Go-carting vehicles with electric drive

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Abstract. The article describes a number of technical solutions that made it possible to develop Russia’s first electric car for domestic go-cart racing, with a power reserve of 40 minutes of active driving, acceleration from 0 to 60 km/h in 9.5 seconds, with the ability to reverse, with functions energy recovery during braking. As battery cells, lithium-iron-phosphate cells were used. The article provides a calculation of the optimal battery capacity, based on the requirements for the mass-overall performance of the machine. The results of test runs of a serial model of cars with a power of 5 and 10 kW are presented. The calculations of the economic payback of a go-cart club equipped with electric traction machines are presented. The E-Cart, developed by teachers and undergraduates of the Department of "Automated electric drive" of the South Ural state University, has high performance characteristics. The technical solutions made it possible to achieve high acceleration dynamics and a range of 30 km. on a single charge, the “evenness” of the machines – the range of speed and torque when the battery charge level is from 15 to 100%.

1. Introduction

The main trend in the global automotive industry in recent years is the production of electric cars. The most successful technical solutions are demonstrated by the Tesla Model S, BMW i3 and others. The flagship of the company Tesla performs acceleration from 0 to 100 km/h in 4.8 seconds, which can not be achieved by any car with an internal combustion drive of the same power. The fact is that the starting moment of the electric drive is 3...4 times higher than the starting moment of the gasoline drive. It is worth paying attention to the fact that the nominal torque of the internal combustion drive can only be produced at a speed of 2000 rpm. For a long time, the main problem of electric cars was their batteries. However, with the development of technology and the advent of lithium batteries, this task has gradually been solved. So, the Tesla Model S has a power reserve of 500 km on a single battery charge.

These advantages of the traction electric drive are also relevant for carting. The winding track requires a "hard" driving style from the pilot, when the movement is a series of sections of braking and acceleration with maximum acceleration. A power reserve of 40 km on a single charge is usually enough for both competitions and for several races in rental clubs.

The operation of an electric cart in comparison with a cart based on an internal combustion drive is much safer. Often, during landing and disembarkation from a gasoline-powered car, the pilot receives burns and may get dirty in oil and other combustion products. In the case of electric traction, there are no such problems.

The advantages of electric traction. E-cart electric carts, developed by employees and undergraduates of the Department of Automated Electric Drive of SUSU, use modern frequency-controlled BLDC drives based on high-torque synchronous motors with permanent magnets. These
electric machines in the range of moments from 25 to 100 Nm have the best overall dimensions, i.e. able to give out the greatest moment, having less weight and size. As power sources, lithium-iron-phosphate batteries with a high charge density are used. In addition, these batteries are made of non-combustible materials, and their ignition is completely excluded. Due to the small mass of electrical equipment and the high torque of the electric motor in E-cart carts, high acceleration dynamics are achieved.

From the point of view of rental, the use of a cart with electric drive is more convenient, as this machine has no exhaust and no noise, allowing you to arrange rental in rooms with standard ventilation in the neighbourhood of crowded places (shopping malls, on the pads in front of them). The performance characteristics of an electric go-cart are significantly higher compared to their petrol counterparts. Batteries are designed for 3000...5000 cycles "charge-discharge".

Separately, the presence of a reverse should be noted. In case the participant of the race crashed into the fence, now there is no need to wait for the help of the maintenance staff, now by means of the toggle switch located on the front panel, the driver can simply switch the electric drive to reverse and drive back independently.

Braking in E-cart models is implemented in two stages. When you press the brake pedal at the beginning of the pedal stroke, the sensor is activated, which turns on the recovery mode in the inverter. In other words, at the first stage, the drive is braked electrically, and all the stored kinetic energy is used to charge the batteries. In this case, the brake pads of the hydraulic brakes are practically not erased. If there is a need for emergency braking, the driver presses the brake pedal harder all the way, and mechanical braking is additionally connected.

2. Materials and Methods
At the stage of selecting electric drive power, an analysis of a typical load diagram of speeds and moments obtained on a standard rolling track was performed [1]. Given the large share of acceleration and braking in the race cycle, it was necessary to calculate the root mean square moment. It turned out to be equal to 56 Nm. Next, the rated power of the drive cart was calculated [2].

\[
P_d = k_1 \cdot M_{RMS} \cdot \frac{2 \cdot V_N}{D} \sqrt{\frac{D_{IF}}{D_{IC}}} = \frac{1.05 \cdot 56 \cdot 2 \cdot 11.9 \cdot 0.94}{0.26} = 5218 \text{ W}
\]

An electric drive based on a 5 kW brushless direct current motor BLDC was chosen as the drive. Table 1 shows the technical characteristics of the electric drive [3].

