Design & Analysis of Six Stroke Petrol Engine for Improving Thermal Efficiency

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***Abstract:-* Fossil fuels are being used at alarming rate and thousands of barrels of fuels are being consumed for transport applications every day. Several attempts are being made to improve the efficiency of I.C. Engines since it is very low due to loss of about 65 percent energy in exhaust and cooling of engines. Most important modifications in IC engines for commercial applications in last decade have been the use of electronic control devices for optimum utilization of fuels for power generation. But these devices are not improving engine efficiency significantly, since waste heat is not recovered. The paper is proposing a design where the waste heat is recovered to the extent possible and uses it in further two strokes to complete the cycle. In the proposed system, existing cycle which is completed in four stroke is converted into six strokes by utilizing a portion of waste energy. Use of this wasted energy is further optimized by the use of couple of fluids which have different boiling temperatures and utilizes different amount of waste energy**

Keywords: Six stoke cycle, I.C. engines, waste heat recovery, improved efficiency

I. INTRODUCTION

The overall efficiency of a most efficient Internal combustion engines is less than 30 percent which is due to 65 percent of energy is lost in cooling and exhaust of the engine. Several authors have proposed various methods for improving the efficiency of the I C Engines. In last decade major improvement in IC engine efficiency was due to use of electronic devices for operation of valves, injection and ignition system. Multi point injection of fuel and also multi point ignition have improved combustion efficiency, flame propagation and thermal efficiency in single digit. However these devices are not able to improve thermal efficiency significantly since about 30 % energy lost in cooling and 35 % in exhaust are not recovered.

In the proposed six stroke petrol engine the first four strokes are identical as in the conventional four stroke engine. Besides, the usual suction, compression, power and exhaust strokes, the proposed cycle will have again power & exhaust strokes. Such configuration makes a cycle to complete in six strokes. The second power stroke is formed by utilizing waste energy of cooling of engine and exhaust gases.

Bruce Crower proposed in 2006 [1], the concept of six stroke engine where he uses the energy lost in cooling of engine in the fifth power stroke. He injected water at the end of the fourth stroke of normal I.C. Engine where super-heated cylinder provides the energy in the fifth stroke and finally exhaust stroke to complete the cycle. He could use the waste energy in cooling of cylinder but exhaust energy was not used. This was modified by Prof. Manglik [2] where he injected water before exhaust of the existing four stroke engine. The extra power now produced is by the use of energy of cooling of engine and also the energy going out in the exhaust. However, a small portion of this energy is used in second compression stroke of the engine. Donghong et al [3] did the analysis based on the organic Rankine cycle and presented their result. They, themselves states such cycle is not efficient due to inherent low efficiency of the organic cycle efficiency

In another concept air is used as heat absorbing fluid to use waste energy . In Velozeta six stroke engine [4] air was injected instead of water or methanol in the 5th stroke to produce power. Major difference between Crower’s six stroke engine and Velozeta’s six stroke engine, is working fluid for Rankine cycle in the remaining two strokes. These system have first four identical stokes as in a conventional four stroke engine. But here the difference is that in the fifth stroke, air is injected and heated to provide work in the fifth stroke . Subsequently, a mixture of this air and remaining exhaust gases are pushed out through the exhaust valve in the sixth stroke.

Conklina, [5] suggested water injection in the fifth stroke after partial exhaust of product of combustion. Water get converted into steam due to super heated cylinder walls and high temperature of the exhaust products. Second power stroke is obtained during expansion of steam in fifth stroke. Waste heat from engine cooling and exhaust gas is used to get extra power stroke. It needs to optimize operation of exhaust valve to obtain highest mean effective pressure. Similar approach is also presented by Prakash et al [6] in their paper recently. Hayasaki et.al.[7] proposed six stroke diesel engine .It has two power stroke. Second power stroke is obtained by combustion of low octane number fuel like methanol. Such engine produce less pollutions and formation of NOx are also reduced considerably. But improvement in efficiency of engine was not significant.

