Compressed Air Vehicle

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Abstract— As the world is hard pressed with the energy and fuel crises, compounded by pollution of all kinds, any technologies that bring out the solutions to this problem is considered as a bounty. In one of such new technologies, is the development of a new engine called as compressed air engine which does not require any of the known fuels like diesel, petrol, CNG, LPG, hydrogen etc. this works using only compressed air. This replaces all types of to-date known fuels and also permanently solves the problems of pollution as its exhaust is clean and cool measured practically as low as 5ºC. A proto type, a horizontal, single cylinder low speed engine was modified to run on compressed air. Since this engine runs only on high pressure compressed air, the exhaust of which is undoubtedly only air, making it a zero pollution engine. No heat is generated because there is no combustion of fuel, hence this engine needs no cooling system and it result in reduced cost, weight, volume and vibration. Early cost analysis shows that it's very cost effective and the operational cost is ten times less than that of petrol or diesel.

Key words: Compressed Air Engine, Pollution, Energy

I. INTRODUCTION

Fossil fuels (i.e., petroleum, diesel, natural gas and coal) which meet most of the world's energy demand today are being depleted rapidly. Also, their combustion products are causing global problems, such as the greenhouse effect, ozone layer depletion acid rains and pollution which are posing great danger for environment and eventually for the total life on planet. These factors are leading automobile manufactures to develop cars fueled by alternatives energies. Hybrid cars, Fuel cell powered cars, Hydrogen fueled cars will be soon in the market as a result of it. One possible alternative is the air powered car. Air, which is abundantly available and is free from pollution, can be compressed to higher pressure at a very low cost, is one of the prime option since atmospheric pollution can be permanently eradicated. Whereas so far all the attempts made to eliminate the pollution has however to reduce it, but complete eradication is still rigorously pursued [1]. Compressed air utilization in the pneumatic application has been long proven. Air motors, pneumatic actuators and others various such pneumatic equipments are in use. Compressed air was also used in some of vehicle for boosting the initial torque. Turbo charging has become one of the popular techniques to enhance power and improve the efficiencies of the automotive engine that completely runs on compressed air. There are at two ongoing projects (in France, by MDI and in S. Korea) that are developing a new type of car that will run only on. compressed air. Similar attempt has been made but to modify the existing engine and to test on compressed air

II. CONCEPT AND METHODOLOGY

A compressed air engine (CAE) is powered by using compressed air, which is stored in a tank. Instead of mixing fuel with air and burning it in the engine to drive pistons with hot expanding gases; compressed-air vehicles use the expansion of compressed air to drive their pistons. One manufacturer claims to have designed an engine that is 90 percent efficient. Compressed-air propulsion may also be incorporated in hybrid systems, e.g., battery electric propulsion and fuel tanks to recharge the batteries. This kind of system is called hybrid-pneumatic electric propulsion. Additionally, regenerative braking can also be used in conjunction with this system.

A. Compressed Air:

Compressed air is a gas, or a combination of gases, that has been put under greater pressure than the air in the general environment. Current applications using compressed air are numerous and diverse, including jackhammers, tire pumps, air rifles, and aerosol cheese. According to proponents, compressed air also has a great deal of potential as a clean, inexpensive, and infinitely renewable energy source. Its use is currently being explored as an alternative to fossil fuels.

B. Behavior of Compressed Air:

Compressed air is clean, safe, simple and efficient. There are no dangerous exhaust fumes of or other harmful by products when compressed air is used as a utility. It is a non-combustible, non-polluting utility.

When air at atmospheric pressure is mechanically compressed by a compressor, the transformation of air at 1 bar (atmospheric pressure) into air at higher pressure (up to 414 bar) is determined by the laws of thermodynamics. They state that an increase in pressure equals a rise in heat and compressing air creates a proportional increase in heat. Boyle's law explains that if a volume of a gas (air) halves during compression, then the pressure is doubled. Charles' law states that the volume of a gas changes in direct proportion to the temperature [2]. These laws explain that pressure, volume and temperature are proportional; change one variable and one or two of the others will also change, according to this equation: $(P_1\ V_1) / T_1 = (P_2\ V_2)/T_2$ Compressed air is normally used in pressure ranges from 1 bar to 414 bar (14 to 6004 PSI) at various flow rates from as little as 0.1 m (3.5 CFM - cubic feet per minute) and up.

C. How Compressed Air Fuel a Car:

The laws of physics dictate that uncontained gases will fill any given space. The easiest way to see this in action is to inflate a balloon. The elastic skin of the balloon holds the air tightly inside, but the moment you use a pin to create a hole in the balloon's surface, the air expands outward with so much energy that the balloon explodes. Compressing a gas into a small space is a way to store energy. When the gas

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expands again, that energy is released to do work. That's the basic principle behind what makes an air cargo [3].

