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The Use Of Microturbines as an Energy Converter For Motor Transport

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Abstract*: At this stage of the development of vehicles with a combined power plant, one of the areas of development is the study of the introduction of a low-power gas turbine engine, the so-called microturbine, as a converter of thermal energy into mechanical. This solution has numerous positive aspects related to its fuel consumption, small dimensions, high efficiency, as well as a number of performance indicators. In this case, the vehicle is also equipped with a high-speed generator with the goal of converting the mechanical energy of the microturbine into electrical energy. This ensures the microturbine operation in a given range on the characteristic of optimal fuel consumption. The article contains an analysis of the use of microturbine generators in vehicles; some constructive solutions are considered as well. An overview of vehicles with microturbine generators and their comparison with traditional internal combustion engines is given. The movement of the vehicle is carried out by one or several traction motors. More than ten developments of motor vehicles using the microturbine as an additional source of energy for vehicles with traction electric drive are already known in the world, including MiTRE (Microturbine Range Extender). Among such vehicles, one can name the Trolza "Ecobus" buses, Delta Hypercar supercar, Isuzu NPR trucks, Mack Truck, Kenworth.

Index Terms*: ecology, electric vehicle, energy efficiency, gas turbine, high-speed alternator, hybrids, microturbine.

I. INTRODUCTION

Before considering the feasibility, advantages and disadvantages of microturbine units used in transport, it is necessary to denote the term itself. It is considered that a microturbine is an autonomous thermal power plant of low power, which has an electrical capacity of up to 1,000 kW [1]. At the same time, the microturbine is a part of an electric generating plant, which produces extremely low emission of nitrogen oxide (NOx) – 15 ppm. This allows using them even in residential areas with high emission requirements. The minimum electric power of a microturbine is 30 kW. Microturbines are easily combined into a cluster – an energy system generating a large amount of electrical power. Also in the cogeneration mode, the microturbine is able to successfully solve the problems of heat supply of various objects. Trigeneration, when applied to a microturbine, makes it possible to convert excess thermal energy into cold produced by absorption chillers. Therefore, microturbine power plants in the transport industry can be very useful for harmful emissions reduction, including greenhouse gas.

As microturbine fuel can be used almost any liquid or gaseous fuel:

- natural gas with any pressure,
- biogas,
- associated petroleum gas with high sulfur content,
- diesel fuel,
- liquefied gas – propane,
- other fuels.

The main advantages of a distributed generation system based on microturbine plants are:

- low noise,
- low vibrations,
- small dimensions,
- small number of moving parts,
- long maintenance intervals,
- ability to work on various fuels (natural gas, gasoline, kerosene, naphtha (ligroin), alcohol, hydrogen, propane, methane and diesel fuel).

However, most units used commercially use natural gas as fuel.

II. METHODS

The study is based on systematic analysis, including optimization of technical solutions. Each selected component was analyzed as part of the problem, in order to identify its positive and negative features. An empirical scientific approach is used, consisting of data collection, scientific analysis, hypothesis formulation and theory development.

III. RESULTS ANALYSIS

Along with the general trend in greenhouse gas emissions reduction, the main focus in road transport power plant development is its electrification. However, the driving range of the electric vehicle is limited by the battery capacity. In order to increase the range of a single charge and at the same time preserve the required level of energy efficiency, a number of combined power plants based on the internal combustion engine (ICE) and an electric motor appeared, where the ICE has no mechanical connection with the wheels [2].

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The advantages of microgas turbine power stations (micro-GTPS) are discussed in scientific works of D. Shlepko and N.N. Kargapolova. [3]. It is indicated that a feature of this type of energy generation is cogeneration – a high capacity to produce heat simultaneously with electricity. This feature may be an important factor in the design of cargo vehicles for countries with cold climates. The heat coupled with low fuel consumption can provide a microclimate, both inside the passenger compartment and in the casing of the traction battery, maintaining the battery in optimum temperature conditions [3].

Microturbines are various fuel-friendly, which allows working without readjustment on different types of gas – natural, colliery, liquefied, associated, with a high content (up to 7%) of hydrogen sulfide, biogas and liquid diesel fuel or kerosene. Low requirements for fuel quality (pollution, impurities) together with a low concentration of harmful combustion emissions should have a positive impact on the future development of autonomous power plants.

