Integration of a hydrogen fuel cell into an electric vehicle for mainline cargo transportation

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Abstract. The paper considers the issue of providing electric power to electric traction tractors. The importance of using electric vehicles from the point of view of the environmental situation is described. The use of electric motors for mainline cargo transportation is justified. In this regard, improving the performance of cargo transportation systems is always an urgent task. Increasing the indicators of efficiency, environmental friendliness, reliability and ergonomics within the framework of traditional power plants used today seems unpromising. In this regard, the application of fundamentally new technical solutions in road freight transport is more relevant. The article provides the rationale for choosing a tractor prototype. Such a car is the KAMAZ-54901. It describes how the layout of the placement of the main units and assemblies in the design of an electric vehicle will be changed. The main difference between the proposed design and classic electric vehicles is the possibility of using hydrogen elements to provide electric energy to the engines. The principle of operation of a hydrogen fuel cell is described.

1 Introduction

Freight transportation by road is important in the modern economy. Road freight transportation is important both for the domestic market of the country and for international trade. Regardless of the degree of development of other types of cargo transportation – water and rail transport, road freight transport will always be relevant as the most mobile and universal means of delivery.

Since wheeled tractors have been developing for quite a long time, many common technical solutions have already been worked out and do not need improvements. First of all, this applies to the general layout scheme: the location of the cabin, the location of the saddle, the number of controlled axles, dimensions, etc. In this regard, it would be rational to choose a prototype from existing products in order to simplify the production of the product and not create additional unique components and parts with parameters close to existing products.

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2 Materials and methods

A car was chosen as a prototype, the production of which is as localized as possible, this will have a positive effect on the price of the product and reduce dependence on foreign components, which in turn will reduce the risks during production. At the same time, it is most important that the power structure, chassis, and cabin are localized, since the power plant, transmission, and fuel system will be upgraded.

KAMAZ PJSC was chosen as the manufacturer of the prototype. Its production is equipped with high-tech equipment and has a high degree of localization. The KAMAZ – 54901 car was chosen as a prototype.

The overall layout of the car remains unchanged, namely: the front location of the cab without a hood, the coupling device is located at the rear. The chassis is biaxial, with a leading rear axle, the wheel formula is 4x2. The front axle is steerable, the rear axle has a gable bushing.

In the front part of the car, under the cabin floor, there are power plant units – power control electronics, frequency converter, inverter, rectifier. A hydrogen fuel cell battery and a buffer battery are located in the inner space of the frame in the middle part of the car (Figure 1). The traction electric motor is located under the saddle device in conjunction with the main transmission crankcase. Fuel tanks are located in regular places – in the middle of the car on the sides.

The power structure of the chassis must meet the specified requirements for the strength of the entire car, both during normal operation and in emergency and emergency situations [1]. Due to the compliance of the standard power structure with the requirements and in order to simplify operation, only minor changes are made to the standard power structure regarding the fastening of new components and assemblies.

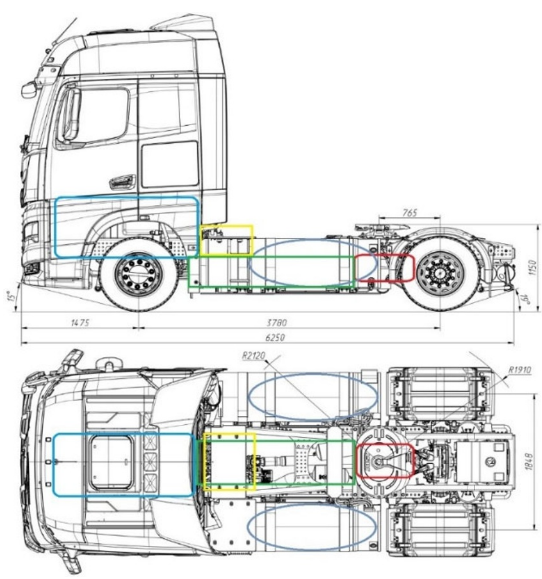

Fig. 1. Assembly of units and assemblies.

