Study and Fabrication of Compressed Air Engine

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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. Experimental analysis were carried out on this modified engine to find out its performance characteristics like brake power, mechanical efficiency, overall efficiency, air to Air ratio, volumetric efficiency, cost analysis etc. Though the efficiencies were low as the frictional forces were high for the proto designed engine, however the concept can be applied on a professionally designed engine to improve its performance.

***Keywords* :** *Compressed air engine, pollution, energy.*

1. 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 green house 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.

2. 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,

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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.

2.1 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.

2.2 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 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.

3. CONSTRUCTION OF COMPRESSED AIR ENGINE

The construction of compressed air engine mainly consist of pneumatic cylinder, pneumatic solenoid valve and working, light chaser circuit, compressor, bearing & its working, and crank shaft[4].

3.1 Pneumatic cylinder

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

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].

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.

3.2 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].

3.3 Light chaser circuit & its components

Light chaser circuits can be used to create lighting animation sequences and have been used in the past to attract attention for advertising and promotion, such as the marquee at the local movie theater. In addition, they can be used to produce pleasing effects for entertainment as well [7].

Table 1 : Technical Data Pneumatic Solenoid Valves

MODEL						
Position number	Two position Five-way	Three position Five-way	Two position Five-way	Three position Five-way	Two position Five-way	Three position Five-way
Effective Section	16 mm^2 (C_v = 0.89)	12 mm^2 (C_v = 0.87)	25 mm^2 (C_v = 1.40)	18 mm^2 (C_v = 1.00)	12 mm^2 (C_v = 0.87)	9 mm^2 (C_v = 0.50)
Working Medium	Air					
Acting Type	Internally pilot-actuated					
Working Pressure	10 to 17 bar					
Proof Pressure	15 bar					
Operating Temperature	5 to 50^0C					
Voltage Range	$\pm$ 10%					
Power Consmption	AC, 4.5 VaDc, 3 W					
Insultation and Protection	F Class, IP65					
Highest Acting Frequency	20 Cycle/Sec					
Response Time	0.05 Second					
Electrical Entry	Lead wire or connector type					

Light chasers consist of several lighting circuits strung together, usually three or four. Every first light in the string is turned on, then off and the next light is turned on and then off, and so on. Although there are eight lights in the example below, there are only four circuits controlling these lights, which are repeated twice. The two lights that are on at any given time are connected to the same circuit. In the Rainbow Kits light chaser, the four circuits can be repeated up to10 times, giving a string of 40 LEDs.

3.4 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).

3.5 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.

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.

4. ADVANTAGES

Compressed-air vehicles are comparable in many ways to electric vehicles, but use compressed air to store the energy instead of batteries. Their potential advantages over other vehicles include:

- Much like electrical vehicles, air powered vehicles would ultimately be powered through the electrical grid. This makes it easier to focus on reducing pollution from one source, as opposed to the millions of vehicles on the road.
- Transportation of the fuel would not be required due to drawing power off the electrical grid. This presents significant cost benefits. Pollution created during fuel transportation would be eliminated.
- Compressed air technology reduces the cost of vehicle production by about 20%, because there is no need to build a cooling system, fuel tank, Ignition Systems or silencers.
- Air, on its own, is non-flammable.
- High torque for minimum volume.
- The mechanical design of the engine is simple and robust.
- Low manufacture and maintenance costs as well as easy maintenance.
- Compressed-air tanks can be disposed of or recycled with less pollution than batteries.
- Compressed-air vehicles are unconstrained by the degradation problems associated with current battery systems.
- The tank may be able to be refilled more often and in less time than batteries can be recharged, with re-fueling rates comparable to liquid fuels.
- Lighter vehicles would mean less abuse on roads. Resulting in longer lasting roads.
- The price of fueling air-powered vehicles will be significantly cheaper than current fuels.

5. DESCRIPTION OF AIR ENGINE

A compressed-air vehicle is powered by an air engine, 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 (CAV) use the expansion of compressed air to drive their pistons. One manufacturer claims to have designed an engine that is 90 percent efficient[9].

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.

5.1 Working of Cycle & Engine

Because of the dwell provided by the special connecting rod assembly, the diesel engine works on constant volume cycle instead of constant pressure cycle. During this constant volume, air is injected by the injection system into the engine cylinder.

