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A Study on the Effect of Operating Conditions for the Stability at Idle

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A gasoline engine with an electronically controlled fuel injection system has substantially better fuel economy and lower emissions than a carburetted engine. In general, the stability of engine operation is improved with fuel injector, but the stability of engine operation at idle is not improved compared with a carburetted gasoline engine. In addition, the increase in time that an engine is at idle due to traffic congestion has an effect on the engine stability and vehicle reliability. Therefore, in this research, we will study the influence of fuel injection timing, spark timing, dwell angle, and air-fuel ratio on engine stability at idle.

Key Words: Stability, Idle, Dwell angle, Fuel Injection Timing, Spark Timing

1. Introduction

The cyclic variation in the combustion process is generally caused by variations in the mixture motion, in the amounts of air and fuel fed into the cylinder and their mixing, and in mixing with residual gases and exhaust gas recirculation, especially in the vicinity of the spark plug (Heywood, 1988 ; Ozdor et al., 1994).

Through some studies (Lee et al., 1995 ; Herweg et al., 1992) it is well known that the mixture formation is one of the most important factors affecting the process of flame development and propagation, and the formation of exhaust emissions. With increasing use of the port injection systems in SI engines there is less time for fuel to vaporize relative to the carburetted system. Therefore it becomes more important to have knowledge of the mixing process and mixture distribution in the combustion chamber (Martin et al., 1988). However, this is very complicated because of the complex phenomena of the random movement of the liquid fuel droplets, their evaporation and the diffusion of the fuel vapor within a engine combustion chamber, all of which are influenced greatly by engine air flow.

The cyclic combustion variations can be characterized by the pressure related parameters, combustion related parameters, and the flame front related parameters. Although the pressure measurement is still one of the most useful tools for analyzing the cyclic combustion variation, the development of advanced techniques for the in-cylinder measurement of the flame initiation and propagation can lead to deeper understanding of the origin and impacts of cycle-by-cycle variation (Salvat et al., 1994 ; Shen et al., 1994, 1996 ; Sztenderowicz et al., 1990).

In this research, authors studied the influence of electronically controlled fuel injection in a gasoline engine on combustion stability with fuel injection time, spark timing, dwell angle, and air-fuel ratio at idle.

2. Experimental Procedure

Figure 1 shows the schematic diagram of the experimental apparatus. The specification of the engine is shown in Table 1. An engine control system (IC 5460, INTELLIGENT CONTROLS, INC.) was used to control the fuel injection

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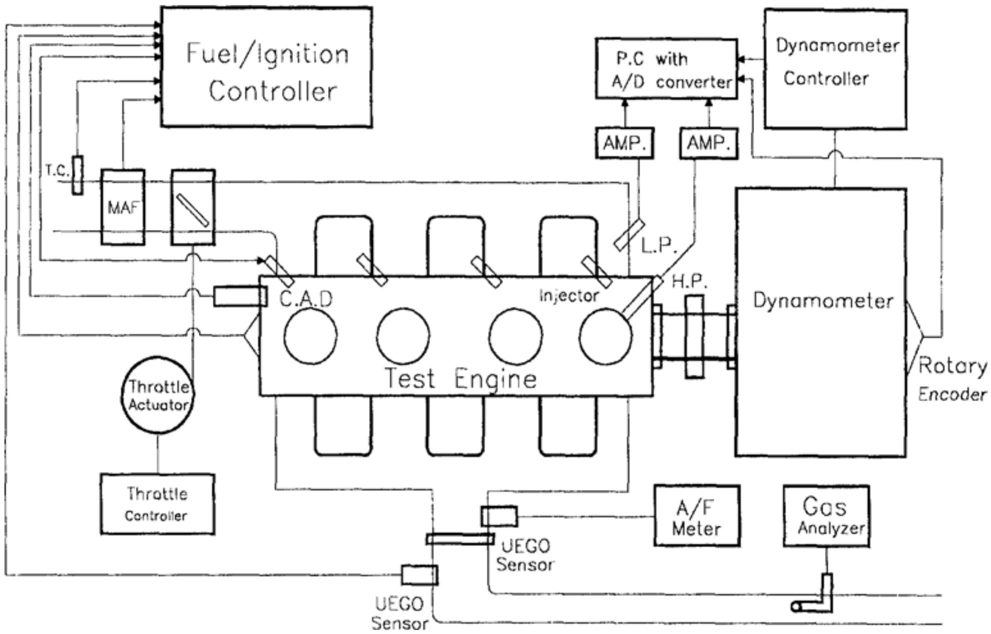

Fig. 1 Insertion sequence for T-shaped object.

