Study on GPF regeneration factors and extreme environmental regeneration methods

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Abstract. In order to cope with the increasingly stringent environmental pollution control target, DI gasoline engines must use particulate filters. In order to ensure that GPF will not block or burn during the process of capturing particulate, the gasoline particulate filter (GPF) needs to be controlled based on current soot mass in real time. The loading capacity controls the regeneration of GPF, and the influencing factors of the regeneration efficiency are highly related to the GPF inner temperature, the amount of oxygen, and the soot loading of the GPF carrier. This paper analyzes the weight of the influencing factors of each consumption rate through mathematical methods, and from real test, it can be seen that there is difficult on regeneration of accumulated soot in low-temperature environments on under floor GPF. In this paper, in the test and inspection of low temperature environment, considering the drivability, the regeneration control scheme is clarified by optimizing the active control, and at the same time, the driving mode of extreme conditions is also required.

With the implementation of the China6 Emissions Regulations, manufactures need to install engine out equipment to control particulate matter emissions of gasoline engines, especially gasoline supercharged direct injection engine. Therefore, Gasoline particle filter (GPF) are widely used. To protect GPF not be blocked or overheating, The EMS system needs to calculate the soot accumulation and dissipation rate in real time to obtain the current soot load, regenerate the GPF according to the current soot load, and monitor the remaining soot in the current GPF with the difference between the two. At the same time, it is necessary to consider how to clean the accumulated soot under different environmental conditions [1].

This paper mainly studies the influencing factors of soot consumption rate, uses mathematical models to model several factors that affect the consumption rate, and then analyzes the importance of each influencing factor through the model. Based on the analysis results, a good soot clean result can be get in cold area through regeneration control optimization.

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1 Test preparation

The test is divided into two parts, the first part is the bench test, and the dissipation model is first tested on the engine; the second part is the cold district road test on vehicle to test the actual vehicle regeneration control effect.

1.1 Test powertrain system

The test engine is a small-displacement three-cylinder DI engine equipped with a underfloor GPF. The basic parameters of the engine are shown in Table 1 below::

Table 1. Engine parameters.

Engine	1.0L
Type	Inline three-cylinder, four-stroke, water-cooled
Power/kw	92(5500r/min)
Max torque(N.m)	190(1500-4500r/min)
Bore/Stroke	73mm/79.6mm
Displacement	0.999L
CR	10:1
Firing order	1-2-3
Ingition type	Electronic controlled independent ignition
Combustion type	Ignition
Injection type	Direct injection
GPF layout:	Under floor

1.2 Test equipment and arrangement for testing

As shown in Figure 1, the engine is equipped with an under floor GPF, which is installed at the end of the exhaust system, a particle mass flow meter (AVL483) is installed at the exhaust outlet, the raw soot load is measured in real time. An oxygen sensor (Lambda sensor) is installed in front of the GPF to measure the amount of oxygen entering the GPF. A thermocouple is installed in the center of the GPF to monitor the temperature, and use a high-precision balance to weigh the soot mass.

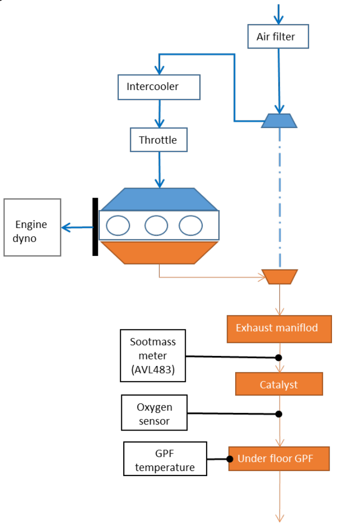

Fig. 1. Testing arrangement.

The vehicle in the road test is a light passenger car equipped with under floor GPF. In the test, thermocouples were installed in the center of the GPF to monitor its temperature change. The purpose of the test is to evaluate the GPF regeneration temperature and other regeneration effects.