This engine works like a diesel engine. At the end of compression stroke, a very high pressure air at room temperature is injected into the cylinder. Injection of air by electro-mechanical injection system is governed by the cam dwell during which the piston also dwells. As the in cylinder hot and compressed air mixes with the externally injected relatively cold and compressed air, injected at relatively higher pressure than the inside pressure, the mixture tries to attain a common equilibrium temperature of this mixture falls down, expansion takes place. The high inside mixture pressure impart a very heavy blow on the head of the piston, which is then set in motion and the engine runs. No combustion takes place; it is the expansive forces, which make engine run.

5.2 Schematic diagram

In this model input is connected with air compressor. This compressor air transfer into two pneumatic piston through 4-solenoid valve, solenoid valve rotate crank shaft. Each solenoid valve gives 90 degree rotation to crank shaft.

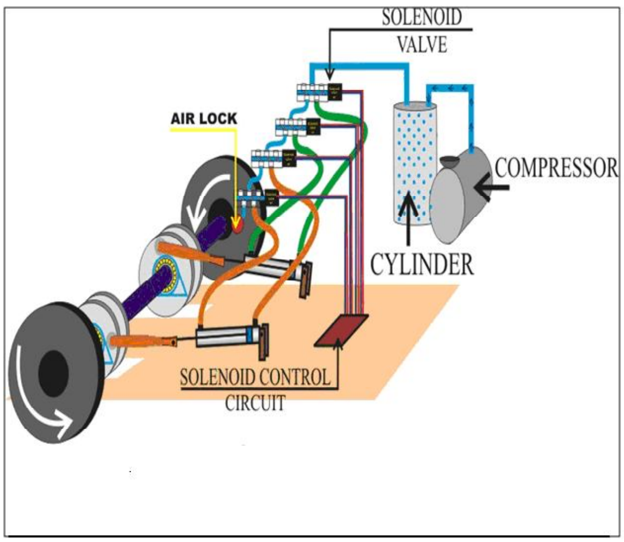

Fig. 1 : Schematic diagram of Air Engine

The preliminary analysis based on the prototype calculation shows that around three cubic meter of air at a pressure more than 30bar can give a mileage equivalent to one liter petrol is Rs 52, and cost of production of one cubic meter of air at a pressure of 50bar is Rs 3. Hence air of Rs 9 can give the mileage of Rs 52 of petrol. However if air is mass compressed and produced, the cost will further come down.

In this project a hermetically sealed reciprocating second hand compressor from a domestic refrigerator is being used in place of air compressor in reference which is shown in the Fig. 2.

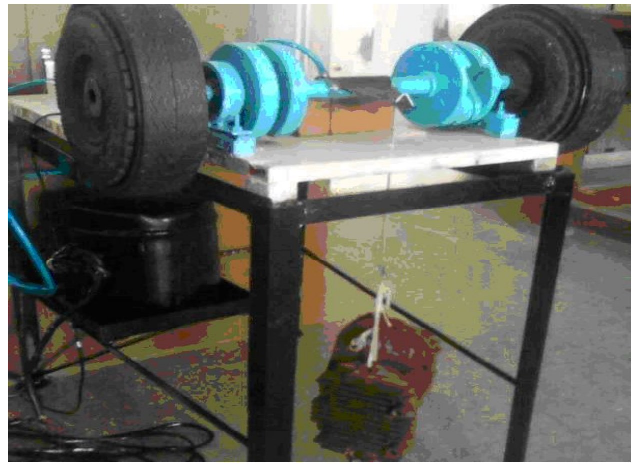

Fig. 2 : Model Project

6. RESULTS AND DISCUSSION

The values noted down are used for calculating the mechanical efficiency, indicated power brake power; etc. Since this proto type was designed for low speed, the output power; applied load was also kept low. The prime aim being to test the concept of application of air and the suitability of special connecting rod assembly with its related advantages, hence the obtain result may not be the exact measure of its potential, since it wasn't very professionally designed.

