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Conversion of Single Cylinder 2-Stroke Petrol Engine into Compressed Air Engine using a Cam-operated DCV

Radheshyam Wagh , Sagar Nikam
Dept. of Mechanical Engg.
Jawaharlal Nehru Engineering College
Aurangabad, Maharashtra – 431001, India
{radheshyamwagh & nikamsagarsn}@gmail.com

Yogesh Salame
Asst. Works Manager
Bafna Motors India Pvt. Ltd.
Waluj, Maharashtra – 431136, India
yogeshsalame@gmail.com

Swamini Chopra*
Dept. of Metallurgical and Materials Engg.
Visvesvaraya National Institute of Technology
Nagpur, Maharashtra – 440010, India
chopra.swamini@gmail.com

Abstract - This study present the modification of a conventional single-cylinder 2-stroke petrol engine into a compressed air engine using purely mechanical components such as custom-made cam and a simple 5/2 DCV. The objective of this study was to fabricate a working model of compressed air engine at low cost and successfully run the engine to obtain more or equal power as that of conventional IC engine. The engine was tested for air pressure between 2 bar to 9 bar. Beyond this pressure the DCV started making excessive noise, thus increasing its chances of damage. The engine speed and engine power increased linearly with increasing air pressure and maximum torque was obtained at 8 bar. This demonstrates the feasibility of the modified air engine for practical applications such as two-wheeler and low load vehicles. With the use of higher capacity DCV, higher air pressures can be used to obtain maximum possible power output from the engine without any significant damage to any of the components.

Keywords - *compressed air engine, modification, custom-made cam, DCV.*

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I. INTRODUCTION

"We do not inherit the earth from our parents; we borrow it from our children". This is a famous saying by a French author; Antoine de Saint-Exupéry. This saying has started making more and more sense as the mankind makes rapid technological progress. Making progress is no sin, yet many problems arise out of it such as global warming, climate disruption, desertification, floods, hurricanes, rising sea levels, etc. Scientific research proves that one of the main causes of global warming is carbon emissions and one of the major sources of carbon emission is automobiles. But rapid depletion of fossil fuels (i.e. petroleum, diesel, natural gas and coal) and also the problems associated with their combustion such as green house effect, ozone layer depletion, acid rains, etc. has made the automobile manufacturers aware of the need of replacing them. As a result of this, many researchers started working on finding an alternative to fossil fuels which will not affect the environment and also maintain the performance characteristics of automobiles. Various types of engines that use green energy have been investigated throughout the years to replace the conventional engines. These modifications majorly include electric engines, hydrogen cell engine and air engines. Electric engines are the most common type that has been developed for a long time. However, they possess few disadvantages such as; they require heavy batteries with slow charging rate, complicated design, expensive, etc.

In recent years, the use of compressed air as a source of power generation in engines has been gaining momentum. Using the potential energy of stored compressed air for moving the piston and propelling the vehicle is a clean as well as cheap alternative. Air is abundantly available in atmosphere and can be compressed to higher pressures in very low costs. So far, all the attempts in replacing fossil fuels has led to a reduction in the amount of polluting gases from the vehicle, but air being non-polluting can help in completely eradicating the pollution from automobiles permanently. Thus, the use of compressed air as fuel source must be encouraged.

II. HISTORY

The use of compressed air as an energy source is not exactly a recent technology. Mankind has been making use of uncompressed airpower from centuries in different application viz., windmills, sailing, balloon car, hot air balloon flying and hang gliding etc. The use of compressed air for storing energy has been in existence since the 19th century as the basis of previous naval torpedo propulsion. By the end of the 19th century, the first approximation of what could one day become a compressed air driven vehicle, was the first pneumatic locomotive used in mining [1,2].

The first patented compressed air vehicle was established in France by a Polish engineer Louis Mekarski in 1870. It was patented in 1872-1873 and was tested in 1876. The Mekarski air engine became the first creation to be used for street transportation. The Tramway de Nantes, located in Nantes, France, was noted for being the first to use Mekarski engines to power their fleet of locomotives. The tramway began operating in 1879. However, the first urban transport locomotive was not introduced until 1898, by Hoadley and Knight. But Charles B. Hodges will really be remembered as the true father of the compressed air concept applied to cars.