2 Calculation of GPF soot dissipation

As mentioned earlier, the rate of soot dissipation in GPF is mainly related to three factors: the amount of oxygen entering the GPF, the temperature of its brick, and the soot load in the GPF, The relationship between them is shown below:

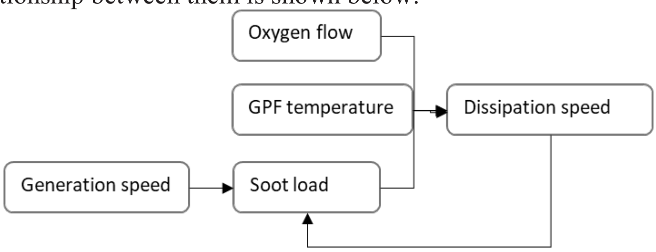

Fig. 2. GPF soot calculation.

From the perspective of combustion characteristics, this three factors have a positive effect on soot dissipation. In the actual vehicle control, in order to describe the soot dissipation rate, it is necessary to consider the real possible operating conditions. Based on the above factors, consider the actual engine operation, the working conditions involved should be analyzed.

Then on the engine bench, the actual dissipation rate of the soot load can be obtained by measuring the mass of GPF after the accumulated soot is consumed in a certain time under different oxygen amounts and temperatures.

Based on the above test methods and the working conditions, and the impact of different soot load on the dissipation rate must also be considered, several points were selected for testing. The GPF soot load point is based on the maximum soot load of 5g, which is appropriately extended outward to 8g, under the premise of considering the test operation and not damaging the GPF sample, try to cover the operating conditions of the engine, the test points are shown in figure 3.

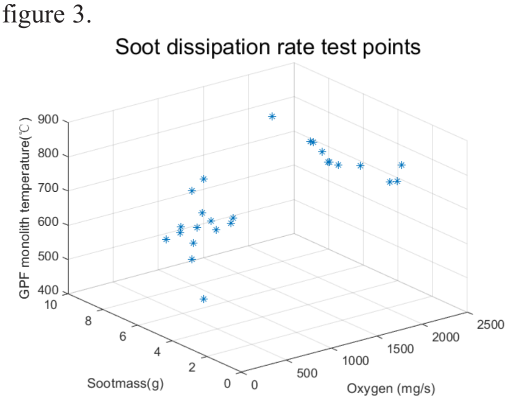

Fig. 3. Soot dissipation rate test points.

After completing the test of the above operating points, the data is modeled by the Gaussian Process. Among the 25 test points, 6 operating points are selected as validation points, and the remaining 19 are observation points. After training and modeling, the soot dissipation rate Burn_rate is evaluated using residuals (residual = actual value-model value) as shown in Figure 4. The residuals of all operating points are at a very low level

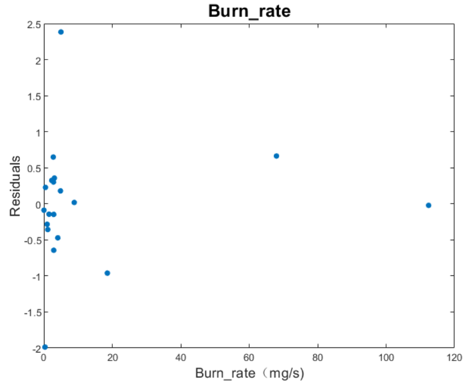

Fig. 4. Residuals of soot dissipation rate.

Carrying out a residual analysis on the validation points, we can see that the overall results are good. This result proves that the quality of the dissipation rate through this model is good.

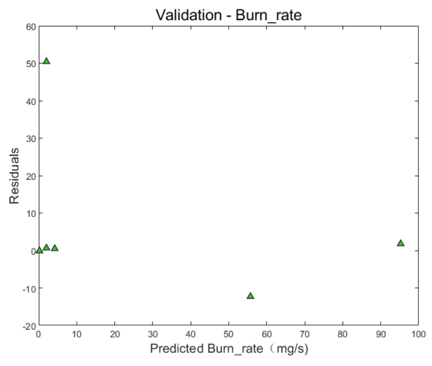

Fig. 5. Residuals of validation points.

3 Soot regeneration condition analyze

After completing the above tests, analyze the factors which affect the soot dissipation rate, and combine with the engine's own control to find out the most efficient way to clean GPF soot.

