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Influence of Fuel Injection on Gasoline Engine Performance

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Abstract

Because of the most common method of preparing the fuel-air mixture for gasoline-fueled engines is port fuel injection (PFI). For reducing the wall-film entering the cylinder in liquid phase, the phenomena of wall-film entering the cylinder in liquid phase should be at minimum lever or be avoided. So the first thing for learning the wall-film is to detect the way of the wall-film entering the cylinder. Therefore, the way of the wall-film enter the cylinder in liquid phase is detected by changing the temperature of the wall-film location and time for wall-film evaporated. Then the way is validated by experiment test bed and it is improved that the way is feasible. At the end the influence of injection timing and fuel ratio on engine performance is studied based on the test bed.The results show that regardless of the expansion stroke or the intake stroke fuel injection the injection timing delay will decrese the engine power and make emission deterioration meanwhile the twice fuel injection can improve the fuel film evaporation resulting of high-speed airflow of intake charge.

Keywords*: gasoline engine; wall-film; body temperature; fuel evaporation*

1. Introduction

Currently, the most common method of preparing the fuel-air mixture for gasoline-fueled engines is port fuel injection (PFI) [1, 2]. For the car gasoline engine, especially for cold start or warm-up phase, the fuel deposited directly in the intake port can be problematic when the intake valve and port walls are not sufficiently warm [3,4]. The liquid fuel spray of 30μ or larger droplet hits on the wall of the intake port and the surface of the intake valve which caused fuel wetting and fuel liquid film flowed into the cylinder without vaporized [5]. The more worse is that neither compression heating nor combustion completely vaporizes liquid fuel films in the combustion chamber [6]. Therefore, the high HC emissions of the engine should be concerned and much more researchers have done to reduce the HC emission during cold start and warm-up phase [7-9].

Compared to car engines, motorcycle engines tend to have lower displacement volumes and the need for high specific output power make it operating at high revolution speeds. So for motorcycle gasoline engine with PFI system, the wall-film thickness is high and wall-film area is small because of compact structure and low injection pressure (250kPa-300kPa), the time of the fuel evaporation is short because of high speed. Therefore, the wall-film on the back of the intake valve and intake-port may be not evaporated completely and enter the cylinder in liquid phase which would cause high fuel consumption and HC emission.

For reducing the wall-film entering the cylinder in liquid phase, the phenomena of wall-film entering the cylinder in liquid phase should be at minimum lever or be avoided. So the first thing for learning the wall-film is to detect the way of the wall-film entering the cylinder. Based on traditional theory the ways for wall-film entering the cylinder include two ways: first, the injected fuel keeps dynamic equilibrium which means there is some fuel in the intake-port with wall-film phase but the injected fuel and the wall-film entering the cylinder in vapor phase is equivalent; the second way is the wall-film entering the cylinder in liquid phase which means the wall-film can not vaporized before the intake valve closing and when the intake valve opens again the fuel strip off the wall and enter the cylinder in liquid phase. The two ways of the wall-

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film entering cylinder is opposite so the detecting whether the wall-film entering the cylinder is emphasized.

2. Scheme of the Experiment

When the fuel injected stays dynamic equilibrium the air-fuel ratio can not be changed if the evaporation rate of the wall-film is changed. Meanwhile, when evaporation rate of the wall-film is accelerated, the air-fuel ratio would be deceased and HC emission would be improved if the wall-film enter the cylinder in liquid phase. Yet for the fixed speed, throttle opening angle and injected fuel the wall-film evaporation rate can be affected by temperature of the wall-film location, time for wall-film evaporated and intake flow intensity. Therefore, the way of the wall-film enter the cylinder in liquid phase is detected by changing the temperature of the wall-film location and time for wall-film evaporated.

