DESIGN AND ANALYSIS OF MODIFIED FOUR STROKE FOUR REVOLUTION ENGINE

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Abstract. In today's world, one of the important tasks is to handle the energy available and to minimize the heat losses. In automotive sector, engine is the primary energy source and there are many losses associated with an engine out of which engine cooling and exhaust losses takes major share. In four-stroke SI/CI engines, four strokes of reciprocating cylinder involve two rotations of the crankshaft. These strokes are suction, compression, power and exhaust respectively. A large amount of fuel energy is wasted when fuel is not compressed completely and also at the exhaust of internal combustion engines. This paper focusses on minimizing losses of internal combustion engine by secondary expansion of exhaust gases through 180° of crank revolution. For this purpose, four stroke four revolution mechanism is proposed and this is achieved by modifying current slider crank mechanism with double connecting rod arrangement. This modified engine shows an increase in the air standard cycle efficiency by 4.10% where as fuel air cycle efficiency rise is observed to be 5.25%. There is also significant rise observed in the modified engine over conventional engine in terms of gross indicated thermal efficiency and brake thermal efficiency as well.

Introduction

Transportation is very important activity in human transformation. The modes of transportation of humans and goods have changed gradually over the years. Earlier travelling was done by walking using legs. Then there was invention of wheel which was revolutionary. With the help of wheels, forming cart and it was powered by muscular energy of animals like bulls and horse. Then James Watt introduced the first Engine which totally evolved the automotive sector. Heat engines perform their work by chemical combustion of fuel and converting it to heat energy. Heat engines are of mainly two type’s external combustion engines and internal combustion engines. In an external combustion engine, combustion reaction takes place outside the engine while in an internal combustion engines combustion reaction takes place inside the engine. Both engines have various applications in many fields.

Now a day for transportation, vehicles are used. These vehicles are powered by internal combustion engines. Internal combustion engines, works on fossil fuels like petrol, diesel etc. The fuel is burned inside the engine and with help of I.C engine components, rotary motion is achieved which drives the wheels of automobiles. There are total four strokes in an engine suction, compression, expansion or power and exhaust. In suction the air fuel mixture is taken inside the combustion chamber as piston inside cylinder moves from top dead center (TDC) to bottom dead center (BDC). In compression stroke, the piston moves from BDC to TDC and fuel air mixture gets compressed and burned. In suction the air fuel mixture is taken inside the combustion chamber as piston inside cylinder moves from top dead center (TDC) to bottom dead center (BDC). In compression stroke, the piston moves from BDC to TDC and fuel air mixture gets compressed and burned. In Power stroke the burned fuel emits energy and moves piston towards BDC. Power stroke is only the work producing stroke. In exhaust stroke, piston moves from BDC to TDC thereby releasing the gases through exit port. And one cycle completes with these strokes and this process is repeated again. Piston transfers
force to connecting rod which is connected to crankshaft. The mechanism converts this reciprocating motion into rotary motion. The engine which works on spark ignition is called as S.I. engine while which works on compression ignition is called as C.I. Engine. There are two types of engines viz; two stroke engine and four stroke engine. In two stroke engine, suction and compression performed in one stroke while power and exhaust in next stroke. In this way two strokes are completed in one revolution of crankshaft. While in four stroke engines four strokes are completed in two revolutions of crankshaft. I.C. Engines works with above processes.

It is estimated that within next 50 years the fossil fuels are going to exhaust from earth. Engine works on fossil fuels such as petrol and diesel. The efficiency of SI engine ranges between 26-30% while that of C I Engine ranges between 30-35 %. It means that if 100 kJ of energy is produced then only 30 to 35 kJ energy is only utilized for desired work. All other energy wastes in the form of different losses such as frictional loss, cooling loss, blow by loss. Along with this, the number of vehicles in the world is increasing every day which also increases fuel demands. To overcome this issue, either non-conventional energy sources are required to be used more or else the efficiency of existing engine needs to be increased.

