E3S Web of Conferences **548**, 04003 (2024) https://doi.org/10.1051/e3sconf/202454804003
AGRITECH-X 2024

On the issue of charging traction batteries for mainline road transport

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Abstract. The preservation of the environment is a very urgent task today. In this regard, work is underway in many countries of the world on the design and production of electric vehicles. However, the operation of such vehicles is inextricably linked with the creation of an infrastructure for charging traction batteries. In urban conditions, the construction of infrastructure does not require the creation of special conditions. To ensure long-distance transportation, the use of electric vehicles is hampered by the lack of supply of electric power, and, consequently, the infrastructure for charging traction batteries. The solution to this problem may be the installation of an electric power generation unit on a vehicle directly during movement. This installation must ensure the necessary level of environmental friendliness during operation. These installations can run on hydrogen or natural gas. In this paper, the possibility of using a hydrogen fuel cell power plant to recharge traction batteries in transport is considered.

1 Introduction

The development of electric-powered vehicles is underway in different countries of the world. The leaders in this issue are China, the United States, Korea and other countries with a developed automotive industry [1]. Electric cars are becoming popular in Russia. At the beginning of 2024, the share of electric buses is about 2% of the total number of bus fleets. Electric vehicles are the most suitable urban vehicles that reduce the negative impact on the environment [2].

The operation of an electric vehicle is inextricably linked with the creation of an infrastructure for charging traction batteries. In urban conditions, the creation of such infrastructure is facilitated by ubiquitous electrical substations that provide consumers with electric energy [3]. It is much more difficult to ensure the charging process of traction batteries of vehicles during mainline traffic on highways and motorways.

The charging process can be provided directly while the vehicle is moving. Solar panels can be used for these purposes, but their use will not allow sufficient replenishment of electric

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energy reserves in the battery. It is proposed to use hydrogen fuel cells for efficient charging [4, 5, 6].

2 Materials and methods

The research was carried out on a fuel cell power plant or another name – FC-power plant (FC – fuel cell), which is a set of units for generating electric energy from the oxidation reaction of fuel (hydrogen, methanol, etc.) without a combustion process. It usually includes an electric motor, a fuel cell battery, a rechargeable battery, a frequency converter, and an air filtration system (Figure 1).

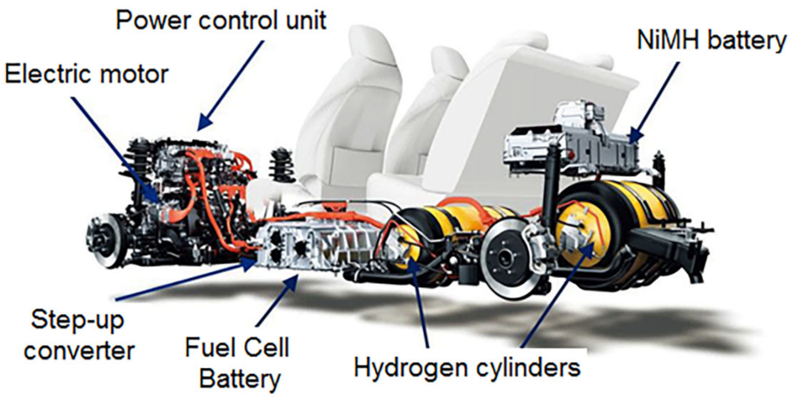

Fig. 1. An example of a fuel cell power plant.

3 Results

To calculate the parameters of an electric vehicle, it is necessary to take into account the change in its mass in comparison with a car with a heat engine.

The calculation of the required power of the electric motor for the movement of an electric vehicle with a maximum specified speed is performed according to the formula:

$$P_{edv} = \frac{m_a * g * \psi_v + k_w * A_l * v_{max}^2}{\eta_{ed}} * v_{max} \quad (1)$$

where m_a is the total mass of the car, g is the acceleration of gravity (~9.8 m/s^2); ψ_v is the coefficient of total road resistance at the maximum set speed v_{max}; k_w is the coefficient of air resistance; A_l is the frontal area of the car; η_{ed} is the efficiency of the engine at nominal speed (~90%); v_{max} – the maximum set speed of the car.

To calculate the required electric motor power, it is necessary to determine the coefficient of total road resistance at the maximum specified speed using the formula:

$$\psi_v = f_v + h_v \quad (2)$$

where f_v is the coefficient of rolling resistance; h_v is the value of the longitudinal road slope.

To calculate the thrust force, the formula is used:

$$F_{т} = M_{ed} * u_{tr.} * \eta_{tr} * \eta_{ed} / r_{к0} \quad (3)$$

where M_{ed} is the torque of the electric motor; u_{tr} is the transmission ratio; η_{tr} is the transmission efficiency; r_{k0} is the rolling radius of the wheels.

The calculation results are shown in Figures 2 and 3.

