Mohammed et al. 2018. *Int. J. Vehicle Structures & Systems*, 10(2), 146-149
ISSN: 0975-3060 (Print), 0975-3540 (Online)
doi: 10.4273/ijvss.10.2.14

International Journal of Vehicle Structures & Systems
Available online at www.maftree.org/eja

Experimental Investigation of Ignition Timing on the Performance and Emission Characteristics of a Crank-Rocker Engine

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ABSTRACT:

The effects of varying the ignition timing on the performance and emissions characteristics of a crank-rocker engine were experimentally investigated. Experiments were carried out at five different ignition timings of 6.5°, 8.5°, 10.5°, 12.5°and 14.5° CA BTDC at engine speed of 2000rpm and wide open throttle position. Performance data such as brake torque, brake power, brake specific fuel consumption and brake thermal efficiency were calculated. Engine exhaust gas emission such as CO, CO_2, HC and NO_x have also been measured. The results showed that at 10.5° CA (BTDC) ignition timing, the crank-rocker engine produce maximum brake torque, brake power, BTE and minimum value for the BSFC. In general, CO and HC emissions decreased while CO_2 and NO_x emissions increased with ignition timing advance. The findings in this paper are useful for researchers and engine developers in understanding the trade-offs and physical limitations of crank-rocker engine designs.

KEYWORDS:

Ignition timing; Curved-cylinder; Crank-rocker engine; Performance and emissions

CITATION:

S.E. Mohammed, M.B. Baharom, A.R.A. Aziz, A.E.Z. Zainal and F. Firmansyah. 2018. Experimental Investigation of Ignition Timing on the Performance and Emission Characteristics of a Crank-Rocker Engine, *Int. J. Vehicle Structures & Systems,* 10(2), 146-149. doi:10.4273/ijvss.10.2.14.

NOMENCLATURE:

CA	Crank angle
BTDC	Before top dead centre
BSFC	Brake specific fuel consumption
BTE	Brake thermal efficiency
CO	Carbon monoxide
CO_2	Carbon dioxide
HC	Hydrocarbon
NO_x	Nitrogen oxide

1. Introduction

Since the first internal combustion engine (ICE) was developed, researchers and engine designers have put a lot of efforts at increasing engine performance and reliability. In order to maximize performance while minimizing fuel consumption and emissions, ignition timing in an SI engine has to be optimized. Several works have been carried out experimentally in order to study the effects of ignition timing on the engine performance and emissions [1-4]. The results showed that ignition timing had many influences on the engine characteristics. The performance of a spark ignition engine has been investigated under different values of ignition advance using numerical models [5-7]. The results obtained from numerical model were analyzed and validated with the results obtained from the experimental work.

Many researchers have been conducted to optimize ignition timing using Design of Experiment (DoE) techniques [8-9]. Basically these techniques were used in order to find the optimum timing for the best output torque. The results showed that advancing or retarding from the optimum point yields significant variation in power, fuel consumption and emissions particularly in HC and NO_x. Many researchers conducted their experiments to determine optimum spark timing for Maximum Brake Torque (MBT) [10-11]. However, Ma at al [12] studied the effect of hydrogen addition on thermal efficiency and emissions both at unchanged spark timing and MBT in order to compare the results. By doing this, they found that optimizing spark timing according to hydrogen's special combustion characteristics could yield better engine's overall performance and emissions.

2. New mechanism for ICE

Engineers, inventors and automobile manufacturers have intensified efforts in developing more powerful and efficient reliable engines since the first ICE was invented. They were trying to make ICEs much better but different from the norms, by looking for alternative engine configurations in order to increase engine performance, efficiency and power-to-weight ratio. Examples of new engine configurations which have been addressed and advanced are radial engine, opposed piston engine, duke engine, rotary engine (Wankel), toroidal engine (curved cylinder) etc. Farrell, Hoose and Morgado [13-15] invented and designed different types of curved cylinder toroidal engines. However, the proposed designs were very complex. Oscillating curved cylinder engine with opposed piston were also patented and developed by Hüttlin [16]. Despite the advantages of this engine, it has a few drawbacks such as the rotation speed was limited to 3000rpm, is very complicated and had low power density [17]. Most toroidal curved cylinder engines used were for two stroke engines. A four-stroke toroidal curved-piston engine was proposed and invented by Taurozzi [18]. Although this engine could be fully balanced, the engine concept was quite complicated and also this engine had low efficiency. Many types of different mechanisms with oscillating motions have been proposed, but the potential problems associated with these mechanisms are that they are very complicated. An alternative way of producing a crank output motion with oscillating curved-piston is through utilizing a four-bar or crank-rocker mechanism.

