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EFFECTS OF IGNITION ADVANCE ON COMBUSTION, FUEL CONSUMPTION AND EMISSION AT 13B WANKEL ENGINE

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ABSTRACT: In this study, the optimum advances for parameters such as specific fuel consumption, emissions were investigated in ignition advances below 10^0 EA and above 10^0 EA. Cylinder pressure was measured for calculating the heat release rate. 13B MSP (Multi Side Port) single rotor and port fuel injection Wankel engine was used in the experiments. In this context, single rotor Wankel test engine was operated at 2000, 3000 and 4000 rpm engine speed, part loads and $\lambda = 1$ condition. The optimum ignition advance is based on the value at which the maximum torque is obtained. Thus, the effect of ignition advance was investigated on Wankel engine. As a result, it is observed that ignition advance has a significant effect on emissions, in-cylinder pressure and fuel consumption in Wankel engine.

Key Words: *Ignition advance, Exhaust emissions, Break specific fuel consumption, Combustion, Wankel engine.*

13B Wankel Motorunda Ateşleme Avansının Yanma, Yakıt Tüketimi ve Emisyona Etkileri

ÖZ: Bu çalışmada, optimum avans, 10 derece EMA altı ve 10 derece EMA üstü avanslarda özgül yakıt tüketimi, emisyonlar, silindir içi basınç ve ısı salımı oranları gibi parametreler incelenmiştir. Motor olarak deneyde 13B-MSP tek rotorlu ve manifolda püskürtmeli bir Wankel motor kullanılmıştır. Bu kapsamda, tek rotorlu Wankel deney motoru 2000, 3000 ve 4000 dev/dak motor hızında, kısmi yüklerde ve λ=1 koşulunda çalıştırılmıştır. Optimum ateşleme avansı maksimum momentin elde edildiği değer baz alınmıştır. Böylece, ateşleme avansının Wankel motordaki etkisi incelenmiştir. Sonuç olarak ateşleme avansının Wankel motorda emisyonlar, silindir içi basınç ve yakıt tüketimi üzerinde büyük bir etkiye sahip olduğu gözlenmiştir.

Anahtar Kelimeler: *Ateşleme avansı, Egzoz emisyonları, Özgül yakıt tüketimi, Yanma, Wankel motor.*

INTRODUCTION

Internal combustion engines have a history of approximately 150 years. Today, it is widely used in sea, air and land. Reciprocating engines convert the reciprocating motion to a rotational motion using a crank-connecting rod mechanism (Ansdale, 1968). To date, the basic parts of the piston engine have not been changed. The best alternative to reciprocating engines is rotary engines. Wankel engines, which are in the class of rotary piston engines, operate with a four-stroke operating principle (Bensinger, 1973).

Wankel engines have many advantages according to piston engines. Wankel engines do not have a crank-connecting rod mechanism like piston engines. In the Wankel engine, the charge change is provided through the ports on the side housings. Advance is determined by the geometry of the port (Yamamoto, 1971). The lateral surface of the rotor limits the opening and closing of the intake and exhaust ports. Simultaneously opening of the intake and exhaust port is extremely short or absent. As the intake and exhaust time is greater, more fresh charge is taken into the engine (Warner, 2009). In the Wankel engine, the rotor serves as the piston-connecting rod mechanism, thus achieving high speeds. Also, it is simpler because of the crank-connecting rod mechanism did not (Froede, 1961). It is light and takes up less space than the piston engine of the same power (Ohkubo *et al.*, 2004). Wankel engine provides minimum noise, inertia momentum in full balance and less torque fluctuation than a piston engine. Thus, the noise level is lower (Froede, 1965). Looking at the other advantages of the Wankel engine, the power obtained from the unit volume is higher, NOx emissions and vibration are lower (Froede, 1968).

There are studies in the literature on the ignition system in Wankel engine. In a study, the effect of leading and trailing spark plugs on combustion was investigated. The use of the trailing spark plug reduces the possibility of knocking in the rear region of the chamber and the likelihood of better combustion inside the chamber (Yamamoto *et al.*, 1972). The number of spark plugs and operating order of the leading and trailing spark plugs affect engine performance and emissions (Kohno *et al.*, *1979*).