The first air cars will have air compressors built into them. After a brisk drive, you'll be able to take the car home, put it into the garage and plug in the compressor. The compressor will use air from around the car to refill the compressed air tank. Unfortunately, this is a rather slow method of refueling and will probably take up to two hours for a complete refill. If the idea of an air car catches on, air refueling stations will become available at ordinary gas stations, where the tank can be refilled much more rapidly with air that's already been compressed. Filling your tank at the pump will probably take about three minutes.

The first air cars will almost certainly use the Compressed Air Engine (CAE) developed by the French company, Motor Development International (MDI). Air cars using this engine will have tanks that will probably hold about 3,200 cubic feet (90.6 kiloliters) of compressed air. The vehicle's accelerator operates a valve on its tank that allows air to be released into a pipe and then into the engine, where the pressure of the air's expansion will push against the pistons and turn the crankshaft. This will produce enough power for speeds of about 35 miles (56 kilometers) per hour. When the air car surpasses that speed, a motor will kick in to operate the in-car air compressor so it can compress more air on the fly and provide extra power to the engine. The air is also heated as it hits the engine, increasing its volume to allow the car to move faster.

III. CONSTRUCTION OF COMPRESSED AIR ENGINE

The constructions of compressed air engine mainly consist of pneumatic cylinder, pneumatic solenoid valve, compressor, bearing & it's working, and crank shaft [4].

A. *Pneumatic Cylinder:*

Cylinders are mechanical devices which produce force, often in combination with movement, and are powered by compressed gas.

A.

To perform their function, pneumatic cylinders impart a force by converting the potential energy of compressed gas into kinetic energy. This is achieved by the compressed gas being able to expand, without external energy input, which itself occurs due to the pressure gradient established by the compressed gas being at a greater pressure than the atmospheric pressure. This air expansion forces a piston to move in the desired direction [5].

B.

Once actuated, compressed air enters into the tube at one end of the piston and, hence, imparts force on the piston. Consequently, the piston becomes displaced by the compressed air expanding in an attempt to reach atmospheric pressure.

B. *Pneumatic Solenoid Valve and Working:*

The term solenoid usually refers to a coil used to create magnetic fields when wrapped around a magnetic object or core. In engineering terms, the solenoid describes transducer mechanisms used to convert energy into motion. Solenoid valves are controlled by the action of the solenoid and typically control the flow of water or air as a switch. If the solenoid is active (current is applied), it opens the valve. If the solenoid is inactive (current does not exist), the valve stays closed. The action of the pneumatic solenoid is controlled by the use of pneumatics. The opening or closing of a valve is referred to as "changing state."

An internally driven pilot valve with four-way connections is generally found in pneumatic operations and is used to move double action cylinders. Pneumatic solenoid valves can be designed as stackable [6].

C. *Compressor:*

A gas compressor is a mechanical device that increases the pressure of a gas by reducing its volume. Compressors are similar to pumps: both increase the pressure on a fluid and both can transport the fluid through a pipe. As gases are compressible, the compressor also reduces the volume of a gas. Liquids are relatively incompressible, so the main action of a pump is to pressurize and transport liquids [8].

Compressed air Piston range operates between 0.75 kW to 420 kW (1hp to 563 hp) producing working pressure at 1.5 bar to 414 bar (21 to 6004psi).

Compressed air Vane compressors operate between 1.1 kW to 75 kW (1.5 to 100hp), producing working pressures of 7 to 8 and 10 bar (101 to 145psi).

D. *Crank Shaft:*

The crankshaft translates reciprocating linear piston motion into rotation. To convert the reciprocating motion into rotation, the crankshaft has "crank throws" or "crankpins", additional bearing surfaces whose axis is offset from that of the crank, to which the "big ends" of the connecting rods from each cylinder attach.

C.

It typically connects to a flywheel, to reduce the pulsation characteristic of the four-stroke cycle, and sometimes a tensional or vibration damper at the opposite end, to reduce the torsion vibrations often caused along the length of the crankshaft by the cylinders farthest from the output end acting on the torsion elasticity of the metal.

IV. WORKING CYCLES OF CONVENTIONAL 4-STROKE ENGINE

The working cycle of a 4-stroke IC engine consists of four stroke and two rotations of crankshaft.

A. *Inlet Stroke:*

Inlet valve remains open as shown in Fig. 1. Exhaust valve remains closed. Mixture of fuel and air is inlet in cylinder. Piston moves from T.D.C. to B.D.C. The piston has now made one stroke and crankshaft 180 degrees of rotation.