The design of the KAMAZ-54901 prototype is based on a spar-type frame. The frame structure has 3 box-shaped and one tubular amplifier. The tubular amplifier is located in the front of the frame, the box amplifiers are located at the inflection points of the spars in the middle part, under the coupling device in the rear of the structure.

According to the modernization project, it is necessary to add mounting brackets for new units on the frame. Namely, the mounting of the control electronics in the front of the car, the mounting of the fuel cell battery and buffer battery in the middle part and the mounting of the traction motor. Fuel tank mounts do not require significant modifications.

A hydrogen fuel cell power plant uses the principle of obtaining energy directly from a chemical reaction, bypassing the thermal stage (Figure 2). In a traditional internal combustion engine, the energy of the chemical reaction is converted first into heat, then into mechanical energy of reciprocating motion, then into the energy of rotational motion of the crankshaft [2, 3]. In a fuel cell, chemical energy is directly converted into electrical energy, with an efficiency of up to 75%.

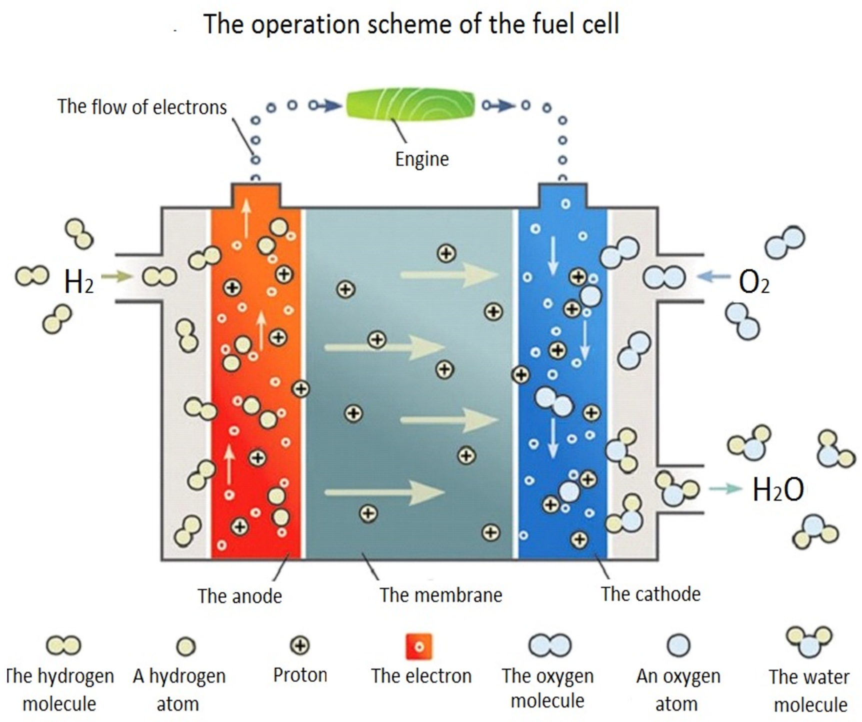

Fig. 2. Operation of the hydrogen fuel cell.

Since the fuel cell generates direct current, a frequency converter is required to power the traction motor. In existing hydrogen cars, 400-650 V converters are used [4, 5]. The control unit controls the fuel cells depending on the required power. A secondary metal hydride battery is used to store energy from regenerative braking.

Since an electric motor will be used as the driving unit, the transmission requires drastic changes. First of all, it is necessary to determine the type of transmission that is most suitable for the operating conditions of the car, and which fully reveals the advantages of an electric motor as an engine type [6, 7].

3 Results

Three basic transmission schemes were considered in the work: the classic standard transmission of the KAMAZ-54901 car, a circuit with on-board motor wheels and a circuit with an electric bridge. All three types have their advantages and disadvantages.

According to the combination of advantages and disadvantages, it was decided to use a transmission circuit with an electric bridge on the project. This scheme most fully meets the expected operating conditions of the product, and creates fewer technical difficulties in implementation. The bridge assembly with all components except for the main gearbox is preserved from the prototype, since its gear ratio will require changes.