A considerable amount of literature has been published on the influences of basic engine parameters on efficiency, performance and emission of multi-cylinder engines and larger displacements. V. Hariram et al. [1] presented that the varying the compression ratios (CR) have substantial effect on the performance, exhaust and ignition parameters. In this work, single cylinder direct CI engine is observed with fluctuating CR viz; 18, 17 and 16 at changing loads. Here, the ignition and variable performance on changing the CR were studied particularly. Decrease in brake thermal efficiency and rise in exhaust gas temperatures were measured when CR was lowered from 18 to 16. The brake specific fuel consumption was seen to be increased on decreasing the compression ratio. Decrease in peak cylinder pressure and increase in ignition delay period was seen on lessening of CR. The peak heat release rate was closer to TDC on changing CR from 16 to 18. The rate of pressure growth was also studied and maximum of 5.38 bar/CA and minimum of 0.78 bar/CA was observed on above CR.

J.S Jadhao et al. [2] presented the inexorably global issue on fast growing economy, a general deficiency of energy, the inner ignition motor smoke dissipate heat and natural contamination has been progressively stressed vigorously as of late. Amount of complete heat provided to the vehicles, on an average, 32 to 45% is transformed into an useful mechanical work; the remaining heat is expelled to the atmosphere through exhaust gases and vehicle cooling frameworks, which leads to entropy rise and natural pollution, hence, it is required to re-use waste heat as an useful work. The recovery and usage of waste heat saves fuel yet, in addition, decreases the measure of waste heat and ozone-depleting ingredients. The study validates the availability and credibility of waste heat from the inward burning motor additionally portray the loss of smoke gas vitality of an interior ignition motor. Possible techniques to regain the waste heat from burning motor and implementation and emanations of the inside ignition motor.

Joshi invented [3] “A mechanism for converting single or each reciprocating motion to two times rotation of the crank by providing a double connecting rod” which can be applicable for all types of IC engines to increase their efficiency. This mechanism comprises of a Piston reciprocating within a cylinder. A double connecting rod which is pivoted to the piston. A cam is mounted to the second connecting rod. The second connecting rod is provided to a crank wheel, which in turn mounted to the shaft end. As piston start moving from TDC to BDC, 180’ rotation of crank is achieved and when it returns to TDC again, a complete rotation of crank is over.

Sun J and Wang [4] highlighted the amelioration with globalization and economic policies that have transformed the trend and momentum of world economy in the last couple
of decades. The main focus is on product quality, rapid design and development and finally an economical product. To survive in this challenging market, industries have to upgrade with technology, skills to offer effective products. Design and analysis of intricate components has now become convenient with the application of Finite Element Method. Automobile Industry has transformed drastically with the evolution of next generation of CAD/CAM technologies, from engine performance to aesthetics. The lead time to manufacture automobiles has dropped marginally over the years; because of betterment with Geometric modelling and Computer Integrated Manufacturing (CIM). Design of Internal Combustion (I.C) Engine parts play a vital role in betterment of the functioning of vehicles. Design and modifications of all the important components are done in view to increase the performance and efficiency.

Siliveri Naresh et al. [5] presented, Piston is a part of To-fro engines, siphons, Air compressors and pneumatic cylinders among other comparable mechanisms of engines, its aim is to exchange constrain from extending gas in the cylinders to the crankshaft by means of a cylinder pole or associating pole. Here the cylinder is structured, broke down and the assembling procedure has been examined. Cylinder temperature has impressive impact on proficiency, emanation, execution of the motor. Motivation behind the examination is estimation of cylinder transient temperature at a few points on the cylinder, from virus begin to unaltering condition and correlation with the consequences of limited component analysis.in this undertaking the cylinder is demonstrated and collected with the assistance of CATIA programming and segment is coincided and investigation is done in ANSYS programming and the warm and static conduct is contemplated and the outcomes are organized.

Jovan Ž. DORIĆ et al. [6] displayed the reproduction of the working procedure in another IC motor idea. The essential element of this new motor idea is the acknowledgment of variable development of the cylinder-piston. The capricious cylinder development, it is anything but difficult to give a variable pressure proportion, adjustable uprooting, and burning amid consistent volume. These preferences over standard cylinder component are accomplished through an amalgamation of the two sets of non-roundabout apparatuses. The introducer system is intended to get a particular movement law which gives better fuel utilization of motors. In this study, Ricardo/WAVE programming was utilized, which gives a completely coordinated treatment of time-subordinate liquid elements and thermodynamics by methods for the one-dimensional detailing. The outcomes acquired in this incorporate the proficiency normal for this new warmth motor idea. The outcomes demonstrate that ignition amid steady volume, variable pressure proportion, and variable removals significantly affect the improvement of fuel utilization.