Shi et al. different ignition advances were given for different mean flow rates in CFD modeling using CONVERGE software. For best mean flow rates, the best ignition advances were obtained at 25 CA BTDC (Before Top Dead Center) for the leading spark plug, while the best results were obtained at 35 CA BTDC for the trailing spark plug (Shi *et al.*, 2019a). Amrouche et al. worked experimentally on a 530 cc single rotor Wankel engine. The engine was operated at 3000 rpm, full load and lean mixture. It was concluded that the optimum ignition advance was 15^0. Thus, the best results were obtained in mass fraction burnt, flame development, maximum heat release rate and indicated mean effective pressure (Amrouche *et al.*, 2018). In another study, the optimization of the ignition advance is suitable for improving combustion performance and is particularly effective in reducing the unburned area due to the large combustion chamber. Experimental and 3-D CFD analysis was performed. When trailing spark plug 335^0 EA, leading spark plug 325^0 EA and trailing spark plug when the minor axis is shifted 20.7 mm, thus, high spark energy, mixture consumption faster, combustion pressure higher and shorter combustion time is obtained (Shi *et al.*, 2019b). Finkelberg et al. are concluded that the ignition advance difference between the two spark plugs is 15^0 EA (Finkelberg *et al.*, 2019). Raju in his study, the single spark plug and double spark plug operation of the Wankel engine discussed with a numerical model. It was observed that fuel consumption decreased by 7.5% as a result of the engine working with double spark plugs at part loads (Raju, 1992). In CFD modeling using CONVERGE software, optimum ignition advance selection was made for maximum cylinder pressure considering NOx emission (Shi *et al.*, 2019c). In an experimental study, the effect of ignition timing was investigated by using a dual fuel (hydrogen and n-butanol) in Wankel engine. Peak pressure and temperatures increased as ignition advance increased. The propagation process of the flame was shortened. Also, HC and NOx emissions increased (Su *et al.*, 2018). Ji et al. in the conducted numerical study, it was observed that the leading spark plug was kept constant and the trailing spark plug slightly affected the mean flow rate (Ji *et al.*, 2019). Fan et al., the effect of ignition parameters on the combustion process as a result of working with natural gas in Wankel engine was investigated. As a result, the tumble near the trailing spark plug was beneficial for the combustion process (Fan *et al.*, 2015). Another study has assessed that the Wankel engine self-ignition process on its own when it reaches high temperatures at high speeds (Iskra and Babiak, 2007). Hwang et al., effect on combustion characteristics was examined in spark plug timing ve leading side spark plug location. The ignition advance had been found that better improve the flame propagation in the combustion chamber (Hwang *et al.,* 2016). Ignition timing is very important in the combustion process. Optimum ignition time increases in-cylinder pressure and reduces soot emissions (Otchere *et al.,* 2019).

Especially in this regard, no studies have been found belong to the 13B-MSP Wankel engine. In this study, a single rotor 13B Wankel engine was used. In this engine, the optimum ignition advance is determined according to the operating condition. Then, the engine was operated with advances of +10^0 EA and -10^0 EA from this optimum advance. Break specific fuel consumption, emissions, in-cylinder pressure and heat release rates of the engine were investigated.

EXPERIMENTAL STUDY

In this study, a single rotor Wankel engine was used (Cihan, 2017). 13B type Wankel engine was used in the experiment. This Wankel engine is a new generation and available on the market. The technical specifications of the used engine were given in Table 1. All devices were calibrated in the test room (Kutlar *et al.,* 2018). The experimental setup showing the used devices and engine was shown in Figure 1. Experiments were performed at 2, 3 and 4 bar loads. The test performed in stoichiometric mixture was carried out at 2000, 3000 and 4000 rpm. The ignition advance in which the obtained maximum torque is called as 0_IA under different operating conditions. Ignition advances below 10^0 EA and above 10^0 EA of this ignition advance had been tested. These were called -10_IA and +10_IA respectively. In this study, break specific fuel consumption, emissions, in-cylinder pressure and heat release rates of Wankel engine were investigated in different ignition advances. The cylinder pressure was measured by Kistler 6118BF107Q01 piezoelectric sensor which was placed on the leading side with a spark plug adaptor. In the experiments, Bosch BEA 350 exhaust emission device was used for emission tests. The fuel consumption measurement system consists of the weighting unit (AVL 733S) and the fuel conditioning unit (AVL 753C). The measuring device used in the experiments operates according to the gravimetric measuring principle and the fuel temperature is set to 25 °C and the fuel pressure is set to 4 bar, recommended for the 13B-MSP Wankel engine.

