Development of autonomous traction system of electric vehicle with electronic differential and fuzzy control system

N S Popov¹, V N Anosov¹, M E Vilberger¹, E A Domakhin¹, V I Anibroev¹, I I Singizin¹

¹Novosibirsk State Technical University, 20, K. Marx Avenuave., Novosibirsk, 630073, Russia

E-mail: nikitaa_popov@mail.ru

Abstract The article discusses the optimal layout of an autonomous vehicle traction system. In modern society, a special place is occupied by environmental issues. From year to year, a huge amount of statistics is published that reflect the scale of the damage that human products cause to the environment. Today, the main “pest” on the planet is surely cars with an internal combustion engine. At the same time, a complete rejection of motor transport, both in Russia and in the world, is impossible, because the life of modern man is inextricably linked with the constant movements, which are not always possible through urban electric transport. In recent years, many manufacturers of transport systems see the way out in autonomous electric transport systems development, which, in the future, will be able to replace vehicles with an internal combustion engine. In this article traction system variants, choice of electric motor optimal location, and also the control systems analysis which would correspond to requirements to the given technical process are considered.

1. Introduction
In addition to urban transport systems and public vehicles, electric transport is also used as a transport complex for production facilities. Electric cars and forklifts are becoming increasingly popular around the world, especially in enclosed warehouses where the use of classic vehicles with internal combustion engines is not possible.

Autonomous electric transport systems, regardless of the manufacturer, face the same problem - a small reserve of autonomous driving. The increase in electric vehicles autonomous driving is currently achieved in various ways. One of the most common is the additional batteries integration into the transport system power circuit. The disadvantages of this method are the increase in the price of the vehicle, mass and dimensions increase. Another method is the vehicle power circuit modern control systems implementation, the so-called hardware method. Its disadvantages are the implementation complexity and of additional equipment introduction in the electrical part of the vehicle [1].

A review of literature on this topic has shown that the authors’ opinion in terms of autonomous electric vehicle traction system layout is different. Here are the most popular electric motors arrangement variants:

- the engine is connected to the primary shaft of the gearbox (figure 1a);
- the engine is connected to the driving axle axial differential (figure 1b);
- the motor is connected directly to the drive wheels (figure 1c).
Each option has its advantages and disadvantages. The variant with the engine connected to the primary transmission shaft significantly increases the transmission weight of the vehicle due to the transmission itself, gearbox, mechanical differential and other parts. Such an increase in mass and dimensions increases the storage batteries charge consumption, which leads to a decrease in the vehicle autonomous drive. As an advantage, it is worth noting the fact that this traction system implementation method implies a wide range of choice among serial excitation electric machines. However, during serial electric machine choosing process, it should be kept in mind that the power reserve should be provided due to losses in the system mechanical parts, which, in turn, again increases the mass performance of the engine [2].

The variant with an electric motor to an axial differential connection significantly reduces mass-size parameters of an autonomous electric vehicle, due to the absence of a reducer, gearbox and other details. However, this method does not completely solve the power reserve problem for a quick start. The advantage, as in the first layout variant, remains the fact that this method implies a wide range of choice among serial electric vehicles [3].

The variant with an electric motor connected directly to the wheel simplifies the transmission design, as there is no need for a clutch, a gearbox, drive shafts and differentials, which significantly reduces the vehicle weight. The system reliability is increased by the simplified design. The optimal control system implementation for all engines will simultaneously improve the system energy efficiency. All the above mentioned traction system layout variants are variable, their practical application is possible both on the basis of an electric vehicle for personal use and on the basis of special-purpose vehicles. In the case of electric cars and forklift trucks, this solution has the added advantage of maneuverability and mobility in limited indoor spaces. Steerable motor wheels can rotate at different speeds and in different directions, this allows vehicle to turn 360 degrees, to park in a limited space. Another important advantage is the brake energy recovery system simplicity, which is crucial for autonomous electric transport. The disadvantage of such a system is a large unsprung mass, which increases suspension wear and transmits more vibrations to the vehicle body [4, 5].

Figure 1. Traction system location in an autonomous electric vehicle. (1 - wheel; 2 - electric motor; 3 - axle half; 4 - differential; 5 - gearbox; 6 - gearbox.)
In preference to the traction system based on engine wheels implementation, attention should be paid to the lack of a gear transmission between engine and steering wheel. This, in turn, leads to the need for an electronic differential. It provides the necessary torque for each drive wheel and allows different wheel speeds. When driving around turns, the inner wheels drive by a smaller radius, so the wheels rotate at different speeds. The electronic differential uses the steering signal and engine speed signals to control the power of each wheel to provide the torque they need.

2. Results and Discussion
The electronic differential has several advantages over the mechanical differential. Above all, the design simplicity, which means no mechanical parts and control system variability for the autonomous vehicle specific conditions, which implies adjustment according to the driver preferences and the driving mode. Also, the presence of four motor wheels means that energy recovery during braking is distributed by four motors simultaneously. The absence of a mechanical component significantly reduces the control system response time.

However, the use of the electronic differential has a number of issues, the most important of which is the electric vehicle stability. For normal driving conditions, all drive wheel systems require symmetrical torque distribution on both sides. It must be understood that a symmetrical torque distribution is not sufficient, as when the tires traction coefficient on the road surface changes, the wheels rotate at different speeds, which results in the need for traction control systems. Up to date, there is no optimal solution to this problem, this issue remains unsolved and is of interest to the scientific community. Further, an electric machine type for autonomous vehicle traction system implementation reasonable choice will be considered. As the main idea is to increase the autonomous vehicle drive, mass dimensions are the main criteria at the electric machine type choice. From all engines types, up to date, the most compact are synchronous motors with permanent magnets excitation. In addition to this advantage, machines of this type have a relatively simple control system, as this type of excitation can be compared with an independent excitation winding in DC motors [6].

This article deals with a traction system based on synchronous permanent magnet motors.
Figure 3. Electronic differential operation algorithm structural diagram.

\[ \omega_{\text{зад}} \]

\[ \delta \]

[Path 1: \( \Delta \omega = f(\delta, \omega_V) \)]

[Path 2: \( K_1 \) and \( K_2 \)]

\[ \omega_2 = \frac{\omega_n + \omega_H}{2} \]

\[ \omega_V \]

\[ \omega_{\text{зад,1}} \]

\[ \omega_{\text{зад,2}} \]

Figure 4. Electric drive structure diagram in MATLAB environment.
A neural network approach is offered as a control system for this traction system. There are several reasons for this at once [7]. Firstly, neural networks, due to their self-learning ability, have a huge advantage in terms of energy efficiency. Secondly, it has a significant advantage in terms of performance over traditional control systems, as well as over adaptive control systems [8-10]. The obtained transition processes quality indicators testify to the modeled system correctness, because speed and the overregulation value correspond to the required values.

3. Conclusion
The analysis performed in the paper deals with optimal selection of traction system design which allows vehicle efficiency improvement. Higher efficiency is reached by means of electronic differential application to the traction system and fuzzy logic controller for closed speed loop. The transition from conventional control system to fuzzy logic control system allows reaching the multiple goals: control system robustness improvement, energy performance optimization.
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