

УДК 621.1

ПАРОВЫЕ ДВИГАТЕЛИ ВЫСОКОГО ДАВЛЕНИЯ**Лашина Екатерина Николаевна,**

Старший преподаватель кафедры иностранных языков Санкт-Петербургского государственного университета промышленных технологий и дизайна. Высшая школа технологии и энергетики, Санкт-Петербург, ул. Ивана Черных, 4.

E-mail: lashinapiter@gmail.com

Аннотация

В статье рассматриваются паровые двигатели высокого давления. Описаны этапы развития этого типа двигателей. Также проанализирован частный случай использования паровых двигателей высокого давления в паровозах.

Ключевые слова: паровой двигатель высокого давления, паровоз, эффективность, мощность.

HIGH PRESSURE STEAM ENGINES**Ekaterina N. Lashina,**

Senior Lecturer of the Department of Foreign Languages, St. Petersburg State University of Industrial Technology and Design. Higher School of Technology and Energy, St. Petersburg, Ivan Chernykh Street, 4.

E-mail: lashinapiter@gmail.com

ABSTRACT

High pressure steam engines are considered in the article. The stages of development of this type of engines are described. A particular case of using high-pressure steam engines in steam locomotives is also analyzed.

Keywords: high pressure steam engine, steam locomotive, efficiency, power.

Rail transport is common today. No one pays attention to diesel locomotives and electric locomotives, pulling more than a hundred wagons, each of which has an average mass of twenty tons, and the cargo transported on each of them has a mass of sixty tons, moving at breakneck speeds [1]. And even more so, no one pays attention to the railway tracks, which daily, repeatedly withstand such frantic loads and do not collapse. It seems that rail transport has existed for a thousand years, but it appeared quite recently and its progenitor was Denis Papin (1647 - 1713), who in 1674 under the leadership of Christian Huygens (1629 - 1695) created a vacuum gunpowder engine [2]. It was with the invention of Papin that the history of railways began, in the

form in which we know it now, and the design of the engine, invented by Papin, determined the development of not only railway transport.

The device of the powder engine was ingeniously simple and consisted of a cylinder and a piston, which was located inside. Gunpowder was placed in the cylinder and ignited, from which the piston inside the cylinder moved upwards. Part of the gases was released from the cylinder through a special valve, and the other part was cooled. A vacuum (albeit a weak one) was formed in the cylinder, and atmospheric pressure lowered the piston down [3]. When testing his engine, Papin revealed a number of shortcomings. One was connected with the explosion of gunpowder. If the explosion turned out to be too large, then the piston could fly out of the cylinder, even the valve, which was supposed to prevent this, did not help. Papin easily eliminated this drawback by using a more powerful valve, which excluded the piston overhang, and also adjusted the amount of gunpowder loaded. But another drawback was much more significant. It turned out that the gas formed during the explosion is not cooled much and therefore the piston drops quite a bit, and therefore the useful work from such a machine turns out to be scanty. Before the powder engine, Papin invented the prototype of the modern pressure cooker, which gave him the idea to use the power of steam instead of the explosion of gunpowder. The steam had the right properties: it expanded greatly and occupied a large volume. In the next version of the engine, Papin tried replacing gunpowder with water (Fig. 1).

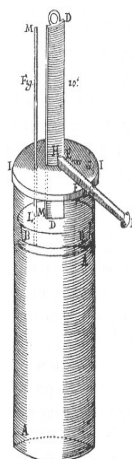


Figure 1. Papin's first steam engine.
[Electronic resource]. <https://uh.edu/engines/CD-RainSteamSpeed/images/papinengine.jpg>

The preparation of the engine for operation remained the same, only instead of laying gunpowder, water was now poured under the piston and fire was brought under the cylinder to heat it. The water evaporated, and the resulting steam raised the piston. Then the cylinder was cooled and all the steam in it condensed, that is, turned back into water, and a rarefied medium was formed. And the piston under the influence of atmospheric pressure fell down. This engine worked better than a powder engine, but it required too complicated maintenance: it was necessary to disassemble and assemble the cylinder, bring and remove fire, wait for the steam to condense. Because of this, the efficiency of the engine was also extremely low [4]. Papin improved the design of the engine and in 1690 presented the final version of his steam engine (Fig. 2).