Table 1 Specification of test engine.

Engine type	4-cylinder, MPI
Bore	75.5 mm
Stroke	82.0 mm
Clearance volume	43.7 cc
Displacement	1468 cc (367 cc/cylinder)
Injection type	Sequence
Compression ratio	9.4
Valve timing	IVO 18.5 BTDC
	IVC 51.5 ABDC
	EVO 51.5 BBDC
	EVC 18.5 ATDC

timing and spark timing. An air-fuel ratio measurement system (UEGO Sensor, HORIBA 110) was used to measure the air-fuel ratio. The fuel injection timing, air-fuel ratio, spark timing, and dwell angle were the experimental operating variables at idle. The engine speed at idle was fixed at 750rpm without the automatic idling control device. The cooling water temperature was fixed at 80℃. To study the influence on idle with fuel injection timing variables, spark timing was fixed at 10BTDC and the fuel injection timing was changed to 180°, 90° and 0°. BTDC, and 45°, 90°, 135° and 180° ATDC. To evaluate the variations of engine speed, the mean value of maximum engine speed and minimum engine speed during 60 seconds were measured. A piezo-electric pressure transducer, Kistler 6061B, was mounted in the cylinder head to measure the cylinder pressure. The average cylinder pressure diagram of the 50 consecutive cycles was used to evaluate the stability at idle. An absolute pressure sensor (Kistler 4045A2) was used to measure the inlet pressure.

In this paper, to study the influence of spark timing variables at idle, the spark timing was changed to 0°, 10°, 20°, 30° and 40°. BTDC. The fuel injection timing then was fixed at the inlet process 100°. BTDC. In order to study the effects of the air-fuel ratio at idle, the air-fuel ratio was changed to 12 : 1, 13 : 1 and 14 : 1. Besides, the dwell angle (ON time interval of primary ignition coil) was changed to 1.2ms, 1.3ms, 1.4ms, 1.5ms, 2.0ms to study the influence of dwell angle variables at idle. The fuel injection timing then was fixed at the 100° BTDC. Also the air-fuel ratio was fixed at the 13 : 1, and spark timing at the 10 BTDC.

3. Discussion Of Influencing Factors

3.1 Effect of fuel injection timing

To investigate the significance of variations in fuel injection timing on engine speed variability, we used a constant spark timing 10° BTDC during the fuel injection timing variables of 7 stages. The air-fuel ratio was changed to 12 : 1, 13 : 1 and 14 : 1.

Sung Bin Han and Yon Jong Chung Figure 2 shows the effect of injection timing on the engine speed variation. It is represented by the mean value of the maximum and minimum engine speed at idle (750 rpm) during the fuel injection period for every 60 second. In this figure, the injection timing for the most stable engine speed for air-fuel ratio is just before the inlet process 90° BTDC. The engine speed variations of maximum and minimum at 90° BTDC in air-fuel ratio each are about 2%. From this figure, the injection timing in the period just before the inlet valve opening helps the stability at idle.

In addition, fuel injection timing during the inlet process or after the inlet valve closed may increase the engine speed variations, and specifically the engine speed variation for injection in the latter portion of inlet process at air-fuel ratio 14 : 1 increases remarkably. This means that the engine speed variation increases with injection timing variation as the air-fuel ratio increases.

Figure 3 shows the effect of injection timing on the fuel consumption rate at idle. The fuel consumption rates are about 0.49kg/h and 0.57kg/h for air-fuel ratio 14 : 1 and 12 : 1, respectively. The fuel consumption rate with injection timing variables at each air-fuel ratio have the same value generally, but they increase somewhat if the fuel injecting timing is after inlet process. The fuel injection timing after inlet process at idle is disadvantageous in terms of fuel economy. It is believed that the fuel injection timing after the inlet process begins does not leave enough time for the formation of a homogeneous mixture, and some mixture left in the inlet runner causes combustion variability.

