The Development Trend of Internal Combustion Engine

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Abstract. With the development of internal combustion engine technology, internal combustion engine has been widely used in automobile, ship, electric power and other industries due to its advantages of high power density, high heat utilization rate and good economic performance. This paper analysed the advantages, the development process and current situation of internal combustion engine technology, while the development trend of internal combustion engine technology is prospected. Internal combustion engine technology will get greater development in the future.

1. Introduction
Since watt improved the steam engine, the efficiency of the steam engine has been greatly improved, at the same time the application range of the steam engine has been more and more extensive. In many trades, human beings are liberated from heavy physical labor, entering the steam age from the human age, so as to improve the social efficiency rapidly. With the development and progress of society, as the representative of the external combustion engine, the steam engine can’t meet the demand, so the internal combustion engine technology emerges as the times require. The fuel of internal combustion engine burns in the cylinder, improving the power and efficiency effectively, so that the technology of internal combustion engine has developed rapidly. The internal combustion engine has developed from gas engine, gasoline engine, diesel engine, gas turbine to rotary engine.

2. The Advantages of Internal Combustion Engine Technology
The advantages of internal combustion engine technology is formatted as follows:

- The utilization rate of heat energy of internal combustion engine is high. The thermal energy utilization rate is high, that is to say, the fuel consumption rate is low and the economy is good, especially for diesel engine, which has the highest thermal energy utilization rate. The thermal efficiency of gasoline engine can reach 45%, and that of supercharged diesel engine can reach 50% [1].
- Internal combustion engine has the advantages of wide power range and good adaptability. The minimum internal combustion engine power is less than 0.5 kilowatts, while the largest internal combustion engine power can reach tens of thousands of kilowatts, which can effectively meet the needs of different power levels and adapt to a wide range.
- Compact structure, small volume, light weight and high power density make passenger car power density up to 150Kw/L.
- Easy operation and quick start is convenient. Under normal circumstances, general diesel and gasoline engine can start quickly within 3 to 5 seconds and reach full load operation in a short time.
3. Development History and Current Status Analysis of Internal Combustion Engine Technology

3.1. Gas Engine

In 1860, the French inventor Etienne Lenoir made the first practical internal combustion engine which is a single-cylinder, two-stroke, uncompressed and electrically ignited gas engine with an output power of 0.74 to 1.47kW and a speed of 100r/min, the thermal efficiency of which is 4%. The French engineer Alphone Beau deRochas realized that in order to increase the thermal efficiency of the internal combustion engine as much as possible, reducing the cooling area per unit cylinder volume and improving the gas pressure in the cylinder before expansion is necessary, while the velocity of the piston is as fast as possible during expansion and the expansion range is as long as possible. On this basis, he proposed the famous four-stroke cycle of constant volume combustion in 1862, including intake, compression, combustion and expansion, and exhaust. In 1876, the German Nikolas Otto made the first four-stroke reciprocating piston internal combustion engine which is a single-cylinder and horizontal gas engine using gas as fuel with an output power of 2.21kW and a speed of 180r/min. On this engine, Otto added a flywheel to make the operation smooth, lengthened the intake port, and improved the cylinder head to make the mixture fully formed. This is a very successful engine, the thermal efficiency of which is equivalent to twice that of the steam engine at that time. Otto combines three key technical ideas of internal combustion, compressed gas and four-stroke, so that this internal combustion engine has a series of advantages such as high efficiency, small size, light weight and high power.

Although the gas engine has great advantages over the steam engine, it cannot meet the high-speed and light-weight performance requirements of the transportation industry in the context of large-scale social production. Because it uses gas as fuel, it requires a huge gas generator and piping system. Moreover, the calorific value of the gas is low at about 1.75×10⁷~2.09×10⁷J/m³, so the speed of the gas machine is slow and the specific power is small. By the second half of the 19th century, with the rise of the petroleum industry, it has become an inevitable trend to replace gas as fuel with petroleum products.

3.2. Gasoline Engine

In 1883, Daimler and Maybach made the first four-stroke reciprocating gasoline engine, which was installed with a carburetor designed by Maybach, while the ignition problem was also solved with an incandescent lamp. In the past, the speed of the internal combustion engine was less than 200r/min, while the speed of Daimler's gasoline engine jumped to 800~1000r/min. It is characterized by high power, light weight, small size, fast speed and high efficiency, especially suitable for transportation. Later, Maybach also designed the honeycomb cooler, which made the Daimler gasoline engine develop into a high-power vehicle engine. At the same time, Karl Benz successfully developed the electric ignition device and water-cooled cooler that are still in use now.