In present paper, authors have selected a four stroke water cooled petrol engine generating 6 kW output power for analysis and to work as six stroke engine. Paper provides thermodynamic analysis of the engine and obtained various parameters at all the critical locations. It

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recovers waste heat of engine cooling and also from the exhaust gases within the constraint of engine design. Waste heat is recovered by using water and methanol as liquids. Recovered heat is used in last two stokes which works as Rankine cycle. Since water and methanol have different boiling temperature they are recovering different amount of energy from cooling of engine and exhaust gases. Paper estimates the amount of waste heat recovered separately for both these fluids. Furthermore improvement of thermodynamic efficiency of the engine is also compared while utilizing the performance of two fluids in the engine.

II. RECOVERY OF WASTE HEAT

Waste heat in cooling engine [8] and also exhaust gases are recovered to the extent possible by using methanol and water separately as working liquid. These fluids have different boiling point and latent heat of evaporation and therefore will absorb different amount of heat. The configuration designed for both the fluids are identical while recovering heat and same constrains of engine design are also imposed on both the liquid.

A. *Heat recovery in cooling of engine*

Heat is recovered in cooling of engine by circulating water and methanol separately. The fluid is circulated in the cooling jacket of four strokes I C Engine. Liquid is pre heated by gaining heat from the hot walls of engine cylinder. Though the cylinder walls of engines are maintained around 200^0c but liquid temperature needs to be maintained around 80^0c since thermostat will switch of ignition, if fluid temperature rises beyond this temperature. Therefore ,these liquid will absorb heat up to 80^0c while cooling of engine takes place. No separate cooling arrangement needs to be incorporated for such engine.

Heat recovery from engine jacket will take place around the atmospheric pressure. Therefore water will gain heat from room temperature to 80^0c only. methanol will absorb sufficiently more amount of heat since its boiling temperature at one atmospheric pressure is 65^0c. It will absorb the latent heat of vaporization at 65^0c and then super heated up to 80^0c in cooling jacket

HEAT RECOVERY FROM EXHAUST GASES.

Heat is recovered from exhaust gases after it exists from engine. Thermal energy is recovered by the heated fluid from the cooling jacket of the I.C. engine. A counter flow heat exchanger is incorporated between the exhaust gases and hot fluid coming out of engine jacket. Though the thermodynamic analysis of engine shows much higher temperature of the gases after four strokes are completed, yet, authors have considered the exhaust temperature of 200^0c only. It is the temperature which is normally available in existing engines. The preheated liquid is circulated around the counter flow heat exchanger from one end and exhaust gases flow through from other end. Such system of arrangements provides maximum out let temperature of the liquid.

III. THERMODYNAMIC ANALYSIS OF EXISTING CYCLE

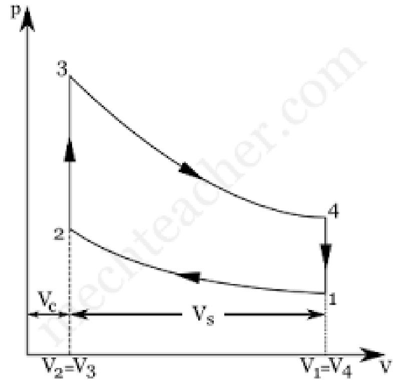
Analysis is based on the two fluids used in six stroke engine. A 110 cc four stroke engine is considered for the analysis. The analysis includes the amount of energy recovered from the waste heat in cooling engine and also from exhaust gases and that energy is used in the Rankine cycle to generate extra power.

Specification of Engine Used

4-stroke, single cylinder, Water cooled engine

Swept volume Vs = 110 cc

Compression ratio = 9.5:1



The compression ratio

9.5= (Vs+Vc)/ Vs = 9.5 (1)

On substitution of stroke volume Vs, it gives

Vc = 12.84cc =V2=V3 (2)

For process 1-2: Adiabatic Process

PV^{γ} = C, where C is constant

The intake of fuel & air mixture is around the atmospheric pressure which is equal to 1 bar

Therefore, P2 = (9.5)1.4*P1

= 23.37 bar (3)

Again, the inlet conditions are near to atmospheric temperature which is considered for analysis at 300k = T1