In Russia, micro-GTPS received a certificate of conformity from the Gosstandart, a permit issued by the State Technical Inspection, a sanitary and epidemiological certificate for compliance with the rules and regulations, a conclusion by the State Fire Safety Service for Fire Safety, a Protocol for compliance with electromagnetic compatibility parameters, a certificate of conformity for the "Svyaz" certification system for electrical equipment communication. Consequently, the development of a domestic power plant based on a microturbine is relevant and will be in high demand since it is necessary to produce autonomous electricity, such as power supply to remote villages, construction sites, oil fields, oil towers, gas pumping stations, remote communication stations and other facilities where the centralized network is unavailable while having large gas reserves, as well as in the automotive industry, both directly on motor vehicles and for electricity production for electric transport charging stations.

Another promising option is wet steam microturbine in small distributed energetics [4]. Under the climatic conditions of Russia, during cogeneration and trigeneration regimes, small steam power plants have the greatest preference in comparison with a gas turbine or gas piston engines. The efficiency of them increases when using equipment of renewable energy sources. Consequently, the microenergy based on cogeneration wet steam microturbines using traditional fuels, such as gas or diesel fuel, will also be in demand.

Progress made in solving problems in the 1950-70s is demonstrated by the automotive engines of a number of companies. The world's first passenger car with a gas turbine engine (GTE) was introduced by Rover in 1950 [5]. Soon, Boeing installed the GTE on a Kenworth truck [6]. General Motors Corporation announced its first GTE in 1954 [7]. One of the versions of this engine was installed on the Turbocruiser I bus. In each of these automotive GTE, a simple cycle without regeneration was used. An improved cycle with exhaust heat recovery was implemented in 1954 by Chrysler on a passenger car [8]. There were engines with the two-shaft and three-shaft scheme.

Currently, microturbine units in the form of a Range Extender have been implemented on a number of vehicles, both passenger and cargo.

In Russia, the trolleybus manufacturer, Trolza, launched an experimental batch of the eco-friendly Trolza-5250 "Ecobus" buses in 2010 (Fig. 1). This model was developed on the basis of the trolleybus Trolza-5265 "Megapolis" and equipped with a microturbine power plant based on the Capstone C65. A microturbine with an electric generator charges a block of condensers that supply asynchronous electric motors with the electric energy of the "Ecobus".

Fig. 1. Trolza-5250 "Ekobus" With Electric Microturbine Power Installation Capstone C65

The power plant is controlled by a microprocessor control unit. Compressed natural gas is used as fuel. Brief technical characteristics of the bus are shown in Table I.

Table I. Brief Technical Characteristics Of The Trolza "Ekobus"

Wheel formula	4x2
Bus resource, years	12
Curb weight, kg	11,080
Full weight, kg	17,620
Power, kWxGTE rotation speed, min^{-1}	65x96,000
Noise level, dB	82
Fuel endurance, km	450

In 2011, the Trolza "Ekobus" successfully passed a run-in and other tests in the bus depot №11 of the GUP "Mosgortrans" (Moscow) and in Sochi, during which its effective operation was confirmed, both in a large metropolis and a resort town with difficult terrain. Currently, several Trolza "Ekobus" vehicles are operated on one of the central routes in Krasnodar.A comparative analysis of the total harmful emissions for engines complying with the Euro-5 standard showed that emissions from buses with microturbine generators running on diesel fuel are lower than those of ICE that run on propane and liquefied gas and are significantly lower than those with diesel ICE.

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Capstone Turbine Corporation, the world's leading manufacturer of microturbine power systems, claimed that it had successfully completed road tests of the Kenworth Class 7 hybrid-electric truck (Fig. 2), with a 65 kW microturbine as an onboard power generating plant.

Capstone C65 microturbine provides an increase in the range of the electric truck, charging the onboard lithium-ion battery of 47 kWh.

Tests showed that the microturbine combined diesel power plant produces 65% less greenhouse gas and more than 90% less NOx compared to a regular diesel engine of a similar vehicle.

Fig. 2. Kenworth Class 7

Delta Motorsport is developing the Micro Turbine Range Extender – MiTRE. In 2016, the first version of the microturbine was produced, generating 17 kW of electrical power (Fig. 3). The next achievement of the company was the microturbine installation, which produced up to 35 kW of electrical power with a mass of 50 kg [9]. Such a generator, according to the manufacturer, is 40% more compact and 50% weighting less than a conventional piston engine, while the efficiency is 30%. After finishing the heat exchanger, the efficiency can reach 35%.