Since the beginning of this century, gasoline engine has made great progress under the impetus of the automobile and aircraft industries. While the power, thermal efficiency and specific power of the gasoline engine have been effectively improved, the fuel consumption of the gasoline engine has dropped significantly. Its structure is getting more and more compact, while its speed is getting higher and higher. Its technical status includes in-cylinder injection, multi-valve technology, intake tumble, lean stratified combustion, electronically controlled ignition timing, gasoline injection, precise control of air-fuel ratio with operating conditions and other comprehensive electronic engine management, exhaust purification technologies such as exhaust gas recirculation and three-way catalysis, etc.

3.3. Diesel Engine

The German Dr. Rudol Diesel obtained the technical patent for the compression ignition internal combustion engine in 1892. In 1897, he made the first compression ignition "Diesel" internal combustion engine, namely the diesel engine. The diesel engine not only can save the carburetor and ignition device and improve the thermal efficiency, but also can use diesel which is much cheaper than gasoline as fuel. Due to its large compression ratio, diesel engine has high maximum power and low fuel consumption per unit of power. In modern excellent engine, the fuel consumption of diesel engine
is about 70% of gasoline engine. Especially like a car, usually driven under partial load, its fuel consumption is about 60% of that of a gasoline engine. The diesel engine is the internal combustion engine with the highest thermal efficiency. Diesel engine is durable and has a long life because of its high compression ratio and robust engine.

In the past hundred years, the thermal efficiency of diesel engine has increased by nearly 80% and the specific power has increased by dozens of times, while the air utilization rate has reached 90%. The technical level of today's diesel engine is as follows, excellent combustion system, using 4-valve technology, super-high pressure injection, supercharging and supercharging intercooling, controllable exhaust gas recirculation and oxidation catalyst, noise reduction double spring injector and full electronic engine management, which are embodied in the feature of a new generation of diesel engine adopting electronically controlled common rail fuel injection systems.

3.4. Gas Turbine

In 1873, George Brayton built a constant pressure combustion engine which can provide the power that can make the gas fully expand to atmospheric pressure. In the early 20th century, Frenchman Bene Armangaud successfully applied the Bratton cycle principle to make gas turbines. However, due to conditions at that time, the thermal efficiency was too low to be developed. By the 1930s, due to the development of aerodynamics and high-temperature alloy materials and cooling systems, conditions were created for gas turbines to enter practical use. Although the gas turbine is an internal combustion engine, it does not have the limitation of burning in a closed space and a limited time like a reciprocating internal combustion engine, so it does not cause worrying knocks like gasoline engine, and it is rarely subject to friction like diesel engine. The gas produced by fuel combustion directly drives the impeller to rotate, so gas turbine has the advantages of simple structure, light weight, small size, low operating cost, multiple fuels suitable and less failures. Although gas turbine currently has some shortcomings of short life, high-grade heat-resistant steel needed, high cost and serious blowdown, the application of gas turbine is still limited to aircraft, ships, power plants and locomotives. However, due to the superiority of the Bratton cycle and the less restriction on fuel oil of the gas turbine and other advantages mentioned above, it is still one of the power technologies that people are devoted to research now and in the future. If the turbine inlet temperature is exceeded and the thermal efficiency is greatly improved, gas turbine is expected to replace gasoline and diesel engine.

3.5. Rotary Engine

In 1954, the German Felix Wankel broke through the key technology of cylinder seal after a long-term research, so that the triangular rotary piston engine with a long and short round external rotation line cylinder body was successfully operated for the first time. Each revolution of the rotor can realize the processes of intake, compression, combustion, expansion and exhaust, operating according to the Otto cycle. The triangular rotary engine was used as a marine power in 1962, later it was used in automobile engines by the Toyo Industries in Japan in the 1980s. It eliminates the crank connecting rod mechanism and valve mechanism, in order to achieve high speed, light weight, simple structure and operation. The weight is decreased by 1/2 to 1/3 compared to the reciprocating internal combustion engine, while the number of parts is 40% less than the reciprocating type and the volume is reduced by 50%. There is also improvement in exhaust pollution, such as less NOx. However, the sealing performance of this structure is poor, so far it can only be used as a gasoline engine with a low compression ratio. At the same time, due to the low torque caused by high speed, the organization of economic combustion process is difficult.