In this study, Crank-Rocker (CR) engine is proposed. The most unique feature of this engine is that it is very simple in design and is easy to manufacture. In addition to that, a special feature of this engine is that it is the combination of both the conventional and toroidal engines. The engine can be modified easily to work on alternative fuels such as compressed natural gas (CNG), hydrogen, ethanol and biodiesel. The proposed design for the new engine is shown in Fig. 1. A single-curved piston assembly travels within a curved engine cylinder. In this work, the effect of ignition timing on the crank-rocker engine performance and exhaust emissions was experimentally investigated. Experiments were performed at a constant engine speed of 2000rpm and Wide Open Throttle (WOT).

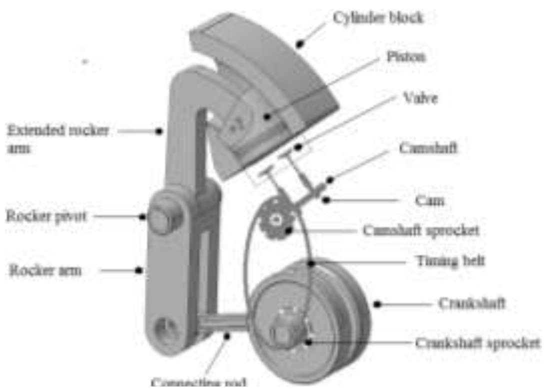

Fig. 1: Proposed design for the crank-rocker engine geometry [19]

3. Experimental setup and details

The engine used in the present work was a crank-rocker, single curved-cylinder, four-stroke spark-ignition with a swept volume of 120cc and a compression ratio of 8:1. The engine specifications are given in Table 1. The schematic diagram of the experimental setup is shown in Fig. 2. All experimental studies were conducted at the Centre for Automotive Research and Electric Mobility (CAREM) located at the Department of Mechanical Engineering, Universiti Teknologi PETRONAS (UTP), Malaysia. The crank-rocker engine was originally designed for gasoline fuel but with a little modification, it could be used for any type of fuels. The engine was coupled to an eddy current dynamometer that allowed engine braking while the performance parameters were measured. A BEA 460® Bosch analyzer is used to measure the exhaust gases in the engine. The gas analyzer is capable of measuring about 5 gas species in the exhaust provide the reading in percentage and parts per million (ppm). The gas analyzer measures the CO, CO_2, O_2, HC and NO_x exhaust gas components for gasoline engines with high measuring accuracy for each gas. The analyzer is able to calculate the lambda values based on the oxygen concentration. By using lambda and stoichiometric air to fuel ratio, it is provides the actual air to fuel ratio. The BEA 460® can be connected to standard laptops via cable or bluetooth in order to run the test sequence and display measurement values. The engine test bed unit for testing of the new engine has also been designed and installed to fit the engine requirements. The crank-rocker engine which is completely assembled with all components and accessories on the test bed is shown in Fig. 3.

Table 1: Single cylinder crank-rocker engine specifications

Property	Value
Cylinder displacement	120cc
Cylinder diameter	55mm
No. of strokes	4
Stroke	50.6
Compression ratio	8:1
Connecting rod	100mm
Rocker and extended-rocker Length	138.9 and 139.9mm
Throw angle	21°
Fuel	gasoline

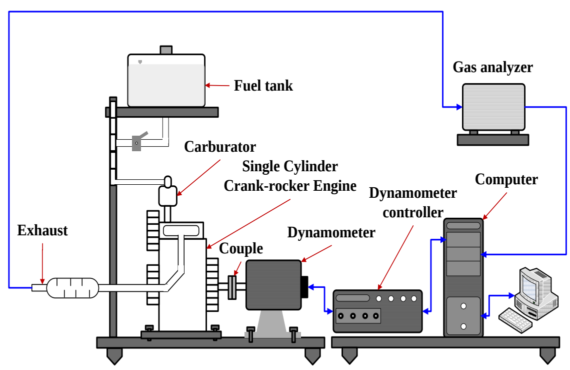

Fig. 2: The schematic diagram of the experimental setup [19]

