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The Analysis And Perspective on Development of Chinese Automotive Heavy-Duty Diesel Engine

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ABSTRACT: In recent years, under the influence of both China's domestic market demand and emissions standard improvement, Chinese manufacturers put great effort on the research and design of automotive heavy-duty diesel engine. This paper analyzes the technical parameters of heavy duty diesel engine in 11 / 13L displacement section and introduces its performance. At the same time, combined with the development of foreign heavy-duty diesel engine, the future development direction of Chinese heavy-duty diesel engine is forecasted.

Keywords: automotive heavy-duty diesel engine ; emission standard ; perspective

I. INDRODUCTION

Since German inventor Rudolf Diesel invented the diesel engine in 1869, it has been widely used in heavy trucks, special vehicles, buses, construction machinery, generating units, ship power and other fields because it owns many advantages compared to the gasoline engine such as higher thermal efficiency, better fuel economy, and stronger power. SinceChinese government decided to implement the reform and opening up policy in 1978, China has made great achievements in economic construction and its GDP amount has overtaken Japan in 2010. During these decades, Chinese diesel manufacturing industry develops and keeps growing, it supports and boosts China's economic take-off in the whole process. At present, China's annual heavy truck sales can be maintained at 600,000 or more, more than half of the world sales. Due to China's natural gas price and supply problems, the vast majority of heavy trucks still use diesel engines as a driving force. Therefore, it is of great practical significance to study the current situation of heavy-duty diesel engine in China and to prospect its future development.

II. DEVELOPMENT STATUS OF CHINESE AUTOMOTIVE HEAVY-DUTY DIESEL ENGINE

A. Development Status of Chinese Automotive Heavy-duty Diesel Engines in Recent Years

When financial crisis occurred in 2008, Chinese government invested ￥4 trillion to sustain economic growth. As a result, the heavy truck market boomed immediately.After experiencing the first few years of volatility, China's heavy truck sales tend to be stable in recent years, annual sales remained at 600,000 or more. (As shown in picture 1)

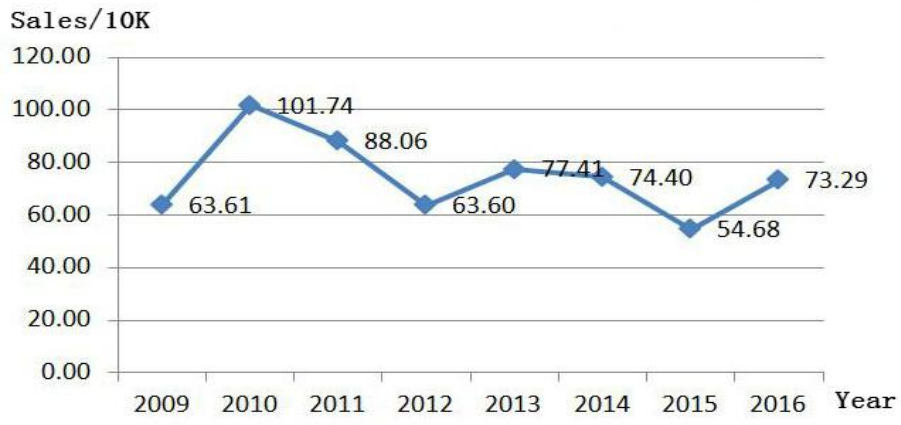

Figure 1. China heavy truck sales over recent years

On the one hand, China's natural gas price ismuch higher than USA and EU, what's worse, the supply is unstable and oil price in recent years stays at a low level, as a consequence,gas truck is unpopular in China. It means that in China diesel truck sales can almost be equal to heavy truck sales. High sales stimulate the

development of Chinese heavy-duty diesel engine. Domestic manufacturers design new types of diesel engines positively and start mass production quickly to seize market share. Weichai, China'slargest independent engine manufacturer, introduced its 13L engine WP13 to the market in 2015, and soon launched newly-designed 10L engine WP10H to replace previous WP10 in 2016 .Another China's engine manufacturer FAWDE launched its new 13L product CA6DM3 to replace previous CA6DN1 in 2016. At the same time, famous foreign diesel engine manufacturers have also strengthen the technical cooperation with Chinese manufacturers.Through technology transfer and joint research and development, some new models have been introduced and put into Chinese market. SFH, a joint venture which owns Fiat's diesel engine R&D resource, launchedits 13L product Cursor13 engine in China in 2013, and thenput the 11L Cursor11engine into mass production engine in 2016. MAN AG and CNHTC began enginelocalization program cooperation since 2009, and successfully achieved MC11/13mass production in 2013, which stemmed from the famous MAN D20/26 engine. Cummins, the world's biggest engine manufacturer,has many joint ventures in China, and one of them, BFCEC, is producing ISG11 / 12 engine in Beijing since 2014.

