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Applicability of Gas Turbine Traction in High-Speed Rail Projects in Russia

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ABSTRACT

Recently, the issue of advisability of building dedicated high-speed railways (HSR) in Russia for transportation of passengers and goods has often been raised in the scientific and industry environment. The key risk of such large-scale investment projects is a significant or rather long payback period due to the lower population density in the areas of the proposed HSR compared to, for example, China. In addition, when planning such capital-intensive and resource-intensive investments, it is necessary to consider plans for development of other modes of transport, namely, express highways, air traffic, as direct competitors to speed and high-speed railways.

A way to increase the competitiveness of HSR may be to reduce capital costs during the construction. The creation of HSR, where multiple-unit trains powered by gas turbine engines (GTE) and using AC-AC electric drive, will allow to renounce investments in expensive design, construction, and subsequent maintenance of energy facilities, specialised HSR catenary, which will ensure reduction in the cost of HSR projects, in construction time, and accelerated payback of railways.

The article describes the advantages of operating gas turbine traction on speed and high-speed railway lines. The possible structure and layout of such trains are shown. The risks of operation of rolling stock powered by GTE are considered as well as the ways to neutralise them. The objective of the study was to identify the comparative advantages of multiple unit trains powered by GTE compared to high-speed electric trains. The study used methods of comparative analysis, content analysis of technical information, and ranking. It is concluded that introduction of GTE will reduce the investment and operating costs of speed and high-speed railways while maintaining the power and dynamic characteristics of trains.

Keywords: *railway, gas turbine traction, multiple-unit trains, turbo-trains, high-speed transport, accelerated cargo transportation.*

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INTRODUCTION

The operating mode of high-speed and speed trains is characterised by the use most of the time of rated power. The key role in movement is played by constant atmospheric resistance, and not by the variable impact of the track profile, therefore, the requirements of low weight and aerodynamic shape of such rolling stock come to the fore.

The *objective* of the article is to show, using the *methods* of comparative analysis, content analysis of technical information, ranking, the conceptual possibility of replacing electric trains with gas turbine multiple-unit trains during construction of HSR to reduce the investment and operating costs of such projects.

According to experts of the Scientific Centre Track infrastructure and issues of wheel–rail interaction of JSC VNIIZhT, the arrangement of 1 km of HSR traction power supply facilities may amount to 48 million roubles. Thus, during the construction, i. e., of Moscow–Adler HSR (1900 km), investment costs will decrease by 91,2 billion roubles, which, with a total estimated cost of the main line of 2,5 trillion roubles, will generate savings in investments of about 4 %.

RESULTS

Comparative Advantages and Disadvantages of Turbo-Trains powered by GTE

The following main advantages of traction GTE were revealed based on full-scale and analytical studies:

1. High power features, operation with maximum efficiency at rated power, at which high-speed trains operate most of the time.

2. Half the cost of consumed fuel (liquefied natural gas, LNG) compared to the cost of 1 kW•h of electricity.

3. Modular design, small dimensions, and weight of the GTE which is an order of magnitude lower than that of a locomotive diesel engine. In particular, when comparing PD1M diesel engine of TEM18DM shunting diesel locomotive and the GTE for the shunting locomotive based on MSU-800 series locomotive, the weight reduction attained 12,16 times (12,6 tonnes versus 1,04 tonnes), the dimensional reduction (the total engine volume) attained 10,19 times (20,17 m^3 versus 1,98 m^3) with comparable engine power of 882 and 860 kW, respectively.

4. Accessibility for inspection, control and diagnostics allows operate GTE according to their condition and reduce repair costs by 15–20 %, and the cost of lubricating oils up to by ten times compared to diesel engines of the same power [1].

5. GTE operation is in good agreement with energy storage devices, which makes it possible to stabilise the engine operation during the period of train departure and arrival.

6. High autonomy and ability to operate high-speed turbo-trains in any weather conditions, including strong wind loads, sand and snow drifts, icing of power lines.