Figure 4 shows the maximum cylinder pressure versus injection timing. The maximum cylinder pressure values remain essentially the same at about 6 bar for each air-fuel ratio. The maximum cylinder pressure with fuel injection timing are almost same. But for the fuel injection timing in the latter period of the inlet process, despite of much injection in the latter period of inlet process as shown in Fig. 3, the maximum cylinder pressure values are somewhat unsteady as shown in Fig. 4. This means that the fuel consumption rates are increased and unsteady at idle by the fuel injection timing in the latter period of inlet process, so it is better to avoid fuel injection in the latter period of inlet process for the stability at idle.

Figure 5 shows the standard deviation of

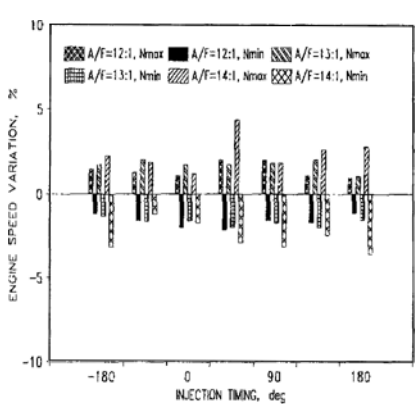

Fig. 2 Effect of injection timing on the engine speed variation.

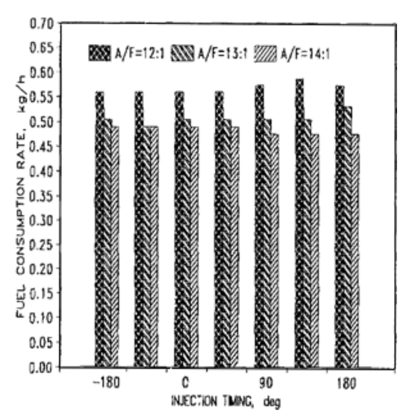

Fig. 3 Effect of injection timing on the fuel consumption rate.

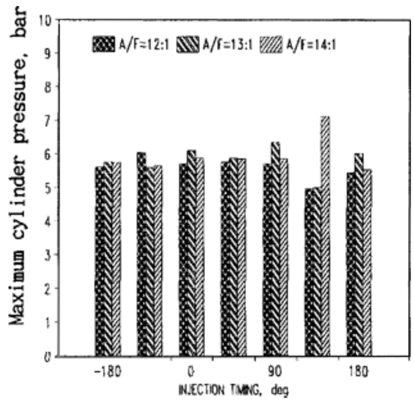

Fig. 4 Effect of injection timing on maximum cylinder pressure.

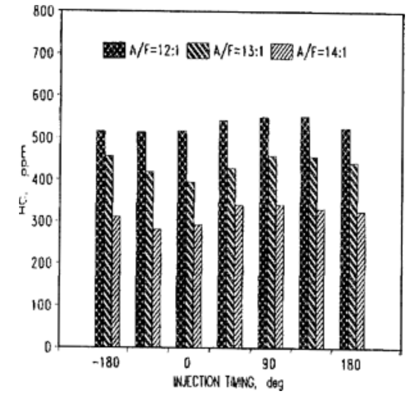

Fig. 6 Effect of injection timing on the hydrocarbon.

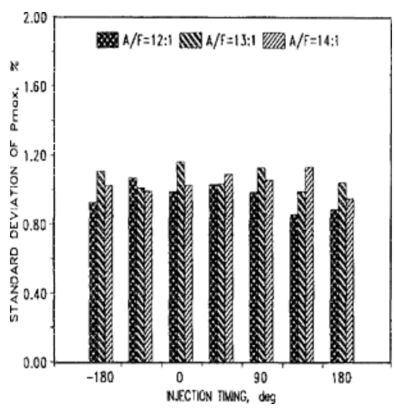

Fig. 5 Effect of injection timing on the standard deviation of Pmax.