On the other hand, in recent years, Chinese people begin to pay more attention to the environment problem, public opinion is appealingbetter air quality improvement strongly. As a result,Chinese government is under great pressure and feels it's necessary to upgrade the engine emission standards as soon as possible. When China wanted to upgrade CN Ⅲ emission standard to CN Ⅳ emission standard, the final execution time was delayed 3 times, from the initial January 1, 2010 to the final January 1, 2015. However, the pace of emissionstandard upgradeaccelerates after that. Since January 1, 2017, China's automotive heavy-duty diesel engines must meet CN Ⅴ emission standard. What's more, the stricterCN Ⅵ standard is expected to be implemented on January 1, 2020. Under the pressure of stringent emission standard, the domestic diesel engine manufacturers will domore research and pay greater efforts to meet emission standard on the basis of keeping existingpower, reliability and fuel economy.

B.A Brief Introduction of China's MainAutomotive Heavy-duty Diesel Engine Models

China's current important automotive heavy-duty diesel engine models are as follows: CA6DM2 /6DM3 produced by FAWDE, DCI11 and ISZ13 produced by DFMC, WP10H and WP13 produced by Weichai, MC11 / 13 produced by CNHTC, ISG11 / 12 produced by BFCEC and Cursor11 / 13 produced by SFH.

From the above we can know that 11L / 13L displacement section is the gold displacement section of automotive heavy-duty diesel engine.Every main manufacturerattaches great importance to their design and production. Besides, these models except CA6DM2 are all developed after 2010, it's reasonable to assume they reflect the latest design skills of the OEM factories.

	WP10H	ISG11	MC11	CA6DM2	DCI11	Cursor11	ISG12
Bore/mm	116	132	120	123	123	128	132
Stroke/mm	150	128	155	155	156	144	144
Displacement/L	9.5	10.5	10.52	11.04	11.12	11.1	11.8
RatedPower/hp	310-400	310-400	320-440	350-460	385-420	350-450	360-460
RatedSpeed/rpm	1900	1900	1900	1900	1900	1900	1900
PeakTorque/N.m	1500-1900	1400-1800	1600-2100	1600-2100	1800-2000	1700-2100	2000-2300
PeakTorqueSpeed/rpm	1100-1400	1000-1400	1000-1400	1100-1400	1200-1400	1100-1500	1000-1400
CompressionRatio			19	18	17.3		
InjectionPressure/bar	1600	2000	1600	1600	1600	1600	2000
ExhaustAfter-treatment	SCR	SCR	SCR	SCR	SCR	SCR	SCR
EmissionStandard	Euro Ⅴ	Euro Ⅴ	Euro Ⅴ	Euro Ⅴ	Euro Ⅴ	Euro Ⅴ	Euro Ⅴ
Weight/kg	810	795	955	1050	985	1050	795

Figure 2. the basic parameters of the engines in 11L displacement section

	MC13	CA6DM3	WP13	Cursor13	ISZ13
Bore/mm	126	126.5	127	135	130
Stroke/mm	166	166	165	150	163
Displacement/L	12.42	12.53	12.54	12.88	12.97
RatedPower/hp	480-540	460-550	480-550	350-480	425-520
RatedSpeed/rpm	1900	1900	1900	1900	1900
PeakTorque/N.m	2300-2500	2100-2500	2350-2550	1800-2200	2000-2500
PeakTorqueSpeed/rpm	1000-1400	1100-1400	1000-1400	1000-1500	1100-1300
CompressionRatio	19	17	17		17.3
InjectionPressure/bar	1600	1600	1600	1600	1600
ExhaustAfter-treatment	SCR	SCR	SCR	SCR	SCR
EmissionStandard	Euro Ⅴ	Euro Ⅴ	Euro Ⅴ	Euro Ⅴ	Euro Ⅴ
Weight/kg	955	1050	905	1225	1195

Figure 3. the basic parameters of the engines in 13L displacement section

Figure 2 and Figure 3 show the basic technical parameters of these models. It can be seen that the main technical route to achieve CN Ⅴ emission standard is the electronic-control high pressure common-rail injection system and SCR.In order to develop fuel economy and improve reliability, EGR technology which was widely used in the CN Ⅲ and CN Ⅳ diesel engines has been abandoned.

