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Thermotechnical Foundations for Creation of Fireless Locomotives Run on Stored Steam

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ABSTRACT

The article deals with the problems of creating and using of locomotives run on stored thermal resources (steam) and intended for industrial enteerprises. The objectives of their development and introduction are still relevant and consist in implementation of economical and environmentally friendly locomotives for non-public access roads.

Shunting operations are considered as an independent type of enterprises' activity that is not related to their main activity. The locomotives of transport workshops used today for this purpose consume diesel fuel, which significantly increases the logistics cost of goods and reduces the final profit.

The article considers one of the possible ways to make the thermal energy (steam) traditionally utilised for technological purposes, to perform other work, which from an energy-economic point of view will be done free of charge, since the cost of energy generation is already covered by the cost of products.

For internal and access roads of enterprises, a version of a fireless locomotive with a traction force of 90 kN (9 t) has been developed. This machine does not need fuel but uses process steam obtained from stationary boilers of enterprises and accumulated in a high-pressure tank with thermal insulation.

The locomotive was created based on the 9P type 0-3-0 tank locomotive, which was common before. The boiler with a furnace was replaced by a steam storage boiler, which is a closed cylindrical tank with a high degree of thermal insulation.

The estimated time of operation of the machine on a single charge is 6–8 hours. The maximum estimated mass of the train on a straight section of the track at a speed of 30 km/h and a traction force of 83 kN•t is 3000 tons.

The use of this type of locomotive makes it possible to save diesel fuel in the amount of 0,75–1,0 t/day, reduce repair costs by 90 % compared to a diesel locomotive, reduce the cost of maintenance personnel, get the opportunity to use it in enterprises requiring increased explosive and fire safety.

An example of calculating the use of six locomotives at an oil refinery is given, which will give an annual saving of 1444 tons of diesel fuel, with a payback period of the locomotive itself of 3,2 years.

Keywords: steam power, steam battery locomotive, industrial transport, economic comparison.

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Текст статьи на русском языке публикуется в первой части данного выпуска.

INTRODUCTION

At present, the performance of shunting operations in railway industrial transport is considered as an independent type of activity. The locomotives of transport shops used for this purpose consume diesel fuel, which significantly increases the logistics cost of goods and reduces the final profit. It is desirable to eliminate unnecessary unproductive costs for shunting operations.

The limit values of diesel fuel consumption by diesel locomotives being in the range of 198–220 g/kW•h are decreasing extremely slowly and have almost reached their operating minimum. Thus, it is pointless to look for a solution within the framework of the existing system; another system is needed, in which, due to the complete energy connection of the elements among themselves, all costs are minimised. At the same time, it is desirable that the system consumes only one type of energy – the most profitable from an economic point of view.

HISTORY

The basic principles for creating such systems were outlined by Professor V. V. Dmitriev back in 1927 in the work «Modern achievements in the field of energy management in industries with high heat consumption per unit of processed product» [1].

This work states that the needs of production in electrical and thermal energy make it possible to arrange them in a special, from the point of view of energy, order, since the consumption rates of these types of energy per unit of produced product have already been established and can be taken as the basis for calculation.

Professor Dmitriev introduced the concept of «energy proportionality factor (EPF)», showing the ratio between the types of energy in production of a unit of product.

For most industries (including metallurgical, petrochemical and many others), EPF is more than 10, which indicates the predominant use of thermal energy, for example, in the form of steam [2]. It is further stated that if this steam, which is used for technological purposes, is somehow utilised to perform other work, then this work from an energy-economic point of view will be done free of charge, since the cost of steam is already covered by the cost of products.

With regard to industrial rail transport, it can be said that if steam energy is directed to shunting work and the unproductive diesel locomotives (in modern terms it concerns also their «carbon footprint») are removed, then the cost of energy will tend to zero.

