place over 540 degrees of crankshaft rotation, 360° of which is in closed combustion chamber, and 180° for expansion [8].
- The glowing combustion chamber allows the optimal burning of any fuel and calcinate the residues [8].
- Distribution of the work: two expansions (power strokes) over six strokes, or a third more than that in a four-stroke engine [8].
- Better filling of the cylinder on the intake due to the lower temperature of the cylinder walls and the piston head [8].
- Elimination of the exhaust gases crossing with fresh air on intake. In the six stroke-engines, intake takes

place on the first stroke and exhaust on the fourth stroke [8].

- Large reduction in cooling power. The water pump and fan outputs are reduced. Possibility to suppress the water cooler [8].
- Less inertia due to the lightness of the moving parts [8].

VI. CONCLUSION

In this paper the modification required to convert the four stroke conventional engine to six stroke engine is illustrated. The modifications are the gear ratio between the crankshaft and the camshaft and modification of the cam shaft [5].

An ideal thermodynamics model of the exhaust gas compression, water injection at top centre, and expansion was used to investigate a modification to recover energy from two waste streams that effectively add two strokes to a common four-stroke internal combustion engine. The additional two strokes require substantial modifications to the exhaust valve operation as well as a manner to inject water directly into the combustion chamber [9].

Because this injection water is heated by the engine coolant, this six-stroke concept presented here recovers energy from both the engine coolant and combustion exhaust gas. Thus, this concept recovers energy from two waste heat sources of current engine designs and converts heat normally discarded to useable power and work [9].

By the utilization of the waste heat, the performance of the internal combustion engine is considerably increased [10].

With the utilization of the waste heat of internal combustion engine the world energy demand on the depleting fossil fuel reserves would be reduced [10].

The fuel efficiency would be increased by the development of six stroke engine with the same amount of fuel the internal combustion engine would give more mileage and it would relief growing demand [10].

VII. REFERENCES

[1] Ravikumar, N., Ramakrishna, K., Sitaramaraju, A. V., Thermodynamic Analysis of Heat Recovery Steam Generator in Combined Cycle Power Plant, Thermal Science, 11 (2007), 4, pp. 143- 156

[2] Polyzakis, A. L., et al., Long-Term Optimization Case Studies for Combined Heat and Power System, Thermal Science, 13 (2009), 4, pp. 46-60. (2009), 4, pp. 46-60.

[3] Mojtaba TAHANI, Saeed JAVAN , Mojtaba BIGLARI , "A Comprehensive Study on Waste Heat Recovery from Internal Combustion Engines Using Organic Rankine Cycle".

[4] Pandiyarajan V., Pandian M. C., Malan E., Velraj R. and Seeniraj R.V.,"Experimental Investigation on Heat Recovery from Diesel Engine Exhaust Using Finned Shell and Tube Heat Exchanger and Thermal Storage System",Applied Energy, Vol. 88(2011).

[5] M. M. Gasim, L. G. Chui and K. A. Bin Anwar, “Six Stroke Engine Arrangement”, May 29, 2012

[6] Proximity Sensor Unit, Retrieved April 12 2013, from http://www.autonics.co.in/products/products_2.php?big=01&mid=01/01

[7] Six Stroke Engine, Retrieved April 12 2013, from http://www.slideshare.net/vibhor_shah/six-stroke-engine-11024509

[8] Performance Analysis, Retrieved April 12 2013, from http://sumitshrivastva.blogspot.in/2011/12/six-stroke-engine.html

[9] James C. Conklin, James P. Szybist. "A highly efficient six-stroke internal combustion engine cycle with water injection for in-cylinder exhaust heat recovery", 2010

[10] Vijay Chauhan, "A Review of Research in Mechanical Engineering on Recovery of Waste Heat in Internal Combustion", 2012

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