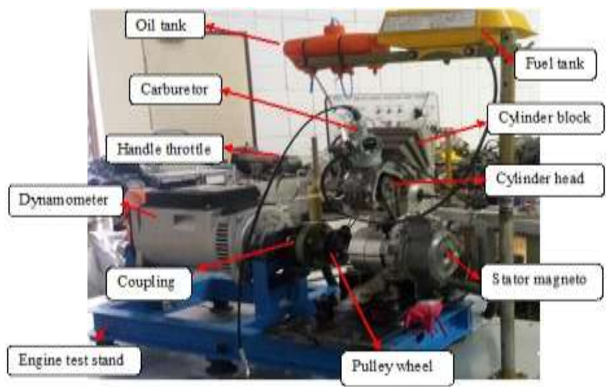

Fig. 3: Crank-rocker engine and the accessories on the test bed [19]

4. Result and discussion

The effects of varying the ignition timing on the performance and emissions characteristics have been experimentally investigated. The experiment tests were carried out at five different ignition timings of 6.5°, 8.5°, 10.5°, 12.5° and 14.5° CA BTDC, wide open throttle and engine speed of 2000 rpm. This engine speed is chosen because it is associated with the maximum power. The variation of brake torque and brake power versus ignition timing at WOT and 2000 rpm are shown in Figs. 4 and 5 respectively. The brake torque and power increase with the advance of spark ignition until 10.5° CA BTDC and then decrease slightly when the ignition timing advances further. The best torque and power are achieved at the optimum timing of 10.5° CA BTDC, while the maximum values for the brake torque and power are 5.01 Nm and 1.1 kW respectively. The torque and power increase when the ignition timing increases due to the increase in cylinder pressure and thus more work is produced by the piston. If the ignition timing is further advanced, the spark ignites very early before the piston reaches the maximum point (TDC). In this case, the peak pressure occurred while the piston was still moving up. As a result, the work produced by the gas to push the piston down would decrease and thus decreasing the performance.

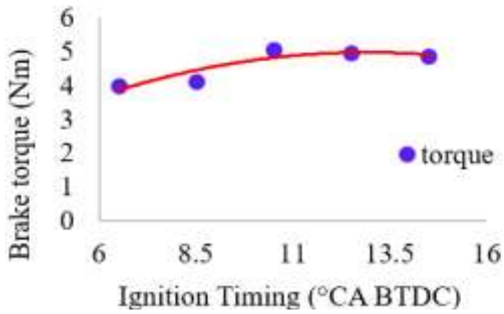

Fig. 4: Brake torque vs. ignition timing at WOT and 2000 rpm

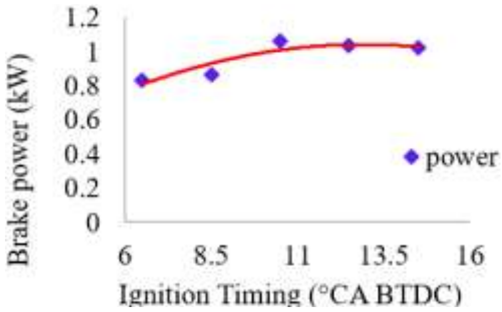

Fig. 5: Brake power vs. ignition timing at WOT and 2000 rpm

Fig. 6 shows the BSFC as a function of ignition timing at WOT and 2000 rpm. The BSFC decreases as the spark timing increases up to 10.5° CA BTDC and then starts to increase when the ignition timing exceeds 10.5°. Higher BSFC is found at 6.5°, 8.5°, 12.5° and 14.5° CA BTDC due to incomplete combustion, heat and friction loss. The minimum brake specific fuel consumption is 345.65 g/kWh which occurs at 10.5° CA ignition timing. Fig. 7 illustrates BTE versus ignition timing at WOT and 2000 rpm. The BTE increases with the advance in spark timing up to 10.5° CA BTDC and then slightly decreases. This is due to the increase in friction loss when the ignition timing is advanced further. The maximum value of BTE is about 21% at the ignition timing of 10.5°.

