Study on the influence of different test cycles on vehicle emission and fuel consumption

Lihui Wang¹, Xionghui Zou¹, Zhikun Deng¹, Peilin Geng¹, Le Liu¹, and Haiguang Zhao²,³,∗

¹ China Automotive Technology and Research Center Co., Ltd., Tianjin 300300, China
² State Environmental Protection Key Laboratory of Vehicle Emission Control and Simulation, Chinese Research Academy of Environmental Sciences, Beijing 100012, China
³ Vehicle Emission Control Center, Chinese Research Academy of Environmental Sciences, Beijing 100012, China

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Abstract. In order to satisfy regulations of CHINA 6 and the corresponding standards of fuel consumption, a variety of advanced technology are adopted. While manufacture calibrate engine based on WLTC and NEDC test cycle during development process, and the technical route is still a lack of a large number of test research on CLTC. This article firstly investigates mainstream technology on market, then in-depth study influence of different test cycle on emissions and fuel consumption, comparing difference of test data to evaluate the potential of each technology route for emission and fuel economy, as well as the adaptability of each technology route under CLTC. Finally, to seek the advanced technology route of energy-saving and emission reduction applicable to national conditions.

1 Introduction

China's automobile industry is developing rapidly. In 2018, the production and sales of automobiles both exceeded 2,300. In the first half of 2019, the number of automobiles in China reached 250 million. The rapid growth of car ownership not only facilitates people's life and provides effective support for economic development, but also brings many problems to the society, such as environmental pollution, traffic congestion and energy crisis. With the increasing awareness of environmental protection and national political air pollution, the control of automobile exhaust emission pollutants has become the key to the technical development of automobile industry. People's attention to hot issues such as energy crisis and global warming leads to increased sensitivity to vehicle fuel consumption, and people from the beginning to the end of the attention to travel cost, maintenance cost and other vehicle cost performance indicators, vehicle fuel consumption control technology is the top priority in automotive product research and development.

* Corresponding author: zhaohg@vecc.org.cn
In order to meet the emission and fuel consumption standards and people's increasing demand for energy saving and emission reduction, the automobile and internal combustion engine have undergone continuous innovation. In recent years, with the development of on-board electronic technology and parts technology, the automobile engine has achieved a qualitative leap. The Sixth National Light Vehicle Emissions Standard was released in December 2016 [1], known as "the strictest regulation in the world", and has been formally implemented in many regions. The five-stage fuel consumption standard has been preliminarily determined, and vehicle enterprises are developing more fuel-efficient and more efficient products to meet the indicators. At present, the oxygen sensor realizes the closed-loop control of the engine and the efficient exhaust gas treatment of the three-way catalytic converter under the theoretical air-fuel ratio. This route can maximize the role of the three-way catalytic converter and effectively reduce the emission of pollutants such as CO, HC and NOx. At the same time, in order to further reduce the level of fuel consumption, improve the efficiency of the engine, turbocharging, direct injection in cylinder (GDI), variable valve timing (VVT) and other technologies have become the national six light gasoline vehicles mainstream in cylinder technology route. Frontier technology routes such as homogeneous compression combustion, exhaust gas recycling technology (EGR) and gasoline engine particle trap (GPF) to reduce PN emissions brought by variable compression ratio technology have also been gradually applied to high-end vehicles. More advanced technology routes such as variable inlet port (VIM), dynamic cylinder deactivation technology (CDA), rarefied combustion, in-cylinder water spraying and so on are still being explored.

2 China VI technical route market research

At present, the country 6 models are mainly ignition engine (gasoline engine) models, a small number of compression ignition engine (diesel engine) of the country 6 models are under development and expected to be launched in 2020. So far, through the motor vehicle environmental information disclosure of the six models have more than 4000, intercepting the mainstream displacement 1.0 - 3.0 L engine models, data show that the configuration of variable valve timing (VVT), multi-stage ternary catalysts TWC, high idle speed of ignition delay time cold start emissions reduction strategies such as technology is the standard on the six models, among them. The big data is analyzed according to the six main technical routes of self-priming and pressurization, direct injection in cylinder and inlet injection, and whether or not there is GPF, as shown in Figure 1.

