Compressed Air Retrofit Kit for Existing Motor Vehicles

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***Abstract*—Keeping in view the climate change, the dependence on petroleum reserves as the primary energy source, and volatile fuel prices, it is imperative to explore possible opportunities in unconventional alternative-fuel technologies. One of the choices available is the Compressed Air Vehicle (CAV), or air car, powered by a pneumatic motor and on-board high-pressure gas tank. While proponents claim CAVs offer environmental and economic benefits like zero emissions (in fact, the exhaust air is cleaner than the ambient air because of the filters used) and the cold exhaust being used for the air conditioning system, the technology has not been subject to more rigorous analysis. Also, in a compressed air engine, air alone can be used as the fuel, or it can be used in amalgamation with traditional fuels or electricity. Just using air is the most suitable option because it drastically reduces weight of the vehicle and improves the efficiency.**

Developing a whole vehicle to run on pneumatic systems will prove an outright tedious and without doubt a costly affair, modification of current internal combustion engines to run on compressed air is an avenue that this paper explores.

***Index Terms*—Alternative fuel, Compressed Air, Small engine, Zero Emission**

I. INTRODUCTION

Of all the problems generated by fossil fuel use, the most challenging will be surviving the withdrawal from that use, after worldwide oil production peaks and begins to decline.

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Peak oil is the point in time when the maximum rate of petroleum extraction is reached, after which the rate of production is expected to enter terminal decline. The oil crisis will begin when demand for oil consistently begins to exceed supply. After the peak, demand and supply can no longer match. Keeping in view the discerning climate crisis, the dependence on petroleum reserves as the primary energy source, and volatile fuel prices, we have to explore possible opportunities in unconventional alternative-fuel technologies. Compressed air as an alternative fuel can offer a solution to most of the aforementioned problems.

At first glance, the idea of running a car on air seems almost too good to be true. If we can use air as fuel, why think about using anything else? Air is all around us. Air never runs out. Air is non-polluting. Best of all, air is free. Using the potential energy stored in compressed air for running engines and propelling vehicles can prove to be a clean and sustainable alternative.

Instead of going into development of a whole new pneumatic system to run on compressed air, which demands appreciable investment of capital and research, the solution proposed here is to run existing two stroke engines on air with no or minimum modification to their construction.

II. WORKING PRINCIPLE

The basic principle of the CAE is quite modest. Instead of the gases produced when a traditional fuel is burnt in the cylinder, the expanding air is used to push the piston down and the remaining functioning of the engine remains unaffected.

The source of energy in a CAE is the high-pressure compressed air tank. Unlike other fuel types, which store energy within the chemical bonds of the fuel, compressed air derives its energy from the thermodynamic work done by an expanding gas. A compressed air tank is energy storage medium similar to an electric battery, in that both are charged from an external source, and release a portion of that power to the vehicle, with the remainder lost to inefficiencies or other limitations. Since the power and range of a CAV depends on the amount of on-board energy, and since its small form factor places restrictions on the size of storage tanks, the vehicle's design requires a high energy-density fuel for acceptable performance. However, compressed air is a poor energy carrier compared to conventional fuels and rechargeable batteries. Greater energy density is possible with greater storage tank pressures but creates trade-offs in terms of losses in gas expansion.

III. DESIGN PLAN

Several key constraints are considered regarding the existing two stroke engine for characterizing the conversion of a two stroke engine into a compressed air engine. The first one is that the base technology is needed to be economically available. Secondly, the final system should not deteriorate the ability of the two stroke engine to operate in hostile conditions. The third constraint is that the simplicity of the existing two stroke engine should not be sacrificed for the attainment of the goal. Fourthly, the part of the energy consumed by the injection system of the compressed air engine should be comparable to the existing two stroke engine. Last but the most important compulsion is that the kit must be inexpensive to install, with commonly available tools and adequate expertise.

IV. CHOICE OF SYSTEM

The two stroke engines studied for the conversion into compressed air engine are: spark ignition engine and compression ignition engine.

The compression ignition (CI) engine is based on diesel cycle which uses diesel oil as fuel due to lower self-ignition temperature. A high pressure fuel pump and injector is required to inject the fuel into the chamber. For direct injection diesel engines with a displacement of 0.5 Lt. per cylinder, the compression ratio is approximately 18: 1 [3]. It has low speed (RPM) due to its heavy weight.

