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Experimental Study on Effect of Valve timing to Performance of Compressed Air Engine

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Abstract: Compressed air engines driven by only compressed air have been used in various fields, and their characteristics also been studied from various viewpoints. In order to clarify the relationship between the valve timing and the performance of the engine, full-load examinations under the different valve timing conditions were conducted. Engine speed, in-cylinder pressure, torque, intake and exhaust temperature were measured. And then, *P-V* diagram, indicated work, indicated efficiency and so on were obtained and discussed as performance characteristics of the engine. As a result, it is found that the advance of intake and exhaust valve timings strongly effect to the engine performance and the advance of intake and exhaust valve timing should be changed individually for the better engine performance.

Keywords: Solar thermal power generation, Compressed air engine, Valve timing

1. Introduction

Compressed air engines driven by only compressed air have been used in various fields, and their characteristics also been studied from various viewpoints [1-9]. In the previous studies [10, 11], in order to apply a compressed air engine to a prime mover for solar thermal power generation, some experiments were conducted. However, the engine had some problems which are lower efficiency and lower brake power when comparing the other prime movers. The performances of compressed air engine change depending on the timings of the intake and exhaust valves like a spark ignition engine. The purpose of this study is to clarify the relationship between the valve timing and the engine performance.

2. Experimental devices

Firstly, it is necessary to obtain the thermodynamic cycle of the compressed air engine before carrying out the experiment. Figure 1 shows the ideal *P-V* diagram of this cycle. In this figure, the subscripts of P and V show each condition. In this figure, the subscripts of P and V show each condition. In this cycle, processes 1-2-3 are the intake period of compressed air, process 3-4 is an adiabatic expansion period and processes 4-5-1 is exhaust period. The theoretical thermal efficiency, η_{th} is calculated by equation (1). As a result, the theoretical thermal efficiency was 0.29 under supply pressure of 0.3 MPaG condition.

$$\eta_{th} = \frac{L}{H_{in}} = \frac{\left[m_3 C_p (T_3 - T_4) - \{V_1(P_3 - P_4)\} + \{(V_4 - V_1)(P_4 - P_1)\}\right]}{m_{in} C_p (T_{in} - T_1)} \quad (1)$$

H_{in} : the enthalpy of inflow gas
C_p : the specific heat at constant pressure
m : the mass of gas
m_{in} : the mass of the inflow gas

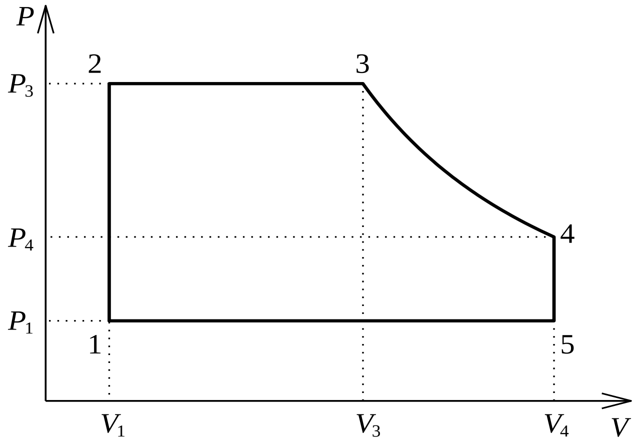


Figure 1. Ideal *P-V* diagram of a compressed air engine

A four-stroke reciprocating SI engine was modified to a two-stroke compressed air engine by changing the gear ratio of the camshaft gear and the crankshaft gear. This compressed air engine can drive by only pressure of compressed air. Figure 2 shows a schematic diagram of the experimental devices. An air compressor provides air to the engine through a pressure regulator. Torque is measured by a torque detector and the output is absorbed by the power generator which adjusts the load. Air temperatures were measured by thermocouples at intake and exhaust port.