Fig. 1. Configuration distribution of China VI.
As can be seen from Figure 1, the engine displacement of light vehicles in the Chinese market is mainly 1.5L, accounting for 37%, followed by 2.0L, accounting for 30%. In order to continuously tighten the emission fuel consumption standard, as well as the influence of vehicle lightweight and engine miniaturization, engine technology has gradually developed from naturally aspirated and inlet fuel injection to pressurized direct injection. Under the same displacement, the supercharged engine can obtain higher power performance, while under the same power performance demand, the supercharged engine can achieve better fuel economy. While the engine is continuously miniaturized, the total output efficiency of the engine is squeezed, and the high torque response at low speed is realized. In-cylinder direct injection technology can enable the engine to realize layered and rare combustion, make the mixture of oil and gas more fully, reduce combustion temperature, improve compression ratio, accurately control fuel injection, and have a better theoretical air-fuel ratio control, further improving the fuel economy and cold emission level of the vehicle [2]. From the technical route analysis in Figure 1, it can be seen that the pressurized intake mode and the in-cylinder direct injection mode have become the mainstream of the market, which also confirms the continuous iteration and upgrading of engine technology. In order to cope with the stricter PN emission of the Sixth National Emitting Standard, some enterprises have adopted the way of adding GPF. However, according to the analysis, the models equipped with GPF account for 27%. Most models still meet the PN emission requirements of the Sixth National Emitting Standard through the optimization of in-cylinder combustion, the control and calibration matching of intake and exhaust VVT and ignition time. The introduction of the idle start - stop function enables vehicles to achieve significant fuel consumption performance in urban road conditions. 65% of the six models in the market are equipped with the idle start - stop function. Through big data, the mainstream technical routes of China 6 models on the market are supercharging, direct injection in cylinder, VVT, cold start emission reduction control strategy of high idle delay ignition time, multi-stage TWC, and idle start and stop function, etc. The specific proportion analysis of some technologies is shown in Table 1 below.

Table 1. Analysis of the mainstream technical routes of the six models in China.

<table>
<thead>
<tr>
<th>Intake way</th>
<th>Injection way</th>
<th>GPF</th>
<th>SS</th>
<th>VVT</th>
<th>TWC+</th>
</tr>
</thead>
<tbody>
<tr>
<td>NA</td>
<td>PFI 31%</td>
<td>80%</td>
<td>9%</td>
<td>50%</td>
<td>98%</td>
</tr>
<tr>
<td></td>
<td>GDI 20%</td>
<td>83%</td>
<td>50%</td>
<td></td>
<td>83%</td>
</tr>
<tr>
<td>TC</td>
<td>PFI 20%</td>
<td>18%</td>
<td>31%</td>
<td>25%</td>
<td>83%</td>
</tr>
<tr>
<td></td>
<td>GDI 69%</td>
<td>82%</td>
<td>50%</td>
<td></td>
<td>83%</td>
</tr>
</tbody>
</table>

By analyzing the data in table 1, most of the naturally aspirated engine with inlet multi-point injection technical route, while the supercharged engine more collocation in cylinder direct injection technology, this is due to the direct injection (gdi) can effectively solve the supercharged engine air inflow increase with high fuel injection quantity, the issues that led to the mixture of oil and gas is not fully and effectively reduce the combustion temperature in cylinder, make the combustion more sufficient, Increase the compression ratio to further improve the engine efficiency and fuel economy [3]. The GPF was added in response to high Pn emissions due to pressurization and direct injection technologies.
3 Study on the influence of different test cycles on vehicle emission fuel consumption

In order to analyze the influence of different technical routes on vehicle emissions and fuel consumption, this paper selects 38 national six sample vehicles with different technical routes to carry out emission and fuel consumption tests respectively, and studies the emission and fuel consumption characteristics based on different test cycles.