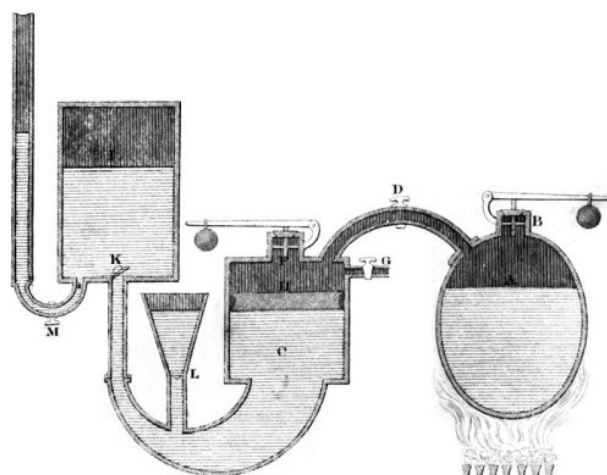


Figure 2. Papin's final steam engine design.
[Electronic resource]. <https://uh.edu/engines/CD-RainSteamSpeed/images/papinsecondengine.jpg>

Papin left the same principle of operation of the engine, but now the vaporization took place not inside the cylinder itself, but in a separate boiler, from which steam was supplied to the cylinder. When the piston was raised to the highest point of the boiler, Papin injected cold water directly into the boiler: the steam cooled, its pressure decreased, the piston went down under atmospheric pressure, while the injected cold water heated up. Thus, he removed the need for assembly and disassembly of the cylinder, reduced the heat loss on heating the cylinder, removed the need to bring fire under the cylinder, reduced the condensation time and the time to heat the cylinder.

Unfortunately, Papin himself failed to make a working industrial prototype of the engine. But in 1705, Thomas Newcomen (1663 - 1729) developed and patented, and subsequently created a working industrial design of the engine, based on the Papin steam-atmospheric engine. This engine was widely used in mines, where it was used as a pump for pumping water out of them. The difference in the principle of operation of the engine from the Papin engine was only that water for steam condensation was injected directly into the cylinder above the piston, but the piston still did work when moving down under the action of the atmosphere [5].

Newcomen's engines existed almost unchanged until 1765. This year Watt James (1736 - 1819) patented an improved Newcomen engine. And over the next fifteen years, Watt made a number of inventions that allowed him in 1782 to create a universal double-acting steam engine with continuous rotation [6]. Watt's universal engine was no longer steam-atmospheric, but the principle of operation of the engine remained the same as that of Papin - the piston moved inside the cylinder under the influence of steam. To exclude atmospheric pressure from the operation of the engine, Watt made a closed cylinder and in the working cycle steam was supplied from below the cylinder under the piston, then from above, above it, while the exhaust steam from the other side of the cylinder was released into the atmosphere or into the condenser. The forward and return stroke of the piston became working and this contributed to a more uniform movement [7]. In terms of power, the double-acting engine became about twice as powerful as the steam-atmospheric engine [8]. Watt could increase engine power by using high pressure steam, but he considered it very dangerous to work with steam engines at high pressure, therefore, in subsequent years, further increases in engine power were insignificant and only through the use of new materials and replacement of parts with more accurate ones, manufactured using new technologies [9]. Up until 1800, when Watt's patents expired, high-pressure steam engines were not used. But after the expiration of the patents, there was an explosive growth in the production and efficiency of engines [10].

Among the inventors who sought to improve Watt's engines was the engineer Richard Trevithick (1771 – 1833). Trevithick achieved a technical breakthrough by developing a high-pressure steam engine that was more compact and efficient than Watt's traditional steam engine. The design of the Trevithick engine differed sharply from the Watt engine: there was no rocker arm and condenser, the steam cylinder was placed inside the boiler, the piston rod was connected by a connecting rod to the crank of the engine shaft, and the flywheel was above the cylinder. The boiler of Trevithick's engine developed pressures of up to 45 psi, versus only 5 in Watt's machine. This made it possible to make the engine powerful and compact enough to create the first full-fledged vehicle on its basis [11]. After several prototypes, in 1802 Trevithick received a patent for both a "self-propelled carriage" and a "high pressure steam engine" (Fig. 3).

