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# ДИЗЕЛЬНЫЕ ДВИГАТЕЛИ

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**Аннотация**

В статье рассматриваются дизельные двигатели. Они на сегодня являются одним из наиболее производительных и экономичных типов ДВС. Описаны этапы развития этого типа двигателей – от первых двигателей до современных устройств.

**Ключевые слова:** дизельный двигатель, цикл Карно, эффективность, мощность, топливный насос высокого давления (ТНВД).

# DIESEL ENGINES

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ABSTRACT

Diesel engines are considered in the article. Today they are one of the most productive and economical types of internal combustion engines. The stages of development of this type of engines are described – from the first engines to modern devices.

**Keywords:** diesel engine, Carnot cycle, efficiency, power, high pressure fuel pump (HPFP).

To date, cars, rail, sea and air transport are used for the transportation of goods, but the most versatile of them is automobile, due to the possibility of using it in different weather conditions, adaptability to transporting goods over various terrain and, which is especially valuable, in urban areas. Depending on the area of use, certain requirements are imposed on the car, for example, compactness, high speed, fast acceleration. And for the delivery of goods – increased traction, high reliability, so that it is possible to deliver a lot of goods in one delivery and at the same time wear is minimal, which would allow the car to be operated for a long time without repairs. All these conditions for a car that is used to transport goods became feasible when the internal combustion engine was invented, running on diesel fuel. The beginning of the invention of the diesel engine in 1824 was laid by the French physicist and military engineer Nicola Leonard Sadi Carnot (1796-1832), who published his work "Reflections on the driving force of fire and on machines capable of developing this force", in which he formulated the main provisions theory of heat engines and for the first time proposed the second law of thermodynamics. But only in 1834, after Benoit Paul Emile Clapeyron (January 26, 1799 – January 28, 1864) gave this theory an accessible mathematical form, Carnot's ideas became widely used to substantiate the second law of thermodynamics [1].

During the operation of a heat engine, the working fluid completes a closed thermodynamic cycle. For any real heat engine, the entire cycle, including its individual processes, is irreversible, which makes it necessary to expend part of the work done to transfer the working fluid to its original state, ensuring the closure of the circular process. These losses lead to the fact that not all of the work done becomes useful, and part of it is lost in the heat engine itself, turning into heat.

The maximum efficiency has a heat engine, in which the cycle of the working fluid consists only of equilibrium thermal processes, and, therefore, is reversible. However, for the implementation of heating and cooling, heat exchange of the working fluid with the heater and refrigerator of the heat engine is necessary, which is all the more effective, the more noticeable the temperature difference. The resulting heat fluxes violate the state of thermal equilibrium and make these processes irreversible. To avoid this, it is necessary to carry out heat exchange at a very small temperature difference, in the limit, to achieve an equilibrium process, at an infinitely small difference. Therefore, it is possible to realize an equilibrium process during heat exchange only in the case of thermal equilibrium of the working fluid and the thermal reservoir. A thermal reservoir with a higher temperature is called a heater, and with a lower temperature, a refrigerator.

Thus, heat exchange with the heater and cooler in the heat engine under consideration must occur during isothermal processes, which is equivalent to the requirement that these processes proceed infinitely slowly. It is obvious that such a condition can only be satisfied approximately.

Another process that can proceed without the occurrence of heat flows is an adiabatic process. If it proceeds infinitely slowly, then such a process is equilibrium and reversible.

These two equilibrium processes (isothermal and adiabatic) can be used to compose a reversible cycle. Such a reversible circular process can, in principle, consist of a large, in the limit even infinite, number of successive isothermal and adiabatic processes. However, to organize the simplest circular process, it is sufficient to use two isotherms and two adiabats. This equilibrium thermodynamic cycle is called the Carnot cycle. The possibility of implementing such a cyclic process is due to the fact that with the help of an adiabatic process, a transition between any isotherms is always possible, and with the help of an isothermal process, between any adiabats.