This approach was implemented in Germany at the beginning of 20^{th} century and gave such outstanding results that it is still being used with constant success. It is associated, first of all, with development of Roots steam accumulators for leveling the load curves of steam boilers with fluctuating steam consumption. If steam is introduced into a closed container filled with water, it will condense, simultaneously raising the temperature of water. As soon as the water temperature reaches the temperature of saturated steam at a given pressure, the flow of steam will stop. If after that the pressure in the tank is lowered, water will boil and give the next portion of the accumulated steam. The amount of steam given off is almost equal to the amount of incoming steam. In this case, the outgoing steam can be used for production of mechanical work.

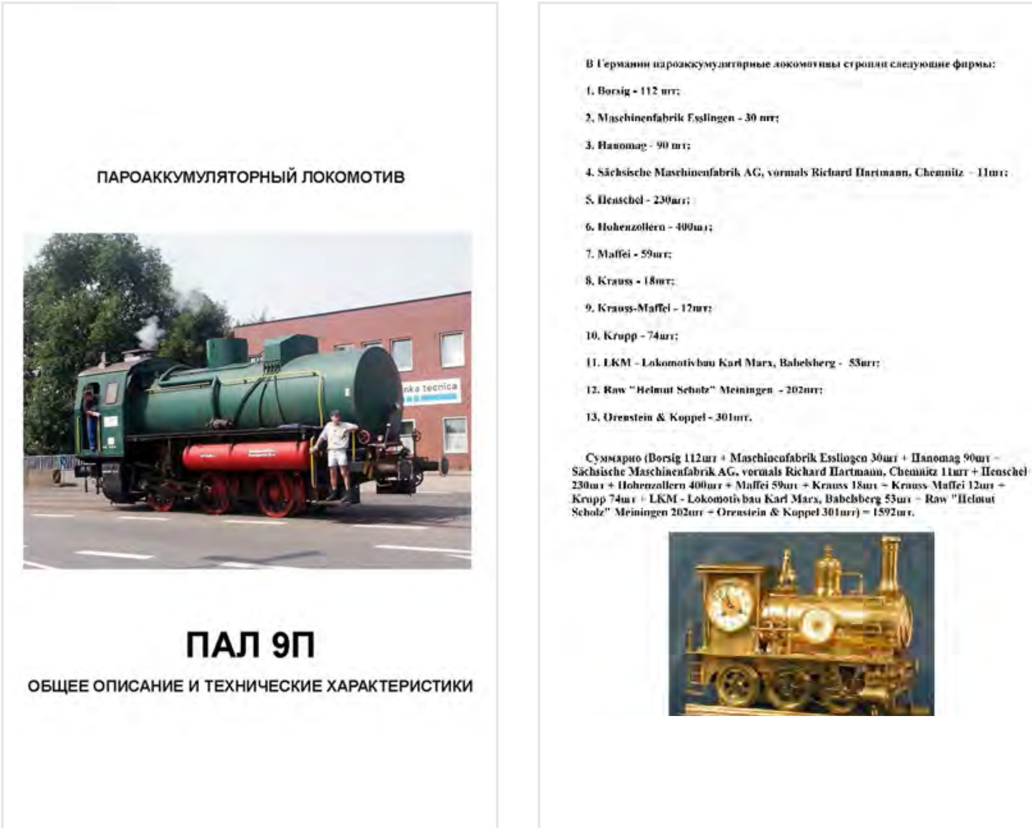
If such a steam accumulator is installed on a railway vehicle driven by a known steam engine, then we get a locomotive running on a stored steam (or stored-steam locomotive, see, e.g. German term «Dampfspeicherlokomotive»). This machine will do work due to the energy of free steam. At the same time, the cost of shunting work will be practically negligible with high reliability and durability of the locomotive (up to 70 years – according to existing data from German sources [2]). The efficiency of such locomotives is so high that there were at one point over 1600 of fireless locomotives including those using steam storage.

Many years of expertise have helped to develop in Germany a type of shunting fireless locomotive[1] with the following characteristics:

- Axial formula – 0–3–0.
- Working (coupling) weight – 55 t.
- Work performed using one steam charge – 6000 t•km.
- Maximum train weight on a straight, horizontal track – 3000 t.