The gear ratio of the main pair should ensure confident acceleration of the car with full weight at the level of the basic prototype. In addition, it is necessary to achieve a maximum speed of 100 km/h with full weight.

To ensure a confident start from a place at full load and confident movement in various terrain conditions, an intermediate planetary gearbox with a lowering row should be used. This gearbox has two gears – a straight one, for movement under normal conditions, and a step-down one, to overcome increased resistance to movement.

During the design calculation, in order to ensure the necessary reliability and the possibility of placing the gearbox in the car, the gear ratio of the downshift was selected – 3.41.

An electric motor is used as a driving unit. To date, there are a large number of types of electric motors, but the motor for transport must meet the following requirements [8, 9]:

- Absence of a brush-collector assembly.
- High torque from low rotor speeds, as well as over the entire speed range.
- Wide range of operating revolutions.
- High power/weight ratio.
- The ability to work in various temperature conditions.
- Dust and moisture protection.

According to the main parameters (Figure 3), the electric motor should provide a full-fledged replacement of the standard power plant while maintaining the traction and speed qualities of the car [10, 11].

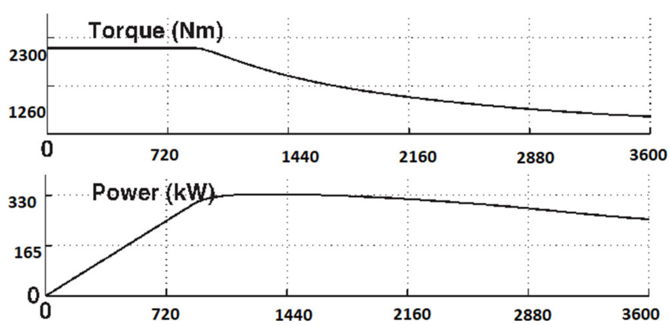

Fig. 3. Characteristics of a synchronous AC motor with permanent magnets. Torque, power.

The TLSRPM 330 LD1 Leroy Somer engine can act as a traction electric motor of the car under development.

RLSRPM Series-Dyneo Leroy Somer:

Technical characteristics of the series:

The motors are powered by an alternating current network with a voltage of 400 V, develop up to 3600 rpm, the speed parameters can be adjusted in accordance with the technical characteristics of the actuators.

With low inertia, the engines provide a torque of up to 2300 Nm. The enclosure protection class is IP23.

Synchronous motor with permanent magnets RLSRPM 330 LD1 Leroy Somer

Technical features:

- Connection voltage – 400 V AC;
- rated power – 330 kW;
- Energy efficiency coefficient – 95.6%;
- rotation speed – up to 3600 turnover/minutes;
- torque – 1260...2300 Nm;
- moment of inertia – 2.98 kg · sq. m;
- weight 883 kg.

On request, a sensor is included in the engine package to monitor the rotation speed parameters. The installation of the equipment is carried out according to the manufacturer's instructions.

4 Discussion

To evaluate the efficiency of the engine, its power required to achieve maximum speed was determined:

$$N_{к} = \frac{f_{c\,min} * G * V_{max}}{\eta_{су} * \eta_{тр} * \eta_{кд}} = 329460\ W \tag{1}$$

where η_{cy} is the efficiency of the power plant (0.956); η_{tr} is the efficiency of the transmission (for a highway tractor = 0.95); G is the weight of a fully loaded road train (= 421200 N); η_{kd} is the efficiency of the drive wheel (for ideal conditions = 0.8); $f_{c\ min}$ is the resistance to rectilinear motion that the car must overcome at maximum the speed, the inertia of the rotating masses, the air resistance are taken into account (for a mainline wheeled tractor = 0.03).

Next, the maximum rotation speed of the machine wheel is determined:

$$n = \frac{V_{max}}{2 * \pi * r_{к}} * 60 = 748\ turnover/minutes \tag{2}$$

The classic differential is used as the main pair. Its gear ratio:

$$U = \frac{n_{м}}{n} = 4.81. \tag{3}$$

It should be borne in mind that this power is consumed when driving at maximum speed at full load. In this mode, not only the fuel cell battery acts as a source, but also the buffer battery.

