Analysis and experimental research on the influence of VVT point selection on exhaust temperature in low speed operating conditions

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Abstract. During the development of a model equipped with dual VVT engines, a higher temperature of the catalyst was discovered. Therefore, the sweep point of VVT is optimized under low speed and high load conditions. The test results show that VVT has a significant effect on the temperature of the catalytic converter, and the temperature of the catalytic converter has decreased after optimization. At the same time, the VVT opening has little effect on the dynamics. In addition, VVT has an effect on the knocking tendency of the engine. When the knocking tendency increases, the temperature of catalytic converter and power performance of the engine are deteriorated. On the contrary, if the ignition angle can be advanced, the performance of the engine can be optimized.

1 Introduction

Currently, light-duty production vehicles need to meet the *Limits and measurement methods for emissions from light-duty vehicles (CN Ⅵ)*. Among them, type I Test requires that the harmful gases emitted by the vehicle in a WLTC cycle meet the legal requirements. [1] During the development of a new model, the catalyst temperature was too high when the vehicle was accelerating in the fourth stage of the WLTC cycle. For the protection of the catalyst, when the ECM detects that the temperature of the catalyst is too high, it will make the air-fuel ratio rich, which directly causes the emission result to exceed the standard. Under the same engine operating conditions, the exhaust temperature is directly affected by the ignition angle. [2-5] Under high load conditions, the closer the ignition angle is to the MBT ignition angle, the higher the combustion efficiency of the engine and the lower the exhaust temperature. At the same time, VVT affects the air intake of the engine, thereby

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affecting the engine's anti-knock ability. The engine used in this model is equipped with dual VVT. Therefore, it is prepared to adjust the VVT opening to try to optimize the vehicle's catalytic converter temperature performance in the emission cycle. At the same time, it is necessary to ensure the power of the engine so that the vehicle can follow the line normally.

2 Dyno test stand construction and data acquisition

The after-treatment layout of the test vehicle is the front-stage three-way catalytic converter and the GPF with precious metal coating. Other parameters are shown in Table 1. The engine is a naturally aspirated DVVT engine. The specific parameters are shown in Table 2. A thermocouple is installed at the center of the catalytic converter to measure the actual temperature to verify the estimated temperature of the ECM. Another knock sensor is installed in the engine block to verify each other with the ECM knock signal. The two-drive chassis dyno made by HORIBA. The schematic diagram is shown in Figure 1 after the completion.

Table 1. Parameters of vehicle.

Reference Mass(kg)	Maximum Mass(kg)	Drive Mode	Engine assembly method	Gearbox	Main Reduction Ratio
1910	2625	FR	Longitudinal	5MT	4.3

Table 2. Engine parameter.

Number of cylinders and cylinder arrangement	Engine capacity (CC)	Cylinder bore (mm)	VVT IN (°CA)	VVT (°CA)
L4	2438	95	0~60	0~-40
Normal idle speed (RPM)	Engine Max speed (RPM)	Max design power/speed (kW/RPM)	Max design torque/speed (N·m/RPM)	Fuel label
750	5200	116/4600-5000	235/2600-3600	92# CN Ⅵ

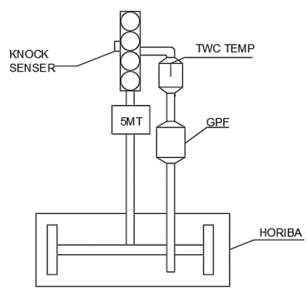

Fig. 1. Schematic diagram of chassis dyno.

In the test, the various pressure and temperature points of the engine, the measured temperature of the catalytic converter, and the internal parameters of the ECM were collected to the computer through INCA, the knock signal was monitored through the speaker, and the actual output torque of the vehicle was collected through the chassis dyno console. The vehicle speed is controlled through the chassis dyno console, and INCA

controls the torque request of the ECU, so that the engine operating conditions can be stabilized. In the case of stable engine operating conditions, collect a set of 8s interrogation data and take the average value. The test results are based on the equivalent ratio of the gas mixture.

