Design and Dynamic Analysis of Single Stroke Compressed Air Engine

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Abstract- Today the whole world is in search of alternative fuel, to fulfill the need of fossil fuel because in coming years there will be scarcity of fossil fuel. There are couples of option of alternative fuel such as solar power, tidal power, geo-thermal power, etc. and one of them is Compressed Air. The important condition for the alternative fuel is it should be renewable and eco-friendly. In India only 52.5% of rural house have access to electricity and 93.1% in urban house. Overall 35.5% of total Indian population doesn't have electricity access to their home. Compressed Air Engine is a better option to produce power to run automobile, generators etc. This paper contains design and dynamic analysis of a light weight single stroke compressed air engine it does not required any of the fossil fuels like petrol, diesel, CNG, LPG, hydrogen etc. to run engine and no power is required to start up engine only compressed air valve is to be opened. It works on compressed pressure air and hence is pollution free and 100% eco-friendly.

Keywords- Compressed air engine, zero pollution, air fuel, eco-friendly engine, single stroke engine

1. Introduction

The main objective of this paper is to design a high power to weight ratio compressed air engine which doesn't require start up power. As we know Fossil fuel which fills the energy production demand of the world is decreasing rapidly and also polluting our ecosystem due to which greenhouse effect, ozone layer depletion, acid rains and air pollution takes place. Energy crisis is due to two reasons, firstly due to population of the world has increased rapidly and secondly the standard of living of human being has increased. This can be reduce and controlled by using compressed air engine to produce energy, which runs on air which is abundantly available in atmosphere. A compressed air engine is a pneumatic actuator that creates useful work by expanding compressed air. They have existed in many forms over the past two centuries, ranging in size from hand held turbines up to several hundred horsepower. Some types rely on pistons and cylinders, others use turbines. Many compressed air engines improve their performance by heating the incoming air, or the engine itself. Some took this a stage further and burned fuel in the cylinder or turbine, forming a type of internal combustion engine. Instead of mixing fuel with air and burning it in the engine to drive pistons with hot expanding gases, compressed air engine use the expansion of compressed air to drive their pistons. Actually all engines work with compressed air. Most engines suck it in, heat it up, it pressurizes and it pushes on a piston. The future of power production will soon be whooshing down the houses in the form of an unparalleled "green" earth- friendly technology that everyone will want to get their hands on as soon as they can: The Compressed Air Engine. It is hard to believe that compressed air can be used to produce power or drive vehicles. However that is true with the "Compressed air Engine".

2. Method

Air is compressible; this property of air makes it a fuel. Energy can be stored in air by compression and store in reservoirs, aquifers, or caverns. The stored energy is then released during periods of peak demand by expansion of the air. Compressed air storage could serve for electric utility load levelling or for storing electrical energy generated from solar or wind energy. The overall recovery efficiency is estimated to be about 65 to 75 percent. A Wind turbine or fluid turbine could be used to directly pump air into a suitable pressurized storage tank. Then later, the energy stored in the air could be utilized to drive an compressed air engine whose shaft would then drive a generator, pump or a vehicle.

3. Construction

Compressed air engine is divided in primary and secondary part, both primary and secondary contain two opening one inlet and one outlet, means total of four opening.

3.1. *Cylinder*- It contain valve and piston inside it, it has four opening in it two for inlet and two for outlet.

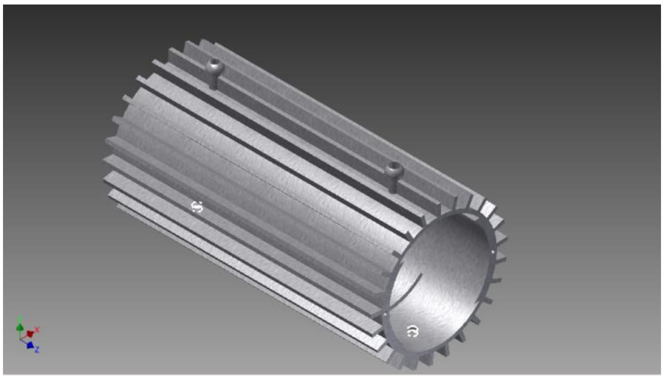

Fig. 1. Cylinder

3.2. *Piston*- It is a movable part inside the cylinder which does the work done.