This electric motor allows you to adjust the rotor speed, its power and torque indicators allow you to install it instead of a standard internal combustion engine in a car without reducing the speed and power characteristics of the product.

5 Conclusion

The problem of modernization of wheeled vehicles due to increased environmental requirements is currently acute [12]. Today, manufacturers are following the path of reducing harmful emissions from internal combustion engines and creating electric platforms. However, the upcoming Euro 7 toxicity standards are capable of depriving almost all modern engines of the possibility of operation. As for electric platforms, so far there have been no successful projects to create mainline tractors powered by batteries. In addition, even successful electric passenger cars have a number of disadvantages, such as low mileage, rapid battery wear.

However, the advantage of electric traction is obvious. And this project clearly shows the possibility of using the advantages of an electric motor while maintaining a large power reserve, even for heavy trucks. The project shows the possibility of upgrading existing cars, and offers solutions for each of the car's systems: power plant, transmission, chassis, brake system, etc. The preferred type of transmission was selected, the type and model of the electric motor, and fuel storage solutions were selected.

This work can be used as a basis for further development and launch into production of a tractor powered by hydrogen fuel cells. Its advantages are that the entire project is carried out on existing nodes, which will significantly reduce the cost of prototype production and test new technologies during the prototype run-in. The development of technical solutions on this project will allow us to create a completely new hydrogen car project in the future, taking into account the experience gained.

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References

1. D.M. Mukhametshin, R.F. Shamarov, V.V. Polyakov, Russian Federation, Utility Model Patent No. 149530 (01.10.2015)
2. A.V. Shestov, A.A. Buravtsova, Ya.S. Karpenko, *Hydrogen engine*, in Social and humanitarian sciences in the XXI century. Results, challenges, prospects 2021: Collection of scientific papers of the II All-Russian Scientific and Practical Conference with international participation dedicated to the Year of Science and Technology, April 16, 2021 (St. Petersburg, Russian Federation) (2021)
3. A.V. Diyakovskaya, L.R. Telekova, *Hydrogen as the fuel of the future*, in Scientific research and innovations: collection of articles of the III International Scientific and practical Conference, February 14, 2021, Saratov, Russian Federation (2021)
4. A.I. Gaivoronsky, M.V. Gordin, V.A. Markov, Engine building **2(288)**, 4-28 (2022) https://www.doi.org/10.18698/jec.2022.2.4-28
5. K. Wróbel, Ju. Wróbel, W. Tokarz et al., Energies **15(23)**, 8937 (2022). https://www.doi.org/10.3390/en15238937
6. A. Kuleshov, A. Kuleshov, V. Markov, F. Karpets, V. Yumagulova, A. Nurullin, E3S Web of Conferences **390** 05020 (2023). https://www.doi.org/10.1051/e3sconf/202339005020
7. Atharva Patki, International Journal of Advanced Research in Science, Communication and Technology, 188-195 (2022). https://www.doi.org/10.48175/ijarsct-7358
8. G.A. Nesterenko, I.S. Nesterenko, Automotive industry **7**, 18-20 (2023)
9. I.D. Dimitrova, T. Megaritis, L.C. Ganippa, E.A. Tingas, International Journal of Hydrogen Energy **47(17)**, 10083-10096 (2022). https://www.doi.org/10.1016/j.ijhydene.2022.01.093.
10. A.A. Orlov, G.A. Nesterenko, I.S. Nesterenko, Trends in the development of science and education **92-11**, 57-60 (2022). https://www.doi.org/10.18411/trnio-12-2022-526
11. D. Koch, G. Krämer, A. Sousa, MTZ worldwide **83(5)**, 66-70 (2022). https://www.doi.org/10.1007/s38313-022-0775- y.
12. A.S. Kuleshov, A.A. Kuleshov, M.V. Gordin, V.A. Markov, F.S. Karpets, Alternative fuel vehicles **3(93)**, 34-48 (2023)