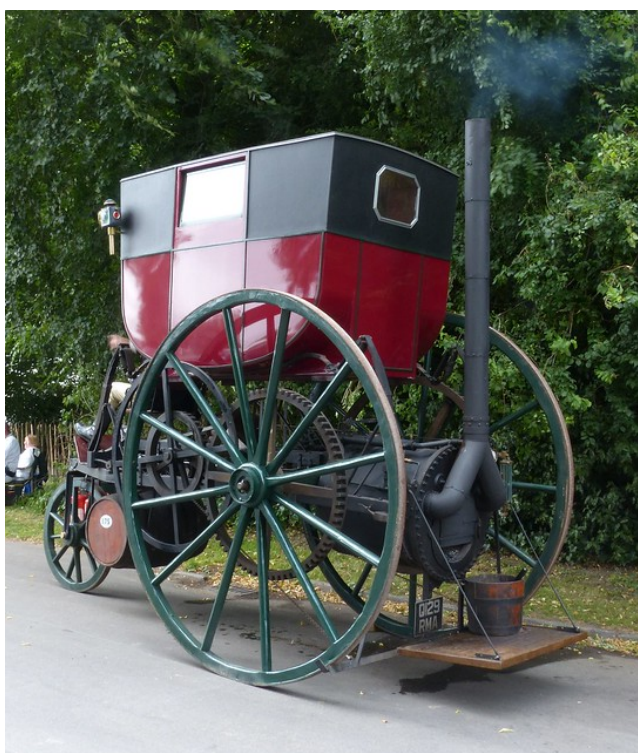


Figure 3. Richard Trevithick's replica "The London Steam Carriage".

[Electronic resource]. https://live.staticflickr.com/2838/11240425533_7c805f6257_z.jpg

The success of the Trevithick automobile depended entirely on the availability of good roads, but the ordinary country roads of the time were terrible. Trips on these roads often ended in breakdowns of cast-iron parts. The impossibility of moving in this carriage along the then usual roads was the main argument of people who refused to buy a car, so Trevithick shifted his attention to industry. English industry used mainly river transport. However, with the development of large-scale industry, there was also a need for overland roads. First of all, they were needed in mines and mines, where the issue of reducing the cost of mass transportation of ore and coal was acute. Wooden rails for trolleys and wooden decks for carts were already laid here, the movement of which along the rails was carried out using horse traction. Subsequently, the wooden rails were replaced by cast iron ones, and by the beginning of the 19th century railroads in the form of access and export roads were already widely used. Trevithick decided to use railroads and set about creating a self-propelled carriage on rails so zealously that on February 21, 1804, the first steam locomotive in the world was tested (Fig. 4) [12].



Figure 4. The working replica in the entire world of first steam-powered locomotive Trevithick's that resides at Blists Hill Victorian Town.
[Electronic resource]. <https://youtu.be/K40XrR67fas?t=41>

The first steam locomotive had a cylindrical boiler mounted on two axles. The firebox was in front under the chimney, so the tender (a wagon in which there was coal and the stoker was sitting) was hooked in front of the locomotive. In a horizontal cylinder with a diameter of 210 mm, the piston stroke was 1.4 meters. The piston rod strongly advanced in front of the locomotive, it was supported by a special bracket. The movement of the piston was transmitted to the wheels of the locomotive by means of a crank mechanism and a system of gears. It is noteworthy that the locomotive did not have brakes, but a reverse motion was implemented in it, which was used to decelerate the locomotive. In general, the locomotive had excellent characteristics. So, with a weight of 5 tons, he could carry 5 wagons with a total weight of 25 tons at a speed of 8 km per hour. Empty speed increased to 26 km per hour [13]. And on the first test, the Trevithick steam locomotive covered the distance of 15.69 km between the cities of Pen-y-Darren and Abercynon in 4 hours with 5 trailer bogies on cast-iron rails, transporting 10 tons of iron ore and 70 passengers in trailer cars [14]. The first steam locomotive did not find commercial success. He burned a lot of coal, and a heavy engine often broke fragile cast-iron rails that were not designed for the weight of the engine. Rail breakage was so common that the tender was loaded with additional stock of rails. The owners of the mines did not finance the construction of new, more durable tracks so that a steam locomotive could be operated, so six months later they abandoned the use of steam traction [15].