The spark ignition (SI) engine is based on otto cycle which uses gasoline as fuel due to high self-ignition temperature. The fuel and air mixture as a gaseous mixture is introduced in the combustion chamber during the suction stroke. A carburetor is used to mix the fuel and air mixture in desired ratio. It has the compression ratio of 10 [3]. It has high speed (RPM) due to its light weight.

The spark ignition engine is found to be more suitable because it inherits several structural features which offer high degree of customizability and tuning. It is much easier to mount and dismount the components like spark plug, carburetor and flywheel form the engine. The low weight of the moving parts offer less resistance, thus an instant torque is obtained even at low pressure of injected air.

V. ENGINE MODIFICATIONS

A. Cylinder Head

Instead of designing and casting a new cylinder head for the purpose of the injecting compressed air into the combustion chamber, the existing cylinder head could be applied to this purpose with minimum modifications. The spark plug is seated at the top of cylinder head of the engine. In general, a spark plug of two stroke SI engine has an isometric screw thread profile: M14x1.25 or M18x1.5 [4]. The spark plug is dismounted and the internal threads present on the cylinder head are machined until it is completely removed.

Thereafter, the plain cylindrical bore obtained is threaded according to profile of given adapter or reducer nipple. The adapter nipple connects the engine cylinder to the solenoid valve as shown in the figure 1.

Fig. 1. Modified cylinder head ready for fitting adapter nipple.

B. Intake Port

The carburetor does not find any application in the engine running on compressed air only which is injected at the top of the combustion chamber. Therefore, it is advantageous to remove the carburetor since it will help to reduce the weight of the engine. Next to carburetor, a reed valve could be located. Its removal will eliminate the pressure force applied to piston in opposite direction during the expansion stroke. Moreover, these modifications will also facilitate the quick removal of the residual air from the combustion chamber at the end of the expansion stroke.

C. Flywheel

The existing flywheel of the two stroke SI engine is magnetized and a stator coil lies underneath the magnetized flywheel. The internal coil and magnet could interfere with the field of the external magnet which leads to malfunctioning of the magnetic sensor. Therefore, the flywheel along with the coil is removed with the help of tools. A steel disc of equivalent weight is attached to a separate fanwheel using nuts and bolts in the manner as shown in the figure 2. The steel disc and fanwheel assembly is then mounted on the crankshaft of the engine. This type of arrangement has an advantage of adding or removing additional weight later without any modification.

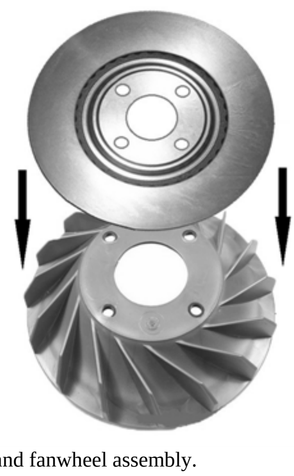

Fig. 2. Steel disc and fanwheel assembly.

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VI. ADDITIONAL COMPONENTS

A. Storage Cylinder

In order to use compressed air engine in vehicles for transportation purpose, high pressure storage cylinder is used to store the compressed air. Therefore, the storage system must be compact and lightweight. Advanced fiber-reinforced bottles are comparable to the rechargeable lead-acid battery in terms of energy density and has longer lifetime. Generally, the cylinder is fitted with stop valve. The valve also includes a pressure relief device.

B. Pressure Regulator

A pressure regulator is used to reduce the high pressure of compressed air in the storage cylinder to working pressure of the engine and solenoid valve. Proper selection is critical for a safe and effective transfer of the compressed air from the supply to the solenoid valve.

A two-stage regulator is used since reduction produces a final delivery pressure showing little effect from changes in cylinder pressure. Generally, the regulator has built-in pressure gauges; one to show inlet pressure and the other to show delivery pressure.

C. Air Filter and Lubricator

This unit usually is a combination of components that filters the air and adds lubricants for moving parts in the circuit. Compressed air contains dust, condensed water, and rust and oil sludge which must be removed to keep moving parts of the machine working properly.

Some of the components of the engine require a small amount of lubrication to extend their life and maintain torque. The air filter and then air lubricator are present in supply line of compressed air as shown in the figure 4.

D. Hoses and Fittings

Hoses are used for carrying compressed air from storage cylinder to the engine. Hoses are made from one or a combination of many different materials. Polytetrafluoroethylene (PTFE) hoses are preferred because it is chemically inert and usable at temperature ranging from -70°C up to +260°C. Hose-barb to male-pipe fitting is used to connect hose to the components like pressure regulator, air filter and lubricator and solenoid valve.