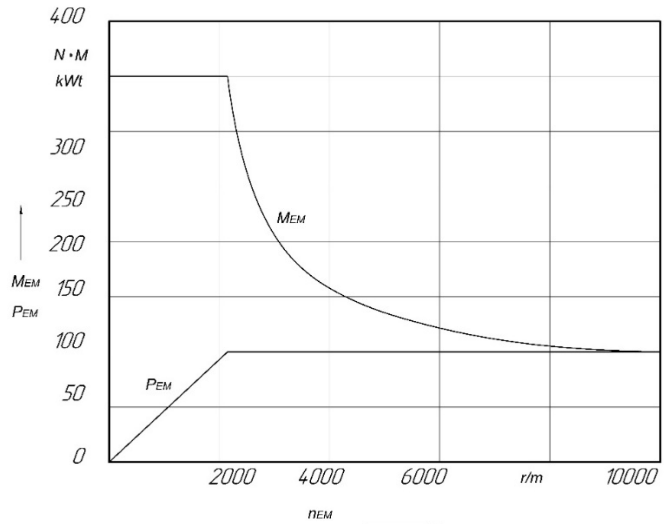

Fig. 2. Adjustment characteristic of the main drive motor.

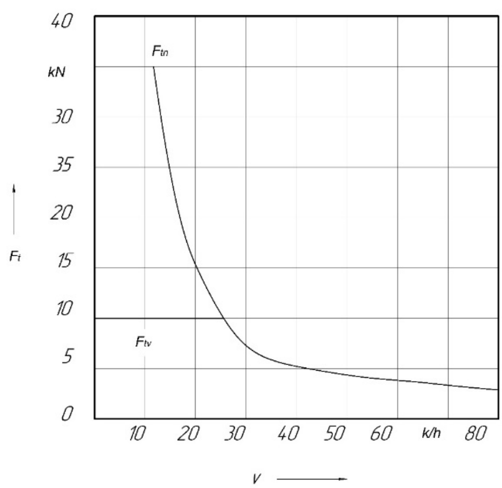

Fig. 3. Traction characteristics of an electric vehicle.

Using the obtained dependencies, the main drive electric motor is selected in accordance with the specified technical characteristics of the electric vehicle.

4 Discussion

The fuel cell is an electrolyzed operating as a generator [7]. The fuel supplied to the cathode is oxidized, forming positive ions. The ions pass through the electrolytic medium, combining with the oxidizer at the anode, and the resulting product is removed from the element. Electrons, passing through an external circuit, perform useful work. Today, there are methanol and hydrogen fuel cells. TE are also divided according to the type of electrolyte: solid oxide, based on molten carbonate, phosphoric acid, with a proton exchange membrane and alkaline [8]. Except for the last two, all the others have a high operating temperature and have not received much distribution. However, these two types also have disadvantages and their improvement continues.

The advantages of fuel cells are the absence of fire, since there is no combustion reaction, high efficiency of chemical energy conversion (up to 70%), energy is converted directly into electricity, unlike conventional generators.

The rechargeable battery is used to store regenerative energy. Its capacity is usually small. When operating at full power, the battery releases stored energy, increasing the output power of the traction electric motor. The battery is also used to start the installation, power consumers (lighting, auxiliary systems), and bring the fuel cell battery to operating mode.

Fuel, depending on its elemental composition, can be stored in various states. Methanol, under normal conditions, is a liquid, so it can be stored in fuel tanks. Melting-boiling range – -97° – -65°. Hydrogen, depending on its aggregate state, can be stored both in liquid and gaseous form. In addition, there is a technology for hydrogen absorption by metal hydrides, in this form hydrogen is completely safe and can be extracted from the sorbent by increasing the temperature. However, this requires a metal hydride heating-cooling system to ensure the process of hydrogen consumption and refueling. In addition, such a "fuel tank" will have a significant mass. Liquid storage requires special cooling systems. This increases the weight of the entire vehicle, complicates its design and requires the cost of part of the stored fuel to maintain the required temperature. Also, during refueling, some of the hydrogen will be used to cool the tank. In addition, with a decrease in the storage volume, the proportion of leaks of liquid hydrogen fuel increases, since the ratio of the internal volume to the surface area of the tank decreases [9].

Storing hydrogen in a compressed gaseous state is the simplest [10]. To date, there are several production vehicles using this particular storage technology. The pressure in the cylinder can reach 60 MPa [11, 12].

Depending on the weight and purpose of the vehicle, the transmission can be made either continuously variable or with a gearbox.

The main advantages of an electric motor over internal combustion engines are:

- A wide range of output shaft rotation speed
- High torque with low output shaft speeds
- Greater torque over a wide range of revolutions
- High efficiency
- High reliability

The key feature of the electric motor is a wide range of operating speeds, as well as high torque in most of it [13]. On large vehicles, it is necessary to include a gearbox in the transmission design to facilitate maneuvering and choosing the most optimal driving mode.

5 Conclusion

Maintenance of electric machines is much easier than that of internal combustion engines. The absence of a lubrication system, the inertia balance of the reciprocating motion, and the overall simplicity of the design make them extremely reliable and maintainable.

The fuel cell power plant can be used in a wide range of vehicles. On mainline vehicles, the important advantages of an electric motor are its reliability, high efficiency and high torque.

The design process of electric vehicles requires the determination of performance characteristics in accordance with the specified operating conditions. Electric vehicles for urban transportation do not require a mobile charging system during operation. For mainline transportation, it is necessary to provide a mobile charging system, for example, using fuel cells.

This paper has been supported by the Kazan Federal University Strategic Academic Leadership Program ("PRIORITY-2030").

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