Compared with the National Fifth Standard, the biggest change of the National Sixth Standard is the change of the cycle condition, which directly affects the vehicle emission performance. The emission and fuel consumption characteristics of different cycle conditions need to be studied. At the same time, the actual road driving conditions in China are different from the NEDC and WLTC which are formulated according to the driving conditions in Europe. With the development of China's automobile industry, the rapid growth of car ownership, China's road traffic conditions have changed a lot, the actual driving fuel consumption of vehicles and laboratory certification results gap is very big, which is also criticized by consumers the most problems. According to the background investigation of China's working condition development projects, the use of NEDC makes the announced fuel consumption of vehicles decrease year by year, but the actual fuel consumption of vehicles does not change much, and the difference between the two is getting bigger and bigger, as shown in Fig.2 [4][5].

![Fig. 2. The difference between the announced fuel consumption and the actual fuel consumption increases year by year.](image)

The main reason for the above problems is the difference between the existing laws and regulations and the actual situation in China. The test conditions (NEDC and WLTC) required by the current standards are obviously different from the actual conditions in China. China Automotive Technology and Research Center Co., Ltd. has successfully developed the "Chinese Driving Conditions" [6] and released the national standard of "Chinese Vehicle Driving Conditions". The maximum speed and average speed of the Chinese driving conditions are significantly lower than that of the WLTC driving conditions. In China, the operating speed is mainly distributed in low speed and medium speed range, with the speed distribution above 80km/h accounting for only 4.7% [7], while the WLTC distribution above 80km/h accounts for up to 20%. Because the test cycle is technology-oriented, these differences are the fundamental reasons why some energy saving technologies can't really play their role in energy saving and emission reduction in China.

In this paper, the influence of different emission technology routes under different test cycle conditions on the emission and fuel consumption of traditional energy light vehicles was deeply studied, and the differences in test data under different test cycles were
compared and analyzed to evaluate the emission potential and fuel economy of each emission technology route meeting the Sixth National Standard. At present, the emission test of light vehicle is subject to the WLTC test cycle, and the fuel consumption test is subject to the NEDC test cycle. Therefore, the company carries out the technology development on the basis of the WLTC and NEDC test cycle in the vehicle model and engine development, and the technical route of all the national 6 models is parallel to the national 5 and national 6 stages. And the technical route of vehicle emissions and fuel consumption in the cases of performance in China is still a lack of a large number of test study, adaptability to Chinese conditions, this paper further analysis the adaptability of working condition of six different countries technical route to China, to explore the feasibility of China under the condition of the technical route, for China's national conditions six stages of the light vehicle the advanced technology for energy conservation and emissions reduction.

3.1 Test vehicle selection

According to the influence factors such as the technical route, fuel type and displacement of CNVI, 23 CNVI test sample vehicles from 14 independent and joint venture enterprises were selected to conduct emission and fuel consumption tests under different test cycles (NEDC, WLTC and CLTC). The test models cover the displacement, quality and various technical routes of mainstream models in the market. The engine displacement ranges from 1.0L to 2.0L, and the quality ranges from 1060kg to 1880kg. The specific parameters are shown in Table 2. The distribution ratio of various technical routes in the test sample vehicles is close to the distribution ratio of technical routes of China Six models in the domestic market, as shown in Fig. 1.

Table 2. Test vehicle parameters.