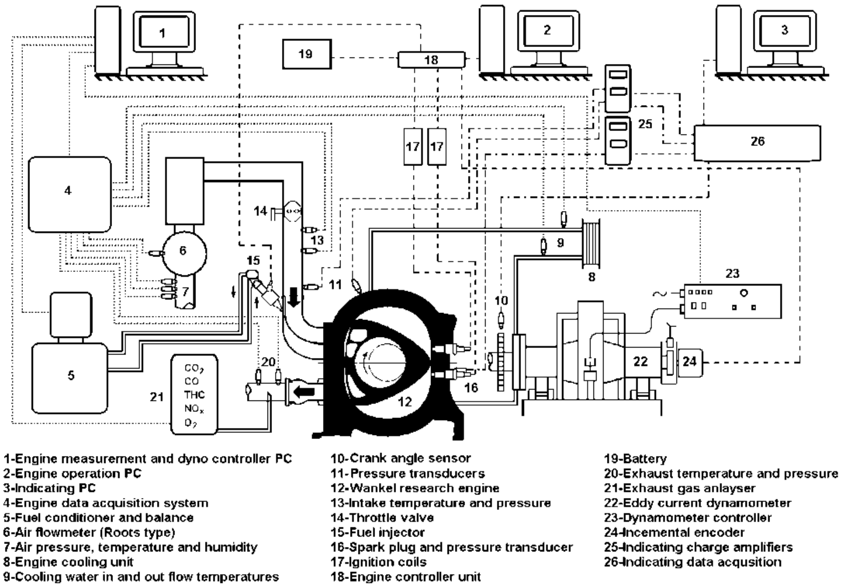

Figure 1. Schematic representation of the experimental setup.

Table 1. Basic and geometric data related to 13B MSP Wankel engine.

Term			Value	Unit
Ignition (Twin spark plug)			Spark ignition	-
Mixture preparation			Port fuel injection	-
Fuel			Gasoline	-
R (Rotor corner-center length)			105	mm
e (Eccentricity)			15	mm
b (Rotor width)			80	mm
ε (Compression ratio)			10	-
Vh (Stroke volume)			654	cm^3
Port Timing	Intake port	Open (ATDC)	12^0	EA
	Intake port	Close (ABDC)	36^0	EA
	Exhaust port	Open (BBDC)	50^0	EA
	Exhaust port	Close (BTDC)	3^0	EA
Intake Charge Type			Natural Aspiration	

RESULTS

Experiments were performed under different engine speeds (2000, 3000 and 4000 rpm) and mean effective pressure of 2, 3 and 4 bar and homogenous condition. The advance where the maximum torque value is obtained for each test point is called 0_IA. The effects of ignition points ± 10° EA different from this advance were investigated. The advance difference between the leading spark plug and the trailing spark plug is kept constant at 15° EA. As shown in Figure 2, a lower break specific fuel consumption was obtained in the optimum ignition advance, in the 0_ID ignition advance. This sequence was then followed by 10° EA more than the optimum advance and 10° EA missing advance than the optimum advance respectively in Figure 2. As a result of over or under ignition advances, engine torque decreased and specific fuel consumption increased.

THC (Total Hydrocarbon) emissions decrease with increasing speed in Wankel engine. Changing the ignition advance affects THC emissions at different loads and 2000, 3000 and 4000 rpm. However, when the advance decreased (-10_IA) at 4 bar mean effective pressure, HC emissions inside exhaust gases were reduced. It was seen from the combustion chamber pressure data that increasing the ignition advance in the experiment did not cause knocking at determined all points (Figure 3).

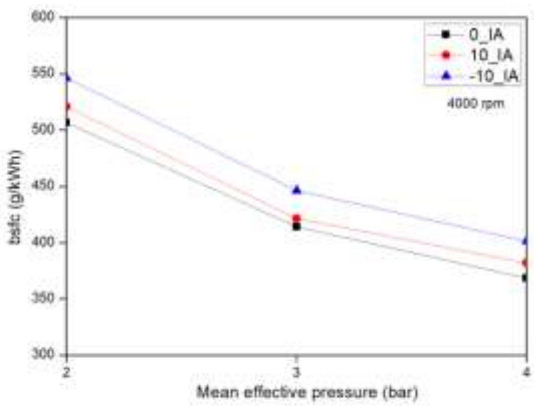

Figure 2. The effect of different ignition advances on break specific fuel consumption at 4000 rpm.