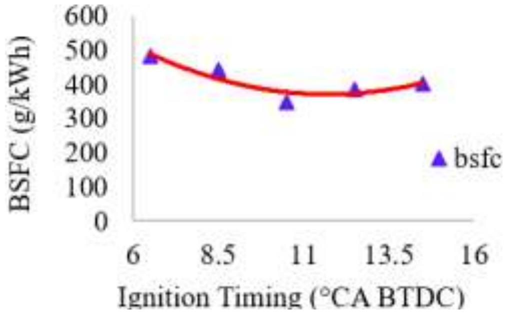

Fig. 6: BSFC vs. ignition timing at WOT and 2000 rpm

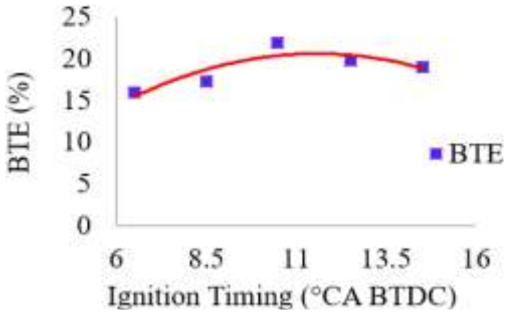

Fig. 7: BTE vs. ignition timing at WOT and 2000 rpm

The HC emission at different ignition timings is shown in Fig. 8. The HC emission decreases with the increase in ignition timing. It can also be observed that when the ignition timing advances from 10.5° to 14.5° CA BTDC, HC concentrations increase. Fig. 9 shows the variation of CO emission versus ignition timings at WOT and 2000 rpm. CO emission decreases when the spark timings advance up to 10.5° CA BTDC. The trend starts to increase with further advance in ignition timings. The decrease in CO concentration means that the combustion process is very good, due to proper air-fuel mixing.

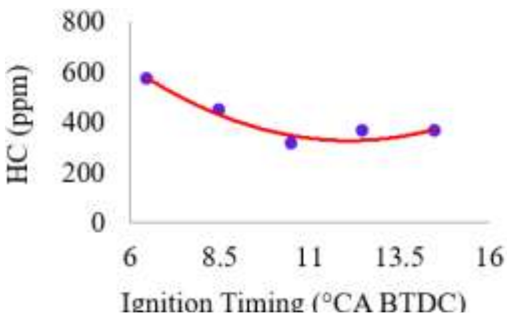

Fig. 8: HC vs. ignition timing at WOT and 2000 rpm

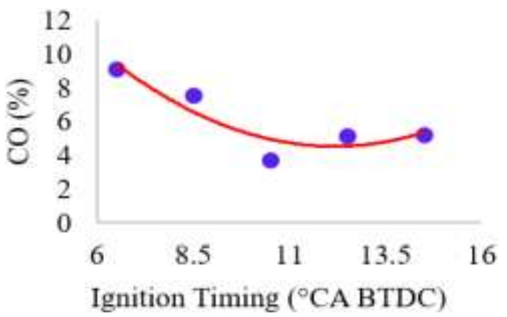

Fig. 9: CO vs. ignition timing at WOT and 2000 rpm

The concentrations of CO_2 and NO_x versus ignition timing at WOT and 2000 rpm are shown in Figs. 10 and 11 respectively. Both CO_2 and NO_x emissions increase with the increase in ignition timing. This can be explained by the fact that if the ignition timing is advanced, the in-cylinder pressure and temperature would increase and thus increasing the NO_x emission.

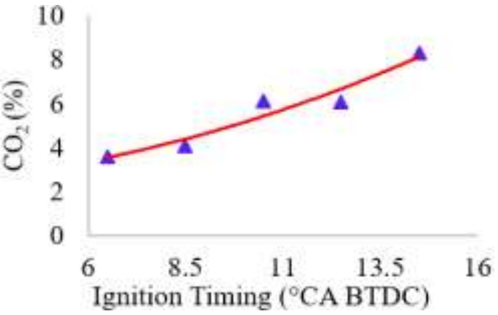

Fig. 10: CO_2 vs. ignition timing at WOT and 2000 rpm

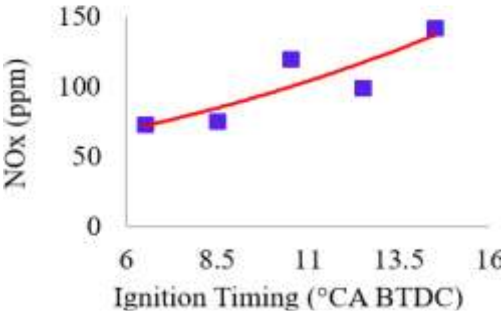

Fig. 11: NO_x vs. ignition timing at WOT and 2000 rpm

5. Conclusion

In this paper the effects of varying the ignition timing on the performance and emission characteristics of a crank-rocker engine was investigated through experiments. Based on the investigation, it was found that the maximum values for the brake torque, power and brake thermal efficiency were 5.01 Nm, 1.1 kW and 21% respectively, when ignition timing was adjusted to 10.5° CA BTDC. From the experimental results it is found that the BSFC decreases as the spark timing increases up to 10.5° CA BTDC and starts to increase when the ignition timing exceeds 10.5°. In general, CO and HC emissions decreased while CO_2 and NO_x emissions increased with ignition timing advancing.

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