Vikas Kumar et al. [7] reviewed at the point when fuel is scorched in an engine, heat is delivered. Extra heat is likewise created by grinding between the moving parts. Just roughly 30% of the energy discharged is changed over into valuable work while staying 70% must be expelled from the engine to keep the parts from dissolving. In air-cooled I.C Engines, expanded surfaces called fin are given at the circumference of engine chamber to build heat exchange rate. That is the reason the investigation of fins is vital to enhance heat dissipation rate. The fundamental of the point of this work is to think about different looks into done in past to improve heat exchange rate of cooling fins by changing cylinder geometry and material.

Kolchin et al. [8] clarified the crankshaft is a standout amongst the most fundamentally stacked segments as it encounters cyclic loads through twisting and torsion amid its life. Its failure will make genuine harm the engine so it's vital at the season of configuration to confirm exhaustion quality and torsional vibration and physical approval on proving ground just as on field vehicles. More difficulties in crankshaft plan because of expanding vehicle payloads, lower weight prerequisite, higher effectiveness and longer solidness life. This paper will give a general rule for the understudy and industry engineers for planning the crankshaft which can serve the more extended toughness existence with no failing.
Methodology

This paper has adopted reverse engineering strategy. Reverse engineering is the procedure of extricating learning or structure data from anything man-made and re-creating anything dependent on the extracted data. For this project the Piaggio Ape Passenger Vehicle engine is selected. The selection is made by considering stroke length, stroke to bore ratio.

Selection

The primary requirement for this project is under square engine. The problem of clashing of the connecting with the cylinder wall is not present in the under square engine. The diesel has higher knock ratings; hence it gives wide range compression ratio selection. Complexity in designing is eliminated as it is naturally aspirated and naturally cooled engine. Single cylinder engine eliminates complex design procedure like multi-cylinder engine.

Ape Piaggio Passenger Vehicle Engine features:
- Diesel engine
- Naturally cooled engine
- Single cylinder naturally aspirated engine.
- Stroke to bore ratio is 0.87 which is under square engine.

Modified engine with four strokes and four revolution engine is compared with the theoretical efficiencies of the existing engine. The assumptions in Modified Engine are:
- Same amount of fuel injected.
- Cut-off ratio = 5%

Comparison of diesel and modified diesel engine

Compared values of existing diesel and modified diesel engine are shown in Table 1

Table 1. Parameter values comparison

| Sr. No | Parameter                                | Existing engine (%) | Modified engine (%) |
|--------|------------------------------------------|---------------------|--------------------|
| 1      | Air Standard cycle efficiency            | 60.65               | 64.5               |
| 2      | Losses due to variation of specific heat | 13                  | 13                 |
| 3      | Loss due to progressive combustion       | 5.5                 | 5.5                |
| 4      | Loss due to incomplete combustion        | 3.5                 | 3.5*               |
| 5      | Direct heat loss                         | 4.5                 | 4.5*               |
| 6      | Exhaust heat loss                        | 1.5                 | 1.5*               |
| 7      | Pumping Loss                             | 0.5                 | 0.5                |
| 8      | Rubbing friction loss                    | 3.5                 | 3.5*               |
| 9      | Fuel Air cycle efficiency                | 47.65               | 51.5               |
| 10     | Gross indicated thermal efficiency       | 32.65               | 36.5               |
| 11     | Brake thermal efficiency                 | 28.65               | 32.5               |
Design of modified engine components

Variable parameters

Large number of varying parameters are to be selected for functional design i.e. estimation of swept volume capacity which the volume displaced by piston in the slider crank mechanism selected to carry out thermodynamic cycle. A piston reciprocates in the cylinder to take the air in and compress it. Thereafter combustion releases the heat and forces the piston to deliver mechanical work to output shaft through a connecting rod and crankshaft. The design process is complete after establishing the dimensions of cylinder, piston, connecting rod, crankshaft and supporting structure to maintain the kinematic relation between these components.