T2 =T1*$(P2/P1)^{(\gamma-1/\gamma)}$ (4)

Thus we get T2 = 738k

Case-1: Ideal gas analysis

P1*V1= mRT1 (5)

1*105 * 121.98 = 1003 * m * 287 * 300

Thus we get m = 0.1416 gm (6)

m = mass of air + fuel

Case-2: Assuming normal running speed of a scooter at 50km/hr

Rim Diameter = 10 inches

Distance covered by wheel in 1 revolution = 2*π*r = 10* π inches = 31.4 inches = 0.00079756 km

It gives 63,291.13 rev / hr. (7)

Thus, total number of cycles in

50 km= 63296.13/2 = 31654.565 (8)

These engines provide on an average of 50 km/ liter

Therefore, fuel consumed is 1 liter to provide 31654.56 cycles

Usage of fuel in 1 cycle = 0.0000316 liter = 0.0316cc (9)

Since the fuel density is 0.719 kg/liter,

The fuel used is 0.0227gm

Considering 15:1 A: F ratio

So air used=0.0227*15 =0.3405 gm (10)

Authors have assumed, on an average 2gm /s fuel injection into the system

Process 2-3:

V2=V3 Process 2-3 Isochoric process

$P3/P2= T3/T2$ (11)

For Otto cycle, to produce optimum power, the compression ratio is given by

$r = (T3/T2)^{1/2(\gamma-1)}$

$9.5 = (T3/300)^{1/2(0.4)}$ (12)

T3 =1816.776 K

P3=1816.77*23.378/738= 57.55 bar (13)

Thus P3 = 57.55 bar

Process 3-4

$P3V3^r=P4V4^r$ (14)

Thus P4 = P3*rɤ

It gives,

P4=2.46 BAR

$T4/T3=(V3/V4)^{r-1}$, (15)

givesT4= 738.26 K

IV. THE ANALYSIS OF EXISTING OTTO ENGINE PROVIDES FOLLOWING DATA,

Pressure	Volume	Temperature
P1 =1 bar	V1 = 12.84 cc	T1 = 300 K
P2 = 23.778 bar	V2 = 121.98 cc	T2 = 738K
P3 = 57.55 bar	V3 = 12.84 cc	T3 = 1816.7K
P4 = 2.46 bar	V4 = 121.98 cc	T4 = 738.26K

Table 1 Analysis of Otto cycle

The energy available in the exhaust gases at the temperature of 365^0C is used further to heat the fluid to convert it into vapors. These vapors will be used in Rankine cycle to produce power in the fifth stroke of the engine.

V. NEW THERMODYNAMIC CYCLE

First four strokes of thermodynamic cycle [9] are identical as four stroke gasoline engine. Even the fourth stroke is complete exhaust stroke where all the products are removed from the cylinder.

A. *Fifth stroke (2nd Power stroke)*

The steam or vapors produced by utilizing the waste heat energy of cooling the engine and also exhaust is injected directly into the cylinder. It works like a Rankine cycle to produce power where piston moves from TDC to BDC. Thus the second power stroke produces power from the waste energy where superheated steam/ vapors expand to provide thrust to the piston.

B. *Sixth Stroke (2nd Exhaust stroke)*

The work carried out by steam/ vapors are exhausted from cylinder as the piston moves from BDC to TDC. The figure no.1 shows all the six strokes which will be encountered in this engine in a cycle.

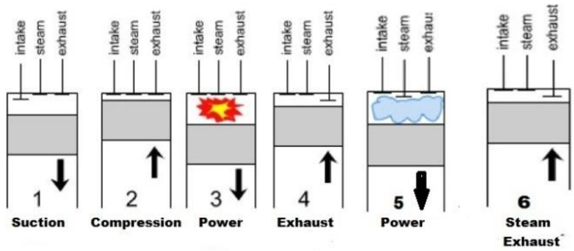


Fig.1 Sixth Stroke cycles

VI. THERMAL ENERGY RECOVERED FROM COOLING OF ENGINE.

Thermal energy lost in cooling of engine is recovered by using water or methanol. These fluids are preheated in cooling of engine before recovery of exhaust heat. Thermal analysis is carried out for both these fluids. The configurations used to recover these energies are already described in paragraph number2 of this paper.