6.1 Indicated power

It can be seen that the indicated power is increasing for increase of load. As load is increased, the speed falls down, to maintain it constant injection pressure has to be increased. As the injection pressure has to be increased, the indicated mean effective pressure gets increased; hence the indicated power is increased. Indicated power is calculated by plotting the P-V diagram and calculating the area under the curve. Initial suction pressure p_1 known as pressure after compression p_2 of air in cylinder is also known because the compression ratio is known and the p_3 is the injection pressure of air from cylinder which can be recorded from the pressure gauge, and the exhaust pressure p_4 is also recorded so the p-v plot can be easily drawn as four pressures are known.

Power is defined as the rate of doing work. In the analysis of cycles the network is expressed in kJ/Kg of air. This may be converted to power by multiplying the mass flow rate of air through the engine in kg/

time[10]. Since, the network obtained from the p-v diagram is the network produced in the cylinder as measured by an indicator diagram, the power based there on is termed indicated power (ip).

Indicated Power = indicated network × cycles/sec.

$$ip = p_{imep}\ LA\ n\ K/\ 60{,}000\ kW$$

Where, p_{imep} = indicated mean effective pressure (15, 16, 17….20) (bar), L = Length of stroke (meter), A = area of piston (m^2), N = speed in revolution per minute, n = no. of power stroke per minute (N for a two stroke engine), K = no. of cylinder.

Observations of indicated power are as follows:-

The value of K = 2, L = 0.11, A = 0.00079

Observation (I), $(ip) = \frac{PimLANK}{60{,}000}$ kW

$$= \frac{0.5x100000x0.11x0.00079x450x2}{60000}$$

= 0.065 kW

Observation (II), $(ip) = \frac{PimLANK}{60{,}000}$ kW

$$= \frac{0.5x100000x0.11x0.00079x570x2}{60000}$$

= 0.165 kW

Observation (III), $(ip) = \frac{PimLANK}{60{,}000}$ kW

$$= \frac{0.5x100000x0.11x0.00079x650x2}{60000}$$

= 0.282 kW

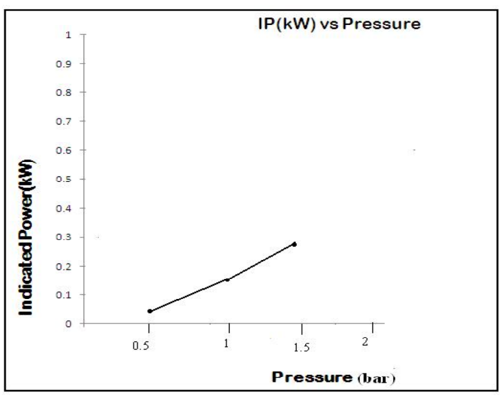

Fig. 3 : Indicated power vs pressure

6.2 Brake Power

As shown in figure, the brake power was increasing upon the application of the load. Though the applied load is smaller, however, the developed power was in proportion to the applied load. As load was applied the speed was reduced, to maintain it constant, the inlet air pressure has to be increased. As shown injection pressure is increased. In the present case the speed was maintained constant as 600 rpm. As the output speed was less the brake power was significantly lower. In general, only the brake power, bp, has been used here to indicate the power actually delivered by the engine.

The product of the moment arm R & the measured force, F is termed the torque of the engine & is usually expressed in Nm. Torque, T is the uniform or fluctuating turning moment, or twist, exerted by tangential force acting at a distance from the axis of rotation. For an engine operating at a given speed and delivering a given power, the torque must be fixed amount, or the product of F and R must be the constant (T=FR). In case, R is decreased, the F will be increased proportionately and vice-versa.

Brake power (bp) $= \frac{2\pi NT}{60{,}000}$ kW

In practice, the length of the moment arm R of the measuring equipment is so designed that the value of the constant 2 and the constant R and 60,000 combine to give a convenient no. (i.e. in thousand and ten thousands) in order to simplify computation

Brake power (bp) $= \frac{2\pi RFN}{60{,}000}$ kW

Where, Length of moment arm should be .06 meter.