He was the first person, not only to invent a car driven by a compressed air engine, but also to have considerable commercial success with it. In 1911 he designed a pneumatic locomotive and sold the patent to the H. K. Porter Company in Pittsburgh for use in coal mines. Due to the safety that this method of propulsion, they were a much safer option in the coal industry [3,4].

Another application of the compressed air to drive vehicles comes from Uruguay in 1984, where Armando Regusci has been involved in constructing these machines. He constructed a four-wheeler with pneumatic engine which travelled 100 km on a single tank in 1992. Another noticeable milestone in the field of compressed air vehicle is the Air Car developed by Luxembourg-based MDI (Moteur Development International) Group founder and former Formula One engineer Guy Negre. He developed a compressed air 4-cylinder engine in 1994 and claimed it to be Zero Emission Vehicle (ZEV) [1,2,4].

Several companies have started to develop compressed air vehicles, although none has been released to the public so far. Tata Motors of India has signed an agreement with MDI to develop a car that runs on compressed air, thus making it very economical to run and almost totally pollution free. Although there is no official word on when the car will be commercially manufactured for India, reports say that it will be sooner than later [2].

III. LITERATURE REVIEW

Developing a whole new pneumatic system to run the engine requires high capital cost and complex designing. The solution for this is incorporating appropriate modifications in existing IC engines and making it suitable to run on compressed air. Many such attempts have been made on workshop levels and few studies have been reported also.

Wang et al. [5] converted a 100cc 4-stroke internal combustion engine into a 2-stroke compressed air engine and later was mounted on a motor vehicle for demonstration. The torque showed an increasing liner relation with increasing RPM, while power output of engine first increased and then reduced with engine speed. The vehicle installed with the compressed air engine operated at a maximum speed of 38.2 km/hr for a distance upto 5 km. These results shows the feasibility of using compressed air engine in a vehicle but it arises the problem of short range due to limited air supply and low energy density of compressed air.

Yadav and Singh [6] modified a single cylinder conventional engine to run on compressed air. They observed that the power of the engine increased with an increase in injection pressure of compressed air, while the friction forces were observed to be higher, thus reducing the mechanical efficiency of the engine. Rohamare et al. [7] modified a single cylinder 4-stroke engine into air engine. They tested the engine for different compressed air pressure values and evaluated the trend of engine RPM. It was found that the engine RPM increased with air pressure.

Saxena et al. [8] converted a 4-stroke SI engine into a pneumatic engine and tested it at the pressure of 5 bars. The engine was modified such that the conventionally separate strokes of suction and compression became a combined suction and power stroke for modified engine and the separate power and exhaust strokes became the exhaust stroke. To avoid the piston locking due to such change of stroke sequence, it is usually suggested to modify the cam profile such that both the valves open in alternating strokes. But in their design the authors solved this problem by incorporating a hole in the piston head to allow the inducted air to escape.

Keeping in view that modifying an existing IC engine into compressed air engine is easier at institute level; this paper makes an attempt at converting a single cylinder 2-stroke petrol engine into a compressed air engine operated with the help of a cam-operated DCV.

IV. EXPERIMENTAL DETAILS

A. *Modifications Incorporated*

A 145.45 cc single cylinder 2-stroke petrol engine was modified into a compressed air engine. The specifications of the engine as provided by the manufacturer are given in Table 1.

TABLE I
SPECIFICATIONS OF THE ENGINE MODEL USED

Make and Type	Bajaj chetak, 2-stroke
Displacement	145.45 cc
No. of cylinder	1
Top speed (on vehicle)	80 kmph
Max. Power	7.5 BHP (5.93 kW) @ 5500 RPM
Max. Torque	10.8 N-m @ 3500 RPM
Ignition type	CDI Electronic
Transmission type	4-speed, Constant mesh
Clutch type	Wet multidisc

For the proper flow of compressed air in and out of the cylinder only two paths are required; one for inlet and one for exhaust. As a 2-stroke engine has three ports, the transfer port needed to be blocked. This was accomplished by sealing off the transfer port using a cylinder liner. A new cylinder liner was fitted inside the cylinder block and was later super-finished to achieve sufficient clearance between piton and cylinder. Fig. 1 shows photographic view of the blocked transfer port after the insertion of cylinder liner and the exhaust port at the side of the cylinder wall.