A. *Heat recovery by water*

Water is circulated around the cylinder to recover the waste heat which is lost in cooling of Engine. The engine walls are normally maintained at 2000C while temperature of the water should not exceed 800c. Since lot of development in materials has taken place in last one decade these temperatures need to be further optimized for more heat recovery during engine cooling. It is presumed water injection rate will be about 2gm/seconds

$Qc = m\ cpw\ \Delta T$

$= 2/1000(4.2) *(80-30)$ (16)

[Where specific heat C pw = 4.2 kJ /Kg-K]

= 0.42 KW

The selected engine is generating output power of 6kw and loosing around 30 percent energy in cooling of the engine. Thus energy lost by engine in cooling is 4.5 KW and recovered is 0.42 KW only.

Thus, the percentage energy recovered during cooling by using water is 9.3 percent only.

B. *Heat recocery by methanol*

Methanol is another fluid selected to recover heat from cooling of the engine. It is selected due to low boiling point of 65^0c and widely available fluid. Methanol will absorb sensible heat to raise its temperature up to boiling point and then latent heat & super heat to maintain cooling fluid temperature of 80^0C. Therefore, it has the capability to absorb higher amount of heat while cooling of the engine.

Pre heating of Methanol

$Q = mc\ \Delta T + LH + SH$ (17)

$= [(2/1000) *2.583*(65-30)] + [2/1000) *1100] + 2/1000 (1.92) (80-65)$

All the heat lost by engine during cooling is possible to recover by methanol. It is much higher than using water.

VII. RECOVERY OF WASTE HEAT FROM EXHAUST GASES

Pre heated liquid in engine cooling will be converted into super-heated vapors by absorbing heat from exhaust gases. A counter flow heat exchanger [10] between the preheated fluid and the exhaust gases is proposed to generate superheated vapors. The thermodynamics analysis of Otto cycle predicts the exhaust gas temperature of 365^{0}c. There is sudden drop in pressure as soon as exhaust valve opens and expansion of gases takes place. Since the thermodynamic analysis is ideal and other heat losses occurs during flow of gases, heat exchanger, silencer etc, it is practically found that that safe available temperature of exhaust gases is 200^{0}c [11]. The vapor so generated from counter flow heat exchanger will be available at 195^{0}c & 8 bar pressure.

A. Super-heated steam

The pre heated water will be converted into super-heated steam by exchanging heat from exhaust gases and pressure will be 8 bar. Since the amount of steam injected at every cycle is very small and heat capacity of exhaust gasses is high, the water will acquire the maximum temperature at these conditions.

Heat gain by heated water

Qw=2/1000[4.18(170-80)+2046.5+2.1(195-170)] = 4.9504KW (19)

(Specific heat of steam Cp= 2.1 KJ/Kg-K)

The energy lost in exhaust is about 35 % and therefore exhaust gases are having amount 5 kW energy. Thus most of the energy is recovered from the exhaust gasses by injecting preheated water.

6.2 Thermodynamics analysis of Rankine cycle

Super-heated steam shall now be used in the engine to work as Rankine cycle. In ideal cycle steam will expand adiabatically to produce power up to atmospheric pressure.

The entropy of inlet super-heated steam at inlet to the engine S1 = Sg + Cp ln (T2/T1) (20)

= 6.6596 + 0.124 = 6.7836

Assuming, adiabatic expansion of steam.

Entropy of steam at inlet and out let of cylinder will be same.

Now S1 = S2 thus S2 = Sf + x*hfg (21)

Thus 6.7836 = 1.3022 + x*6.0571

Thus x = 0.904

(Dryness fraction of steam at outlet of the engine)

Enthalpy of outgoing steam

h2 = hg2 + x*hfg2 (22)

= 417.5 + (0.904) (2257.9)

= 2458.64 KJ/Kg

Enthalpy of steam entering into Rankine cycle

h1 = 2767.5 kJ/kg

Thus net work done = h1 – h2 = 308.85 kJ/kg (23)

Power generated= 308.85*2/1000 =0.617 kW

This is extra power generated by addition of water from same engine without extra fuel added into the engine. It will improve the cycle efficiency by 11% approximately.

