Incorporating Additional Power Cycle In Conventional Four Stroke SI Engine To Develop Six Stroke Engine

Shreyas Abhyankar ,Agnel Thomas, Leslie Fernandes, Rohan John, Kamlesh Sasane and Aqleem Siddiqui

Mechanical Engineering Department
Fr. C. Rodrigues Institute of Technology
Vashi, Navi Mumbai, India
Kamleshsasane75@gmail.com

Abstract— The challenges faced by engine technology today are the urgent need to increase engine thermal efficiency and decrease fuel consumption. The concept of six stroke engine involves adding two strokes to the Otto cycle to increase fuel efficiency. The current setup involves a four-stroke Otto cycle followed by a two-stroke heat recovery steam cycle. A water injection system using a plunger pump is used create atomized steam so as to produce an additional power stroke. The six stroke engine is an advancement over the usual four stroke engine with lesser emission of air pollutants being its major advantage. The comparison of six-stroke engine with a four-stroke engine is aimed to establish the relative parameters of the six stroke engine majorly in terms of brake power, fuel economy and pollutant emission in percentage. Analysis and simulation of the engine performance is obtained by using ANSYS© and MATLAB© software for four stroke engine and mathematical formation is proposed for thermal efficiency of six stroke engine.

Keywords—engine; six-stroke; four-stroke; heat recovery; injection; pollution; emission; analysis; simulation.

1. Introduction

It is imperative for the automotive industry to reduce emission levels as it contributes a large amount of air pollution globally. Hence it is desired to design and develop a six stroke internal combustion engine so as to improve efficiency and decrease specific fuel consumption. This concept involves adding two strokes to the Otto cycle to increase fuel efficiency. It can be understood as a four-stroke Otto cycle followed by a two-stroke heat recovery steam cycle. In the four-stroke internal combustion engine used today, there involves four separate strokes namely Suction, Compression, Combustion and Exhaust. Here, a stroke refers to the full travel of the piston along the cylinder, in either direction. The prototype is designed to provide reciprocating piston combustion engine constructed in a manner whereby the engine will be of the six stroke type and appreciable portions of the residue of the heat of combustion will be maintained within the combustion chamber of the engine at the end of the exhaust stroke (fourth stroke) thereof and finely atomized water may be injected into the combustion chamber at the end of the exhaust stroke for instant flashing into steam to thereby again increase the pressures within the combustion chamber for driving the piston of the engine through a second power stroke. This is followed by the final stroke which is exhaust of steam residue.

2. Previous Studies On Six Stroke Engine

Many researchers have performed various tests and attempted to successfully fabricate their respective designs into working models, a brief of which is further discussed in this section.

Robert C. Tibbs[1] suggested a reciprocating piston engine of the type including a piston reciprocal in a cylinder toward and away from an expansion chamber at one end of the cylinder and also provided with intake and exhaust valves which could be opened or closed in timed sequence with reciprocation of the piston. The valves are closed during the compression and power strokes of the piston and the exhaust valve is opened during the third stroke of the piston toward the expansion chamber. During the fourth stroke of the piston, a readily vaporizable liquid is injected into the expansion chamber under pressure for flashing into a vapor upon being heated by the residue heat of combustion

James L. Pace[2] suggested a six cycle combustion engine which utilizes the 5th and 6th cycle for drawing in and expelling preheated air to further warm the combustion chamber. The flow of the coolant water has been reversed so that heat absorbed in the engine head will flow to the cylinder walls and give a warming trend thereto.

David M. Prater[3] concluded that during the fuel exhaust stroke, the products of combustion are directed through a heat regenerator located in a vapor heating chamber adjacent the combustion chamber. Upon completion of the exhaust stroke, fluid is injected directly into the heat regenerator and heated. In this manner, the present invention provides an engine which efficiently recovers a significant portion of the heat normally rejected by an internal combustion engine and converts this otherwise wasted heat into useful work.

Satnarine Singh[4] has mentioned use of a computer controlled, internal combustion engine designed to operate on a Six-Stroke cycle, wherein water is injected into each of the one or more cylinders during a predetermined portion of the six-stroke cycle depending upon the energy content within the cylinder subsequent to ignition of the conventional air-fuel mixture. The residual heat from the ignited air-fuel mixture serves to convert the injected water into Steam on a controlled basis, thereby creating an auxiliary power stroke.

Szybist et al.[5] provides information on engines which operate on an improved six-stroke cycle having water injection directly into the combustion chamber which offers improved operating efficiency of the engines. The engine includes a fourth stroke cycle in which combustion gases of the engine are partially vented proximate to a bottom-dead-center position of the fourth stroke cycle, and water is injected proximate a top-dead-center position of the fourth stroke cycle.