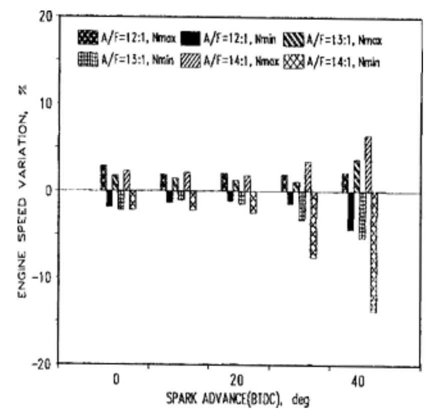

Fig. 7 Effect of spark advance on the engine speed variation.

maximum pressure in the cylinder with fuel injection timing. Standard deviation in the cylinder pressure is determined from a sample of 50 cycles. In this figure, the standard deviation of maximum pressure in cylinder at idle is about 1%, and it decreases somewhat as the fuel injection timing is delayed during the inlet process.

Figure 6 shows the engine out HC concentration versus fuel injection timing. The HC concentration at idle is determined by air-fuel ratio. HC concentration for air-fuel ratio 12 : 1 and 14 : 1 are about 500 ppm and 300 ppm, respectively. When the fuel injection is on the latter period of the inlet process, HC concentration increases somewhat with the fuel supplied as shown in Fig. 3.

3.2 Effect of spark timing

The engine speed variation with spark timing are shown in Fig. 7. As the spark timing is advanced, the engine speed variations increase. From this figure, the engine operation is impossible for spark advance over 30° BTDC due to the stability at idle. For the air-fuel ratio 12 : 1, the engine speed variations do not change much as the spark timing is advanced. But if the air-fuel ratio is high as in 14 : 1 condition, the air-fuel ratio combined with the spark timing have a large influence on the engine speed variations. Therefore, considering the idling engine speed variations with the spark timing and air-fuel ratio, the stable spark timing is about 10° –20° BTDC.

Figure 8 shows the standard deviation of maximum pressure in cylinder with spark timing.

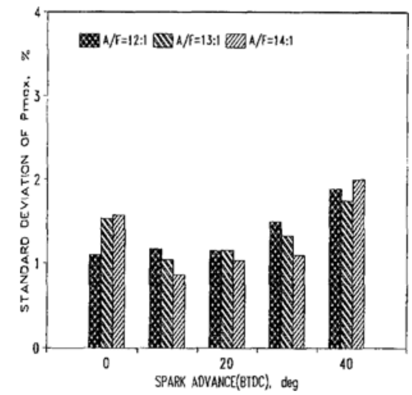

Fig. 8 Effect of the spark advance on the standard deviation of Pmax.

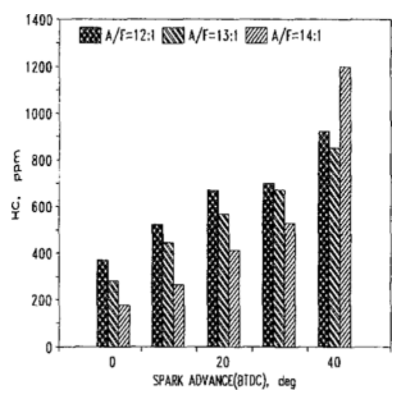

Fig. 9 Effect of spark advance on the hydrocarbon.

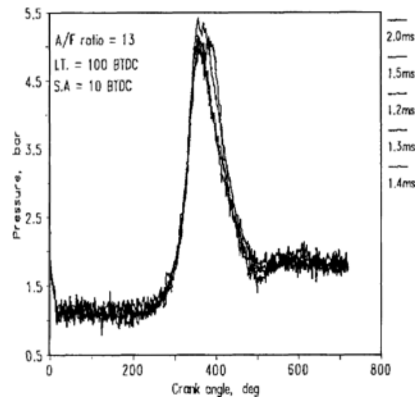

Fig. 10 Effect of dwell angle on the pressure in the cylinder.

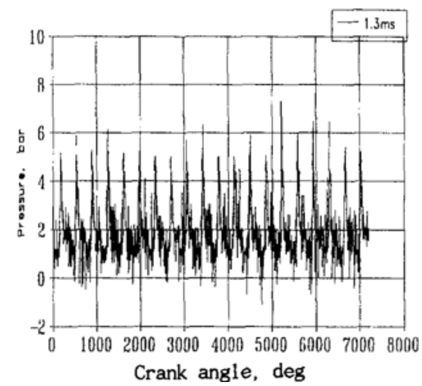

Fig. 11 Effect of dwell angle on the pressure in the cylinder.