<table>
<thead>
<tr>
<th>No.</th>
<th>Technical route</th>
<th>Market share</th>
<th>Curb weight</th>
<th>Displacement</th>
<th>NEDC</th>
<th>WLTC</th>
<th>CLTC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Turbo+GDI+GPF</td>
<td>18.2%</td>
<td>1365-1700</td>
<td>1.5-2.0</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>Turbo+GDI</td>
<td>35.4%</td>
<td>1455-1880</td>
<td>1.4-2.0</td>
<td>13</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>3</td>
<td>NA+GDI</td>
<td>6.2%</td>
<td>1280-1510</td>
<td>1.5-2.0</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>NA+PFI</td>
<td>23.8%</td>
<td>1060-1230</td>
<td>1.4-1.6</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>Turbo+PFI</td>
<td>10%</td>
<td>1440-1450</td>
<td>1.4-1.5</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>Turbo+PFI+GPF</td>
<td>3.8%</td>
<td>1403</td>
<td>1.5</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>NA+GDI+PFI+HEV</td>
<td>0.2%</td>
<td>1650-1725</td>
<td>2.0-2.5</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>NA+PFI+HEV</td>
<td>2%</td>
<td>1548-1623</td>
<td>2.0</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

3.2 Analysis of fuel consumption results

Fig. 3 shows the measured fuel consumption performance of all the test sample vehicles in the three test cycles of NEDC, WLTC and CLTC. As can be seen from the figure, compared with NEDC and WLTC cycles, the fuel consumption under CLTC test cycle is the smallest, while the fuel consumption of the whole vehicle gradually increases with the increase of engine displacement. The average fuel consumption of users of various models was inquired through the platform of "Bear Check Fuel Consumption", and then compared with the results under each cycle, it was found that the average deviation of fuel
consumption under NEDC was 22%, the deviation of WLTC was 17%, and the deviation of CLTC was 10%.

**Fig. 3.** Fuel consumption under different test cycles.

To analyze the influence of different working conditions on vehicle fuel consumption, the first thing to consider is the average speed of each working condition. 80km/h is the vehicle speed corresponding to the optimal fuel consumption, and when the speed is lower than 80km/h, the speed is inversely proportional to the fuel consumption. Because the WLTC operating condition with the highest average speed and closer to the optimal fuel consumption speed has the lowest fuel consumption, while the CLTC operating condition with lower average speed, higher idle speed and more complex operating condition has the highest fuel consumption, this result is particularly obvious for the supercharged engine with more engine power. For vehicles with low-power naturally aspirated engines, the frequent transient changing conditions and ultra-high speed of WLTC and CLTC make the engines work at full load, so the fuel consumption of such vehicles is slightly higher than that of NEDC, but the difference between cycle conditions is not obvious, as shown in Fig. 4.

**Fig. 4.** Comparison between CLTC fuel consumption and announced fuel consumption.

Figure 4 shows the comparison results between the measured fuel consumption results of vehicles with different technical routes under CLTC and the announced fuel consumption of this model. The research shows that the measured fuel consumption under the CLTC cycle is 14.9% higher than the announced fuel consumption of this model, among which the difference value of the supercharged engine model is 17.6%, half of the models is more than 20%, and the difference value of the self-primING engine model is only 7.2%. This indicates that the supercharged engine has a wider operating area under the more complex driving conditions of the CLTC, resulting in more air-fuel ratio intensification, while the self-priming engine has similar operating conditions under different cycles.
3.3 Analysis of emission results

Figure 5- Figure 7 respectively show the emission of THC, CO and NOx of all the test sample vehicles in NEDC, WLTC and CLTC test cycles. As can be seen from the figure, the CO, THC and NOx emissions of all vehicles under the WLTC test cycle are all below the national 6B limit after deterioration calculation. Except for some vehicles, the emission rules of all pollutants under the NEDC and WLTC test cycle are the same for most vehicle types, with an increase compared with the test results of WLTC. The reason for this result is that the most core means of emission control development is emission control calibration matching in addition to engine hardware design. However, at present, all enterprises carry out optimization matching of emission calibration based on the WLTC test conditions, without considering the actual road or other cycle conditions. Therefore, when the vehicle is tested under NEDC or CLTC cycle conditions with different characteristics such as average speed, acceleration ratio and idle speed ratio, the load area of engine operation will change, and the calibration and matching parameters of different engine load areas are different, without careful optimization work. This results in different emission results when vehicles switch to different working conditions and increase. At the same time, the test results of most of the vehicles in the figure indicate that even if the China 6 models without calibration and optimization are switched to NEDC or CLTC for emission test, they can still meet the limit requirements of China 6B, and may get lower emission results after calibration and optimization.