The first steam locomotive inspired many inventors, but Trevithick himself did not quit locomotive building. The fourth version of the steam locomotive, created by him in 1808, could reach speeds of up to 30 km / h and was given the name "Catch Me Who Can". This version of the Trevithick steam locomotive went down in history as the first fare-paying passenger train on a circular demonstration track in London. The working version of the steam locomotive of that time has not been preserved, moreover, the dimensions of the locomotive aren't recorded in any surviving document. However, the enthusiasts decided to recreate the closest possible version of "Catch Me Who Can" (Fig. 5). It was built using a high-pressure stationary engine built by

Hazledine & Co that is in the Science Museum in London. The boiler is about 10 inches longer than the one in the Science Museum [16].



Figure 5. Replica "Catch Me Who Can" at Bridgnorth – April 2018.
[Electronic resource].

<https://preservedbritishsteamlocomotives.files.wordpress.com/2018/08/catch-me-who-can-at-bridgnorth-april-2018.jpg>

Unfortunately, this locomotive did not have wide recognition at the time and became the last locomotive from Trevithick.

Another inventor of the steam locomotive was more successful than Trevithick and many others, and that was George Stephenson (1781 – 1848). In 1814 he built his first steam locomotive, called the "Blucher" (Fig. 6).

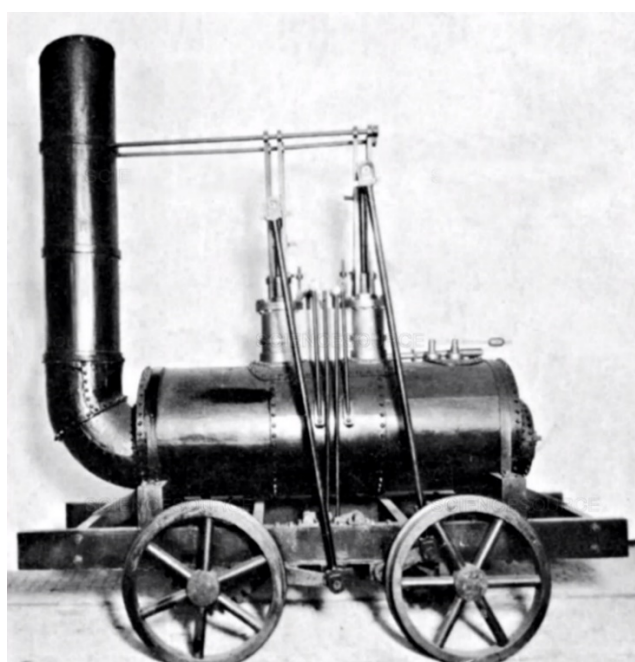


Figure 6. Stephenson's first steam locomotive "Blucher".
[Electronic resource]. <https://youtu.be/60E3jhwuhng?t=14>

On this locomotive, he tested the developments of other inventors John Blenkinsop (1783 – 1831), Hedley William (1779 – 1843) [17]. The locomotive consisted of two cylinders 8 inches in diameter with a stroke of 24 inches. The cauldron is 34 inches in diameter and 8 feet long with a single flame tube 20 inches in diameter running through it. The cylinders were arranged vertically along the centerline of the boiler, similar to the locomotive of mining engineer and inventor John Blenkinsop. The use of two cylinders gave a smooth movement. The exhaust steam was vented directly into the atmosphere. The pistons through the connecting rods rotated the gears through which the wheels were set in motion, as on engineer William Hedley's locomotives. The cross beams were attached to the top of the cylinder with the help of guides. The locomotive had four wheels attached to flanges without springs. The rear driving wheels and the front wheels of the car, carrying coal and water, had a grooved rolling surface, and were interconnected by an endless chain in order to improve traction. The locomotive was tested on 27 July 1814 at the Killingworth Mine Railway, where it climbed downhill pulling eight laden wagons weighing about 30 tons at a speed of four miles per hour. The steam locomotive was put into operation at the mine and it was soon discovered that it did not need grooved disks on wheels to do its job. The chain drive created a lot of problems, especially when it began to wear out, causing twitching and a lot of noise. Blucher was the first locomotive to use smooth flanged wheels [18].