The cycle composed in this way is of the same essential importance for thermodynamics as the material point in mechanics. Any quasi-equilibrium process can be approximated by a large number of such elementary cycles. Just as in mechanics the question of the possibility of considering a body as a material point is decided depending on the conditions of a particular problem, so in thermodynamics the question of whether a cyclic process is quasi-equilibrium or not depends on the conditions of the problem to be solved.

It is obvious that heat exchange cannot occur between bodies that are at the same temperatures and, therefore, in a state of thermal equilibrium. It follows from this that if we consider the processes to be strictly isothermal, then during their course the working fluid should not be heated from the heater and cooled by the refrigerator. That is, in a cyclic process consisting of two isotherms and two adiabats, heat cannot be transferred between the heater (or cooler) and the working fluid. However, on the example of such a simple ideal cycle (similar to how it is done in mechanics on the example of a material point), one can study the basic laws of thermodynamics and analyze them.

The reversible Carnot cycle consists of two isotherms that describe the process of heat transfer from the heater to the working fluid and from the working fluid to the cooler, and two adiabats that describe the expansion and contraction of the working fluid in a heat engine (Fig. 1). The heater temperature is considered equal to T1, and the temperature of the refrigerator, respectively, T2. In this case, the temperatures of the heater T1 and the cooler T2 are constant, which must be ensured by the infinitely large heat capacity of the heat reservoirs used.

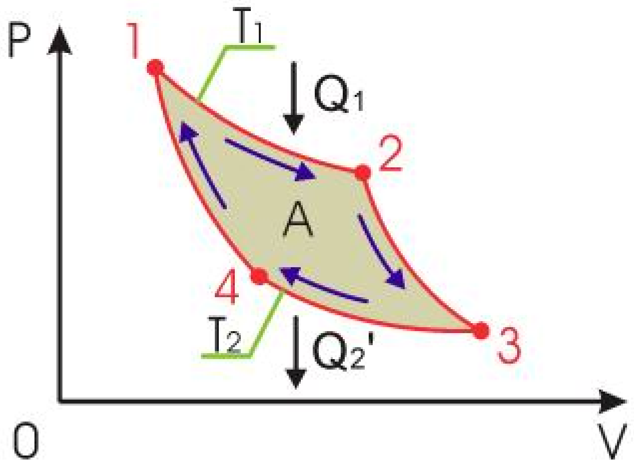


Figure 1. Thermodynamic Carnot cycle. [Electronic resource]. http://fn.bmstu.ru/data-physics/library/physbook/tom2/ch3/images/image3_7.jpg

During the first isothermal process 1-2, heat Q1 is transferred to the working fluid, and this heat is transferred infinitely slowly, with almost zero temperature difference between the heater and the working fluid. Next, the working fluid is subjected to adiabatic expansion without heat exchange with the environment (process 2-3). During the subsequent isothermal process 3-4, the refrigerator takes heat Q2 from the working fluid. Process 4-1 is an adiabatic compression that transfers the working fluid to its original state [2]. But in real heat engines it is impossible to create conditions under which their operating cycle would be a Carnot cycle. Since the processes in them occur faster than is necessary for an isothermal process, and at the same time not so fast as to be adiabatic [3].

Sadi Carnot proved that the maximum possible efficiency (ηmax) that can be achieved by an ideal heat engine is determined using the following formula [4]:

$$\eta max=1-T2/T1$$

Rudolf Christian Karl Diesel (18.03.1858 – 29.09.1913) a German engineer and inventor set out to build an economical engine proposed by Sadi Carnot. In 1892, R. Diesel began research work in Augsburg, which was based on the idea of creating an engine with compression ignition of a combustible mixture. For 4 years, four experimental versions of the engine were built. The fourth, final version was ready by the end of 1896. During official tests in February 1897, conducted under the guidance of Professor M. Schroeter, this engine consumed 0.24 kg per 1 hp. per hour of kerosene, its effective efficiency was 0.26, and thermal – 0.29. None of the engines that existed up to that time had such indicators. This unit had a number of advantages in comparison with the already widespread steam engines and piston engines with ignition of the mixture from a spark. It consumed noticeably less relatively cheap fuel and could develop significantly higher power.