As for HC emission, the main peak value comes from the cold start stage. After the start of the test, HC emission tends to be stable and at a low level, so the calibration and matching work of HC emission control is relatively simple. The optimization is focused on the cold start stage, so as to shorten the ignition time of the catalytic converter and make the catalytic converter enter the high efficiency working state faster. In addition, longer cycle mileage can weaken the impact of cold-start HC emissions on the overall cycle emissions. As shown in Fig. 5, the HC emission level of each working condition from high to low is NEDC, Chinese working condition and WLTC, which is almost inversely proportional to cycle mileage. However, there are also certain differences in the results of some vehicles. The HC emission results of most vehicles under CLTC cycle conditions meet the requirements of the National 6A and 6B limits, except that the HC emission results of some vehicles slightly exceed the National 6B limit. It can also be seen from Figure 5 that the THC emission of the self-priming model is significantly lower than that of the supercharged model.
CO emissions of the vehicle test results showing a different situation, mainly because of the CO emissions control calibration match more complex, CO emissions mainly come from cold start phase, stages of transient speed and high speed working condition of air-fuel ratio and thick, and the air-fuel ratio and strong will directly lead to vehicle fuel consumption increased, so weigh the CO emissions and fuel consumption of the calibration optimization work is relatively complicated, Different models show different trends due to calibration differences. In general, the CO emissions of the six models developed for WLTC still maintain the lowest level under WLTC, but the CO emissions of different vehicles under CLTC and NEDC conditions vary from high to low. In Fig. 6, the engine displacement of each vehicle with technical route is arranged from low to high. It can be seen that CO emission increases with the increase of engine displacement. At the same time, the CO emission results of almost all vehicles under NEDC and CLTC cycle conditions meet the limit requirements of Country 6B. As can be seen from Fig. 6, the CO optimization of the turbocharged direct injection model can reach the level of the self-priming model, but the factor that has the greatest influence on CO emission is the vehicle's quality of preparation. The test results show that the CO emission increases significantly with the increase of vehicle quality of preparation.

Due to the low NOx emission limit of the six countries, it is more difficult to control, and the NOx emission value of most vehicles in good condition is relatively low, as shown in Figure 7. NOx emission is basically from the cold start stage, and the NOx emission in other stages of NEDC is close to zero. However, a small part of NOx emission will be generated in the high-speed driving stage of WLTC and CLTC cycle conditions, mainly because the proportion of constant speed of WLTC and CLTC is low, and the proportion of acceleration, maximum acceleration and maximum speed are large. This indicates that these two working conditions have more transient driving conditions and high speed driving conditions, higher exhaust temperature, and NOx is generated by rich oxidation reaction at high temperature. However, the vehicle WLTC after calibration and optimization has the
lowest NOx emission, while the CLTC without calibration and optimization and with more complex working conditions has a slightly higher NOx emission than the vehicle NEDC. At the same time, it can be found from Figure 7 that the NOx emission of the self-priming engine is significantly lower than that of the supercharged engine, mainly because the operating temperature of the supercharged engine is higher than that of the self-priming engine and it is more likely to produce NOx emission.

Fig. 8 shows the PM and PN emissions of all the country 6 test sample vehicles under three test cycles. It can be seen from the figure that different test cycle conditions have little influence on vehicle Pn and PM emissions. Except for the 3 vehicles of Model 8, Model 15 and Model 22, which are not equipped with GPF and already exceed the Pn limit of National Sixth 6E+11, the Pn and PM emissions of other vehicles under the three conditions all meet the requirements of National Sixth 6E+11 limit. It can be seen from the results that the addition of GPF has a significant effect on the control of vehicle PN emissions, which can make the PN emission level of the turbocharged direct-injection model reach the level of the self-priming model.