The standard deviation of maximum pressure in cylinder with spark timing is about 1 to 2% on the whole. For the lowest standard deviation of the maximum pressure the best timing is about 10° to 20° BTDC.

The HC concentration versus the spark timing is shown in Fig. 9. The HC concentration increases as the air-fuel ratio is richer at the same spark timing as shown in Fig. 6. As the spark timing is advanced, HC concentration increases rapidly. In the spark timing 40° BTDC for air-fuel ratio 14 : 1, HC concentration is highest. In this case, the HC concentration is increased by intermittent misfiring. The change of temperature at the end of expansion/beginning of exhaust is higher with retard timing, leading to more post-flame HC oxidation and lower HC emissions. Generally HC concentration increases at idle or low load ; to decrease HC concentration at idle, it is advantageous to retard the spark timing.

3.3 Effect of dwell angle

Figure 10 shows the pressure in the cylinder with variation of dwell angle. The dwell angle was changed to 1.2ms, 1.3ms, 1.4ms, 1.5ms, 2.0ms. Fuel injection timing was fixed at its optimum value, 100° BTC. In order to study the effects of the dwell angle at idle, the air-fuel ratio was fixed at 13 : 1, and spark timing was fixed at 10° BTDC. The pressure in the cylinder is determined from a sample of 50 cycles. For the highest pressure in the cylinder the dwell angle is about 1.3ms. But the dwell angle of this commercial engine was fixed.

Figures 11 and 12 show the pressure in the cylinder with dwell angle 1.3ms and 2.0ms, respectively. Figure 13 shows the effect of dwell

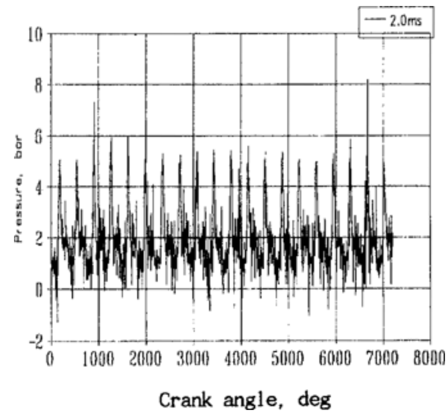

Fig. 12 Effect of dwell angle on the pressure in the cylinder.

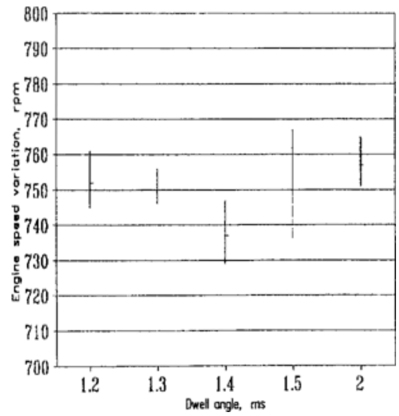

Fig. 13 Effect of dwell angle on the engine speed variation.

angle on the engine speed variation. It is represented by the mean value of the maximum and minimum engine speed at idle during a 60 second interval for each dwell angle. In this figure, the dwell angle for the most stable engine speed is about 1.3ms. The engine speed variations of maximum and minimum at dwell angle 1.3ms is the smallest. From this figure, setting the dwell angle to be 1.3ms in the period of primary ignition coil can help the stability at idle.

4. Conclusions

(1) A fuel injection timing before the inlet process 90° BTDC is the best for the stability at idle in electronically controlled multi-point fuel injected engine.

(2) For air-fuel ratio 12 : 1 to 14 : 1 at idle, the maximum pressure in cylinder with air-fuel ratio and fuel injection timing is almost constant, and the maximum pressure variation in the cylinder with injection timing at idle is about 1%. HC concentration at idle is proportional to fuel injection quantities.

(3) The spark timing for best stability at idle is 10°–20° BTDC. To reduce HC concentration at idle, it is advantageous to operate with a retarded spark timing.

(4) The dwell angle for the most stable engine speed is about 1.3ms. The engine speed variations of maximum and minimum at dwell angle 1.3ms is the smallest. Setting the dwell angle to be 1.3ms in the period of primary ignition coil can help the stability at idle.

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