VII. ELECTRICAL COMPONENTS

A. Reed Switch

The reed switch is an electrical switch operated by an applied magnetic field. As shown in the figure 3, reed switches comprise of two ferromagnetic reeds placed with a gap in between and hermetically sealed in a glass tube. The glass tube is filled with inert gas to prevent the activation of the contacts. The surfaces of the reed contacts are plated with rhodium.

As shown in the figure 3, reed switches are operated by the magnetic field of an energized coil or a permanent magnet which induces north (N) and south (S) poles on the reeds. The reed contacts are closed by this magnetic attractive force. When the magnetic field is removed, the reed elasticity causes the contacts to open the circuit. The reed contacts are closed by this magnetic attractive force.

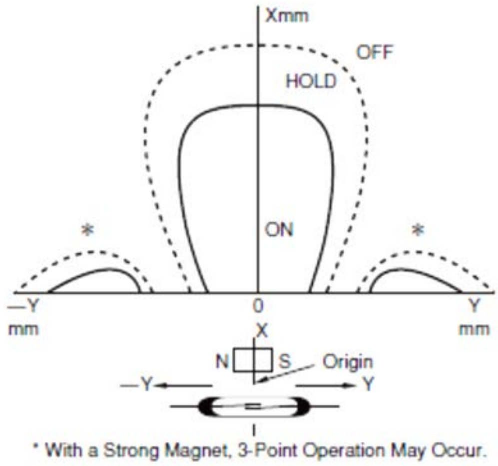

Fig. 3. Reed Switch in presence of magnetic flux.

When the magnetic field is removed, the reed elasticity causes the contacts to open the circuit. When a reed switch is operated by a permanent magnet, its ON-OFF domains will differ according to the type of the reed switch, its pull-in and drop out values, read forming conditions as well as the permanent magnet material, its shape, and magnetizing conditions.

B. Solenoid Valve

A solenoid valve is an electromechanically operated valve. The valve is controlled by an electric current through a solenoid. They are found in many application areas. Solenoids offer fast and safe switching, high reliability, long service life, good medium compatibility of the materials used, low control power and compact design.

Most solenoid valves operate on a digital principle. They therefore possess two distinct states, which are (1) - when the coil is activated by an electrical current, and (2) - when the valve is resting (without electricity). Valve functions are defined from the resting position. A solenoid valve is normally closed (abbreviated - NC) if there is no flow across the valve in its resting position (with no current on the solenoid contacts). The key to the operation of a proportional valve is a balance established between the forces in action on the plunger.

These balanced forces include a mechanical force provided by a spring specially developed for proportional valves and a magnetic force created by the current level passing through the coil. The spring force is proportionally opposed by the magnetic force.

Taking into account the working parameters and with an estimated range of working pressure between 0-10 bar a NC 24v DC Solenoid Valve constructed of brass was selected .The technical Specifications are given in table I.

TABLE I
TECHNICAL SPECIFICATIONS

Parameter	Specification
Supply Voltage Max	24VDC
Operating Pressure Max	10bar
Fluid Temperature Max	50°C
Material	Brass with stainless steel inner parts.

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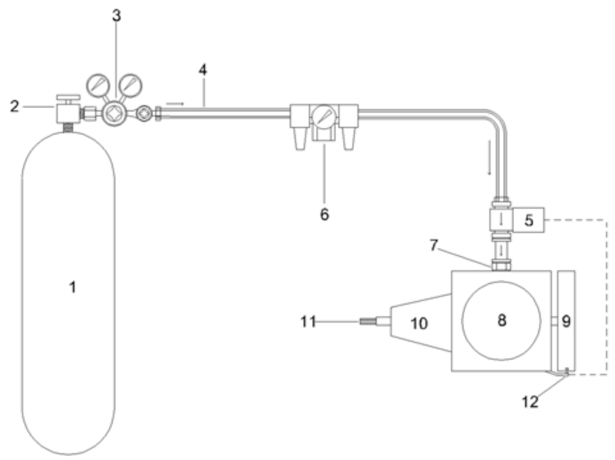