Kazou Ooyama[6] establishes that in conventional four-stroke engines, expansion ratio of combusted gas is determined by the compression ratio. Since the compressed air is then combusted in the temperature-raised condition and then converted into driving force via an expansion that occurred during an explosion or expansion stroke by an extent corresponding to the compression ratio, the exhaust valve opens itself while the internal pressure still remains higher than the external pressure, thus causing energy of exhaust gas to be released into atmosphere.

Keshav Gupta et al.[7] studied and modified a four-stroke cycle gasoline engine and converted it into a six-stroke cycle engine and also conducted an experimental study using gasoline and acetylene as fuel with water injection at the end of the recompression stroke. Acetylene has been used as an alternative fuel along with gasoline and performance of the six-stroke spark ignition (SI) engine with these two fuels has been studied separately and compared. Brake power and thermal efficiency are found to be 5.18 and 1.55% higher with acetylene as compared to gasoline in the six-stroke engine. The thermal efficiency is found to be 45% higher with acetylene in the six-stroke engine as compared to four stroke SI engine

Massimo Borghi et al.[8] has established the main advantages of the two-stroke engine and may be summarized as lower weight (35%), higher brake efficiency (6%, on average), less heat rejected (18%), lower thermal and mechanical loads within the cylinder (40%).

Emre Arabaci et al.[9] investigated the effects of water injection quantity and injection timing were investigated on engine performance and exhaust emissions in a six-stroke engine. For this purpose, a single cylinder, four-stroke gasoline engine was converted to six-stroke engine modifying the existing cam mechanism and adapting the water injection system.

Bobin Cherian Jos et al.[10] have obtained significant graphical results using simulation and analysis software MATLAB© to create an ideal thermodynamic model. Also, they have used the principle of water to steam conversion in this virtual set-up. The values of mean effective pressure, power and thermal efficiency of a six stroke engine has been estimated using this model. From these parameters obtained it has been concluded that waste heat recovery is an effective method to improve efficiency of internal combustion engines.

to the overall power output, thus increasing the amount of power/torque generated by up to a possible 35%, in essence, the engine results in having two pistons operating and producing power within each cylinder. The absence of valves, springs, retainers and guides, mean that the engines bottom end has been freed up from laboring and is allowed to spin up producing more power. The additional torque and power further generated by the top piston/crank of the cylinder head is then channeled via the connecting drive chain to the bottom crank. The net result of the engine is tractor type pulling torque never before realized from a four stroke internal engine, the sort of steady locomotive type performance gained can only be likened to steam locomotives or diesel engines. The net results are, increase in power/torque by 35%, simpler and less expensive manufacturing and tooling, reduction of cylinder head reciprocating parts, lowering maintenance costs due to less wearing parts (cylinder head), longer service intervals possible due to lower operating temperatures recorded, increased economy due to the ability to operate and produce full operating power of much higher air to fuel ratios, reduction of exhaust emissions due to less fuel being consumed and the prospect of meeting EURO-4 emissions standards, doing away with the catalytic converter, incorporates one piece engine block and head casting, saving manufacturing costs.

3. Determination Of Engine Parameters

The following equations have been used for developing MATLAB© programming for simulation of a four stroke engine which is required for comparison purpose. For process, we use the (1) to obtain C_v, which is the specific heat at constant volume, R is the gas constant equal to 0.287 and γ is the ideal gas specific heat ratio equal to 1.3.

$$C_v = R/(\gamma - 1) \qquad (1)$$

To obtain value of temperature at inlet T_1, (2) is used where T_i is the initial temperature, T_e is the exhaust temperature, P_i is the initial pressure, P_e is the exhaust pressure and f is the residual fraction. Residual Fraction is an important parameter to get good performance with high efficiency and low emissions.

$$T_1 = (1-f)T_i + f[1-(1-P_i/P_e)\gamma]T_e \qquad (2)$$

To obtain values of pressure and temperature at different states, we use (3) to (10), where P_1 is inlet pressure and P_2 is pressure at state 2, T_1 is inlet temperature and T_2 is temperature at state 2, T_3 is temperature at state 3 and q_{in} is heat given to the system, P_3 is pressure at state 3, P_4 is pressure at state 4, T_4 is temperature at state 4, P_5 and T_5 are pressure and temperature at blowdown respectively.

$$P_2 = P_1 \times r^{\gamma} \qquad (3)$$

$$T_2 = T_1 \times r^{\gamma-1} \qquad (4)$$

$$T_3 = T_2 + q_{in}(1-f)/C_v \qquad (5)$$

$$P_3 = P_2 \times (T_3/T_2) \qquad (6)$$

$$P_4 = P_3 \times (1/r)^{\gamma} \qquad (7)$$

$$T_4 = T_3 \times (1/r)^{\gamma-1} \qquad (8)$$

$$P_5 = P_e \qquad (9)$$

$$T_5 = T_e \qquad (10)$$

For determining f_{new}, which is the new residual fraction, equation (11) has been used.