This locomotive can be used on non-public access roads and is a universal shunting

[1] Steam transport yesterday and today Ivan Trokhin, engineer. 2019 year. [Electronic resource]: https://perevozki-stolitsa.ru/parovoj-transport-vchera-i-segodnya/. Last accessed 18.03.2022.



ПАРОАККУМУЛЯТОРНЫЙ ЛОКОМОТИВ

ПАЛ 9П

ОБЩЕЕ ОПИСАНИЕ И ТЕХНИЧЕСКИЕ ХАРАКТЕРИСТИКИ

В Германии пароаккумуляторные локомотивы строили следующие фирмы:

1. Borsig - 112 шт;

2. Maschinenfabrik Esslingen - 30 шт;

3. Hanomag - 90 шт;

4. Sächsische Maschinenfabrik AG, vormals Richard Hartmann, Chemnitz - 11шт;

5. Henschel - 230шт;

6. Hohenzollern - 400шт;

7. Maffei - 59шт;

8. Krauss - 18шт;

9. Krauss-Maffei - 12шт;

10. Krupp - 74шт;

11. LKM - Lokomotivbau Karl Marx, Babelsberg - 53шт;

12. Raw "Helmut Scholz" Meiningen - 202шт;

13. Orenstein & Koppel - 301шт.

Суммарно (Borsig 112шт + Maschinenfabrik Esslingen 30шт + Hanomag 90шт + Sächsische Maschinenfabrik AG, vormals Richard Hartmann, Chemnitz 11шт + Henschel 230шт + Hohenzollern 400шт + Maffei 59шт + Krauss 18шт + Krauss-Maffei 12шт + Krupp 74шт + LKM - Lokomotivbau Karl Marx, Babelsberg 53шт + Raw "Helmut Scholz" Meiningen 202шт + Orenstein & Koppel 301шт) = 1592шт.

Pic. 1. Data from the brochure describing the locomotive PAL 9P [developed by the authors].

locomotive, which simplifies its manufacture, maintenance and operation [3; 4].

A system consisting of a steam boiler, a technological consumer of steam and a stored-steam locomotive (or several) is called a transport and energy hub and changes cost items when performing railway shunting operations.

In addition, it becomes possible to accurately record the shunting work performed. A stored-steam locomotive consumes 0,37 kg of steam per 1 t•km [5], while there is no steam consumption when the locomotive is parked. Knowing the amount of steam consumed, one can accurately estimate the work done in t•km, and not in locomotive hours, which cannot be units of work (Historically, accounting for work in locomotive hours goes back to shunting steam locomotives, the boiler of which, working continuously, consumed a certain amount (up to 80 kg) of fuel per hour. Thus, in those years, accounting for the fuel consumed by locomotives was achieved).

In 1954, Murom and Kolomna plants designed and built a fireless steam locomotive BP1-01 [5, pp. 522–523].

To reduce steam consumption from the boiler, the locomotive had larger main tanks, which were charged with compressed air in parallel to filling the storage boiler with steam. Charging took 30–40 minutes.

The cyclical operation of the locomotive between steam fillings was 4–6 hours, depending on the shunting load. According to experiments, this locomotive could pull a train weighing 325 tons at a speed of about 15 km/h for a distance of up to 30 km [6].

The latest fireless steam locomotive was that of type BP1-02, which showed excellent results in the summer of 1955. During the tests, it moved trains of 1700 tons from the start, and it itself could move at a pressure in the boiler of 1 kgf/cm^2.