3. Test equipment and test methods

The test bed consists of K157 FMI engine (specific parameters shown in Table 1), electric eddy current dynamometer, dynamometer control system, gasoline engine ECU, speedy data collection system, five gas analyzer (specific parameters shown in Table 2), wide-band oxygen sensor and computer. The bed is shown in Figure 1, where the electric eddy current dynamometer and dynamometer control system are used to control and measure the load of the engine, engine fuel injection system are used for controlling timing of fuel injection and ignition, and the computer's serial communication can be used to control gasoline engine ECU as to control fuel injection and ignition.

Table 1 Parameters of the K157 FMI

Parameter	Value
type	Single, four-stroke
Bore x stroke (mm)	56.5×49.5
displacement /L	124
Compression ratio	9：1
Cooling style	wind cooling

Table 2 Five Gas Parameters Analyzer

Parameter	Range	Resolution	Error
HC(10-6)	0-10000	1	±12
CO(%)	0.00-10.00	0.01	±0.06
CO2(%)	0.00-20.00	0.1	±0.5
O2(%)	0.00-25.00	0.1	±0.1
NOx(10-6)	0-5000	1	±25

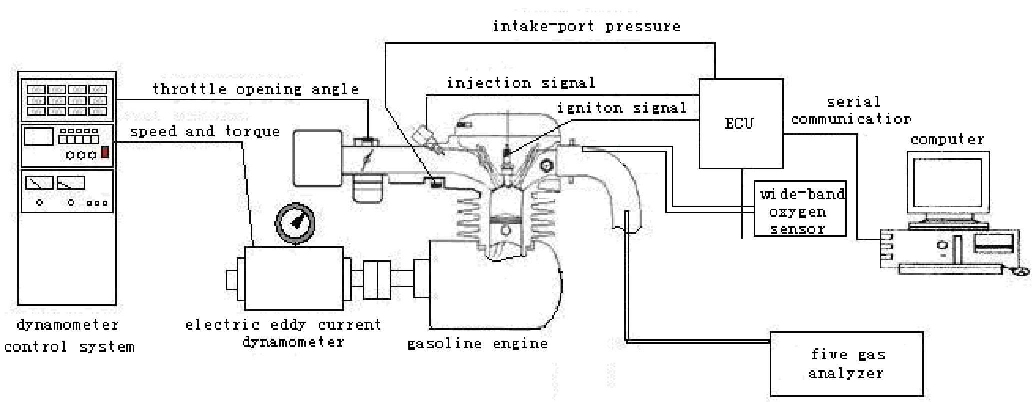

Figure1. Diagram of Experimental System

4. Selection of Reference Temperature Point of the Engine

For the intake-port fuel injection engine, the temperature of the wall-film area determine As we all known that the motorcycle is cooled by air and the temperature of this pint can be easily affected by cooling condition since the surface temperature is changed more easily than inner temperature for the engine’s specific heat capacity. But the inner temperature of the engine is hard to measure and the thermodynamic state is can be valued by surface temperature such as temperature of the spark plugs. In order to value the thermodynamic state of the engine with surface temperature the relationship of the inner temperature and surface temperature should be studied firstly. So two more measure points are added beside the spark plug, one is on the surface of the intake-port nearing the intake valve and the other is on the back of the intake valve. And the sensor on the surface of the intake-port nearing the intake valve is sheathed thermocouple meanwhile the sensor on the back of the intake valve is thermocouple wire which is adheres to intake valve using high-temperature glue because of the high temperature of the valve. The location of the measure points are shown in Figure 2.

The Figure 3 shows the vibration of temperature for measure points under no cooling and cooling condition. It can be seen form the Figure that the trend of temperature at all measure points is same which is increased as time goes by. Also it is indicates that the temperature at the back of the valve is the highest and the temperature at the intake-port is the lowest which is 30 degree lower than the temperature of the spark plug and 60 degree lower than the temperature of intake valve. But under cooling condition, the temperature of the spark plug is decreased rapidly while the temperature of other measure points is decreased slowly and the time for temperature decreasing is delayed. The reason for this phenomenon is that the measure point on the spark plug is engine surface temperature which can be easily affect by cooling air meanwhile the temperature of the intake-port and intake valve are inner temperature of the engine which can not be affected by cooling air directly

From the above analysis, it can be concluded that all three measure points can be selected for valuing engine thermodynamic state with no cooling. However, under cooling condition it is hard to value the engine thermodynamic state with only one measure point. So in order to value the engine thermodynamic state all experiment are done with no cooling condition and the temperature at the spark plug is selected for easily be get.