The first prototype of the MiTRE microturbine was built into the E4 Coupé’s vehicle concept. In this car, the combined power plant is made in a sequential scheme and the microturbine charges the battery. The main difference between MiTRE and piston engines is the ability to work on various fuels: diesel fuel/biodiesel, liquefied natural gas, associated gas, kerosene, propane, fuel oil.

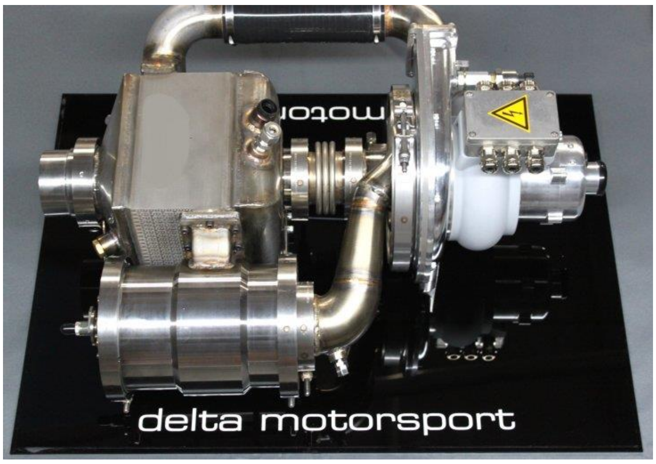

Fig. 3. Delta Motorsport Micro Turbine Range Extender

In 2016, Mack Trucks [10] demonstrated the Mack LR. This model, together with the manufacturer of transmissions Wrightspeed, was upgraded to a truck with a combined power plant (Fig. 4). The transmission from Wrightspeed Route is realized without a mechanical connection from the microturbine (Figs. 5, 6). The truck is able to ride up to 24 miles with electric haulage. Then, the turbogenerator turns on and charges the battery. Both natural gas and diesel fuel can be used. The regenerative braking system Route 730 is also implemented, which produces electricity when the car stops.

Fig. 5. Mack LR

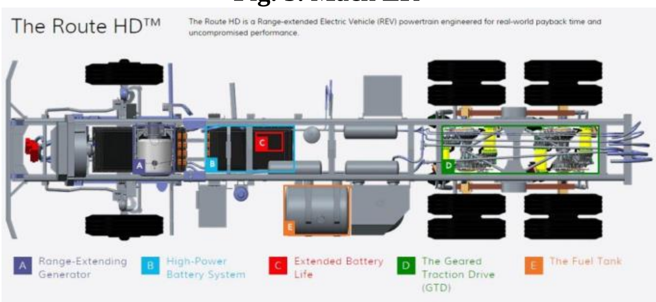

Fig. 6. Route Transmission

Currently, a multi-purpose environmentally friendly GTE for power plants of various purposes is being developed at the State Research Center of the Russian Federation, NSUE "NAMI". Within the project, a prototype model of a multi-purpose environmentally friendly GTE with a power of 25-75 kW for power plants of various purposes will be

designed and manufactured. This power plant is intended for use on vehicles (to increase drive range as well), ships and ship platforms as autonomous power sources that exceed the world level in basic technical and economic characteristics (specific fuel consumption, power density, simplicity services) using different types of fuel, including associated petroleum gas, which provides greater efficiency in the use of environmentally friendly energy sources. As a result of the project implementation, a useful scientific, technical, technological and social effect will be obtained, which will be ensured by using the obtained results in terms of bringing modern scientific and technical products and world-class technologies to the market.

IV. CONCLUSION

After analyzing existing vehicles with a microturbine-based combined power plant as a heat energy source, it can be concluded that the use of a microturbine will make it possible to get into a high ecological class without developing and producing an exhaust gas neutralization system. Also, the use of microturbines allows achieving the complete absence of particulate matter in emissions when operating on diesel fuel.

The use of a microturbine motor combined with an electric motor on a truck chassis allows for fuel savings of up to 30% compared with similar chassis during the urban traffic cycle (figures for world fuel savings on heavy trucks with combined power plant are no more than 10%). The implementation of an external power exchange system (Plug-in-Hybrid principle) will provide additional fuel savings of up to 50%. Another obvious advantage of using a microturbine is a relatively low noise level.

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