Fig. 1 Photographic view of Cylinder block after modifications

Also, the spark plug in petrol engine is not required for compressed air engine, so it was also needed to be removed. After the removal of spark plug, one additional opening was created in the cylinder head. This opening was used as inlet port for compressed air. It was speculated that if the high pressure compressed air entered the cylinder from top and hit the piston on its head, it will convert maximum potential energy of the air into useful power. Thus, for that purpose the flexible pipe from the compressed air tank was fixed at the position of spark plug with the help of a connector. To accommodate the connector at the position of spark plug, counter-threads of the same dimension as that of the connector were tapped on the cylinder head opening.

After modifying the cylinder head, the conventional inlet port was then used for providing lubricant into the cylinder and piston assembly. There was a possibility of high pressure compressed air coming out of the lubricant entry opening through the reed valve at the beginning of inlet port. To avoid this type of leakage, it was ensured that the valve was screwed tightly enough to hold the high pressures acting on it from inside.

A direction control valve is the most important component of a pneumatic system. Commonly known as DCV, this is a mechanically operated valve that helps to control the direction of air flow. For present study, a 5/2 DCV valve was used, whose specifications are given in Table 2. Fig. 2 shows the photographic view of actual DCV used.

TABLE II
SPECIFICATIONS OF THE 5/2 DCV USED

Make and Model	JELPC, MSV86522R
Working medium	40 micron filtered Air
Pressure range	0~0.8 MPa
Temperature range	0~60ºC
Effective section area	16 mm^2 (CV=0.67)
Joint pipe bore	G1/4”

Fig. 2 Photographic view of JELPC 5/2 DCV

The DCV was operated using a cam mechanism. A simple custom-made cam was provided on the flywheel such that the position of the piton inside the cylinder was represented as close to the reality as possible. Fig. 3 shows the close up view of the cam mounted on the flywheel face and the path of motion of the DCV roller.

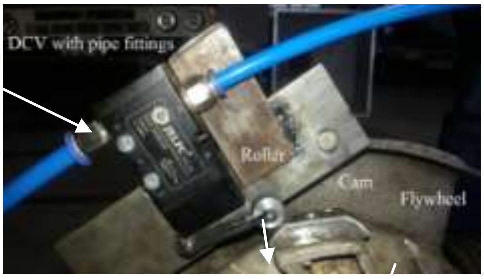

Fig. 3 Photographic view of DCV roller and cam mounted on flywheel

B. Working of compressed air engine

The complete assembly of the modified air engine having the cam operated valve mechanism, flywheel and piping system is shown in Fig. 4 and its working is explained below:

Fig. 4 Photographic view of complete assembly of modified air engine

For initial start of the engine the cam mounted on the flywheel is held stationary on upper side as seen in Fig. 4. When initial rotary motion is given to the flywheel by external means, the cam triggers the DCV with the help of the roller. As the inlet of the DCV opens, compressed air enters the cylinder through the cylinder head when the piston is at 5 degrees after TDC. The expansion of the air inside the cylinder exerts the

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necessary force to push the piston downward, thus completing the power stroke. When the piston reaches BDC, the air escapes from the exhaust port at the side of the cylinder wall into the atmosphere. When at BDC, the piston moves upward due to the inertial motion of the flywheel and reaches TDC. At 5 degrees after TDC, the DCV actuates again and the cycle is repeated.

C. Experimental Procedure

The objective of this experiment was to study the performance of the modified engine with different air pressures. The compressed air was supplied through an air tank at a constant pressure value which was measured using a pressure gauge mounted at the outlet of the air tank. At every pressure reading, the engine RPM was measured from the flywheel centre by using a tachometer and the torque of the engine was also measured using an inertial dynamometer. An average of three readings was taken as final. From the final value of torque, the brake power of the engine at each air pressure value was calculated mathematically using the formulae:

$$Power = \frac{2 \times \pi \times Speed \times Torque}{60} \qquad (1)$$

where, Power is in Watt

Speed is in RPM

Torque is in N-m

V. RESULTS AND DISCUSSION

During the trial run it was observed that the engine did not start until 0.7 bar of air pressure. Beyond that the engine started to run but at very small RPM values. The range of RPM became noticeable around 1.1 bar air pressure. Also, the capacity of the DCV specified by the manufacturer is 0.8 MPa i.e. 8 bar. Beyond that the DCV started to make excessive noise, thus increasing its chances of damage. Hence, for the purpose of calculation of engine power, the air pressure values were taken from 2 bar to 9 bar. Table 3 shows the values of air pressure, engine speed and torque obtained after testing the modified compressed air engine along with the calculated values of power. Fig. 5 shows the combined graph of speed, torque and power versus air pressure.