B. *Compression Stroke:*

Inlet and exhaust valves remain closed as shown in Fig. 2. Piston moves from B.D.C. to T.D.C. Fuel and air mixture is compressed up to its clearance volume.

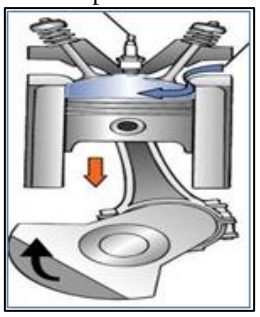

Fig. 1: Inlet Stroke

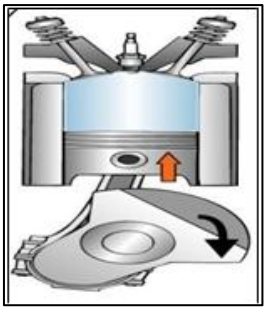

Fig. 2: Compression Stroke

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C. Power Stroke:

Inlet and outlet valve remain closed. Mixture burn and High pressure and temperature gases push down the piston to create motive power. Piston moves from T.D.C. to B.D.C as in Fig.3.

D. Exhaust Stroke:

Inlet valve remains closed and exhaust valve is open. The piston moves from B.D.C. to T.D.C. During this motion, the piston pushes out the burnt gases from the cylinder as shown in Fig. 4.

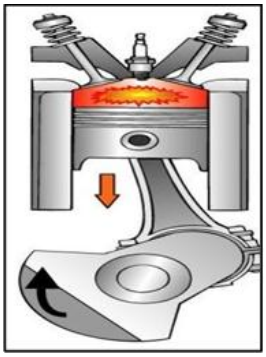

Fig. 3: Power Stroke

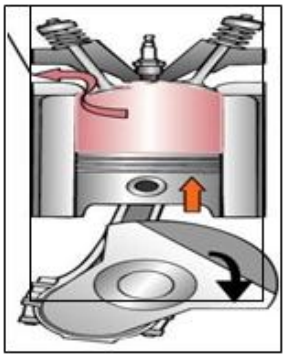

Fig 4: Exhaust Stroke

V. WORKING CYCLES OF COMPRESSED AIR ENGINE

A. Intake cum Power Stroke:

Compressed air from the storage tank enters the engine cylinder with opening of inlet valve and piston at the T.D.C. This exerts pressure on piston which drives piston downwards towards B.D.C. allowing compressed air to expand. This is the power stroke which is the main source for engine power and torque. This stroke is indicated in Fig. 5.

B. Exhaust Stroke:

The inlet valve is closed and exhaust valve opens making way for the expanded air in the cylinder to evacuate the cylinder. The expanded air is at slightly higher pressure than atmospheric pressure for easy evacuating of cylinder. This is shown in Fig. 6.

Two stroke fuel engine every stroke is power stroke but air compressed engine only one stroke is power stroke. To complete one cycle 360º revolution completed in crank shaft or one revolution completed. In this engine, zero percentage pollution will be produced.

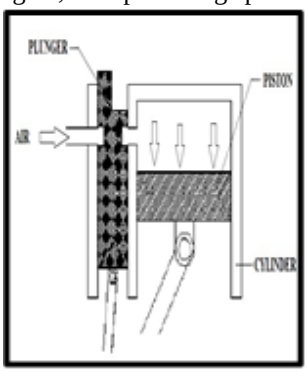

Fig. 5: Intake cum Power Stroke

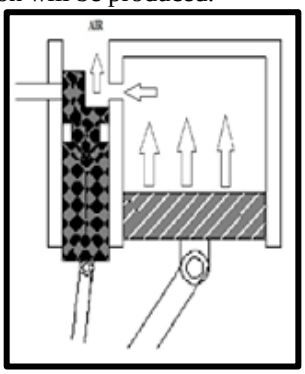

Fig. 6: Exhaust Stroke

VI. VALVE TIMING DIAGRAM AND CAM DESIGN

A. For Conventional 4-stroke Engine:

The Camshaft is the "heart" of the gasoline engine. The engine will not perform to its highest potential unless the cam is precision ground to provide performance at the speeds required. The valve timing diagram for the conventional 4-stroke engine is shown in Fig. 7.

B. For 2-stroke Pneumatic Engine:

From the comparison of the cycles of conventional IC engine and pneumatic engine, it is evident that the intervals for operation of the inlet and outlet valves are different. The valves must operate twice for retrofitted engine as compared to those of conventional engine. Thus the cam for the retrofitted 2-stroke pneumatic engine must have double lift i. e. for 360o of rotation; cam must actuate the valve twice. So considering the above, valve timing diagram was made as shown in Fig. 8.