B. Super-heated methanol vapors

The super heat methanol vapor will be further heated by the exhaust of the engine as discussed in previous paragraph. It will be superheated to around 7.46 bar (data available) pressure and 195^{0}c as is the case in steam. The heat gains by methanol vapors

$Q = mc\,\Delta T + SH + LH$ (24)

= [(2/1000) *2.533*(150-80)] + [850*2/1000] + [(2/1000) *1.92*(190-150)] = 3.5902 KW

Thus, energy gain from 5KW of exhaust energy is 72% by methanol.

Total energy available by methanol

3.5902 + 2.434 = 6.024 kW. (25)

Authors were not able to get all the entropy data for methanol at various pressure and temperature condition in short time. Therefore, considering overall efficiency of Rankine cycle as 20 % the extra power produce by using methanol will be approximately 1.2 kW.

The improvement in the efficiency of petrol engine when methanol is used as absorbing heat will be 20%.

Following is the summery of energy collected and used for development of power for these two fluids

Energy	Water	Methanol
Waste energy available	9.8 KW	9.8 KW
Energy collected from cooling of engine	0.42 KW	2.434 KW
Energy Collected from exhaust gases	4.95 KW	3.5902 KW
Percent of total available energy collected	52.75%	61.5 %

Table2. Comparison of energy gain for water and methanol

Modifications

Otto cycle engine will need several modifications to use as combined petrol and Rankine engine. The performance of engine will also improve significantly if new materials are used in petrol engine so that fluid working temperature increases beyond 100^{0}c. This will facilitate the use of water beyond its boiling point to improve collection of energy during cooling of engine.

Some of the modifications [12] needed are discussed in the next paragraph.

C. Valve timing diagram for six stroke engine

There will be changes in the valve timing diagram in comparison to available four stroke engine. The number of valves needed to complete one cycle will be three instead of two used in conventional engine. One extra valve will be needed for intake of vapors whereas same exhaust valve can be used. The cycle will now be completed in three revolution of the crank instead of two revolutions. These processes need to be further optimized to obtain maximum power from the waste energy.

D. Gear ratio between crank shaft tocam shaft

The camshaft for six stroke engines need to be designed to rotate by one revolution while the crank shaft turns by three revolutions instead of two revolutions in the convention engine. Therefore, for six-stroke engine, the crankshaft must rotate 1080^0 to rotate the camshaft by 360^0 to complete one cycle. Hence their corresponding gear ratio is 3:1 instead of 2:1 for the conventional Otto engines. The new gear at the crank shaft shall have 18 teeth and the cam shaft gear 54 teeth to provide required gear ratio. The helical gear is suggested since it is suitable for high-speed, high power application and works satisfactorily at high rotational speed for long time.

E. Design of new Cam & Cam Shaft

The existing camshaft has two lobes, one for the intake valve and one for the exhaust valve. Each lobe is in contact with a flat follower pushrod which moves a rocker arm inside of the head. The other side of the rocker arms pushes the valve inside of the cylinder. A valve spring returns the valve back to the original position. The six stroke engine will have three lobes on the cam shaft to operate three valves at the require timings. The amount of lift and operating timings need to be optimized for producing maximum power in six stroke engine.

F. Spark plug timing

The timing of spark for six stroke engine needs to be optimized. There will be the change in the timing of the spark compared to that of conventional four stroke engine. The spark is initiated near to end of second stroke and it remains ideal for next four strokes. In six stroke engine the spark will remain ideal for next six strokes. The timing will be further optimized to re-gain maximum amount of heat from the waste energy

VIII. FUTURE SIX STROKE ENGINES

Most of the work carried out on six stroke engines is based on the modification of the existing engine. These designs are not optimum for six stroke engines. The heat recovery from cooling of the engine is limited due to fluid temperature is maintained at 80^0C where as wall temperature of engine is 200^0 c. The reduction in temperature difference will improve energy collection proportionately. Similarly the thermodynamic analysis shows the temperature of gases after expansion is 365^0c where as exhaust gas temperature is 200^0c. Such gap also needs to be reduced. Controlling the opening and closing of suction and exhaust valve will also improve the efficiency of engine significantly.