3.3. *Piston Rod*- One end of rod is fixed with piston which reciprocates and another end with the connecting rod. It is fixed in the secondary side of the piston.

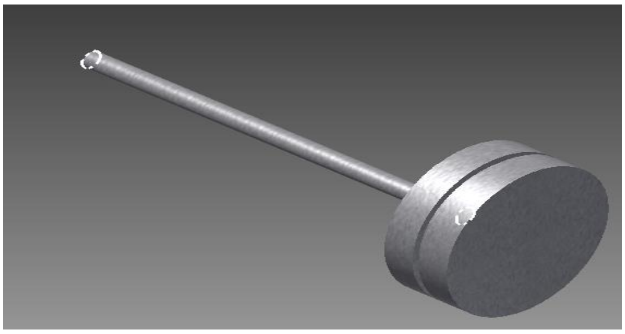

Fig. 2. Piston and Piston Rod

3.4. *Valve Cage*- It is a cage like cylinder in which piston is place and it has four opening which helps in opening and closing of primary and secondary inlet and outlet opening.

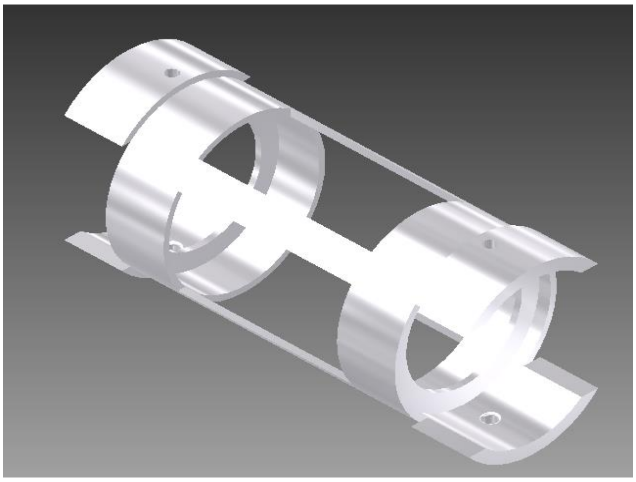

Fig. 3. Valve cage

3.5. *Head Cap*- It is attached to the primary side of the cylinder

3.6. *Tail Cap* - This cap is attached to the secondary side of the cylinder

3.7. *Compressed Air reservoir* - It store compressed air as a fuel for the engine to run.

4. Terminology

4.1. *Primary Inlet* - It is an opening on the primary side of the cylinder which allow the compressed air to come inside the cylinder during the primary stroke. It is attached with the compressed air storage cylinder.

4.2. *Primary Outlet* - It is the opening on the secondary side of the cylinder which allow the exhaust air to move out of the cylinder during primary stroke.

4.3. *Secondary Inlet*- It is an opening on the secondary side of the cylinder which allow the compressed air to come inside the cylinder during the secondary stroke. It is attached with the compressed air storage cylinder.

4.4. *Secondary Outlet*- It is the opening on the primary side of the cylinder which allow the exhaust air to move out of the cylinder during secondary stroke.

4.5. *Primary Stroke*- During this stroke piston moves from primary side of the cylinder to the secondary side of the cylinder. Primary part of the piston will produce power due to expansion of compressed air and movement of piston and at the same time exhaust takes place in the secondary part of the engine.

4.6. Secondary Stroke- During this stroke piston moves from secondary side of the cylinder to the primary side of the cylinder. Secondary part of the piston will produce power due to expansion of compressed air and movement of piston and at the same time exhaust takes place in the primary part of the engine.

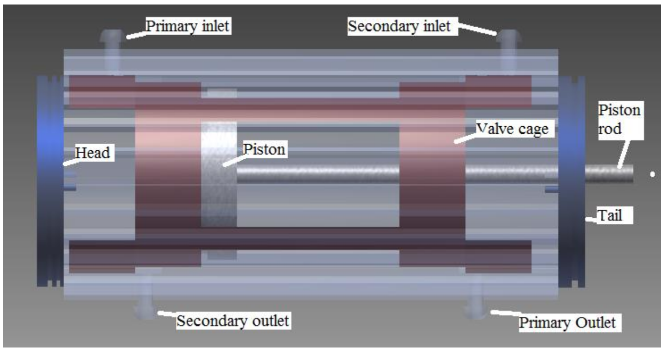

Fig. 4. Assembly with Terminology.