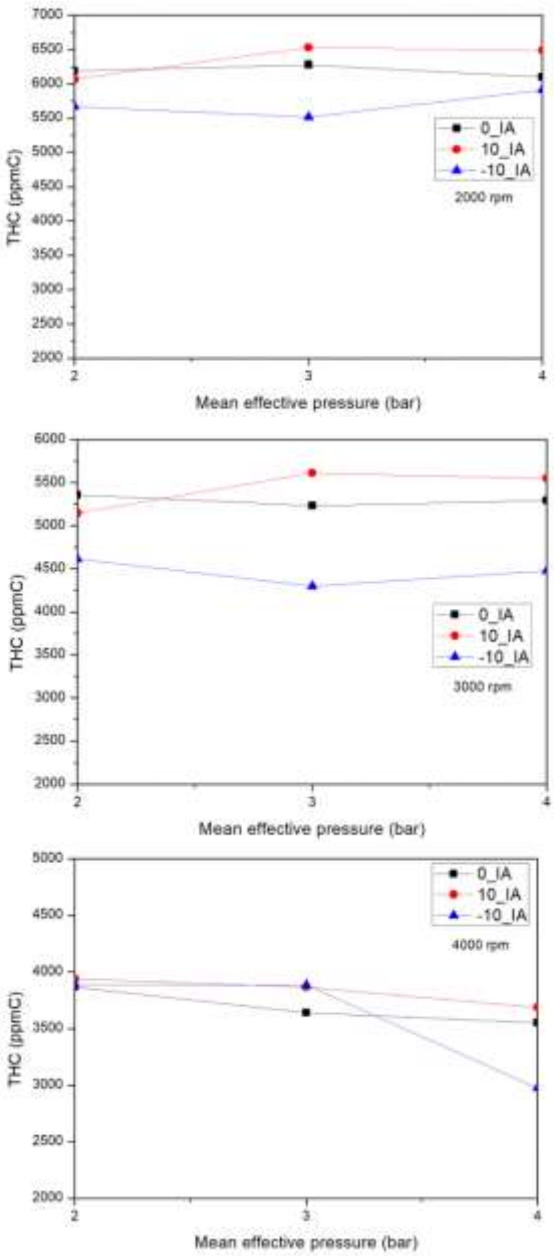

Figure 3. Effect of different ignition advances on THC emissions.

The other combustion products CO, CO2 and O2 have not been changed significantly in this operating conditions. Since the experiment was carried out under stoichiometric condition, CO2 concentration was measured around 14%, CO concentration was 0.8% and O2 concentration was measured as 1.5%.

Figure 4 showed that the effect of different ignition advances on NO emissions at 3000 rpm engine speed and under different load conditions. Nitrogen oxides are formed by the combination of nitrogen in the air with oxygen at high temperatures reached as a result of combustion. The parameters which affect nitrogen formation are temperature, time and excess air coefficient. The increasing of engine speed and load rises temperature and pressure. Nitrogen oxide emissions increase with rising temperature and pressure. The NO emission values have increased due to sufficient time to complete combustion. When the advance was reduced, NO emissions were reduced due to combustion chamber temperatures and pressures decreased and the progression of combustion to expansion. In the experiment, it was observed that the velocity did not affect NO emissions.

