The Applications of Piston Type Compressed Air Engines on Motor Vehicles

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Abstract

This study presents the applications of piston type compressed air engine on a small size motor vehicle. A conventional 100cc four-stroke internal combustion engine (IC engine) was modified to a two-stroke compressed air engine and the power output has been examined with different intake valve timing and supply air pressures on a test bench. The compressed air engine was installed on a motorcycle for the demonstration of vehicle application. The success of this application demonstrates the concept of green energy vehicle with zero emission using compressed air energy. The motorcycle installed with the compressed air engine can operate at maximum speed around 38.2 km/hr. and distance up to 5 km.

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1. Introduction

In the past few decades, energy conservation and carbon reduction is an important issue in the world. Therefore, researchers have been searching for solutions to reduce carbon dioxide emission and improve fuel consumption. On the other hand, researchers have been also trying to find alternative energy sources like compressed air [1,2]. Different kinds of engine integration or combination that uses green energy have been investigated to replace or assist conventional IC engines. These engines using green energy applications include electric engines, nature gas

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engines and air engines. Hybrid electric engines are the most common engines and had developed for a long time. A hybrid electric engine includes two power sources, a conventional IC engine and an electric motor, that can be operated separately or integrated to provide power output. During deceleration, the electric motor can transfer kinetic energy of vehicle to electric power and store in batteries. This stored energy can be re-applied when vehicle accelerates and known as regeneration. However, there are some disadvantages of electric engines that they require heavy batteries and slow recharge rate. Due to the power integration of electric motor and IC engine in hybrid electric engines, they are complicated in the transmission design and expensive. In the recent years, some researchers proposed the utilization of compressed air engines that use compressed air as power source in piston type engines which are similar to IC engines [3-5]. Selecting piston type engine for compressed air operation has the advantage of easy adapting to conventional IC engines in the consideration of hybrid vehicles.

2. Experimental method

A 100 cc IC engine was modified from four strokes to two strokes for compressed air operation. The intake system of compressed air engine was examined at different intake valve timings, -10° to 80°, -10° to 120°, and -10° to 150°. The power outputs of different intake valve timings were recorded at different supply air pressures and rotational speeds. Fig. 1 shows the comparison of torque and power output from different valve timings acquired at 9 bar air pressure. The results show that the timing of intake valve from -10° to 120° can provide higher power output, and the timing of -10° to 150° can provide more torque at low rotation speed due to longer time of valve open for compressed air filling. After the examination of compressed air engine performance on a test bench, the engine was installed on a motorcycle for test drive. For vehicle application using compressed air engine, compressed air was stored in two compressed air tanks (9L x 2) at ~250 bar air pressure as power source. Two pressure regulators were used to connect the compressed air tanks and engine for adjusting the air pressure. A buffer tank (5L) was installed between the regulators and compressed air engine to stabilize the air pressure during operation. A ball valve installed before the engine intake host is to control the speed of motorcycle by adjusting the air flow rate. The configuration of compressed air engine installed on a motorcycle is shown in Fig. 2 and Fig. 3 shows the picture of the motorcycle with the compressed air engine.

There are two reduction gear ratios 6.1 and 3 examined in the transmission system of motorcycle with compressed air engine. The first one uses conventional CVT driving system from factory installed on motorcycle and the second one has a chain system at gear ratio of 3 instead of the CVT system as shown in Fig 4(a) and Fig 4(b), respectively.

Fig 1. Comparison of power output and torque from different intake valve timings at 9 bar air pressure
Fig 2. Configuration of compressed air engine installed on a motorcycle

Fig 3. Picture of motorcycle installed with compressed air engine

Fig 4. Transmission system (a) reduction gear ratio of 6.1 (b) reduction gear ratio of 3
3. Results and discussion

After the installing the compressed air engine and modifying transmission system on the motorcycle, the test drive has been performed inside the campus of National Tsing Hua University, Taiwan and the driving time and distance were recorded by a GPS system. The evaluation of motorcycle performance during test drive uses the data including maximum speed, average speed, and maximum travel distance. Table 1 shows the results acquired at different reduction gear ratios and different supplying air pressure (as working pressure). Lower supplying pressure (5 bar) can increase the travel distance (2.5 km) of motorcycle; however, it has lower maximum speed (28.9 km/hr) during driving. On the other hand, higher supplying pressure (9 bar) can increase the maximum speed to 36.5 km/hr but it also increases the air consumption and the travel distance reduces to 1.7 km. The maximum speed and travel distance can be improved if changing the reduction gear ratio from 6.1 to 3 as shown in Table 1. It is need to notice that the aforementioned test drive were performed at the same intake valve timing of -10° to 120° and under the condition that the ball valve kept open all the time to ensure the maximum air flow rate, even during braking and turning.

The application of compressed air engine on motor vehicles has been further examined with different driving modes during operation and intake valve opening times. The driving mode has been changed by adjusting the ball valve opening (adjusting the air flow rate) during operation to improve air consumption and increase travel distance. The engine with different intake valve timing has been examined and the performances with vehicle application are shown in Table 2. The results show that the intake valve timing of -10° to 150° can provide faster speed (maximum speed of 35.4 km/hr), which shows highest torque output during the measurements on a test bench. But it has shortest travel distance due to the longer valve opening and higher air consumption. The motorcycle using intake valve timing of -10° to 80° can travel longest distance, up to 5km with average speed of 16.7 km/hr.

| Working pressure (bar) | Reduction gear ratio | Source pressure (bar) | The maximum speed (km/hr) | Average speed (km/hr) | Travel distance (km) |
|------------------------|----------------------|-----------------------|---------------------------|-----------------------|----------------------|
| 5                      | 6.1                  | 250                   | 28.9                      | 18.9                  | 2.5                  |
| 7                      | 6.1                  | 240                   | 35.2                      | 20.7                  | 2.1                  |
| 9                      | 6.1                  | 245                   | 36.5                      | 23.1                  | 1.7                  |
| 9                      | 3                    | 250                   | 38.2                      | 23.7                  | 2.3                  |

| Working pressure (bar) | Intake valve timing | Source pressure (bar) | The maximum speed (km/hr) | Average speed (km/hr) | Travel distance (km) |
|------------------------|---------------------|-----------------------|---------------------------|-----------------------|----------------------|
| 9                      | -10° ~150°          | 250                   | 35.4                      | 20.2                  | 2.5                  |
| 9                      | -10° ~120°          | 250                   | 38.2                      | 22.4                  | 3.3                  |
| 9                      | -10° ~80°           | 250                   | 33.2                      | 16.7                  | 5                   |

4. Conclusion

In this study, the success of motorcycle test drive with compressed air engine demonstrates the feasibility of vehicle applications; however, it also shows the problem of short range with limited air supply and also due to the low energy density of compressed air. Even though the operation of compressed air can be integrated with conventional IC engine using the same arrangement with piston and cylinder, the application as main power system on motor vehicles still have the limitation of short range vehicles like golf cars or ATVs. Further applications on
motor vehicles will need to take the advantages of piston type operation and integrate with conventional IC engines as secondary power system for starting or regeneration during deceleration.

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