As shown in Figure 6, a comprehensive analysis of the oxygen flow rate and exhaust flow rate shows that under the premise of the same oxygen flow rate, as the GPF temperature rises, the soot dissipation rate shows a obvious upward trend, and from the data, although there is regeneration occurs at 520℃, the speed is very slow, and effective regeneration can only happen when the temperature is above 600℃, while the oxygen flow rate is about 600mg/s, and the regeneration rate can also reach 2.5mg/s. It takes about 7 minutes to complete 1g of soot cleaning, so effective regeneration can be achieved above this temperature.

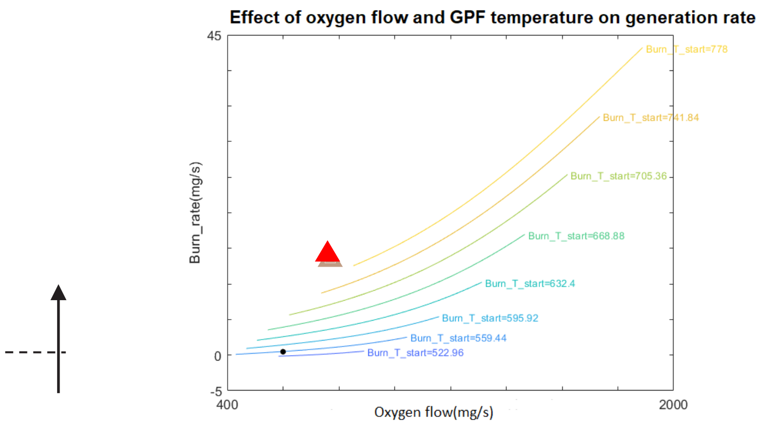

Fig. 6. Effect of burning rate.

Based on the above analysis, for this gasoline engine, if it can be operated at an oxygen flow of more than 600mg in actual operation, if the temperature of the GPF can be controlled above 600°C, a higher regeneration rate can be achieved, but the actual oxygen flow is affected by excess air limits after it increased to 1.1, the combustion will be unstable and cannot be controlled well. Therefore, except for fuel cut-off conditions, the oxygen flow increasing is very limited.

As shown in Figure 7, the actual road driving test was conducted in Heihe -20℃ environment. From the data collected, the vehicle speed is basically below 80km/h, some operating conditions are around 30km/h, and the ratio of oxygen flow exceeding 500mg/s is still relatively high. Due to driving conditions, the problem of under floor GPF is that the brick temperature is not high, and it is difficult to achieve the ideal temperature above 600°C during normal operation, while it is easy to achieve the oxygen flow rate above 600mg/s in the actual driving conditions controlled at the stoichiometric air-fuel ratio. So increasing the GPF temperature is the key to achieve effective soot regeneration rate.

Fig. 7. Analyze of real driving condition.

On the other hand, when the oxygen flow rate increases to 2000 mg/s, its soot dissipation rate also increases obviously. Corresponding to the actual deceleration and fuel cut in actual operation, the high rate above 60 mg/s comes from the fuel cut control, which also shows that the fuel cut control is a very efficient way to removing soot deposits. In actual vehicle driving, try to decelerate and cut off fuel to complete efficient soot generation sometime after high speed driving will be good for GPF regeneration.

4 Soot generation method analyze

From the perspective of GPF central temperature, effective regeneration can only be achieved when it is above 600℃. When the temperature is higher than 750 degrees, the regeneration rate can be significantly improved. Therefore, in regeneration control, raising the central temperature of GPF is a very effective method. For the gasoline direct injection engine, due to its better combustion stability, by retarding more ignition angle, the combustion efficiency is reduced, the fuel energy is controlled in GPF for heating, and its temperature is increased [1].