7. Significant improvement of the environmental situation in the areas of HSR. «Thermodynamic and environmental advantages of gas motor fuel compared to diesel fuel are due to the energy and physical characteristics of gas. The values of emissions of toxic substances in terms of hydrocarbon composition and nitrogen oxides are by 1,5–2 times lower» [2].

8. «A gas turbine is a rather soft damping element under dynamic impact, therefore, even on powerful GTEs, one can expect fairly stable and reliable operation of gimbal systems» [2].

It is worth noting the most significant disadvantages of operation of turbo-trains with GTE, as well as ways to eliminate them:

1. The need to place large containers on rolling stock for gas supply. Based on the results of the several meetings of scientific and technical councils and brainstorming sessions in 2003–2005, JSC Russian Railways made a strategic decision that development of railway rolling stock running on compressed natural gas (CNG) is unpromising, primarily due to the failure to provide the required range of a train running on CNG [4], and liquefied natural gas (LNG) should be used as the main fuel, including in a supercooled state [5].

2. The high temperature of the exhaust gases of a gas turbine can lead to burnout of the contact wire when turbo-trains operate on electrified lines. In this regard, it is necessary to use exhaust gas coolers, as well as the installation of exhaust pipes directed towards the track infrastructure.

3. Large gas consumption in the low load mode, as well as when starting the GTE. In such modes, the power supply of turbo trains must be provided from energy storage devices (batteries, supercapacitors).

4. Fire and explosion hazard of LNG. «CNG is more consistent with safety of its use since in case of leaks it quickly goes up, while LNG vapours or oil gases (propane, butane) concentrate in the lower part of the body of the rolling unit, which requires constant monitoring of the gas-air state under the rolling stock and its forced ventilation» [5]. At a gas concentration in the air of 4–15 %, flammable and explosive mixtures are created. «To improve safety of gas equipment of turbo-trains and reduce gas leaks, it is necessary to reduce the length of train gas pipelines, to use welded joints instead of threaded ones, reduce the number of flange and nipple connections, reduce the number of devices built into gas pipelines: thermometers, pressure sensors, electromagnetic valves, gates» [5].

The advantages of using multiple-unit trains in cargo traffic are described in the articles [6; 7] and consist in improving train controllability, increasing acceleration, and braking characteristics, traffic safety, energy efficiency of this type of traction, and increasing railway transit capacity.

Proposed Concept

Comparing the power of 8500 kW GTh1 gas turbine locomotive created in Russia in 2010 with the total power of the Sapsan ten-car high-speed electric train, we can conclude that it is possible to create a multiple-unit train powered by GTE, comparable in power to an electric multi-car train. The layout of the power plant of turbo-trains equipped with GTE should include the following set: control cabin – power plant – gas cylinder – trailer cars – gas cylinder – power plant – control cabin. Thus, trains of this type must have a constant composition. With a decrease in the mass of trains, it is possible to turn off the turbine in the tail section of the train. When the GTE is located on the roof of the train, it is most simple to ensure the process of suction of clean air into the compressor, removal of exhaust gases from the turbine, noise suppression, etc. The onboard gas supply in one tank of GTh1 gas turbine locomotive is 40 tonnes, which is sufficient for a cruising range of 1400 km [8]. Thus, two cryogenic tanks located at the head and tail of the turbo-train will be able to provide a range of up to 2800 km without refuelling. Considering the small weight of a GTE, the mass of the cryogenic tank of 40 tonnes, the standard requirement for the maximum axial load of a high-speed turbo-train up to 17 t can be met.

Equipping gas turbine trains is possible in two ways:

• Refuelling directly into the cryogenic plant from the discharge rack.

• Use of tanks that are removable or connected to cryogenic product pipelines. This option is more technologically advanced and allows you to quickly refuel the locomotive tank with LNG at different stations, however, it requires large investment and operational investments in the gas distribution infrastructure [9; 10].