3 Test results and analysis

According to the actual operating conditions of the engine, some VVT sweep points are prepared for WOT where the engine speed is 1600~2000 rpm. Among them, the ignition angle is adjusted so that the engine can produce a slight knock (1 to 2 times per minute without strong knock are heard, while the ECM can detect the knock and produce a retard angle of less than 2°CA). The original VVT distribution of the engine is shown in Figure 2 and Figure 3.

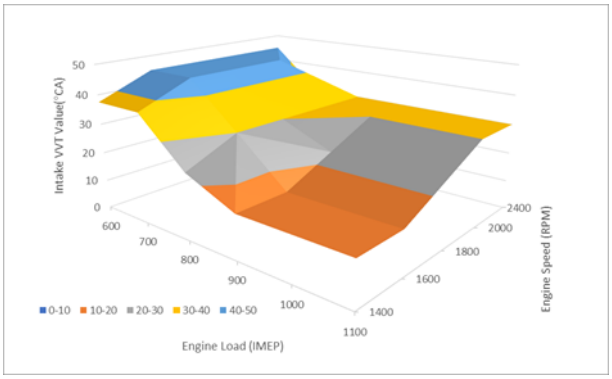

Fig. 2. Original Intake VVT distribution.

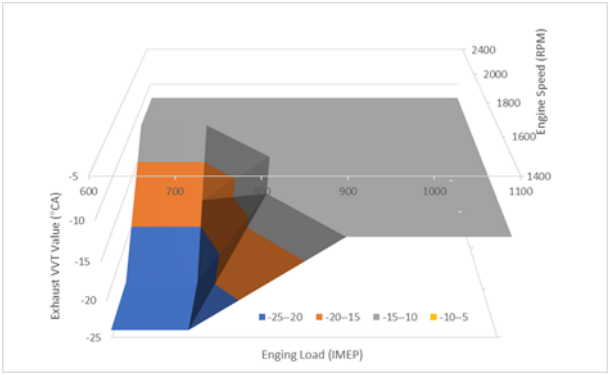

Fig.3. Original exhaust VVT distribution.

The original VVT was selected through the engine dyno bench test. It can be seen from Figure 2 that in WOT area, the speed is from 1400 to 2400 rpm, the intake VVT is gradually opened early, and the opening degree is increased from 15°CA to 30°CA. It can be seen from Figure 3 that the exhaust VVT remains unchanged at -12°CA in WOT conditions. The VVT selected by the bench has a certain degree of rationality, and a certain balance has been made in terms of economy and emissions, and it is not suitable for large-scale changes. At the same time, in consideration of ride comfort, it is not advisable to make the VVT of WOT area have a large change from the adjacent operating conditions, which is not conducive to the control of the engine. Therefore, only select the range close to the original selected point to scan the points to see if there is room for optimization.

3.1 Test result and optimization of VVT sweep point in 1600rpm

At 1600 rpm, the VVT of the engine is 18° for intake and -12° for exhaust. Besides, choose 4 operating points that the intake VVT unchanged, the exhaust is 0°CA, -18°CA; the exhaust VVT is unchanged, the intake is 24°CA, 12°CA.

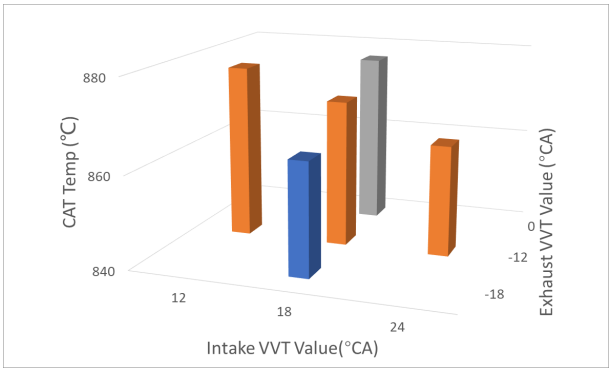

Fig.4. Catalytic Converter Temperature Results in 1600rpm.

Figure 4 shows the effect of VVT combination changes on the temperature of the catalytic converter at 1600 rpm. It can be seen that when the intake VVT remains unchanged, as the exhaust VVT continues to close late, the catalyst temperature gradually decreases. When the exhaust VVT remains unchanged and the intake VVT is gradually opened early, the catalyst temperature also gradually drops. In terms of overall performance, in 1600rpm operating conditions, the greater the valve overlap angle, the better the catalytic converter temperature performance. But from the point of view of the temperature distribution range of the catalytic converter, the overall change is little, and they are all between 860°C and 880°C.