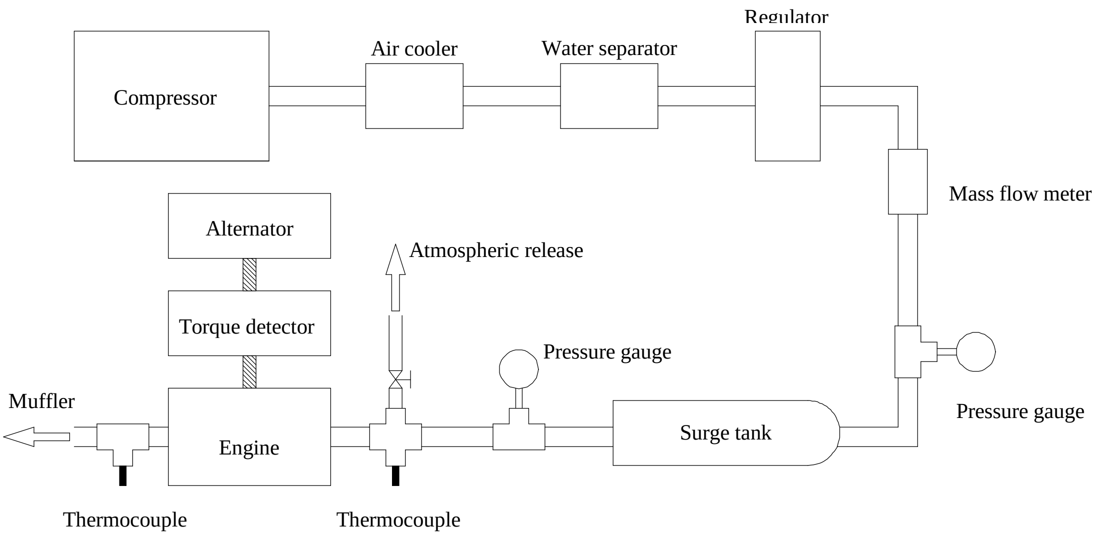


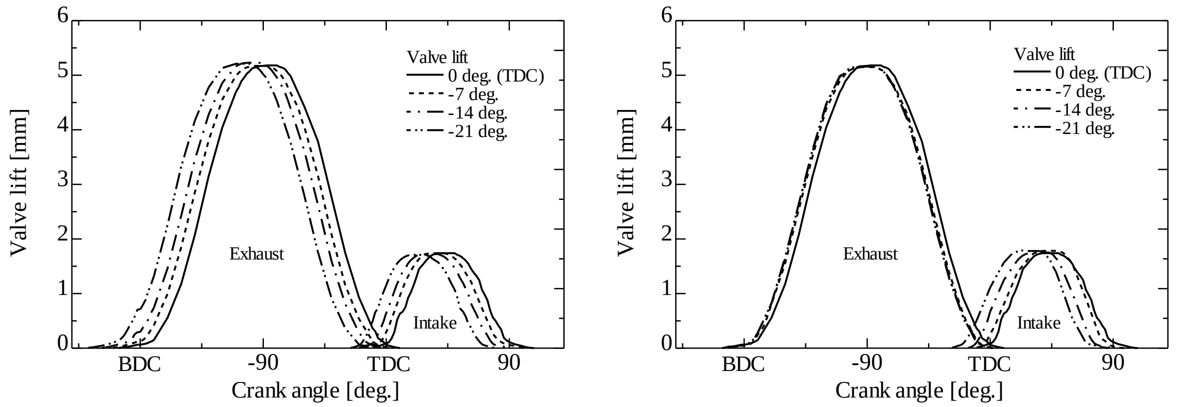
Figure 2. Schematic diagram of the experimental devices.

3. Experimental methods

Table 1 shows the experimental conditions. The experimental conditions are roughly classified into two. Case 1 is the condition that the exhaust valve timing is changed simultaneously with intake valve timing. This engine has single overhead camshaft mechanism which has intake and exhaust cam on the same shaft, so intake and exhaust valve timings are easily advanced at the same angle by the cam gear adjusting. Case 2 is the condition that the intake valve timing is changed and exhaust valve timing is fixed. In this case, the exhaust cams which have the different advance profiles are used for each condition. These valve timings are shown in Figure 3. In both cases, the effective operating angle of the intake cam and the exhaust cam are fixed. The opening timing of the intake valve is advanced each 7 deg. from 0 deg. (top dead center) to -21 deg. Experiments were conducted under the pressure of 0.3 MPaG and engine speed was changed from maximum speed to 1000 rpm every 500 rpm by the load.

Table 1. Experimental conditions

	Case 1	Case 2
Intake valve opening timing [deg. ATDC]	0, -7, -14, -21	
Exhaust valve opening timing [deg. ABDC]	-0, -7, -14, -21 (Changed)	0 (Fixed)
Supply pressure [MPaG]	0.3	
Effective working angle (Intake/Exhaust) [deg.]	90 / 170	



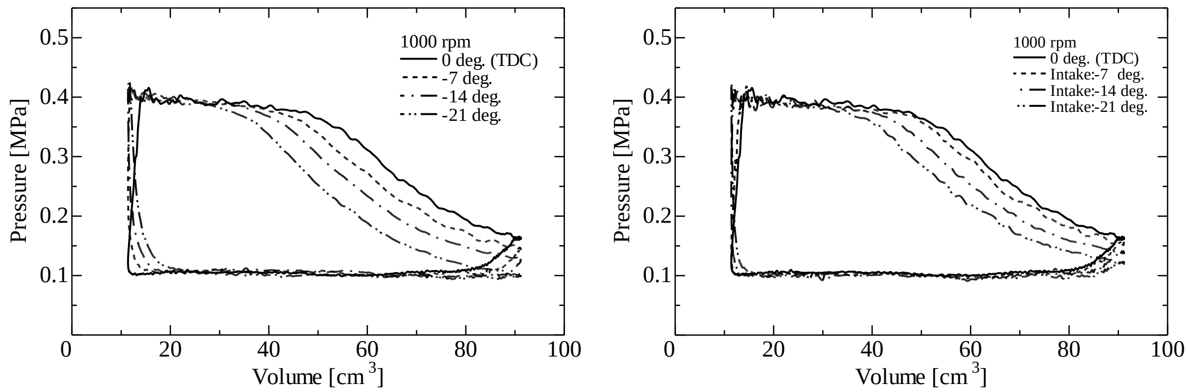
(a) Valve lift curves under the case 1 (b) Valve lift curves under the case 2