International and domestic experience

Projects aimed at developing turbo-trains using various types of fuel were carried out in Canada, the USA, France, and the former USSR.

In 1968, Canadian Rail introduced a seven-car, 185-tonnes turbo-train made of aluminium alloys. In the head car of the train, five gas turbine engines were installed, with a capacity of 295 kW each, four of them provided train traction, and one supplied electric power to the cars. During testing, this turbo-train reached a speed of 274 km/h [11].

In France, the high-speed rail project initially focused on the use of gas turbine traction (*turbine grande vitesse TVG* – high-speed turbine). The gas turbine was chosen as the engine thanks to its relatively small size and high specific and output power. However, the energy crisis of 1973, caused by growing gas prices, forced to abandon turbines in favour of electric traction.

In the USSR in 1970, an experimental train was built that consisted of two head motor cars equipped with an aircraft twin-shaft gas turbine engine. The front part of the roof of each car had an elevation with blinds, the power plant was located here. It consisted of a gas turbine engine weighing 135 kg and supplying power of 662 kW, with forced ventilation and a generator with a speed of up to 6000 rpm, generating current with a frequency of up to 200 Hz. The efficiency of the train was 19 %. The estimated speed of the train was 180 km/h. The engine was started electrically, and kerosene was used as fuel [12].

In 2000, a diesel high-speed gas turbine train with a design speed of 250 km/h was

Table 1

Assessment of the main parameters of autonomous locomotives

Parameter	Power plant				
	Diesel	Gas generating	Gas diesel	Gas turbine	Gas turbine + hybrid
Cost	2	2	2	3	1
Maintenance and repair cost	1	1	2	3	3
Fuel consumption	2	3	1	1	1
Fuel cost	1	3	2	3	3
Oil consumption	1	2	2	3	3
Environmental friendliness	1	1	2	3	3
Power	2	1	3	3	3
Efficiency	3	2	2	1	2
Weight and dimensions parameters	3	1	2	1	1
Total	16	16	18	21	20

developed in the USA. The gas turbine engine had a power of 3750 kW with a rotation speed of 16000 rpm and AC traction drive [13].

The operator of Indian Railways plans to operate multiple-unit trains and locomotives for passenger trains powered with LNG.

In addition, experimental locomotives and multiple-unit trains were produced in Spain, Indonesia, and the USA [14]. With high gas and combustible fuel prices, projects of gas engine turbo-trains are mainly developed in oil and gas producing countries.

Evaluation of the Main Parameters of Autonomously Powered Locomotives

We have carried out a scoring of the main parameters of autonomously powered locomotives, where 3 is the best indicator of the parameter, 1 is the worst. The results are shown in Table 1.

Thus, according to the results of the qualitative assessment, locomotives with gas turbine and gas turbine and hybrid installations scored the highest number of points.

CONCLUSION

Considering potentially incomplete loading of HSR capacity, the operation of speed and high-speed multiple-unit autonomously powered turbo-trains will make it possible to renounce construction and maintenance of an expensive high-speed catenary, i. e., to reduce investment and operating costs, to implement the potential of gas-powered engines in Russia, to implement using a single transport infrastructure, including electrified one, mixed cargo and passenger traffic at different speeds. It should be noted that Russia has the largest proven reserves of natural gas in the world (50,5 trillion m^3) [15, and development and operation of turbo-trains with gas turbine engines fits into the government strategy for development of gas fuelled vehicles.

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Editorial remark. The proposals outlined in the article certainly merit greater attention particularly in the context of economic reasoning and from the standpoint of investment costs implied by HSR construction. With that, the issue including by force of its relative novelty, does not seem currently univocal due to the need to consider the problem in its entirety including its engineering, technological, operational, environmental aspects. In this regard, the published paper might become a good starting point for scientific discussion and a subject of further perspective study.