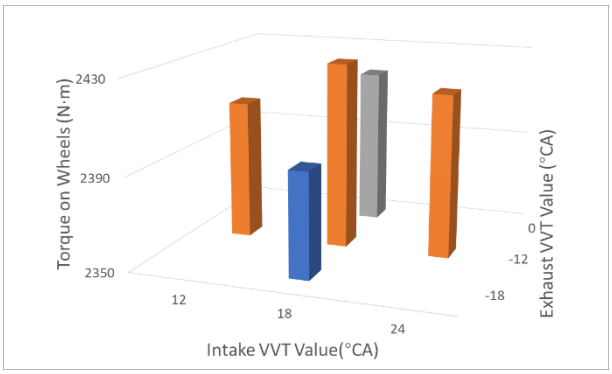

Fig. 5. Results of wheel break torque in 1600rpm.

Figure 5 shows the effect of VVT combination changes on wheel break torque at 1600rpm. Except for the poor performance of intake VVT18°CA and exhaust VVT-18°CA, other VVT combinations have little effect on torque. The original VVT combination is the best choice for power. If considering the exhaust temperature comprehensively, the intake VVT24°CA and the exhaust VVT-12°CA are also more appropriate.

3.2 Test result and optimization of VVT sweep point in 1800rpm

At 1800 rpm, the original VVT of engine is 24.5°CA for intake and -12°CA for exhaust. In addition, 4 operating conditions are selected, which are divided into the same intake opening degree, the exhaust opening is 0°CA, -24°CA; the exhaust opening degree is unchanged, the intake opening degree is 20°CA, 30°CA.

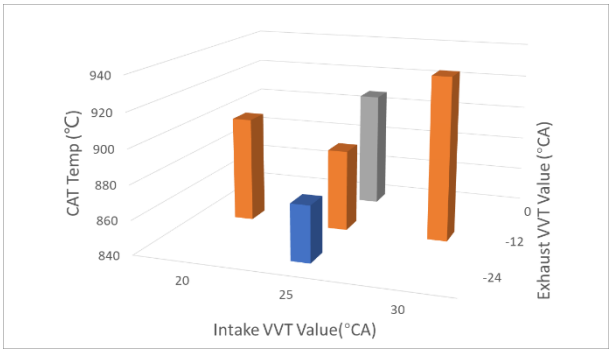

Fig. 6. Catalytic Converter Temperature Results in 1800rpm.

Figure 6 shows the exhaust temperature difference caused by different VVT combinations at the current speed. It can be seen that when the intake VVT remains unchanged, the catalyst temperature gradually decreases with the late closing of the exhaust VVT, and the exhaust VVT reaches the lowest value when the exhaust VVT reaches -24°CA. When the exhaust VVT is maintained at -12°CA, as the intake VVT continues to open early, the temperature of the catalyst will first decrease and then increase. Overall, when the VVT combination is 30°intake and -12°exhaust, the catalyst temperature is the highest.

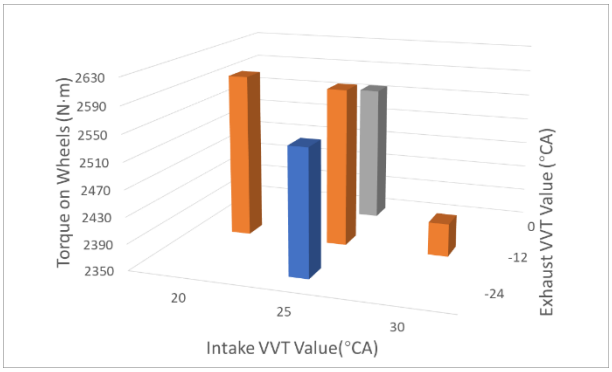

Fig. 7. Results of Wheel Break Torque in 1800rpm

Figure 7 shows the wheel break torque changes under different VVT combinations when the engine speed is 1800 rpm. It can be seen that when the intake VVT is 25°CA, the torque performance is not much different, both are between 2500 and 2600 N·m, showing a trend of increasing first and then decreasing. However, when the exhaust VVT is fixed at -12°CA, when the intake VVT is advanced from 25°CA to 30°CA, a significant drop in torque appears. Combined with the performance of exhaust temperature, at this time, the engine has the worst combustion condition and the lowest thermal efficiency, the actual output power drops and the exhaust temperature rises.