The operation of the engine was carried out in four cycles. During the first stroke of the piston, air was sucked into the cylinder, during the second it was compressed to approximately

3.5-4 MPa, while heating up to approximately 600 °C. At the end of the second stroke of the piston, liquid fuel was introduced into the medium of compressed (heated by compression) air through an air spray nozzle (compressed air at a pressure of 5-6 MPa) (kerosene was used during tests). Once in a heated air environment, the fuel spontaneously ignited and burned at almost constant pressure (but not at constant temperature, as Diesel expected when he patented the cycle) as it was fed into the cylinder, lasting about 1/5-1 part of the third piston stroke. The rest of the piston stroke was the expansion of combustion products. During the fourth stroke of the piston, the exhaust products of combustion were released into the atmosphere. The working cycle of the created engine was very different from the patented one [5]. In the diagram (Fig. 2), the Diesel cycle looks like this:

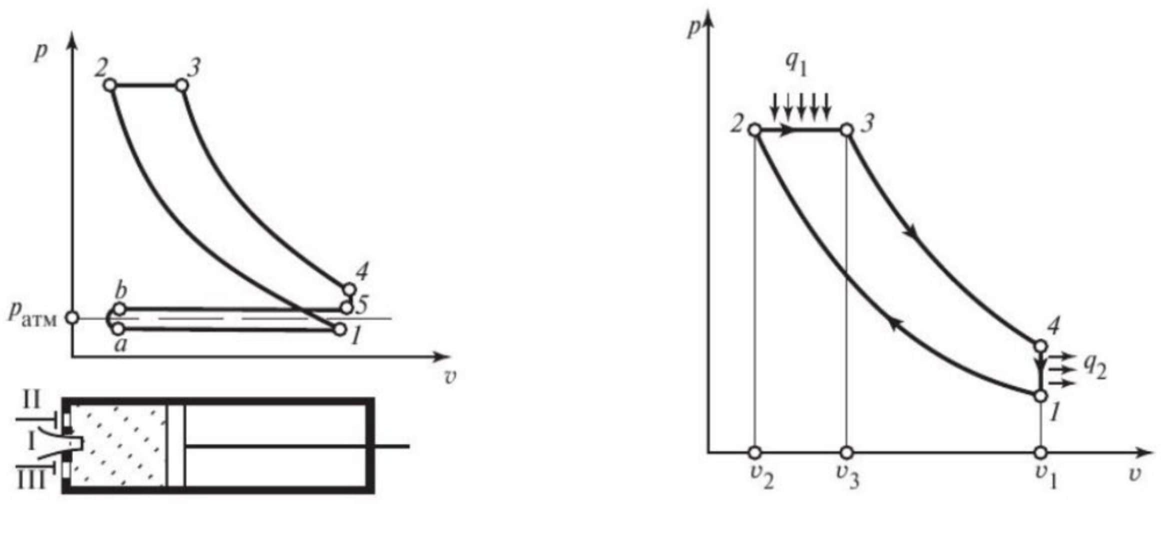


Figure 2. Diesel cycle. [Electronic resource]. http://www.itp.nsc.ru/msmakarov/papers/000066/000066.pdf

In process a-1, clean atmospheric air is sucked into the engine cylinder; in process 1-2, this air is adiabatically compressed to a pressure p2 (the value ε = v1/v2 is called the compression ratio, in engines with the Diesel cycle it usually reaches ε = 15-16). Then the process of air expansion begins and at the same time fuel is injected through a special nozzle. Due to the high temperature of the compressed air, the fuel ignites and burns at a constant pressure, which is ensured by the expansion of the gas from v2 to v3 at p = const. Therefore, the Diesel cycle is called the constant pressure combustion cycle. After the process of introducing fuel into the cylinder ends (point 3), further expansion of the working fluid occurs along the 3-4 adiabat. In the state corresponding to point 4, the exhaust valve of the cylinder opens, the pressure in the cylinder decreases to atmospheric (along isochore 4-5) and the gas is pushed out of the cylinder into the atmosphere (line 5-b) [6].