5. Working

Single stroke compressed air engine is divided into two part primary and secondary part

5.1. Primary Stroke- During primary stroke primary inlet and outlet is open so that compressed air can get inside through inlet and expand, due to which piston moves and produce mechanical work and in the meanwhile outlet allow air in opposite side to move out of cylinder (exhaust).As the expansion is about to complete it will hit the valve which will close the primary inlet and outlet and open secondary inlet and outlet, hence secondary stroke will be activated.

5.2. Secondary Stroke- After complementation of Primary stroke secondary stroke gets activated, during this stroke secondary inlet and outlet is open so that compressed air can get inside through inlet and expand, due to which piston moves in opposite direction and produce mechanical work and in the meanwhile secondary outlet allow air to move out of cylinder (exhaust) which was filled-in in the primary stroke. As the expansion is about to complete it will hit the valve which will close the secondary inlet and outlet and open primary inlet and outlet, hence primary stroke will be activated.

This Cycle will repeat till the compressed air is available.

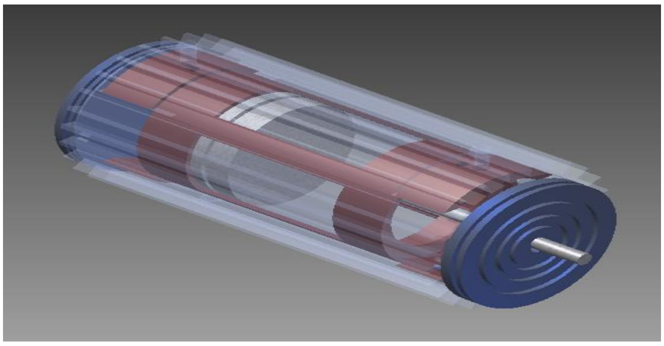

Fig. 5. Assembly

6. Dynamic Analysis of Engine

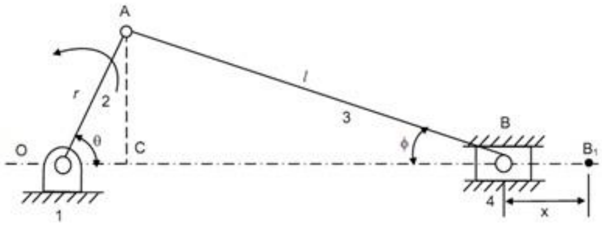

Fig. 6. Mechanism

Fig. 6. Show a slider crank mechanism in which the crank OA rotates in the counter clockwise direction. l and r are the length of connecting rod and the crank respectively.

6.1. Displacement of piston

Let x be the displacement of piston from outer-dead centre.

Θ be the angle between crank and connecting shaft at moment

$X = BB_1 = B_1O - BO$

$= B_1O - (OC + CB)$

$= (r + l) - (r \cos \Theta + l \cos \Phi)$

(taking $l/r = n$)

$= (r + nr) - (r \cos \Theta + nr \cos \Phi)$

$= r[(1 + n) - (\cos \Theta + n \cos \Phi)]$

Where $\cos \Phi = (1 - \sin \Theta)^{1/2}$

$= (1 - AC^2 / l^2)^{1/2}$

$= (1 - (r \sin \Theta)^2 / l^2)^{1/2}$

$= 1/n\,(n^2 - \sin^2\Theta)^{1/2}$

$X = r \sin[(1 - \cos \Theta) + n - (n^2 - \sin^2 \Theta)^{1/2}]$

6.2. Velocity of Piston

$$v = \frac{dx}{dt} = \frac{dx}{d\theta}\frac{d\theta}{dt}$$

$$= \frac{d[r\{(1 - \cos\theta) + n - (n^2 - \sin^2\theta)^{1/2}\}]}{d\theta}\frac{d\theta}{dt}$$