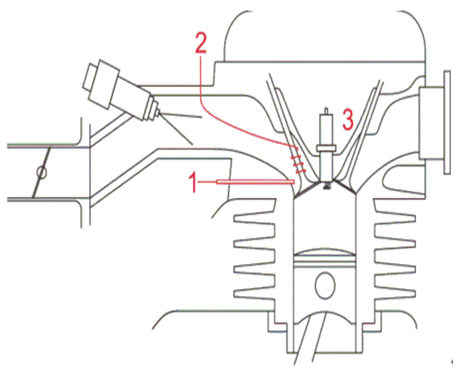

Figure 2. Diagram of Measure Point

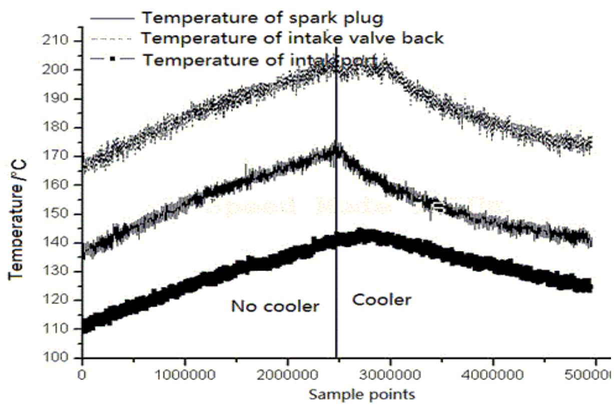

Figure 3. Trend of Temperature At Different Measure Points

5. The Validation of Detection Way

When the dynamometer control system is on N/P model which means the speed and throttle open angle remain constant and the value is 5000r/min and 40% respectively, the trend of HC and NOx with gradually increase of engine body temperature is shown in Figure 4. It can be seen from the Figure that with increase of engine temperature the value of HC decreases and the value of NOx increases. If the injected fuel keeps dynamic equilibrium there is no change of the F/A ratio because the fuel entering the cylinder in vapor phase. But if fuels entering the cylinder in liquid phase the F/A ratio will alter with the engine temperature for the change of fraction of liquid phase entering the cylinder. So when the engine temperature is low the HC emission is high and NOx is low for incomplete combustion meanwhile the HC emission is low and NOx is high because of combustion improvement and the fraction of liquid phase entering the cylinder is reduced. Therefore there is fuel entering the cylinder in liquid phase for this engine.

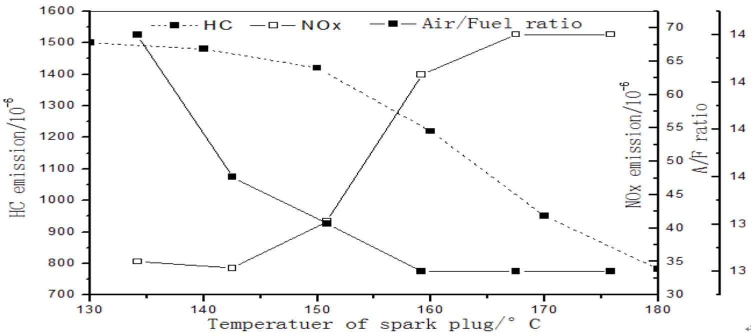

Figure 4. Trend of HC and NOx With Increase of Temperature

6. Results and Discussion

In order to study the influence of injection timing on engine performance twice fuel injection (TFI) strategy is applied in this research. It means that the fuel injected is divided as two pulses where the first injection is started at compassion stroke which is called as first injection while the second injection started at intake stroke.