4 Analysis of the advantages and disadvantages of different technical routes

Through the emission and fuel consumption results of 38 test sample vehicles, the advantages and disadvantages of each technical route were analyzed, and the horizontal comparison was made according to the division of vehicle technical route. As can be seen from Figure 5-8, self-priming vehicles of technical routes 3, 4, 7 and 8 have lower emissions, especially HEV models of technical routes 7 and 8, which have great potential for emission control. Moreover, the HEV model has the lowest fuel consumption, and the fuel saving rate of the 2.5L engine can reach 35% after the addition of hybrid electric technology, as shown in Figure 9.
Fig. 9. Analysis of the advantages and disadvantages of light vehicle technical route.

Can be seen from the diagram, naturally aspirated technical route in fuel consumption, THC and NOx emissions has obvious advantages in many aspects, and inlet multi-point injection on the PN emissions of vehicles ahead of the other three routes (not add GPF), so the imbibition with inlet of multi-point injection optimal models of each pollutant emissions and fuel consumption performance and control a great development potential.

Route at the same time, direct injection (gdi) technology in the CO and THC emissions there is a big advantage, CO and THC are the main reason is that, as a result of the mixture incomplete combustion of fuel enrichment, and through direct injection technology will fuel in cylinder direct injection in cylinder, the fuel atomization is more meticulous, precise control of fuel injection, in large load, using homogeneous combustion, Effectively improve the engine compression ratio and thermal efficiency, air fuel ratio control is more accurate, reduce CO emissions under transient acceleration and high speed; During cold start, it can accurately control the fuel injection amount to solve the incomplete combustion problem caused by excessive concentrated air-fuel ratio during cold start. Combined with layered combustion, it can effectively control CO and THC emissions during cold start. Compared with the traditional inlet multi-point injection technology, the in-cylinder direct injection technology further optimizes the in-cylinder combustion, improves the efficiency of the engine, and improves the fuel economy and power performance of the engine.

Under the background of the global automotive market increasingly miniaturization, mostly with pressure in cylinder direct injection technology, pressurization technology improves the charging efficiency of engines, and in cylinder direct injection technology improve the combustion efficiency, the two combination, more improved its dynamic performance, and it can solve the supercharged engine in cylinder direct injection in low and middle speed of dynamic response under defects, As a result, the engine can maintain high torque output over a wider range of RPM. Compared with self-priming models with the same power performance, supercharged and direct injection models are regarded as more energy saving and environmental protection products. But dynamic performance often manifests itself in the daily vehicle driving, and in the regulations of driving cycles test, turbocharged, direct injection model of fuel consumption is significantly higher than the imbibition models, and in cylinder direct injection technology, due to the time of oil and gas combined with short and insufficient mixing result in inadequate local combustion in cylinder, severe carbon deposition, high PN emissions cannot be avoided, Therefore, it is more necessary to add GPF to supercharged and direct injection models to solve the PN emission problem.

Hybrid technology can make the engine work in the efficient range, maintain the optimal performance of emissions and fuel consumption, avoid the vehicle idling, low
speed engine bad conditions, and with the help of the auxiliary motor, can give the self-priming vehicle more robust power performance.

5 Conclusion

Through the experimental study of vehicle emissions and fuel consumption of different technical routes under different test cycles, the advantages and disadvantages of different technical routes, as well as the adaptability and development potential of different technical routes for China's working conditions are analyzed, and the following conclusions are drawn:

(1) The test results under different cycles indicate that the emission under WLTC is the lowest, and when the emission test of China 6 models calibrated and optimized based on WLTC cycle switches to NEDC or CLTC, the emission test can still meet the limit requirements of China 6B.

(2) The emissions and fuel consumption of models with natural inspirations and multi-point injection at the inlet ports are relatively low and the development potential is greater. With hybrid power technology, it can give full play to the advantage of technical route. Under the premise of considering better power performance, the supercharged, in-cylinder direct injection and GPF models have low emissions, provide higher power and power output, and relatively high fuel consumption. Combined with the idle start-stop function, lower fuel consumption performance can be obtained.

Reference

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