PAL-9P

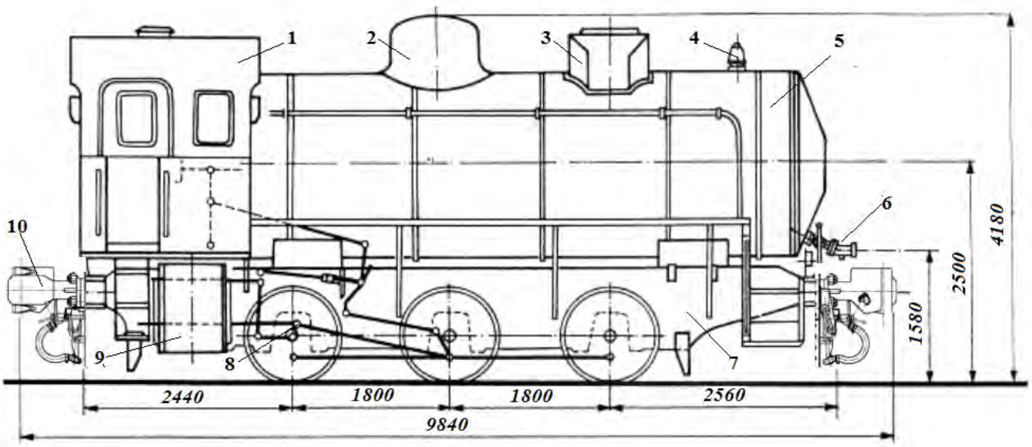
Technical Features

To reduce the cost of shunting work on non-public access roads (oil refineries, chemical industry plants, metallurgical, mining and processing and woodworking plants, thermal power plants, etc.),

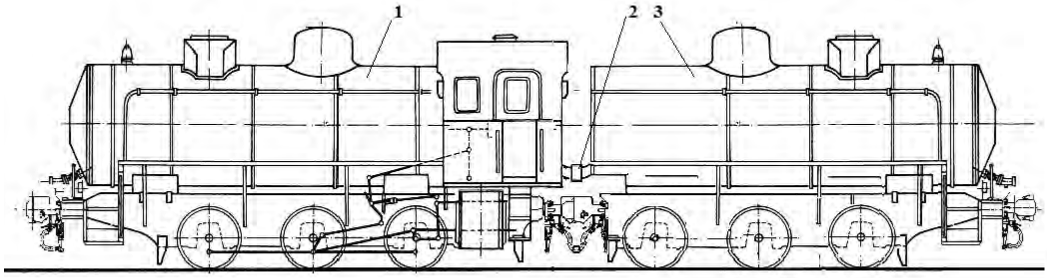
Technical features
(the locomotive complies with type 5 GOST 22339-88*,
size 1-VM, 02-VM according to GOST 9238-83)

Gauge, mm	1524
Boiler volume, m^3	21,0
Steam pressure, MPa (kgf/cm^2)	2 (20)
Mass of the locomotive in working condition, t	56,5
Traction force working, kN	90
Traction force when starting off, kN	125
Traction force, minimum, kN	83
Maximum speed, km/h	30
Maximum train mass on a straight line at a speed of 30 km/h and a traction force of 83 kN, t	3000
Length along the axes of automatic couplers, mm	9820
Wheel diameter, mm	1050
Minimum curve radius, m	40

* GOST 22339-88 Diesel locomotives, shunting and industrial. Types and basic parameters. [Electronic resource]: https://docs.cntd.ru/document/1200011008. Last accessed 21.04.2022.



Pic. 2. Scheme and overall dimensions of PAL-9P locomotive:
1 – control cabin; 2 – dry steamer; 3 – sandbox; 4 – safety valve 5 – steam accumulator – boiler; 6 − outfitting branch pipe; 7 – locomotive frame; 8 – driving mechanism; 9 – steam cylinder; 10 – automatic coupler [developed by the authors].



Pic. 3. A variant of PALt-9P tender locomotive:
1 – PAL-9P; 2 – connecting steam line; 3 – tender [developed by the authors].

Pic. 4. Fireless steam storage locomotive. DLM AG [https://dlm-ag.ch/wp-content/uploads/2020/10/2020-10-07_Energy-Steam-and-Fireless-Technology-homepage.pdf].

a version of a stored-steam locomotive (PAL, from abbreviation in Russian) with a traction force of 90 kN (9 t). This machine does not need fuel, but uses process steam obtained from stationary boilers of enterprises and accumulated in a high-pressure tank with thermal insulation.

PAL-9P was created on the basis of the 0–3–0 type tank-engine 9P, which had been common before. The crew part and the steam engine were used without changes. The boiler with a furnace was replaced by a steam storage boiler, which is a closed cylindrical tank with a high degree of thermal insulation.