Fig. 4. Schematic diagram of compressed air engine.
1. Storage Cylinder
2. Stop Valve
3. Pressure Regulator
4. Hose
5. Solenoid Valve
6. Air Filter and Lubricator
7. Adapter Nipple
8. Two Stroke SI Engine
9. Flywheel
10. Gearbox
11. Transmission Shaft
12. Magnetic Sensor

VIII. CAE KIT OPERATION

Unlike gasoline or diesel engines, the CAE technology does not use any form of internal combustion. Compressed air (or other gases or combination of gases) is used as energy carrier and storage medium. The air is stored at pressure of around 200bar in compressed air storage cylinders. For energy carrying purpose, the pressure of the compressed air is reduced to around 10 bar or less using pressure regulator connected in front of cylinder valve. The air with reduced pressure is carried by poly-Teflon hose. The hose is then connected to the solenoid valve using barbed fitting. The air inlet timing and duration is controlled by the Solenoid valve. A small magnet is attached on the flywheel and a sensor is fitted very close the flywheel. After each revolution of the flywheel, the sensor gets activated by the magnetic field of the magnet passing nearby and sends signal to solenoid valve. The air is fed through an air injector to the engine and flows into which air expands. The air pushing down on the piston moves the crankshaft, which gives the vehicle power. The flywheel stores some energy to provide it back during the upstroke.

The process taking place inside the cylinder could be divided into four stages (in reference to the figure 5):

A. Stage 1

The Reed switch sensor detects the magnets attached to the flywheel and the signal is transmitted to the solenoid valve. As a result compressed air at 10bar or less is injected at TDC by injector at the cylinder head. The compressed air is injected till 10-15 degree after TDC. The injected air immediately acquires the passage above the piston.

B. Stage 2

As the magnet moves away from the Reed switch, the signal transmission is discontinued and hence, the solenoid valve closes, disrupting the flow of air in to the engine. The compressed air in passage in the cylinder then starts to expand and forces the piston down. The piston moves the crankshaft which powers the vehicle, reducing the air pressure inside the cylinder.

C. Stage 3

At about 35 degree before BDC, both the exhaust and transfer ports are exposed to the chamber having reduced air pressure (still greater than the atmospheric pressure). The pressure is relieved and chamber’s pressure becomes equals to the atmospheric pressure.

D. Stage 4

From 35 degree after BDC, the air remaining in chamber at atmospheric pressure is compressed by the upward movement of the piston and the cycle is repeated.

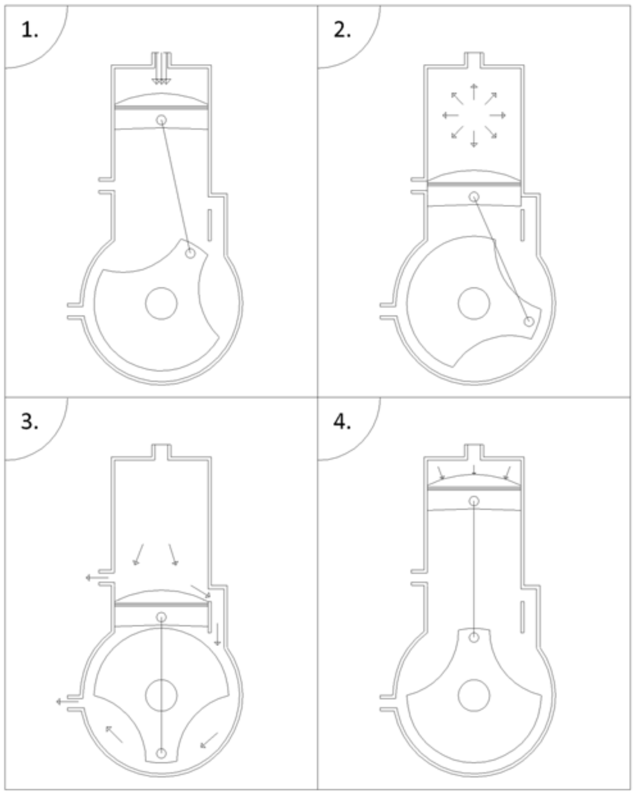

Fig 5. Different stages in CAE working cycle.

IX. RESULTS AND FINDINGS

The significant part of experimentation was concentrated on two aspects:
1) Running the engine at different pressures and observing the differences in speed (RPM) and,
2) Varying the injection timing by some degrees before or after TDC by moving the timing magnets along the rim of the flywheel.