$$f_{new} = (1/r) \times (P_e/P_4)^{1/r} \quad (11)$$

For finding output parameters of four stroke internal combustion engine, (12) to (17) has been used. Here, η is ideal thermal efficiency, I_{mep} is indicated mean effective pressure, P_{mep} is brake power, η_{net} is net thermal efficiency, I_{mepnet} is net indicated mean effective pressure and η_{vol}, volumetric efficiency.

$$\eta = 1 - 1/r^{\gamma-1} \quad (12)$$

$$I_{mep} = P_1(q_{in} \times (1-f)/RT_1/(1 - (1/r))\eta \quad (13)$$

$$P_{mep} = P_e - P_i \quad (14)$$

$$\eta_{net} = \eta(1 - (P_{mep}/I_{mep})) \quad (15)$$

$$I_{mepnet} = (I_{mep} - P_{mep})/100 \quad (16)$$

$$\eta_{vol} = 1 - (P_e/P_i - 1)/\gamma(r-1) \quad (17)$$

To analyze conventional single cylinder four stroke engine in MATLAB©, (1) to (17) are used. Table 2.1 gives the summary of the results from the simulations performed on MATLAB© software

.

Parameter	**Value**
Ideal Thermal Efficiency	0.565
Net Thermal Efficiency	0.526
Exhaust Temperature (Kelvin)	1368.1
Volumetric Efficiency	0.9
Residual Fraction	0.065
Net IMEP (Bar)	6.86
Brake Power (W)	1574.732

Table.1. MATLAB© simulation results

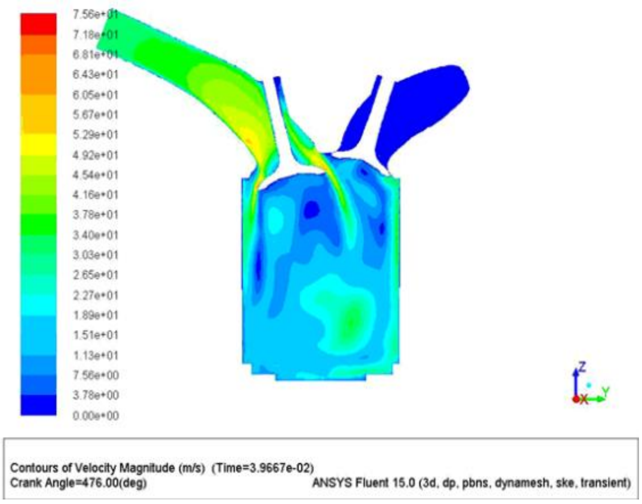

Fig. 3. Engine Head Simulation

Cold flow simulation was carried out by adding input parameters like engine speed, crank radius, connecting rod length and minimum lift. Simulation analysis generated valve lift profile versus crank different flow pattern and velocity contours during a four stroke cycle is shown in Fig. 3.

4. Six Stroke Ideal Cycle

The modified Otto cycle is depicted in Fig. 4.

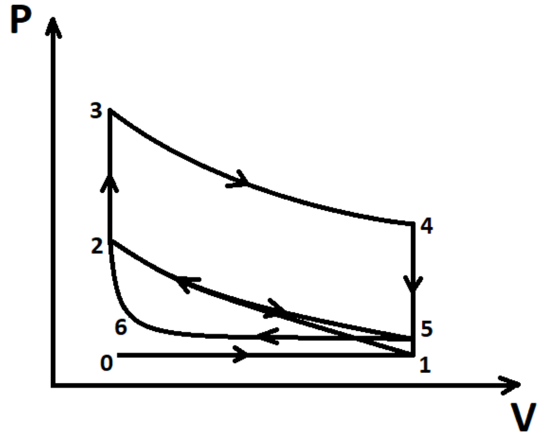

Fig. 4. Modified Otto Cycle

Process 1-2	Isentropic Compression
Process 2-3	Heat Addition
Process 3-4	Isentropic Expansion
Process 4-5	Heat Rejection
Process 2-5	Isentropic Expansion
Process 5-1	Steam Rejection

Work done in first four stroke Otto cycle is given by

$$W_1 = mC_p[(T_3 - T_2) - (T_4 - T_5)] \quad (18)$$

For the fifth and sixth stroke,

$$W_2 = m_w C_{pw}[(T_2 - T_6) - (T_5 - T_1)] \quad (19)$$

The thermal efficiency is given by,

$$\eta = \frac{mC_p\{[(T_3-T_2)-(T_4-T_5)]+[(T_3-T_2)-(T_4-T_5)]\}}{mC_p(T_3-T_2)-m_w C_{pw}(T_2-T_6)} \quad (20)$$

From (18) to (20) are equations proposed for six stroke engine as per Fig. 4.