The scheme and overall dimensions of PAL-9P locomotive, developed by the authors of the article, are shown in Pic. 2.

A variant of PALt-9P tender locomotive with a double supply of working steam is shown in Pic. 3.

Fireless locomotives practically do not require maintenance and repair, while the locomotive itself is serviced by one driver.

The main disadvantage of this type of locomotives is a limited range.

A variant of Estimate of the Efficiency of PAL 9P Locomotive Operation at an Oil Refinery

Traditionally, the refinery is a large consumer of thermal energy, in particular of steam of high parameters. Separately, of steam is consumed for its own energy needs – for steam pumps and compressors. Steam of industrial parameters (pressure 0,8–3,5 MPa) comes from external sources through the main steam pipelines. To provide consumers with steam of different pressures, a reduction or reduction-cooling unit is located in the central heating point.

Main characteristics of the refinery [7; 8]:

• Refining volume – 12 mln tons oil per year.
• Technological facilities – more than 30.
• Area of the enterprise – 286 hectares.

The annual weight of the transported cargo, taking into account the tare of tanks, is 1,4 x 12 000 000 = 16 800 000 t.

The daily weight of the transported cargo is 16 800 000 / 365 = 46027,4 t.

The average path of cargo moving within the area of the plant is 3 km.

Daily cargo work is 3 x 46027,4 = 138 082,2 t•km.

Energy consumption per 1 t•km when using diesel traction with an efficiency of 13 % – 0,35 kW•h/t•km.

The energy intensity of 1 kg of diesel fuel with a heat output of 10 500 ccal/kg is 10500 / 860 = 12,21 kW•h.

The work performed on movement of cargo per 1 kg of diesel fuel is 12,21 / 0,35 = 34,9 t•km.

The total fuel consumption of diesel locomotives per day, taking into account the operation of the diesel engine at idle, will be 138 082,2 / 34,9 = 3956,5 kg.

The required number of PAL-9P locomotives with four steam charges per day and work performed on one steam charge equal to 6000 t•km or 24,000 t•km per day (steam costs – 0,37 x 24,000 = 8,880 kg = 8,88 t/day) will be 138 082,2 / 24,000 = 5,75, or six locomotives.

The total consumption of process steam with a pressure of 20 kgf/cm^2–6 x 8,88 = 53,3 t/day.

Annual savings in diesel fuel is 365 x 3,9565 = 1444,2 t.

1 kg of diesel fuel costs 51,85 x 1,25 = 64,81 rubles (prices are per litre).

The annual savings when using PAL 9P will amount to 1 444 200 x 64,81 = 93,600,000 rubles or 93,6 mln rubles.

The estimated cost of the locomotive at the current moment is 50 000 000 rubles, the payback period for six locomotives is 6 x 50,000,000/93,602,212, 5 = 3,2 years (3 years 3 months) with a service life of 60–70 years.

THE HISTORY CONTINUES

The efforts to create modern steam locomotives applying steam storage continue also in other countries (e.g.[2, 3]). Pic. 4 shows an example of a stored-steam locomotive[3].

CONCLUSIONS

As a result of the use of PAL-9P, it is possible to achieve the following positive results:

1. In comparison with locomotives running on diesel fuel, PAL-9P allows saving diesel fuel in the amount of 0,75–1,0 t/day per unit.

2. Repair costs reduced by 90 % compared to a diesel locomotive.

3. Reduced costs of maintenance personnel (the machine is serviced by one driver without an assistant).

4. Ability to use in dusty and polluted conditions without reducing the resource.

5. Possibility of use at the enterprises demanding high explosion and fire safety.

6. Environmental friendliness (exhaust gas consists of water vapour only).

[2] Dampflokwerk Meiningen (Meiningen Steam Locomotive Works) Website. [Electronic resource]: https://www.dampflokwerk.de/en/. Last accessed 24.03.2022.

[3] Technology of fireless steam locomotives. Steam storage technology uses the ability of water to store large amounts of energy under pressure. Website of DLM AG. [Electronic resource]: https://dlm-ag.ch/en/fireless-technology/. Last accessed 24.03.2022.

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