CONCLUSIONS

Water is able to collect 4.95kW & methanol 3.59 kW from the total energy of 5 kW from the exhaust gases. It is about 99% for water and 72 % for methanol. However, the energy collected by circulating water in cooling engine is only 11 % in comparison to methanol which is 72 % of total energy of 4.5 kW. The overall energy collected from waste heat is 52.75 % for water and 61.5 % for methanol.

The overall improvement in the efficiency of six stroke engine will be 20 % while using methanol and 11 % only for water. There will be significant improvement in the efficiency of six stroke engine if fluid temperature is allowed to be raised beyond 100^0c while cooling of the engine. Even in present design where engine wall temperature are maintained 200^0c, the jacket cooling design needs to be modified to allow fluid temperature around 110^0c. Further improvement in engine efficiency is possible by modification in the materials of engine so that wall temperature are allowed beyond 200^0c .

REFERENCES

[1] M. M. GasimL. G. Chuiand K. A. Bin Anwar , "Six stroke engine arrangement", Military Technical CollegeKobry El-Kobbah,Cairo, Egypt. Proceedings of fifteenth international conference on Applied mechanics and Mechanical engineering, May, 2012

[2] V. K. Manglik, "Development of High Efficiency Engine by combining I. C. Engine and E C Engine" ,Published in IOSR Journal of mechanical & Civil Engineering Volume 10, e-ISSN:2278-1684 , p-ISSN: 2320-334X . Jan 2014.

[3] Donghong Wei , Xuesheng Lu, Zhen Lu, Jianming Gu, Dynamic, " modeling and simulation of an Organic Rankine Cycle (ORC) system for waste heat recovery", Available online at www.sciencedirect.com, Applied Thermal Engineering 28 (2008) 1216–1224

[4] Prashant Haridas Pande, Mechanical Engineering Amravati University, Maharashtra, "Velozeta Six Stroke Engine", International Journal of Research in Advent Technology (E-ISSN: 2321-9637) Special Issue 1st International Conference on Advent Trends in Engineering, Science and Technology "ICATEST 2015", 08 March 2015

[5] Conklina J. C. and Szybist J. P., "A Highly Efficient Six-Stroke Internal Combustion Engine Cycle with Water Injection for In-Cylinder Exhaust Heat Recovery", Energy, Volume 35, Issue 4, pp. 1658-1664 (2010).

[6] Vikash, Prakash Kumar Sen, Gopal Sahu, Ritesh Sharma, Shailendra Bohidar, "A review on six stroke engine", International journal of research in aeronautical and mechanical engineering ISSN (online): 2321-3051 Vol.3 Issue 11,November2015Pgs: 8-13

[7] Hayasaki, T., Okamoto, Y., Amagai, K., and Arai, M., "A Six-Stroke DI Diesel Engine Under Dual Fuel Operation," SAE Technical Paper 1999-01-1500, 1999, doi: 10.4271/1999-01-1500.

[8] Kiran P , " A feasibility study on waste heat recovery in six stroke I.C. Engine", International Journal on Mechanical Engineering and Robotics (IJMER), Volume-1, Issue-1, 2013

[9] Dr. Keith McMullan, "Thermodynamic Analysis, Testing and Validation of a 6 Stroke Engine", 2011, Institute of Technology, USA,

[10] 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).

[11] James C. Conklin, James P. Szybist, "A highly efficient six-stroke internal combustion engine cycle with water injection for in-cylinder Exhaust heat recovery". Energy, The International Journal, Volume 35, Issue 4, pp. 1658-1664 (2010).

[12] M. M. Gasim, L. G. Chui and K. A. Bin Anwar, "Six stroke engine arrangement ", Proceedings of the 15 MP 175th Int. AMME Conference, 29-31 May, 2012