5. Conclusion

In current paper analysis of single cylinder four stroke petrol engine is done by using basic fundamental equations of Otto cycle in MATLAB© software along with cold flow analysis in ANSYS© software, which provides strong foundation to formulate mathematical equations representing additional power stroke in conventional single cylinder four stroke SI engine.

6. Future Scope

This requires more space and cost due to the presence of additional accessories for steam inlet and outlet. Injecting relatively cold water onto a hot metal piston can damage it over time from thermal expansion and contraction. In cold climate, anti-freezing and anti-corrosion measures would be needed in the water reservoir. Separate water tank would have significant weight and space penalties leading to a major design overhaul.

7. References

[1] Robert C. Tibbs, “Six Cycle Combustion And Fluid Vaporization Engine”, United States Patent No. 3,964,263, June 22, 1976

[2] James L. Pace, “Apparatus For Insuring The Complete Burning Of Fuel In A Six Cycle Combustion Engine”, United States Patent No. 4,367,700, January 11, 1983

[3] David M. Prater, “Multiple Stroke Engine Having Fuel And Vapor Charges”, United States Patent No. 6,253,745 B1, July 3, 2001

[4] Satnarine Singh, “Computer Controlled Six-Stroke Cycle Internal Combustion Engine And Its Method Of Operation”, United States Patent No. 6,571,749 B2, June 3, 2003

[5] James P. Szybist, James C. Conklin, “Highly Efficient 6-Stroke Engine Cycle With Water Injection”, United States Patent No. 8,291,872 B2, Oct 23, 2012

[6] Kazou Ooyama, “6-Cycle Engine With Regenerator”, United States Patent No. 2010/0050963 A1, March 4, 2010

[7] Keshav Gupta, Kishanlal Suthar, Sheetal Kumar Jain, Ghanshyam Das Agarwal, Ashish Nayyar, “Design and experimental investigations on six-stroke SI engine using acetylene with water injection”, Environmental Science and Pollution Research Journal, May 24, 2018

[8] Massimo Borghi, Enrico Mattarelli, Jarin Muscoloni, Carlo Alberto Rinaldini, Tomasso Savioli, Barbara Zardin, “Design and experimental development of a compact and efficient range extender engine”, Applied Energy 202 (2017) 507–526, May 18, 2017

[9] Emre Arabaci, Yakup Icingur, Hamit Solmaz, Ahmet Uyumaz, Emre Yilmaz, “Experimental Investigation Of The Effect Of Direct Water Injection Parameters On Engine Performance In A Six Stroke Engine”, Energy Conversion and Management 98 (2015) 89–97, March 12, 2015.

[10] Bobin Cherian Jos, Sathyajith Raj, Jayakrishnan U, Sijil P, Vishnu Gopan M V, “Thermodynamic Analysis of In-cylinder Exhaust Heat Recovery in I.C. Engine using Water Injection”, International Journal Engineering Research and Technology(IJERT), Volume 4, Issue 04, April 2015.

[11] Nayyar A, Sharma D, Soni SL, Mathur A, “Experimental investigationofperformanceandemissionsofaVCRdieselenginefuelled with N-butanol diesel blends under varying engine parameters”. Environ SciPollutRes24(25):20315–20329,(2017)

[12] Abedin MJ, Masjuki HH, Kalam MA, Sanjid A, Ashrafur Rahman SM, and Masum BM (2013) Renewable and Sustainable Energy Reviews 26. Elsevier, pp 20–33. https://doi.org/10.1016/j.rser. 2013.05.049

[13] Bae C, Kim J (2017) Alternative fuels for internal combustion engines. Proc Combust Inst 36(3). Elsevier Inc.):3389–3413. https://doi.org/ 10.1016/j.proci.2016.09.009

[14] Çengel Y, and Boles M (2008) Thermodynamics, an Enginnering approach. McGraw Hill Choudhary KD, Nayyar A, Dasgupta MS (2018) Effect of compression ratio on combustion and emission characteristics of C.I. Engine operated with acetylene in conjunction with diesel fuel. Fuel 214(November 2017):489–496.

[15] Da Costa R, Jerônimo Y, De Lima AGB, Filho CRB, Lima LDA (2012) Energeticandexergeticanalysesofadual-fueldieselengine.Renew Sust Energ Rev 16(7):4651–4660.