TABLE III
EXPERIMENTAL AND CALCULATED READINGS

Sr. No.	**Pressure (bar)**	**Speed (RPM)**	**Torque (N-m)**	**Power (kW)**
1	2	353	51.65	1.909
2	3	417	51.68	2.257
3	4	462	48.98	2.37
4	5	524	52.71	2.892
5	6	565	50.26	2.974
6	7	592	52.52	3.256
7	8	618	52.96	3.427
8	9	667	51.83	3.62

From the results of the testing, it was clear that the engine speed increased linearly with the pressure of compressed air. This happens due to the fact that higher pressure of air signifies higher amount of potential energy stored in the air. At higher pressures, more energy is released in the same amount of space. This pushes the piston faster than that at lower pressures and hence increases the RPM with increased pressure. The graph of torque versus pressure shows that the torque fluctuates with increasing speed and there is no fixed trend in its behavior. Irrespective of this, the value of torque remains in more or less closer range. It was observed during the experiments that the DCV started making excessive noise at 7 bar pressure and above. This increased the vibrations in the engine set-up at the junction of DCV assembly. Hence, for given range of air pressures, the maximum torque of 52.96 N-m is observed at 8 bar air pressure and 618 RPM engine speed. The power calculated later mathematically also shows a liner trend with respect to air pressure. Maximum power of 3.62 kW was calculated for 9 bar air pressure and 667 RPM. From the graph of power versus pressure it can be expected that higher pressures may give more power output.

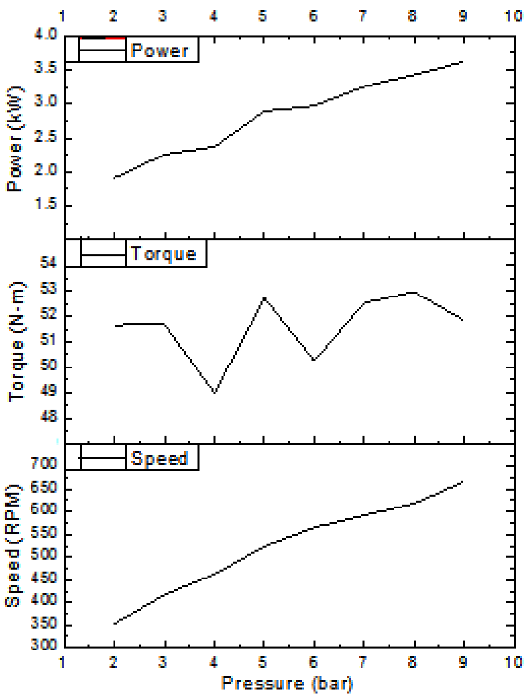

Fig. 5 Combined graph of speed, torque and power versus pressure

VI. CONCLUSIONS

This study was carried out to evaluate the performance characteristics of a modified compressed air engine. The modifications incorporated in the engine were; the transfer port was sealed off, the spark plug was removed, the spark plug cavity was used as inlet for compressed air, the conventional inlet was used to supply lubricant into the cylinder, a DCV was used to control the flow of compressed air and a custom-made cam was mounted on the flywheel to actuate the DCV. From the results obtained, it can be concluded here that the modification of conventional single cylinder 2-stroke engine into compressed air engine was successful. This demonstrates the feasibility of the modified air engine for practical applications such as two-wheeler and low load vehicles. Purely mechanical modifications such as custom-made cam and DCV make the modification of conventional engine easier and in low budget cost. With the use of higher capacity DCV, higher air pressures can be used to obtain maximum possible power output from the engine without any significant damage to any of the components.

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