As shown in Figure 8, the temperature of the GPF was tested at a low temperature environment of -20°C. When the regeneration control state was not performed (ignition efficiency = 1, excess air coefficient lambda = 1), the central temperature of 100 km/h GPF was required in order to reach 600℃:

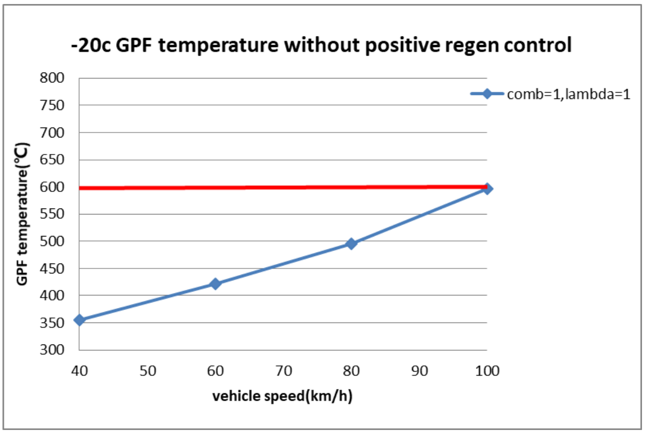

Fig. 8. -20℃ GPF central temperature without generation control.

In order to increase the center temperature of the GPF, it is necessary to reduce the combustion efficiency of the engine, so that part of the fuel energy can enter the exhaust system for secondary reaction. At the same time, due to the reduction in combustion efficiency, more combustible mixture is required to maintain the current load of the engine. In fact, the higher the energy of combustion into the exhaust system under the same load, more heat will increase the temperature in the GPF brick [2].

As shown in Figure 9 below, when the engine combustion efficiency was reduced to 70%, 60%, and 50%, respectively, the GPF center temperature is measured at different vehicle speeds. From the results, it can be seen that when the combustion efficiency drops to 50%, the GPF brick temperature at 60km/h can reach 600°C. According to this temperature, 4g soot can burn out in half an hour theoretically. Therefore, in extreme low temperature environments, in addition to positive regeneration control, the driver should keep a relative high vehicle speed to increase the heat flow through the increase of load, so a good way in real driving is: when the soot load reaches a certain higher limit, a light or screen prompt will be given to remind the driver pay attention to the state of GPF, when there is a high amount particulate matter accumulation, the driver need to pay attention to driving habits, run in suburbs or high speed appropriately to avoid GPF jams.

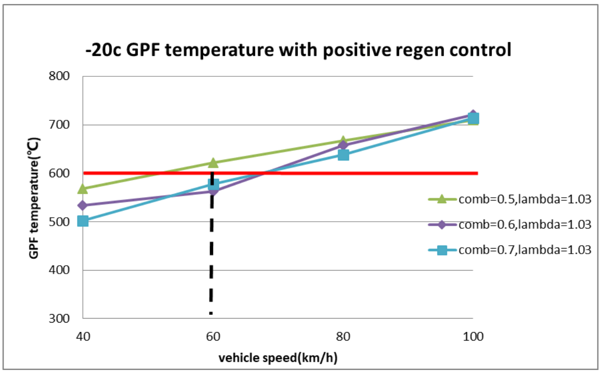

Fig. 9. -20℃ GPF central temperature with generation control.

5 Conclusion

Through the above analysis, the following conclusions are:

5.1 By fitting the data of the soot dissipation rate, it can be found that both the oxygen flow rate and the central temperature of the GPF have a significant effect on it, but the limit of the excess air coefficient on the combustion stability cannot be too lean. Increasing the GPF temperature in normal driving is more effective. The rapid increase in oxygen flow rate during deceleration and fuel cut can also greatly increase the consumption rate.

5.2 In the actual driving process, such as in extreme urban conditions, the vehicle cannot basically achieve effective regeneration without regeneration control. The reason is that the vehicle load is too low and the heat flow does not meet the GPF regeneration temperature.

5.3 By reducing the combustion efficiency of the engine, the central temperature of the GPF can be significantly increased, but to achieve efficient regeneration, the vehicle still needs to be run at a higher speed. Therefore, when the GPF light on in the China6 vehicle, the user needs to adjust the driving habits to carry out soot regeneration.

5.4 Due to the location of the underfloor GPF, it is difficult to increase the temperature. More and more vehicles have used close couple type to increase GPF brick temperature. To do so, the vehicle manufacture needs to consider to improve engine cabin heat dissipation.

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