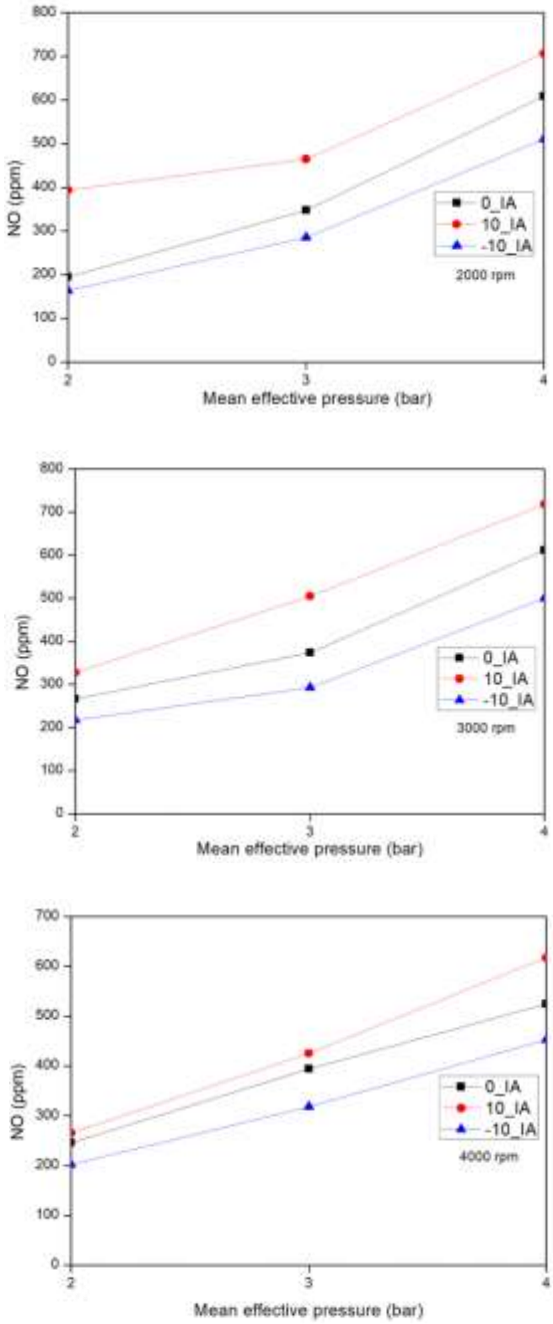

Figure 4. Effect of different ignition advances on NO emissions at different engine speeds.

Figure 5 showed that the p-V diagrams and heat release rates at 4 bar engine load and 4000 rpm. As seen in the p-V diagrams, the pressure obtained from the engine increased as the ignition advance increased. As the advance increases, the highest pressure approaches the top dead center (TDC). As the advances increase, NO emissions have increased for the temperature and pressure will increase in the chamber (Figure 4). As the ignition advance is reduced, the combustion shifts towards expansion stroke. This situation is reflected in the graphs that give the cumulative heat release rates (Figure 5). Also, it was seen that as the advance of ignition increased, combustion occurred earlier and faster.

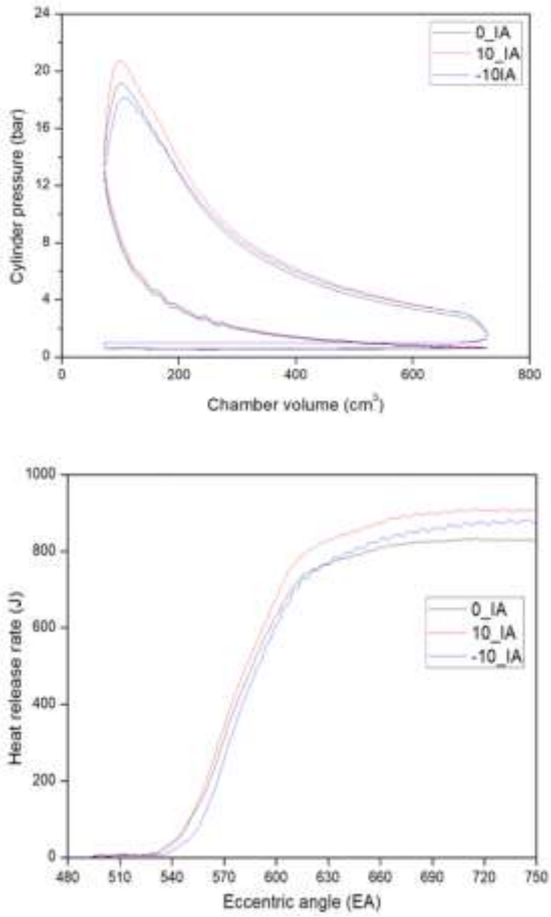

Figure 5. The effect of ignition advance on the heat release rate and p-V diagram.

CONCLUSIONS

In this study, experiments were carried out under stoichiometric conditions at different engine speeds (2000, 3000 and 4000 rpm) and mean effective pressures of 2, 3 and 4 bar. For each experiment point, ignition delay obtained maximum break torque was called as 0_IA. The effect of ± 10° EA ignition advance difference from the 0_IA (optimum advance) was investigated on the engine. The ignition advance difference between the leading spark plug and the trailing spark plug is kept constant at 15^0 EA (Optimum value).

As a result, there was observed a decrease in engine torque and an increase in specific fuel consumption due to more (+10^0 EA) and less (-10^0 EA) ignition advance in operating conditions. At 4 bar mean effective pressure, the HC emissions in the exhaust gases were reduced with the advance reduction (-10_IA). There was no change in the CO, CO2 and O2 values of exhaust emissions. When the advance was reduced, NO emissions were reduced with the combustion shifted to expansion process and the combustion chamber temperatures and pressures decreased. As seen in the p-V diagrams, the pressure obtained from the engine increased as the ignition advance increased. According to the results obtained from heat release rate and pressure data, As the advance increased, the highest pressure approached TDC. As the ignition advance is reduced, the combustion shifts towards expansion process.

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