Mean effective pressure: Mean Effective pressure is the normal pressure inside the cylinders of an I.C Engine dependent on the determined or estimated power yield. It rises as manifold pressure increases. For any engine, working at given speed and power yield will be explicit shown mean effective pressure, IMEP and relating brake mean effective pressure, BMEP.

Cylinder bore (d): The inside diameter of the working cylinder is called as cylinder bore.

Stroke length (L): The distance through which a piston moves between two consecutive reversals of its direction of motion is called stroke length

Piston area (A): The area of a circle of diameter equal to the cylinder bore is called the piston area.

Design of gear components:

The main running gear components of reciprocating IC engine such as slider crank, four bar chain configurations are to be designed to bear the load to which they are subjected primary elements are

- Cylinder
- Cylinder Head
- Piston Assembly
- Connecting Rod Assembly
- Crankshaft

Design of cylinder:

Fine grained cast iron or cast steel is the most suitable material for cylinder liner. It offers better resistance to wear due to sliding of piston in it and corrosion when corrosive residual gases are left during non-operation. The material should have ultimate tensile strength of 300Mpa. The liner has to withstand maximum gas pressure during the cycle. It will be designed for static strength under maximum gas pressure with factor of safety so that fatigue will be covered.

\[ t = 5 \text{ mm} \] (Thickness of Cylinder)

Design of cylinder head:

Initially the head is to be treated as a flat circular plate secured to one end of the cylinder, by cylinder bolts at pitch circle diameter and subjected to uniform maximum gas pressure. Actual
cylinder head has circular holes to accommodate inlet and exhaust valves and the fuel injector. These will weaken the head. However, reinforcement of the port passage will compensate for loss of strength.

**Design of cylinder bolts:**

Bolts withstand the entire gas pressure force during the operation which varies between 0.1 MPa (atmospheric to 8MPa) during each cycle of operation.

Using the Soderberg Equation

For a smaller engine number of bolts selected is generally four.

Minimum no. of studs = 0.01D + 4 = 4.86.

Maximum no. of studs = 0.02D + 4 = 5.72.

Therefore the no. of studs are = 5

Core Diameter $d_c = 8.6 \times 10^{-3} = 9$ mm (approximately)

**Piston design:**

The cylinder-piston needs to transmit the gas power to the interfacing bar through the pivot association known as cylinder stick or little end of interfacing bar. The gas drive follows up on the best surface of the cylinder known as a crown and is transmitted by means of the supervisors holding the cylinder stick and the bearing and after that on to the little end of the associating pole. The rest of the barrel some portion of the cylinder far from a crown, past focus of stick goes about as a guide for straight movement and takes the side push because of obliquity of the associating pole to transmit it to the chamber liner.

*Crown thickness* $= d_c = 8.42$ mm

**Barrel thickness:**

Taking the mean breadth of that area as 85% of the cylinder-piston distance across, the thickness of this segment can be determined. 10% of that area is decreased give to a radial allowance in this area.

Thickness ($t_w$) = 4.21 mm

Unless radial width of piston ring which to be accommodated in grove is decided, barrel thickness cannot be finalised.

**Piston ring design:**

General practice is to choose 2 to 4 gas rings and one oil ring. Oil ring is obliged in the skirt some portion of the cylinder.

Barrel thickness $= t = 3.64$ mm

Hence, barrel thickness = 4.21+3.64 = 7.85 mm (approx. 8 mm)

In this calculation, w does not play any role and is adopted equal to $t = 4$ mm.

Hence barrel thickness = 6+4 = 10 mm.

**Frees size of ring:**

The ring needs to apply the required pressure force when fitted in section. This is acquired by initial pressure of ring in the cylinder bore diameter. The gap between free ends before assembly and after assembly is given as-

Total Gap (Ig) = 11.50×0.5 = 12 mm
**Piston pin design:**

The overall length of the pin is about 90% of cylinder width, to accommodate circlips and to prevent the pin from fouling with cylinder liner.

\[ \therefore \text{Length of pin} = 77 \text{ mm} \]

Inner Diameter of piston pin = di = 36 mm

Outer Diameter of piston pin = do = 35 mm

**Design of connecting rod:**

The connecting rod is designed for a varying load from 0 to 53kN for every working cycle. The connecting rod is subjected to whipping force in the plane of rotation due to the mass inertia of rod itself, which further introduces the bending stresses in the rod. Section selected is I section.