Table 2: Observation of torque

S.No.	RPM (avg)	Load (Newton)	Length (m)	Torque = (load/2) *x* length
1.	570	7.6	.06	$T = \frac{7.6x.06}{2} = 0.228$
2.	570	8	.06	$T = \frac{8x.06}{2} = 0.24$
3.	570	8.4	.06	$T = \frac{8.4x.06}{2} = 0.252$

The observational view of braking power is as follows :

Observation I, (bp) $= \dfrac{2\pi NT}{60,000}$ kW

$= \dfrac{2x3.14x.228x570}{60000}$

= 0.013 kW

Observation II, (bp) $= \dfrac{2\pi NT}{60,000}$ kW

$= \dfrac{2x3.14x.24x570}{60000}$

= 0.0143 kW

Observation III, (bp) $= \dfrac{2\pi NT}{60,000}$ kW

$= \dfrac{2x3.14x.252x570}{60000}$

= 0.0150 kW

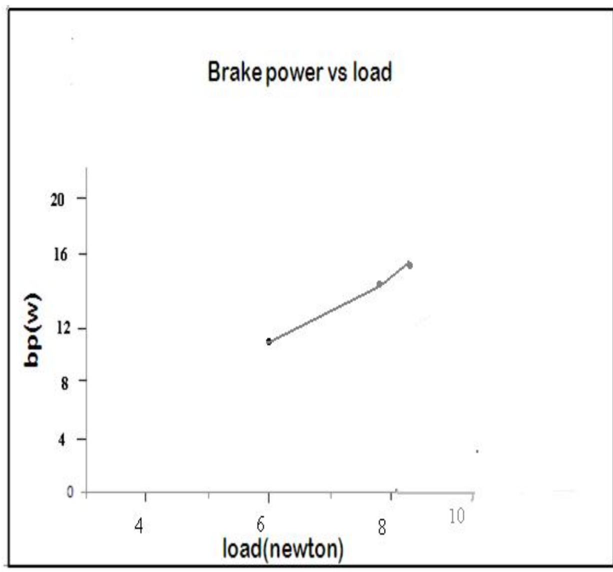

Fig. 4: Braking powers vs load

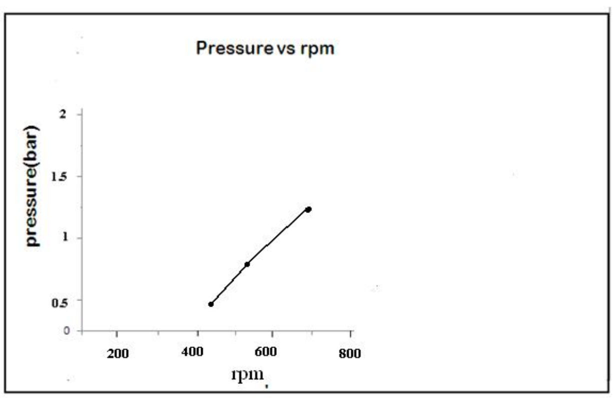

Fig. 5: Pressure vs rpm

6.3 Mechanical Efficiency

The mechanical efficiency is increasing with the increase of output power. At lower output it was very low. However the overall mechanical efficiency is low compared to the conventional engine, the reasons being the addition of three extra joints and the rotating pairs which has increased the frictional loss. The slightly oversized links also has contributed significantly in increasing the frictional force and high initial torque required to set the link in the motion. This can however be improved by optimizing the link siz es, and reducing the frictional loss in the rotating pairs.

$$\text{Mechanical Efficiency } (\eta_m) = \frac{\text{Brakeing Power}}{\text{Indicated Power}}$$

$$(\eta_m) = \frac{0.13}{0.065} = 20\%$$

7. CONCLUSION

This is a revolutionary engine design which is eco friendly, pollution free, but also very economical. This redresses both the problems of fuel crises and pollution. However excessive research is needed to completely prove the technology for both its commercial and technical viability.

It can be seen that the indicated power is increasing for increase of load. As load is increased, the speed falls down, to maintain it constant injection pressure has to be increased. As the injection pressure has to be increased, the indicated mean effective pressure gets increased; hence the indicated power is increased upon the application of the load. Though the applied load was small, however, the developed power was in proportion to the applied load. As load was applied the speed was reduced, to maintain it constant, the inlet air pressure has to be increased. As shown injection pressure is increased. In the present case the speed was maintained constant as 600 rpm. As the output speed was less the brake power was significantly lower. The mechanical efficiency is increasing with the increase of output power. At lower output it was very low.

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