6.1. Influence of First Injection Timing

In order to analysize the influence of injection timing on engine performance, the second injection timing is fixed at 320ºCA where the top dead center of compression stroke is defined as 0ºCA. The engine power, the air-fuel ratio of the measured and HC emissions change with the first injection timing are shown in Figures 5 and 6 and in order to exclude the influence of the body temperature, the spark plug gasket at the temperature is maintained at 135ºC, the engine speed is 4000r/min and the throttle opening angle is 20% WOT (wide open throttle). It can be seen from the Figure that when first injection timing postponed to the 150ºCA the engine power is reduced to 1.92kW while when first injection timing is 10ºCA the engine power is 1.96kW. Meanwhile the measured air-fuel ratio increased to 14.7 from 14.4, HC emissions rose from 764 × 10^{-6}to843 ×10^{-6}.

Due to the fuel injected before the intake valve opens all arrives the combustor wall, when the first fuel injection timing is postponed the amount of fuel entering the cylinder in liquid form is increased for shorter film evaporation time. Then the measured the value of the air-fuel ratio becomes large and the engine emission is deteriorated. However the vibration of injection timing just changes the time that the fuel absorbs heat from the wall which can’t improve the film evaporation essentially and the changes of engine power as well as the air-fuel ratio is small.

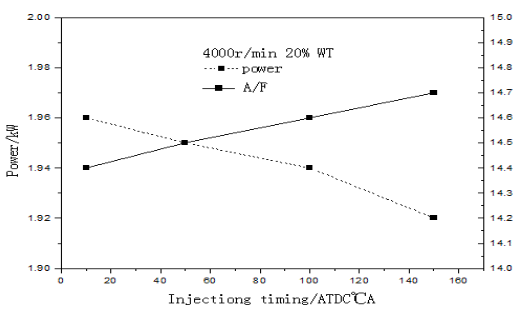

Figure 5. Engine Power And A/F Ratio Changed With Injection Timing

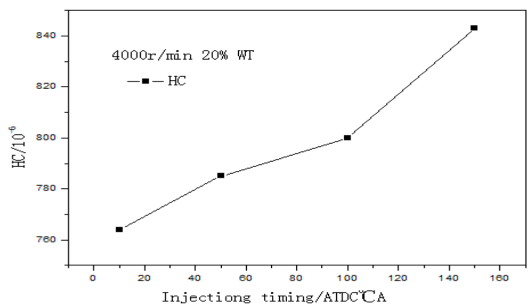

Figure 6. HC Emission Changed With Injection Timing

The engine power, the air-fuel ratio of the measured and HC emissions change with the first injection timing are shown in Figures 7 and 8 when the spark plug gasket at the temperature is maintained at 155ºC, the engine speed is 4000r/min and the throttle opening angle is 100% WOT. It is shown that the engine power and the measured A/F ratio are not changed when the injection timing is changed and the HC emission keeps at 860×10-6. It can be concluded that there is change of the engine performance at wide throttle open.

The reason is that the engine body temperature and air velocity are high which will result less fuel film entering the cylinder in liquid form at WOT. So the influence of injection timing is small on engine performance.