Area = 1.394×10⁻⁴ m²

This area can be provided by selecting any cross-section- circular, elliptical, rectangular or I section. Thickness of I section (t) = 3.5 mm

Buckling stress in XX plane (σxx) = 259.11 MPa

Buckling stress in YY plane (σyy) = 185.84 MPa

**Checking for whip stress:**

Connecting rod is the only component in the engine which is subjected to very complex kinematics and dynamics.

\[ BM_{\text{max}} = 11.24 \text{ Nm} \]

\[ \sigma_{tc} = 9.41 \text{ MPa}. \]

\[ \therefore \text{Angle} \, \alpha, \, s = 9.46^o \]

**Compressive Force** = 14.133 KN

**Compressive Stress** = 73.61 MPa

**Total force** = 73.61 + 9.41 = 83.02 MPa. (This is safe.)

**Design of small end:**

Length and diameter of bearing in connecting rod has been already established.

Volume of piston material = 309.62 CC

Mass = 839.06 gm

Mass of piston pin = 158.85 gm

Mass of piston assembly = 997.55 gm

**Inertia Force (F) = 6.64 KN**

**Tensile stress in eye = 58.3 MPa**

This value is very small compared with strength of forgeable steel \( S_y = 750 \text{ MPa}, \, S_e = 150 \text{ MPa} \)

**Design of big end:**

Design consideration for big end of the connecting rod is based on bearing requirement. The bearing load continuously varies during the cycle.

Gas pressure force (pb) = 30.735 N/mm²

Inner diameter of crank pin eye, where thickness of bushing is approx. 2 mm

\[ I_s = 42 + 2 \times 2 = 46 \text{ mm}. \]
The thickness is maximum at centre where the B.M is maximum, but can be reduced to about 7 mm at the end of diameter. The cap is subjected to a fluctuating stress 0 to 100 MPa. By Soderberg equation, Factor of safety = \( f_s = 2.45 \)

**Design of bolts:**

Two bolts are used to hold the cap rigidly, with tightening force twice that of the inertia force required to be transmitted to the piston to retard it.

\[ \therefore \text{Initial Tightening Force} = 2 \times 6.61 = 13.322 \text{ KN} \]
\[ F_{\text{max}} = 19.983 \text{ KN} \]
\[ F_{\text{vary}} = 3.3305 \text{ KN} \]

Soderberg equation gives:

Core diameter (\( d_c \)) = 7.518 mm

\[ \therefore \text{Approximate diameter} = 8 \text{ mm.} \]

Previously assumed diameter to estimate centre distance was 10 mm, to calculate the bending movement of cap is on higher side. Hence the design is safe.

**Design of crankshaft:**

It has been already stated during the bearing design process that rigidity of crankshaft is the most significant parameter of the crankshaft design. This leads to under stressing the crankshaft. However, one has to check the bearings of shaft support. For making the design compact, \( l/d \) ratio for the main bearing is also much less than 0.75.

Therefore, core diameter of crankshaft (\( d \)) = 38.125 mm

**Design of telescopic rod:**

Assuming 70% of pressure falls down during first expansion

\[ F_{\text{max}} = 10455.9 \text{ N} \] and \( F_{\text{min}} = 0 \text{ N} \)

By Soderberg Equation, assuming the cross-sectional area is to be circular,

\[ \frac{\pi}{4}d^2 = 8.3648 \times 10^{-5} \]
\[ d = 10.32 \text{ mm} \]

The fig 1 shows front view and detailed 3 D view of modified engine.
Conclusion

The four stroke four revolution engine mechanism is mainly developed for getting more work output than traditional engine. Theoretically it can be justified that efficiency increases by 4% and can give improved work output. However, there are some practical limitations in working of model viz. precision of telescopic rod, plunger pin. Also, the engine is bulkier. If these limitations are overcome by alternatives in the future then this engine will stand tall as the milestone in the field of IC engine.

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