$$= r\omega[\sin\theta + \frac{\sin 2\theta}{2(n^2 - \sin^2)^{\frac{1}{2}}}]$$

If n^2 is large compared to $\sin^2\Theta$

$$v = r\omega[\sin\theta + \frac{\sin 2\theta}{2n}]$$

6.3. Acceleration of Piston

$$f = \frac{dv}{dt} = \frac{dv}{d\theta}\frac{d\theta}{dt}$$

$$= \frac{d}{d\theta}[r\omega(\sin\theta + \frac{\sin 2\theta}{2n})]\omega$$

$$= r\omega^2(\cos\theta + \frac{\cos 2\theta}{n})$$

If n is very large

$$f = r\omega^2 \cos\theta$$

6.4. 6.4 Piston Effort

Let A_1 = cross section area of the piston head

A_2 = cross section area of the piston end

P_1 = pressure on the piston head

P_2 = pressure on the piston end

m = mass of reciprocating parts

Force on the piston due to compressed air pressure,

$F_p = P_1 A_1 – P_2 A_2$

Inertial force,

$$F_b = mf = r\omega^2(\cos\theta + \frac{\cos 2\theta}{n})$$

F_b is in the opposite direction to that of the acceleration of the piston.

In case frictional resistance F_f is taken under consideration

Net Force on the piston, $F = F_p – F_b – F_f$

7. Literature Review

At present reciprocating compressed air engine is modified version of 2-stroke S.I engine which gives one power stroke at every 360° rotation of crank shaft due to which there is fluctuation in output torque which is removed with the help of flywheel, in the presented design we get one power stroke at every 180° rotation of crank shaft which reduce the fluctuation in output torque as we can see in Fig.7.Due to less fluctuation weight of flywheel is reduced to great extent which increase the efficiency of the engine.

Power of present design is high as compared with other reciprocating compressed air engine. During one rotation of crank shaft we get two power strokes which increase the power and efficiency of the engine.

Valve opening and closing mechanism of current design is automatic sliding type and no valve time tuning is required whereas in other engine there is separate arrangement such as rocker arm, overhead cam follower mechanism, which require regular maintenance.

Small size engine can be manufactured because of its simple design and automatic sliding valve.

8. Result and Discussions

It can be seen in the turning moment diagram just after the completion of primary stroke secondary stroke start which decreases the fluctuation in power output. Both the expansion and exhaust of air takes place during single stroke which make it a single stroke engine. Its power output is more than any other compressed air engines, as it is Single stroke engine rate of work done is high. Exhaust gas which is air is clean and cool (5°C). Manufacturing of light weight engine can be done.

It can be used to produce power for domestic purpose, and can replace inverters in terms of cost and pollution, as we know lead batteries are costly and produce toxic gas. Because of light weight efficiency of vehicle can be increased. It can be used in rural area for the generation of electricity or running pumps.

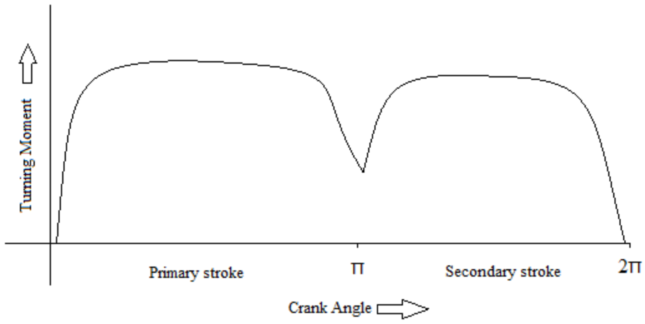

Fig. 7. Turning Moment Diagram

Advantage of compressed air energy storage

1. Compressed air storage has quick startup (typically 10 minutes) and long storage capability
2. Energy from windmill or solar energy can be stored during the time of low demand and can used during the time of high demand.
3. Underground caverns or disused mines are being used for storage of compressed air and salt caverns are particularly suitable because of its self-sealing property under pressure.

4. Longer lifetimes of pressure vessels and lower material toxicity as compared with conventional batteries.

9. Conclusion

With the use of non-conventional energy sources such as compressed air engine we can set a milestone in the field of green technology because it is the demand of the time to adopt green technology.

- Weight of the engine is reduced to great extent.
- High power to weight ratio.
- Power loss due to inertia of the moving parts is reduced.
- Start-up power is not required to run engine.
- Exhaust air causes no harm to environment as it is cold and clean.

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