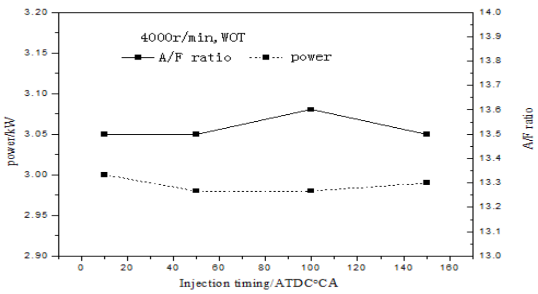

Figure 7. Engine Power And A/F Ratio Changed With Injection Timing

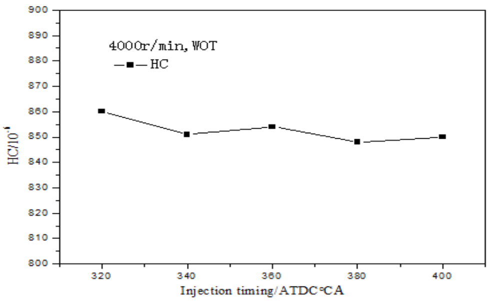

Figure 8. HC Emission Changed With Injection Timing

6.2. Influence of Second Injection Timing

In order to analysize the influence of second injection timing on engine performance, the first injection timing is fixed at 40ºCA where the top dead center of compression stroke is defined as 0ºCA. The engine power, the air-fuel ratio of the measured and HC emissions change with the first injection timing are shown in Figures 9 and 10 and in order to exclude the influence of the body temperature, the spark plug gasket at the temperature is maintained at 137ºC, the engine speed is 4000r/min and the throttle opening angle is 20% WOT.

It can be seen from the Figure that when second injection timing postponed to the 400ºCA the engine power is reduced by 0.2kW while when second injection timing is 320ºCA the engine power is 1.96kW. Meanwhile the measured air-fuel ratio increased to 14.7 from 14.4, HC emissions rose from 860 × 10-6to 890 ×10-6.

In order to improve the fuel evaporation of the second injection the intake airflow is needed. When the intake flow rate is reduced resulting of the injection timing delay there is more fuel film on intake port which can't use the interaction of the intake flow, then the fuel film entering the cylinder in liquid form is increased which causes the deteriorate of the engine emissions and engine power decrease.

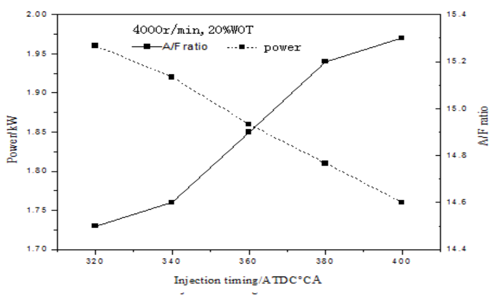

Figure 9. Engine Power And A/F Ratio Changed With Injection Timing

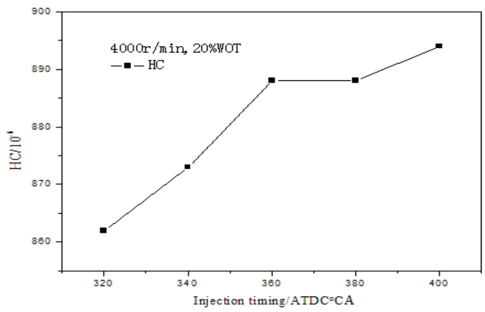

Figure 10. HC Emission Changed With Injection Timing

The engine power, the air-fuel ratio of the measured and HC emissions change with the first injection timing are shown in Figures 11 and 12 when the spark plug gasket at the temperature is maintained at 158ºC, the engine speed is 4000r/min and the throttle opening angle is WOT. It is also shown that the engine power and the measured A/F ratio are not changed when the injection timing is changed and the HC emission keeps at 860×10-6. It can be concluded that there is change of the engine performance at wide throttle open.

Also the reason is that the engine body temperature and air velocity are high which will result less fuel film entering the cylinder in liquid form at WOT. So the influence of injection timing is small on engine performance.