3.3 Test result and optimization of VVT sweep point in 2000rpm

At 2000 rpm, the VVT opening of the engine is 30° for intake and -12° for exhaust. Choose another 5 operating conditions, respectively, the intake opening is unchanged, the exhaust is 0°CA, -24°CA; the exhaust opening is the same, the intake opening is 25°CA, 20°CA, 15 °CA.

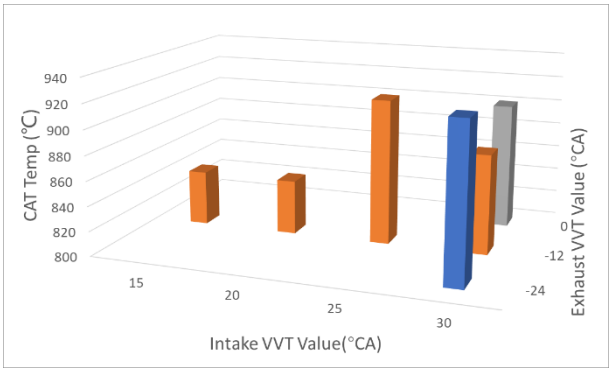

Fig. 8. Catalytic Converter Temperature Results in 2000rpm.

Figure 8 shows the change of exhaust temperature under different VVT combinations. It can be seen that as the intake VVT continues to increase, the exhaust temperature has a trend of flattening and then increasing and then slowly decreasing. As the exhaust VVT turns off gradually, the exhaust temperature first drops and then rises. When the VVT combination is 25° intake and -12° exhaust, the exhaust temperature is the highest.

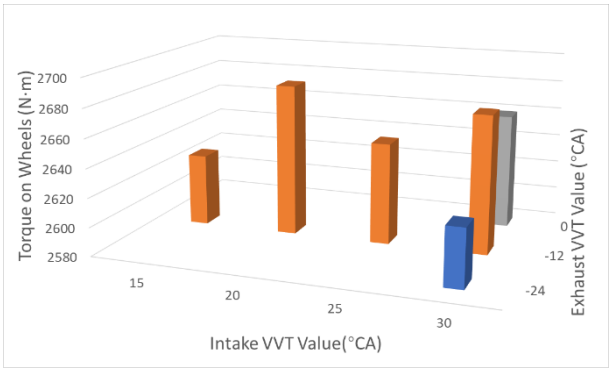

Fig. 9. Results OF Wheel Break Torque in 2000rpm

Figure 9 shows the actual on-wheel torque performance under different VVT combinations. It can be seen that as the intake VVT is gradually opened early, the torque performance shows a fluctuating trend. As the exhaust VVT turns off gradually, the torque first increases and then decreases. The performance of the increase is not obvious, but the magnitude of the decrease is large. In general, when the VVT combination is 20°intake and -12°exhaust, the torque on the wheels is the largest and the power is the best. In terms of comprehensive exhaust temperature and power performance, when the VVT is combined with an intake of 20° and an exhaust of -12°, the performance is best.

According to the sweep point results of the above three speed conditions, the change of VVT has a more obvious impact on the temperature of the catalytic converter, while relatively speaking, the impact on the torque is not so obvious. Due to the limitation of the test conditions, unlike the engine flywheel torque that can be directly measured on the