For convenience of analysis, we replace the considered Diesel cycle by the thermodynamic an idealized closed cycle equivalent to it, carried out with clean air (Fig. 2). As can be seen from this diagram, the idealized Diesel cycle consists of two adiabats (compression adiabat 1-2 and expansion adiabat 3-4), isobar 2-3, along which heat is supplied from a hot source, and isochore 4-1, along which heat transfer to a cold source. The thermal efficiency of the Diesel cycle will be calculated using the following formula (Fig. 3).

$$\eta_T = 1 - \frac{|q_2|}{|q_1|} = 1 - \frac{c_v\left(T_4 - T_1\right)}{c_p\left(T_3 - T_2\right)} = 1 - \frac{1}{k}\frac{\left(\frac{T_4}{T_1} - 1\right)}{\left(\frac{T_3}{T_2} - 1\right)}\frac{T_1}{T_2}.$$

Figure 3. Diesel thermal efficiency cycle. [Electronic resource]. http://www.itp.nsc.ru/msmakarov/papers/000066/000066.pdf

where cv is the average heat capacity of the working fluid in the considered temperature range. Taking into account the fact that v1=v4, and p2=p3, using the main property of the adiabat pvк=const, the equation of state of an ideal gas, and introducing the concept of the degree of preliminary expansion ρ = v3/v2, we can obtain the following formula (Fig. 4).

$$\eta_T = 1 - \frac{1}{k}\frac{\rho^k - 1}{\rho - 1}\varepsilon^{1-k}$$

Figure 4. Diesel thermal efficiency. [Electronic resource]. http://www.itp.nsc.ru/msmakarov/papers/000066/000066.pdf

The ratio (Fig. 4) shows that the thermal efficiency of the Diesel cycle is the higher, the greater the compression ratio ε and the smaller the degree of pre-expansion ρ [7].

The main problem in creating a diesel engine was its feature that it uses the principle of spontaneous combustion of fuel under the action of compressed and heated air in the cylinder, and for successful ignition it is necessary to supply fuel to the cylinder at about the end of the compression stroke, and since the air in the cylinder is highly compressed, fuel must also be supplied under high pressure – in practice, in different engines, fuel is injected under pressure from 100 to 2500 atmospheres. On the other hand, it is not enough just to supply fuel to the cylinder – this must be done in such a way as to provide the best conditions for spontaneous combustion and the most complete combustion.

Diesel engines use fuel injection systems, and all of them, regardless of type, have two main components: a high pressure fuel pump (HPFP) and injectors. And the differences between the systems are in the design of the pump and nozzles, their location and the presence of additional components.

There are several types of injection systems for diesel engines, among which the following are the most common:

- Systems with in-line HPFP;
- Systems with HPFP of distributive type;
- Systems with pump nozzles;
- Battery systems of the Common Rail type.

The in-line HPFP is the simplest solution that has been actively used for many decades and is still very popular even today. Compared to other systems, the in-line HPFP is bulky and heavy, so it is widely used only on powerful automobile and tractor engines.

The basis of the in-line HPFP is made up of plunger pairs, the number of which is equal to the number of cylinders. In the general case, a plunger pair is an all-metal cylinder (plunger) moving in a sleeve. Moving up, the plunger compresses the fuel, when a certain pressure is reached, the delivery valve opens, which releases the compressed fuel – it is sent to the nozzle, which is injected into the cylinder. Moving in the opposite direction, the plunger opens the inlet channel, and the space above it is filled with a new portion of fuel. A special booster pump is used to fill the plunger pair with fuel.

The plungers are driven by a camshaft similar to the engine's camshaft. The shaft is driven by the engine, the injection pump is connected to the engine through an injection advance clutch, which allows you to adjust the pump operation depending on the engine speed and strokes.

The distributor-type injection pump in terms of the device repeats as a whole the in-line HPFP, however, it uses only one or two plunger pairs (one pair can serve from 2 to 6 cylinders). The principle of operation of the distribution pump is that the plunger not only moves up and down, but also simultaneously rotates around an axis and alternately opens the outlets through which fuel is supplied under pressure to the cylinders.

A more modern and efficient type of distribution injection pump is rotary. It uses a rotor with installed plungers (from 2 to 4, they move towards each other), which rotates and distributes fuel to the cylinders.