According to informationfrom other sources, we can also draw the following conclusions:

1. As an assistant method of vehicle brake, engine exhaust brake has become thestandard configuration of mainstream engine. BFCEC ISG engine uses iBrake technology, which claims the braking power is up to 370 horsepower. Weichai cooperates with Jacbos in the development of WCBS, a new mode called after compression release brake. WCBS is declared that its braking power is up to 26kW / L, it means that WP10H engine can achieve maximum 336 horsepower breaking power.

2. Fuel economy has been highlighted in the industry, engine design engineers is racking their brains for how to organize better burning in the combustion chamber. Different OEMs have made different attempts on injection time, injection pressure, injection angle and valve timing. Some models have used VGT to realizehigher combustion efficiency.For the engines above, theirspecific fuel consumption keeps about 185g /kWh.

3. Modular design and lightweight design concept are fully implemented.Facing the fierce competition, the design engineers are willing to try new materials and new manufacturing process. FAWDE, CNHTC and BFCECengines are equipped with vermicular cast iron cylinder block and plastic cylinder head cover. Plastic oil pan, spinning pulley, assembled camshaft, powder metallurgy valve and valve seat are also becoming a standard configuration. BFCEC ISG engine strictly follows the concept of modular design, its part number has been reduced to less than 700, almost half the number of traditional engine parts.Thanks to the less parts, it's not only easierto disassemble andmaintain, but also easier to seal. Lightweight design greatly reduces the engine mass, 85kg / L has become the mainstream standard of mass per liter, the mass per liter of ISG engine is even lower than 80kg / L.

4. Reliability requirement continues to improve. Due to its use characteristics, automotive heavy-duty diesel engine requires a high reliability. The existing design capability has been able to keep the diesel engine working stably in the high pressure, high heat load conditions.The main models' B10 life is higher than 1.5 million kilometers, a few superior ones' B10 life is even up to 1.8 million kilometers.

5. Lowspeed high torque and large displacement highpower is the current trend. On the one hand, performance development engineers are always in pursuit of automotive heavy-duty diesel engines smoothly output large torque in a wide range of low speed.The current main models could reach the maximum torque in 1000 rounds per minute, torque per liter has risen to 200Nm / L. On the other hand, with the maturity of China's heavy truck market, the users desire to have a more powerful engine, even its displacement is lager. In the past 300 horsepower-based heavy engine was thought enough. However, nowadays 400 horsepower has become the first choice, and It is common that an engine owns even more than 500 horsepower.As the consequence, engines in the 9L displacement section are gradually left out, the OEMs launch 13L products.

II. DEVELOPMENT OF AUTOMOTIVE HEAVY-DUTY DIESEL ENGINE IN CHINA

A. Development Trend of Automotive Heavy-duty Diesel Engine in the World

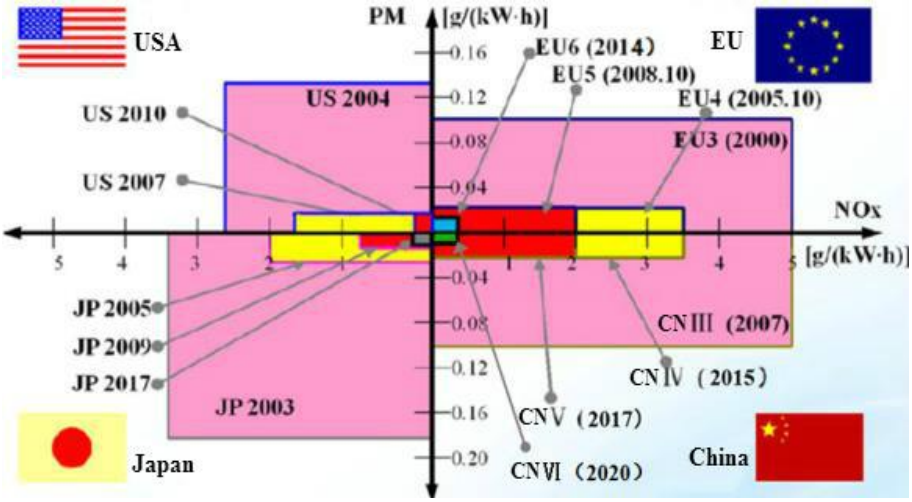

Figure 4.the implementation time of diesel engine emission standards in the world

In 1897, the thermal efficiency of the early diesel engine prototype was 27%. After 100 years of research and development, the thermal efficiency has increased to about 42%. With the implementof United States EPA2010, European EU6 and other stringent emission standards, diesel engine emissions are almost reduced to zero. It is clear that the current diesel engine industry is entering a new era that everyone is chasing better fuel economy and higher thermal efficiency.