With "Blucher" Stephenson began a long journey of fifteen years of improving the steam locomotive. Over the years, Stephenson greatly improved the design of the steam locomotive. Many of his improvements became the basis for all steam locomotives that were later produced until the end of their widespread service. Its main improvements were aimed at increasing the power of the locomotive, at smooth running, and at increasing the adhesion of wheels to rails.

In order to increase the power of the steam locomotive, it was necessary that the boiler produced more steam. To do this, Stephenson increased the evaporation surface by adding 25 copper tubes to the boiler. The gases heated by the flame rose up the tubes passing through the boiler and heated the water much faster than conventional designs with one or two chimneys. Stephenson also began to release exhaust steam into the chimney, according to the principle that was first applied by Trevithick in 1804 [19]. The exhaust steam displaced the heated air from the tubes, which significantly increased the draft in the furnace, and this led to a significant increase in the flame temperature. Thus, the efficiency of the engine has increased significantly.

To eliminate shaking and jolts, Stephenson installed springs. In order to reduce wheel slip, he connected the front wheel of the locomotive to the rear wheel with a rod, so that these two wheels had to move together with the other, which had the desired effect. To pass the extreme positions of the cylinder (dead spots), two cylinders and their pistons were placed so that each of them helped the other to pass them [20]. All these and other minor improvements enabled Stephenson to build a steam locomotive in 1829, which he called the "Rocket" (Fig. 7).



Figure 7. Stephenson's locomotive replica "Rocket".
[Electronic resource].<https://youtu.be/EjcPHABEVVo?t=797>

Although the "Rocket" was not the first steam locomotive, it was the first to combine several innovations to create the most advanced locomotive of its time. Its average speed with a load of 13 tons was 12 miles per hour (about 19 km/h), and the maximum speed reached 30 miles per hour (48 km/h) [21]. This is the most famous example of the evolving design of locomotives by Stephenson that became the template for most steam engines in the following 150 years [22].

So, high-pressure steam engines and steam locomotives, which were built on their basis, played an important role in the development of society, making it possible to significantly reduce the time for delivering goods and transporting people.

Список литературы:

1. Характеристики грузовых вагонов, платформ и контейнеров <https://vezemnegabarit.ru/information/reference/harakteristiki-gruzovyh-vagonov-platform-i-konteynerov/>
2. Inventing the Steam Engine <https://uh.edu/engines/CD-RainSteamSpeed/track8.html>
3. Паровая машина Дени Папена <https://sites.google.com/site/parovaamasina/istoria-raz>
4. Дени Папен <https://autohis.ru/lichnosti/deni-papen.php>
5. Пыхтящий двигатель прогресса <https://www.vokrugsveta.ru/telegraph/technics/613/>
6. УАТТ Джеймс <https://www.eduspb.com/node/1306>
7. Дж. Уатт: изобретатель «универсального двигателя промышленности» <http://comstol.info/2014/01/obshhestvo/8457>
8. Паровая машина https://ru.wikipedia.org/wiki/%D0%9F%D0%B0%D1%80%D0%BE%D0%B2%D0%B0%D1%8F_%D0%BC%D0%B0%D1%88%D0%B8%D0%BD%D0%B0#cite_note-zal-10
9. Создатель «пыхтящего дьявола» <https://stimul.online/historical-dates/sozdatel-rykhtyashchego-dyavola/>
10. Против интеллектуальной монополии <https://habr.com/ru/post/571930/>