engine dyno bench, only the actual wheel torque of the vehicle can be measured on the chassis dyno. From the engine crankshaft to the wheels, it passes the gearbox, drive shaft, final drive, rear axle and tires. The transmission gap and elastic twisting of each component will cause significant fluctuations in the torque on the wheel. So on the whole, VVT has no obvious influence on engine power, but the influence trend is limited by the test conditions and cannot be clearly drawn. The effect of VVT on the temperature of the catalytic converter is relatively obvious. It can be basically seen that in the low-speed external characteristic operating range, when the intake VVT is opened to a certain degree early, it will adversely affect the temperature of the catalytic converter. The specific degree of early opening is affected by engine speed. When the exhaust VVT is completely closed, the catalytic converter temperature performance is poor. When the exhaust VVT is turned off later, the temperature of the catalytic converter is better, but the power performance is reduced. On the whole, it is not appropriate to turn off exhaust valve later. Combined with the control parameters of the engine original VVT, the intake VVT at 1800rpm is adjusted from the original 24.5°CA to 20°CA, and the intake VVT at 2000rpm is adjusted from the original 30°CA to 20°CA. The exhaust VVT remains unchanged at -12°CA. The adjustment of 1800rpm is more about the smoothness of VVT changes during the increase of engine speed. From the results of data point, the exhaust temperature has increased under the adjusted 1800rpm working condition, but in exchange for a better performance of the exhaust temperature at 2000rpm. Considering the overall operating conditions of the engine, 2000rpm is used more frequently, and the adjusted overall catalyst temperature is more reasonable.

3.4 Influence of ignition angle on engine power and the temperature of the catalytic converter

In the process of sweeping points, according to the actual engine knock performance, the ignition angle of certain working conditions was adjusted. Take the engine speed 1800rpm, intake VVT30°CA, exhaust VVT-24°CA operating conditions as an example. It can be seen from Figure 6 and Figure 7 that its performance is significantly worse than other VVT combinations. In the test, it was found that when the VVT combination is adjusted to this working condition, the engine knocking tendency suddenly increases, which is manifested by the ECU's retreat angle control, and the loudspeaker can hear obvious and frequent knocking sound. Therefore, the ignition angle has to be adjusted down.

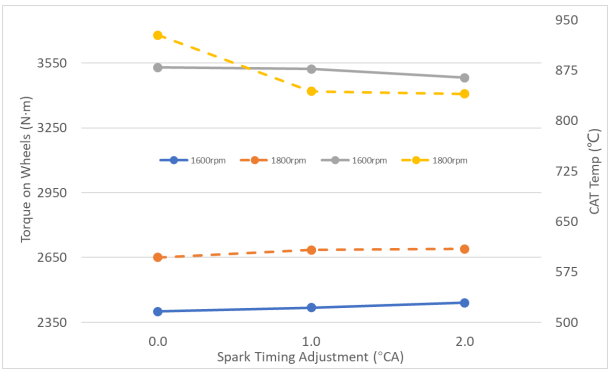

Fig. 10. Influence of ignition angle on engine power and the temperature of catalytic converter.

Figure 10 shows the measured temperature of the catalytic converter and the torque on the wheels with the ignition angle under the operating conditions of 1600rpm, intake

18°CA, exhaust 0°CA and rotating speed 1800rpm, intake 20°CA and exhaust -12°CA. The trend of change. As can be seen in the figure, when the ignition angle is advanced by 1°CA or 2°CA from the basic ignition angle, the temperature of the catalyst will decrease accordingly. Under 1800rpm working conditions, it even dropped by close to 80°C. The measured torque on the wheel also increases with the advancement of the ignition angle. Due to the high load area, the gasoline will knock, and the ignition angle cannot be set according to the MBT ignition angle. Therefore, when the ignition angle is advanced and closer to the MBT ignition angle, the engine's power and economy will be better.

5 Conclusion

The combination of intake and exhaust VVT can have a significant impact on the temperature of the catalyst. This impact has a certain trend, but the specific setting parameters need to be analyzed according to the engine operating conditions.

The effect of VVT combination on the engine power performance at low speed is not obvious. When the temperature of the catalyst or other parameters that need to be considered are more important, a certain power performance can be sacrificed.

Excessive valve overlap angle makes the engine's knock tendency obvious, and the advance angle has to be reduced, which leads to the deterioration of engine power and economy. On the contrary, a proper VVT combination can advance the setting of the ignition angle and make the engine perform better.

We should not pursue the optimal solution of the VVT combination under each engine operating condition, but consider the overall smoothness principle, sacrificing the engine performance in some operating conditions in exchange for the smoothness of engine control.

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