The United States has continuouslypushed forward two-stage "super truck" program since 2009. The goal of the first phase in the project is to reduce fuel consumption by 50% compared to the original truck in the period2009 to 2015. What's more,the "super truck" will also own 50% higher engine thermal efficiency and its emissions should be lower than the Euro 6 emission standard. The first phase of the plan has made significant success, Navistar and Volvo enginesboth come up with 50%thermal efficiency, while the Cummins engine reaches a staggering 55% thermal efficiency. Although the engine manufacturers use different methods to achieve the goal, they all adopt three aspects of technologies, including an improved combustion process, energy recovery and reduce the pump loss.

In addition, high-tech performance indicators like 30-300-3000 are widely talked about as the future development trend in the industry. 30 represents 30 bar effective average pressure, it provides high power density; 300 represents the maximum 300 bar cylinder pressure, so it can be possible to improve thermal efficiency by using very early injection timing, high engine compression ratio and significantly reduced displacement; 3000 stands for the maximum 3000bar injection pressure to control in-cylinder nitrogen oxides and soot emissions and improve combustion efficiency.

In terms of durability and cost attributes, there are similar high expectations, such as a longer B10 life and the removal of nitrogen oxide post-processing devices.

B. Prospects for Development of Diesel Engines for Heavy Duty Vehicles in China

Due to the vigorous development period of China's diesel market is only ten-years long and China's emission standards implement time and manufacturing level are both far behind United States and Europe, China's diesel engine research and development level has been in abackward state for a long time. Domestic manufacturers don't have much research and development experience, in a large extent they even depend on the consulting services provided by AVL, FEV and other engine design consulting firm.However, in recent years, thanks to the growth of a generation of young engineers, a leap of CAD / CAE skillsand supplier manufacturing level, the experience accumulation of the new model design, the pace of technology development goes faster and faster. In the view of power per liter, China's engine has been almost the same with the world's advanced level. But in the areas of thermal efficiency, reliability, NVH performance, there is still a certain gap.

With the implementation of CN Ⅵemission standard in 2020, we will stand on the same starting line with foreign engine manufacturers for the first time. At present, China's mainstream diesel engine manufacturers have explored a lot, the current consensus is that the basic technical route which fits the emission standard is electronic-control high-pressure common-rail system(injection pressure 1800-2000bar) with DOC, DPF, SCR, ASC. But in view of the chaos when CN Ⅲupgraded to CN Ⅳ, a large number of urea injection problems happened, as well as foreign endless diesel engine emissions fraud, how to keep the diesel engine maintaining a good level of emissions in the more harsh conditions is still arduous work.

According to the research information at home and abroad, there may be the following breakthrough points in the future:

1. Further understanding of the combustion theory. The thermal efficiency of diesel engines depends on the better combustion organization, relying on the guidance of combustion theory. Tianjin University Professor Su Wanhua questions the internal combustion engine is a open system, it does not require to discharge the heat to the "ambient" state of the low temperature heat source, so its efficiency is not similar to the Carnot cycle. He advocates an active analysis of the combustion process to improve the efficiency of the combustion engine.

2. Further optimize the system design theory and process. Diesel engine is a complex thermodynamic coupling system.In the diesel engine design process, it's necessary to arrange the design process and decompose design tasks properly to balance the various design goals, and then the best performance can be achieved.

3. The breakthrough of material and manufacturing process. The use of vermicular cast iron has been discussed since 1980s, but just in recent years we can see it is used in cylinder block.Due to its characteristics, the cylinder block is not only able to withstand higher burst pressure and heat load, but also thin surface thickness can be thinner 1-1.5mm than gray cast iron. Similar breakthroughs in materials and manufacturing process may occur in the future, providing improvements in the weight and performance of the engine.

4. The improvement of NVH performance. In the past, design engineers focused on the fuel economy,reliability, power and exhaust emissions.In recent years, with the improvement of people's needs, NVH performance improvement is also put on the agenda. When NVH engineers fully participate in the design progress of diesel engines, diesel engine NVH performance will be greatly improved.

III. CONCLUSION

With its superior thermal efficiency and reliability,diesel engine will continue to be the most important power source in heavy duty transportationin the next few decades. Strict emission standard and fuel economy regulations, the growing user demand in power, noise, vibration and reliability will pose a greater challenge to future diesel engine technology. As an engineer working in engine industry, we should pay close attention to the technology development trend, maintain a keen sense of new technology, new manufacturing process and new materialsand constantly contribute to the promotion of China's diesel engine.

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