11. 24 марта 1802 года <https://scientificrussia.ru>
12. Создатели двигателей <https://history.wikireading.ru/308306>
13. Паровоз <https://mirnovogo.ru/parovoz/>
14. Первый в мире паровоз <http://elpat.com.ua/khronograf-izobretenij/364-pervyj-v-mire-parovoz/>
15. Тернистый путь паровых машин <https://trainandbrain.ru/history/thornypath>
16. Richard Trevithick 1808 Catch Me Who Can <https://preservedbritishsteamlocomotives.com/richard-trevithick-1808-catch-me-who-can/>
17. Locomotive <https://kids.britannica.com/students/article/locomotive/110740/related#nodeId=main&page=1>
18. Первые паровозы Стефенсона <https://pro-parovoz.ru/index.php/component/k2/1038-pervye-parovozy-stefensona>
19. Паровоз «Ракета», созданный Джорджем Стефенсоном https://runivers.ru/lib/anons.php?ID=62366&IBLOCK_ID=33
20. Первый локомотив Стефенсона <http://files.school-collection.edu.ru/dlrstore/de77ddeb-cb42-433c-b3d7-e47ead80a1bc/LOKO.htm>
21. Знаменитый паровоз Стефенсона совершает турне по городам Великобритании https://polit.ru/news/2018/07/24/ps_stephensons_rocket/
22. History of Train Stephenson's Rocket <https://www.youtube.com/watch?v=EjcPHABEVVo>

References:

1. Characteristics of freight wagons, platforms and containers <https://vezemnegabarit.ru/information/reference/harakteristiki-gruzovyh-vagonov-platform-i-konteynerov/>
2. Inventing the Steam Engine <https://uh.edu/engines/CD-RainSteamSpeed/track8.html>
3. Steam engine by Denis Papin <https://sites.google.com/site/parovaamasina/istoria-raz>
4. Denis Papin <https://autohis.ru/lichnosti/deni-papen.php>
5. The chugging engine of progress <https://www.vokrugsveta.ru/telegraph/technics/613/>
6. WATT James <https://www.eduspb.com/node/1306>
7. J. Watt inventor of the "universal engine of industry" <http://comstol.info/2014/01/obshhestvo/8457>
8. Steam machine https://ru.wikipedia.org/wiki/%D0%9F%D0%B0%D1%80%D0%BE%D0%B2%D0%B0%D1%8F_%D0%BC%D0%B0%D1%88%D0%B8%D0%BD%D0%B0#cite_note-zal-10
9. Creator of the "puffing devil" <https://stimul.online/historical-dates/sozdatel-pykhtyashchego-dyavola/>
10. Against the intellectual monopoly <https://habr.com/ru/post/571930/>
11. March 24, 1802 <https://scientificrussia.ru>
12. Engine makers <https://history.wikireading.ru/308306>
13. Locomotive <https://mirnovogo.ru/parovoz/>

14. The world's first steam locomotive <http://elpat.com.ua/khronograf-izobretenij/364-pervyj-v-mire-parovoz/>
15. The thorny path of steam engines <https://trainandbrain.ru/history/thornypath>
16. Richard Trevithick 1808 Catch Me Who Can <https://preservedbritishsteamlocomotives.com/richard-trevithick-1808-catch-me-who-can/>
17. Locomotive <https://kids.britannica.com/students/article/locomotive/110740/related#nodeId=main&page=1>
18. Stephenson's first steam locomotives <https://pro-parovoz.ru/index.php/component/k2/1038-pervye-parovozy-stefensona>
19. The Rocket locomotive designed by George Stephenson https://runivers.ru/lib/anons.php?ID=62366&IBLOCK_ID=33
20. Stephenson's first locomotive <http://files.school-collection.edu.ru/dlrstore/de77ddeb-cb42-433c-b3d7-e47ead80a1bc/LOKO.htm>
21. The famous Stephenson steam locomotive makes a tour of the cities of Great Britain https://polit.ru/news/2018/07/24/ps_stephensons_rocket/
22. History of Train Stephenson's Rocket <https://www.youtube.com/watch?v=EjcPHABEVVo>