Figure 3. Valve lift curve: (a) Valve lift curves under the case 1 conditions; (b) Valve lift curves under the case 2 conditions

4. Results and discussion

4.1. P-V diagram

As typical results of valve timing change, *P-V* diagrams of Case 1 and Case 2 at 1000 rpm are shown in figure 4. In both cases, the pressure during the adiabatic expansion period was kept higher in delayed opening timing condition, so indicated work increased. In the case 1, pressure rising timing before TDC is faster with intake valve opening timing advance and exhaust valve closing timing advance. In the case 2, in contrast, pressure rising timing before TDC is not faster with intake valve opening timing advance.



(a) P-V diagram under the case 1 (b) P-V diagram under the case 2

Figure 4. *P-V* diagram: (a) *P-V* diagram under the case 1 conditions; (b) *P-V* diagram under the case 2 conditions

4.2. Performance characteristics of the engine in each valve timing conditions

Figure 5 shows the performance characteristics of the engine under each valve timing advance conditions. In this figure, the horizontal axis shows the advance of the intake valve opening timing. Hereinafter, the broken lines show the results of case 1 and the solid lines show the results of case 2.

In the case 1, the indicated work decrease with the advance of the valve open timing in every engine speed. In the case 2, however, the indicated works had flat properties. Comparing between case 1 and case2, the indicated work in case 2 was higher than case 1 in every advance condition.

The indicated efficiency was obtained from the indicated power and the enthalpy of inflow air. In both cases, the indicated efficiency had flat properties, so it was found that the advance of intake valve timing did not affect the indicated efficiency under both the case 1 and the case 2.

The brake power was calculated from the measured torque and engine speed. In the case 1, as the opening timing of the intake and exhaust valves became earlier, the brake power decreased considerably. In the case 2, the decrease in brake power was smaller than the case 1. Comparing brake power between the case 1 and the case 2, the brake powers of case 2 were bigger than case 1 at each valve timing. It was caused by the torque because the torques in case 2 were bigger than the case 1 in all engine speed.

From the results, total performance of the case 2 conditions was better than the case 1. It was found that the advances of intake and exhaust valve timings should be changed individually for the better engine performance.

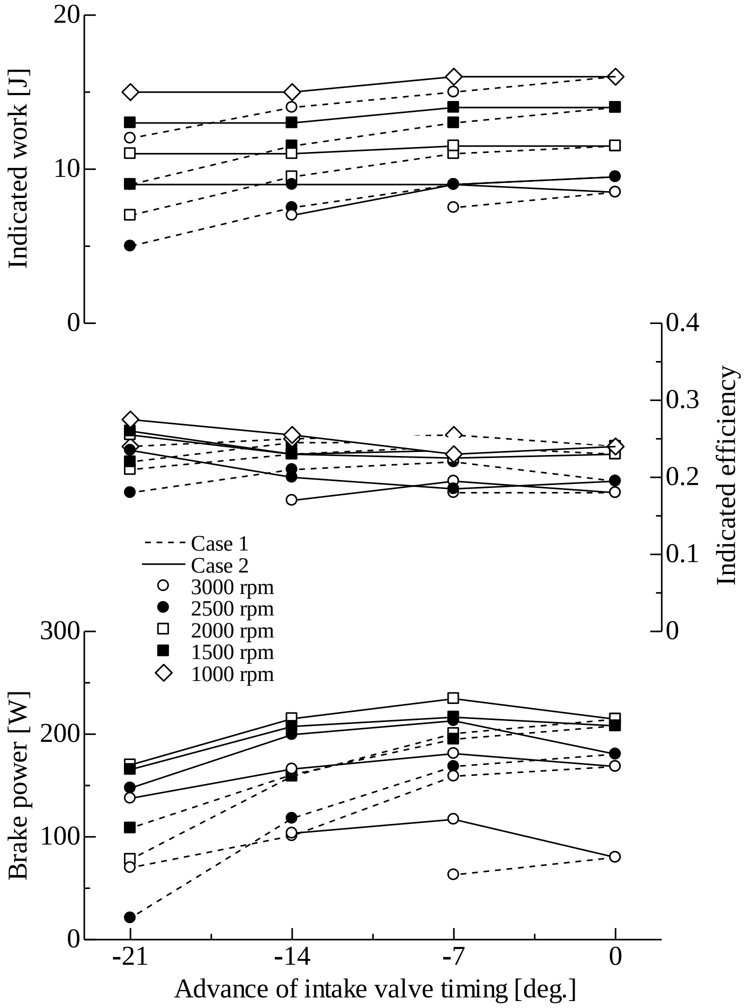


Figure 5. Performance characteristics of the engine in each valve timing conditions