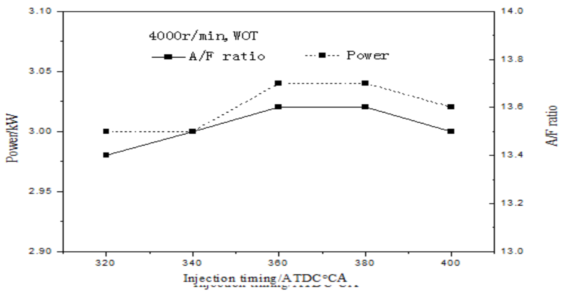

Figure 11. Engine power and A/F ratio changed with injection timing

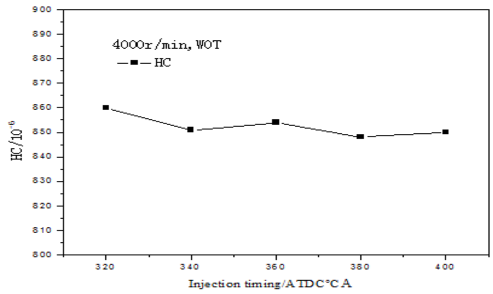

Figure 12. HC emission changed with injection timing

6.3. Influence of Fuel Ratio on Engine Performance

For studying the impact of fuel ratio on engine performance the first fuel injection timing is fixed at 40ºCA and second fuel injection timing is fixed at 320ºCA and the adjustment of injection pulse width is done in accordance with the calibration of the nozzle to ensure that the overall amount of fuel injection is unchanged.

Table 3 is the comparison of engine performance at different fuel ratio when the engine speed fixed at 5000r/min and throttle valve opening angle is 20% WOT.

From the table, the engine power is 1.94kW when the first fuel injection pulse width and the second injection pulse width is 5ms and 3.6ms respectively while the engine power was 1.93kW when the first fuel injection pulse width and a second injection pulse width was 3.6ms and 5ms respectively. But the measured value of the air-fuel ratio increased from 14.5 to 14.7. It also can be seen from the table that the measured value of the air-fuel ratio rose from 14.4 to 14.8 when the fuel injection pulse width adjust from 6ms to 2.6ms.

Similarly, it also can be seen from table 4, when the throttle opening angle is 100%, the larger first fuel injection pulse width the bigger measured air-fuel ratio value is also.

Table3. Comparison of A/F Ratio and Power At Differenct Fuel Ratio when The Engine Speed Fixed At 5000r/Min and Throttle Opening Angle Is 20%Wot

Second fuel injection/ms	First fuel injection/ms	Power/kW	Torque/N·m	A/F ratio
4.3	4.3	1.91	14.8	14.6
5	3.6	1.94	14.7	14.5
3.6	5	1.93	14.6	14.7
6	2.6	1.91	14.5	14.4
2.6	6	1.95	14.7	14.8

Table 4. Comparison of A/F Ratio and Power At Differenct Fuel Ratio when The Engine Speed Fixed At 5000r/Min and Throttle Opening Angle 100%WOT

Second fuel injection/ms	First fuel injection /ms	Power/kW	Torque/N·m	A/F ratio
5.5	5.5	3.49	21.2	13.9
6	5	3.48	21.3	13.9
5	6	3.47	21.1	14.1
7	4	3.49	21.1	13.9
4	7	3.42	20.9	14.2
3	8	3.4	20.6	14.3
8	3	3.5	21.1	13.9

From the above analysis it is shown that the twice fuel injection technology should utilize the intake flow for improving fuel evaporation. So the fuel needs to be fitted with the high-speed airflow, the intake stroke fuel injection amount should not be excessive. Otherwise, if the fuel injection time is too long the intake airflow with the interaction effects between the fuels is weakened for the airflow velocity decreases which will reduce the fuel evaporation rate and affect engine performance.

7. Conclusion

Based on the research it can be included in follows:

1) Under cooling condition it is hard to value the engine thermodynamic state with only one measure point.
2) The way of the wall-film enter the cylinder in liquid phase can be detected by changing the temperature of the wall-film location .
3) When the engine is in a small throttle opening angle, regardless of the expansion stroke or the intake stroke fuel injection, the injection timing delay will reduce the film evaporation, then decrese the engine power and emission deterioration.
4) When using twice fuel injection technique, the fuel injection amount should not be excessive for intake stroke injection for high-speed airflow.

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