4. Development Trend of Internal Combustion Engine Technology

4.1. Inexhaustible New Generation of Advanced Combustion Technology

In the mid-1990s, it was thought that the harmful emissions of traditional diesel engine, such as NOx and soot, have generation limits. But in the past 20 years, the international internal combustion engine industry, including China, has already broken through this limit, making great progress in high thermal
efficiency and ultra-low emissions. Existing advanced combustion technologies include gasoline compression ignition (GCI), dual fuel reactivity controlled compression ignition (RCCI) [2], gasoline/diesel dual fuel highly premixed cool combustion (HPCC) [3], homogeneous charge compression ignition (HCCI), moderate and higher stratified gasoline direct injection compression ignition (GDCI), which all have very high thermal efficiency.

4.2. High Pressure Boost and Small Strengthening Technology
In recent years, advanced high-pressure boosting technology has developed rapidly, including electric boosting technology (eBooster), variable geometry turbocharging technology (VGT) and regulated two-Stage turbocharging (RTST) technology. Among them, eBooster can greatly improve the response characteristics of the intake system and improve the large load efficiency of the internal combustion engine, but there are problems such as high cost and poor heat resistance of electrical equipment [4]. VGT technology is a technology that is commonly used in high-grade small-displacement cars today. This supercharging technology can improve low-speed torque characteristics, greatly improve the power density of internal combustion engine, and promote the development of internal combustion engine toward miniaturization. The regulated two-Stage turbocharging technology mainly includes WGT+FGT and VGT+FGT two supercharging methods, which are mainly matched with larger displacement internal combustion engine [5].

The Liu Ruilin team of the Army Military Transportation College designed and developed a VGT+FGT supercharging system for a heavy diesel engine in the plateau, designing a corresponding variable altitude control strategy, in which the performance test of the two-stage adjustable supercharged diesel engine under different altitudes and working conditions was conducted using the high-altitude simulation test system of the internal combustion engine [6]. The results show that at an altitude of 5500m, the maximum torque and the rated power of the two-stage adjustable supercharged diesel engine have increased by 11.0% and 11.8%, respectively.

4.3. Multi-variable and Multi-system Internal Combustion Engine Intelligent Control Technology
In recent years, multi-system and multi-parameter variable control technology has developed rapidly, accelerating the intelligence of internal combustion engine. Among them, each subsystem of the engine contains a large number of control parameters, including the VGT blades and exhaust bypass valve opening of supercharging system, the pre-injection, main injection, injection timing and fuel injection amount of fuel injection system, the valve opening degree and opening and closing time of exhaust gas recirculation, and the valve lift and timing of valve connecting rod mechanism etc. The variable intelligent technology of internal combustion engine includes variable supercharging technology, variable EGR technology, variable valve timing and lift technology, variable direct injection and dual injection technology, and variable compression ratio technology, etc. [7]

4.4. Improving the Efficiency of Each Link of the Internal Combustion Engine
Ameliorating fuel consumption and improving the effective thermal efficiency of the internal combustion engine are related to seven factors, including compression ratio, specific heat ratio, combustion period, combustion time, wall heat transfer, pressure difference between intake and exhaust strokes, and mechanical resistance. Losses during engine operation include discrete losses, exhaust losses, cooling losses, pumping losses and mechanical friction losses, etc. Optimal control of supercharging and compression ratio and waste heat utilization can reduce misfire loss and exhaust loss, while low heat dissipation technology can reduce cooling loss. Variable frequency pump can reduce pumping loss, while lubrication technology can reduce mechanical friction loss. But how to control the comprehensive cost is a problem that needs to be solved [8].

4.5. Other Advanced Technologies of Internal Combustion Engine
In order to further improve the thermal efficiency of the internal combustion engine and ameliorate fuel consumption and emission performance, in addition to the main technologies mentioned above, there are also a number of technologies such as intelligent cylinder stopping technology, working fluid
cylinder moving technology, in-cylinder water injection technology and increasing the octane number of gasoline engine.

5. Conclusion
The internal combustion engine technology has made significant progress after more than 100 years of development. The internal combustion engine will continue to play a pivotal role in the automobile, ship, power and other industries in the future. At this stage, internal combustion engine technology has unparalleled advantages over new energy technology, which is booming at present. With the rapid development of efficient, energy-saving and clean internal combustion engine technology, internal combustion engine technology remains the most important source of power for a long time foreseeable.

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