4.3. Performance characteristics of the engine in each engine speed

Generally, the engine performance is discussed from the point of view of the relationship between performance characteristics and engine speed. Figure 6 shows the performance characteristics of the engine under each engine speed conditions. In this figure, the horizontal axis shows the engine speed.

The indicated work in both case 1and case2 decreased with the engine speed. The results of case 2 were almost the same in each advanced condition, however, the results of case 1 were decreased with the increase of valve opening timing advance. Indicated efficiency in both cases was almost the same and slightly decreased with the increase of engine speed. Each brake power curve was upwardly convex and had a peak at near 1500 or 2000 rpm. The curves in both cases went downward with the increase of valve opening timing advance. Comparing both cases, decreasing rate of case 2 was smaller than case 1.

The evaluation of performance characteristics of the engine in each engine speed also shows that total performance of the case 2 conditions that the intake valve timing is changed and exhaust valve timing is fixed was better than the case 1 conditions that the exhaust valve timing is changed simultaneously with intake valve timing.

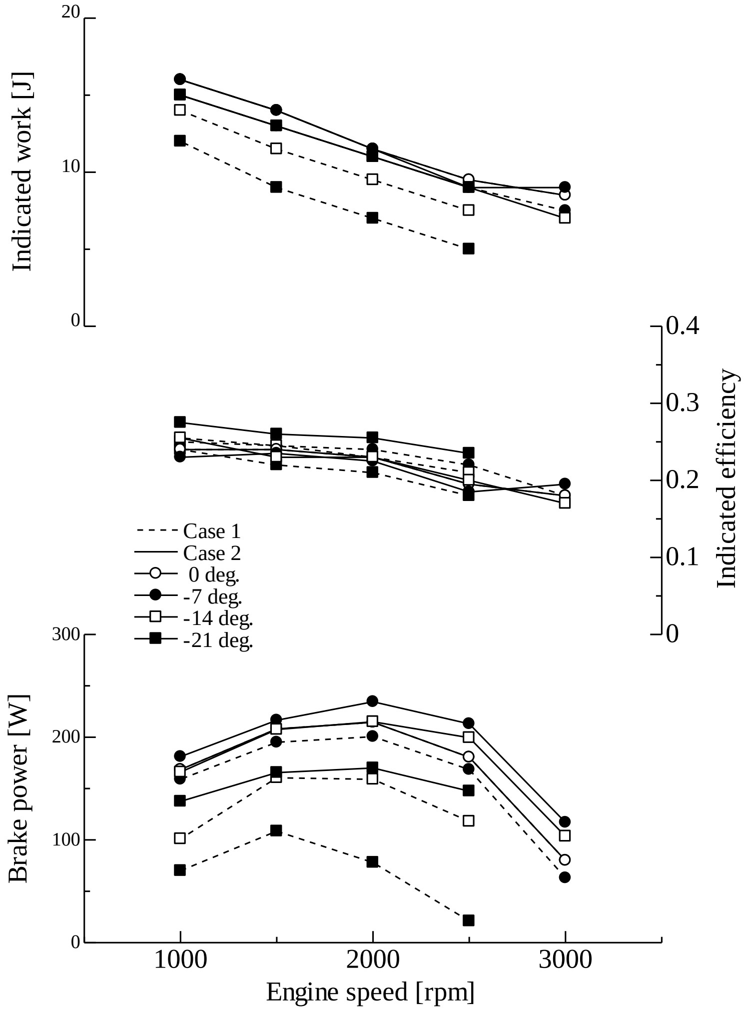


Figure 6. Performance characteristics of the engine under each engine speed conditions

5. Conclusions

In order to clarify the relationship between the valve timing and the engine performance, the load experiments in the different valve advance conditions were conducted. The major conclusions are as follows:

1. The advances of intake and exhaust valve timings strongly effect to the engine performance as indicated work and brake power.
2. Comparing between case 1 and case 2, the brake powers of case 2 were bigger than case 1 at every advance of valve timing.
3. In both conditions, the indicated efficiency has almost flat property against the advance of valve timing. The significant difference between case 1 and case 2 was not found.
4. The advances of intake and exhaust valve timings should be changed individually for the better engine performance.

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