A. Analysis of results

The engine was successfully tested at majorly two pressures. At a lower ~10 bar with a lower capacity (max. 10 bar) two-way NC solenoid valve and a higher ~25 bar with a higher capacity (max. 30 bar) three-way NC solenoid valve. Both valves had a similar delay period of about 20ms. At each of these pressures, the position of the timing magnets was varied, hence varying the injection time which had significant effect on the engine speed. Few of the observations are tabulated in table II.

TABLE II
VARIATION OF RPM WITH THE CHANGE IN PRESSURE AND INJECTION ANGLE

Work Pressure	Injection Angle	RPM (Maximum)
10 bar	10° before TDC	715
	At TDC	845
	5° after TDC	910
	10° after TDC	993
	15° after TDC	964
25 bar	10° before TDC	1191
	At TDC	1332
	5° after TDC	1450
	10° after TDC	1483
	15° after TDC	1472

B. *Utility of results*

The study of the flywheel rotation pattern helps in coming to the following conclusions:

1) The optimum point of injection is about 10-15degree after TDC.
2) The non-availability of standard parts severely restricted the maximum achieved speed (RPM) of the engine. The solenoid valves used had a delay time of ~20ms. If a valve with delay time of the order of ~2ms was to be used, theoretically, the maximum speed can be increased to about 5 times that of what was observed here.
3) The low speed calls for incorporation of a CVT (Continuous Variable Transmission) in place of a normal gear box for real world utilization.

Taking into totality the amount of time, effort and capital input in the project, it can be safely inferred that yes, this is a technology that does hold up to its promise of replacing fossil fuels as the energy source to power our automobiles but not at this point of time. The technology is in its infancy and demands full scale research and investment for its full scale.

X. MERITS & DEMERITS

Some advantages and drawbacks of the system are quite apparent even from a layman point of view like the kit enables to look beyond fossil fuels for the daily transportation fuel needs and the vehicles employing the kit losing some power and range. But some points are not so obvious and this calls for a clear listing that follows.

A. *Merits of the system*

1) Much like electrical vehicles, the system would ultimately be powered through the electrical grid, which makes it easier to focus on reducing pollution from one source.
2) Transportation of the fuel would not be required due to drawing power off the electrical grid. This presents significant cost benefits. Also, pollution created during fuel transportation would be eliminated.
3) Air, on its own, is non-flammable. Hence high degree of safety is maintained.
4) The mechanical design of the engine is simple, robust and already proven for fossil fuels that produce significantly tougher operating conditions.
5) Low manufacture cost of the kit as well as easy maintenance.
6) Compressed-air tanks can be disposed of or recycled with less pollution than batteries.
7) Compressed-air system components are unconstrained by the degradation problems associated with current battery systems.
8) The tank may be refilled more often and in less time than batteries can be recharged, with re-fuelling rates comparable to liquid fuels if a full-fledged system exists.

B. *Demerits of the system*

1) When air expands, as it would in the engine, it cools dramatically (Charles law) and must be heated to ambient temperature using a heat exchanger similar to the intercooler used for internal combustion engines. This might be problematic if the kit is employed on a full scale automobile.
2) Refueling the compressed air container using a home or low-end conventional air compressor may take as long as 4 hours (although the specialized equipment at service stations may fill the tanks in only minutes).
3) Tanks get very hot when filled rapidly. SCUBA tanks are sometimes immersed in water to cool them down when they are being filled. That would not be possible with tanks in a vehicle and thus it would either take a long time to fill the tanks, or they would have to take less than a full charge, since heat drives up the pressure.
4) The limited storage capacity of the tanks will severely hinder the distance possible to cover with even a fully charged cylinder.

XI. CONCLUSION

This kit basically represents the idea about providing an alternative to the current energy scenario by modifying existing vehicles rather than altogether manufacturing new, more efficient ones, and doing so in an affordable and economical way.

The CAV is aimed to open new avenues to explore in the area of fuels as needless to say, conventional sources of energy are limited and due to that, the price of petroleum products also continues rise by the day. Also, while considering alternate fuels, some factors are to be considered like availability, economy, and environment friendliness etc., based on that compressed air technology is the best technology and demands more attention as it tends to take the engine to zero pollution running on a fuel that is

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freely available. Even though the vehicles running on the CAV kit seem to compare poorly to gasoline and electric vehicles in range and power & their applications severely constrained due to their limited driving range, it may be an ideal mode of transportation once enough research and analysis are put in the field.

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