Fig. 7: Valve Timing Diagram for Gasoline engine

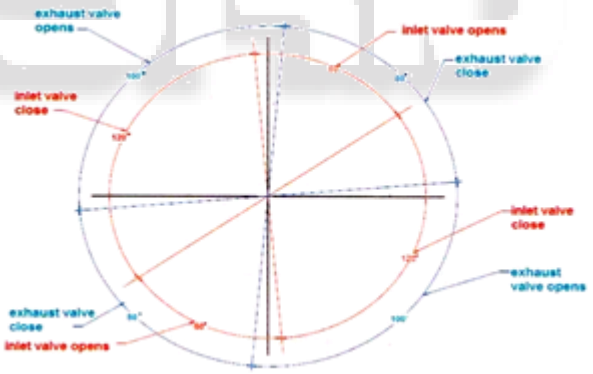

Fig. 8: Valve Timing Diagram for Retrofitted compressed air engine.

Some part of the opening of the inlet and outlet valves must overlap in order to make sure that engine locking is avoided. The cam and camshaft were manufactured separately and cam was later mounted on camshaft. Cam is manufactured using wire cut machine. Design of cam was prepared in CAD software which was the required as input data for the computer controlled wire cutting machine.

VII. DESIGN AND IMPLEMENTATION

The dimensions and design of the cams developed based of the discussions provided are given under.

A. Inlet Cam:

1) Base Diameter : 20 mm

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2) Lift : 5 mm
3) Open/Close : 355^0 to 55^0 (shm\ua)
: 175^0 to 235^0 (shm\ua)
4) Thickness : 12 mm

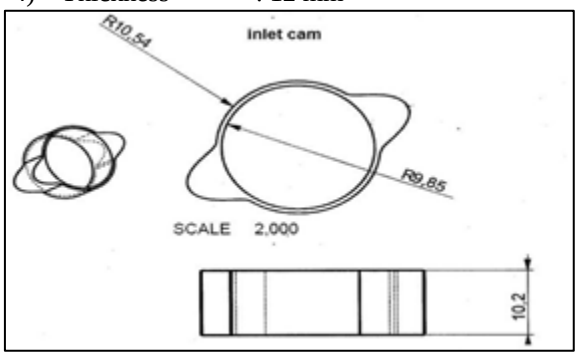

Fig. 9: Inlet Cam

B. Exhaust Cam:

1.	Base Diameter	: 20 mm
2.	Lift	: 5 mm
3.	Open/Close	: 85^0 to 185^0 (shm\ua) 265^0 to 5^0 (shm\ua)
4.	Thickness	: 12 mm.

Table 1: Exhaust Cam

The cam and camshaft were manufactured separately and cam was later mounted on camshaft. Cam is manufactured using wire cut machine. Design of cam was prepared in CAD software which was the required as input data for the computer controlled wire cutting machine.

As per the data provided outer profile of cam is cut on the wire cutting machine on a 12 mm thick steel plate. Centering and

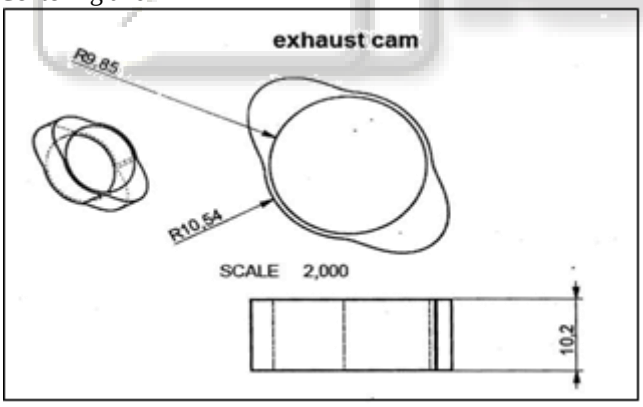

Fig. 10: Exhaust Cam

drilling on cam is done as per the required base radius. Camshaft is manufactured on precision lathe machine. Design specifications of camshaft were given to technician on lathe machine to get the camshaft of required design. Simple turning on steel rod was done to get required camshaft.

VIII. Conclusion

The careful design of valve timings and cam profile allows conversion of conventional 4-stroke IC engine into Compressed air engine. The cam needs to be manufactured with care and assembled with correct relative positions. Single cylinder pneumatic engine can encourage for its use as an alternate for an IC engine in future. Exhaust of gases is at very low temperature than conventional IC engine which solves problem of engine heating up to a great extent. Engine can be made up of lighter weight as heating of engine is reduced. Zero carbon emission can be achieved if air is compressed from the renewable source of energy like wind, flowing water, dams or tidal energy. This can be a major step towards pollution free environment. This concept can also be used in stationary applications where space is available and power is produced by single cylinder IC engine.

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