The distribution pump is compact and lightweight, but it requires more careful tuning, so today electronic regulators are widely used to control it.

The name "pump-nozzle" speaks for itself – it combines the nozzle and the pump section, which is based on the same plunger pair. The advantage of this solution is that it allows you to easily regulate the fuel supply to each cylinder, and if one pump fails, the rest will remain in service.

The pump nozzle has a great advantage, since it can be controlled using the engine camshaft, which is located in the cylinder head, that is, in the same place as the nozzles. So here it is not necessary to use a separate drive system, but it is enough to use an existing a gas distribution mechanism (GDM) shaft.

The pump nozzle is widely used on diesel engines of trucks, as well as on SUV engines.

Common Rail is the most advanced fuel injection system that can provide the best engine performance. This system has been used since the late 1990s by Bosch, and today, almost three-quarters of all diesel engines rolling off the assembly lines are equipped with it.

A distinctive feature of Common Rail is the presence of a so-called accumulator, in which fuel is under constant high pressure and is supplied from it to the injectors. The battery is a common fuel rail (this is reflected in the name Common Rail) or a fuel rail into which fuel is injected using a high-pressure fuel pump.

The presence of an accumulator makes it possible to significantly improve fuel injection through injectors (since they operate under constant pressure and only open at the necessary moments, and up to 9 injections can be made in one cycle), as well as to simplify the high-pressure fuel pump and other parts of the injection system.

On modern engines, Common Rail is fully electronically controlled. The control unit, based on data from several sensors, determines the amount of fuel supplied, the moments of its supply to the cylinders, etc. This allows you to achieve the best engine performance and reduce its toxicity in all modes [8].

Thanks to modern technologies, the efficiency of a diesel engine often exceeds 50% and today it is one of the most productive and economical types of internal combustion engines [9].

Despite all the advantages of diesel engines, there is now a steady trend towards the transition to electric motors in the medium term, as they are more efficient and environmentally friendly.

**Список литературы:**

1. Клапейрон (Clapeyron), Бенуа Поль Эмиль http://www.physchem.chimfak.sfedu.ru/Source/History/Persones/Clapeyron.html
2. Цикл Карно http://fn.bmstu.ru/data-physics/library/physbook/tom2/ch3/texthtml/ch3_2.htm
3. Тепловой двигатель http://fizmat.by/kursy/termodinamika/teplovye_dvigateli
4. КПД теплового двигателя https://obrazovaka.ru/fizika/kpd-teplovogo-dvigatelya-formula.html
5. История создания дизельных двигателей https://press.ocenin.ru/istoriya-sozdaniya-dizelnyh-dvigatelej/
6. Рудольф Дизель https://www.mrmz.ru/article/v8/article1.htm
7. Техническая термодинамика http://www.itp.nsc.ru/msmakarov/papers/000066/000066.pdf
8. Системы впрыска дизельных двигателей https://www.autoopt.ru/articles/products/3590558
9. Дизельный мотор и бензиновый: сравнение КПД http://krutimotor.ru/kpd-dizelnogo-dvigatelya/

**References:**

1. Clapeyron, Benoit Paul Emile http://www.physchem.chimfak.sfedu.ru/Source/History/Persones/Clapeyron.html
2. Carnot cycle http://fn.bmstu.ru/data-physics/library/physbook/tom2/ch3/texthtml/ch3_2.htm
3. Heat engine http://fizmat.by/kursy/termodinamika/teplovye_dvigateli
4. Heat engine efficiency https://obrazovaka.ru/fizika/kpd-teplovogo-dvigatelya-formula.html
5. History of diesel engines https://press.ocenin.ru/istoriya-sozdaniya-dizelnyh-dvigatelej/
6. Rudolf Diesel https://www.mrmz.ru/article/v8/article1.htm
7. Technical thermodynamics http://www.itp.nsc.ru/msmakarov/papers/000066/000066.pdf
8. Diesel injection systems https://www.autoopt.ru/articles/products/3590558
9. Diesel engine and gasoline: efficiency comparison http://krutimotor.ru/kpd-dizelnogo-dvigatelya/