| Table 1. Technical characteristics of the electric drive |
|--------------------------------------------------------|
| Electric drive                                         |
| Power, kW                                              | 5 |
| Operating speed range, rpm                             | 2000...6000 |
| Rated voltage, V                                       | 48 |
| Efficiency coefficient                                 | 91% |
| Frequency converter                                     |
| Model                                                  | VEC300-48 |
| Rated voltage, V                                       | 48 |
| Maximum current at the input of the DC BUS Converter, A | 200 |
| Rated current, A                                       | 120 |
| The maximum phase current, A                           | 300 |
| Mechanical transmission                                | Chain or belt |
| Type                                                   | |
| Number of teeth on the motor shaft                     | 11 |
| Number of teeth on the chassis shaft                   | 41 |
Gear ratio 3.72

| Rechargeable battery |  |
|----------------------|--|
| Capacity, A * h      | 40 |
| Cell type            | LiFePO4 |

A 5 kW electric drive was installed on a standard rental car. Figure 1 shows its appearance. Battery cells were covered with plastic boxes [4]. The electrical installation was located behind the driver. Such a symmetrical mass distribution, when the batteries are located to the right and left of the pilot, and the electric drive at the rear, allowed to achieve greater stability of the machine on the track. In gasoline vehicles, as a rule, the drive is located to the right or left of the pilot [5]. The low height of the axis of rotation of the drive allowed to reduce the center of mass of the entire machine, which also positively affected its stability and controllability. In addition, modifications were made of 3 kW for children's rental and 10 kW for sports competitions [6].

![Figure 1. Appearance of the E-cart electrocart.](image)

On the rear panel of the cart there is a battery charge level sensor that works on the principle of integrated calculation of capacity according to the consumed current / charge current. The fact is that the voltage level in lithium-iron-phosphate batteries can not always clearly speak about the battery charge level, since the discharge characteristics are rather gentle (hard). The calculation of capacitance as a function of current is more accurate [7].

The model has a leakage current protection system. Moreover, since we are talking about direct current, it is impossible to solve the problem by installing a differential automaton [8]. For this purpose, the machine uses a specially developed system based on the AtMega8535 microcontroller, which measures the current at the output of the battery and at the input of the inverter [9]. If they differ by more than 20 mA, that is, in case of leakage to the housing, the transistor key opens the power supply chain. The "inverter-motor" circuit also provides protection against short circuit and leakage current, implemented on the standard control system of the inverter [10].

**Electric battery configuration.** A distinctive feature of lithium-iron-phosphate cells is the stability of the voltage at the discharge characteristic in the range from 10 to 80% of the charge. In the specified range, the bit characteristics of LiFePO4 cells can be considered linear. With high thermal stability and a fairly high energy density of 90-120 W*h / kg, these cells are suitable for traction drives. Since the rated voltage of a single cell is 3.3 V, the drive requires a serial connection. During a 100% to 15% discharge, the cell voltage drops from 3.6 V to 2.8 V [11].

**Table 2. Charge indicators for batteries with 16 and 18 cells.**

| Charge level. % | Total battery voltage. V | Inverter output voltage. V | Maximum speed. km / h |
|-----------------|--------------------------|-----------------------------|-----------------------|
| 16 cells        |                          |                             |                       |
| 100             | 57.6                     | 48                          | 60                    |
| 83              | 55.0                     | 48                          | 60                    |
| 66              | 52.5                     | 48                          | 60                    |
Obviously, the total battery voltage also drops. A simple calculation of the nominal parameters shows that in order to provide a supply voltage of the 48 V drive, 15 cells in series with a nominal voltage of 3.2 V are required [12]. However, this solution is unsatisfactory from the point of view of rental [13].

Since the competition should be as fair as possible, it is necessary to ensure the identity of the traction characteristics of all machines. For the same purpose, for example, machine weights are often used to ensure an equal mass of machines together with the pilots (since pilots can be of different weights) [14].

Gasoline cars do not differ in their characteristics. For the electric drive, it was important to expand the range of the flat speed shelf as a function of the battery charge level. In table 2 and in figure 2, the voltage characteristics for a battery consisting of 16 and 18 cells are presented in numerical and graphical form [15].

As can be seen from figure 2, a, when the battery is discharged below 30%, the total battery voltage drops below 48 volts, which causes the maximum voltage on the drive to fall below the rated voltage. At this point, the maximum speed that the map is able to develop begins to decrease. It is this circumstance that does not suit the distributors. Because, unlike the petrol drive, where it is enough to simply top up the fuel, the electric car can not be quickly charged. As a result, riders are in unequal conditions.

You can solve this problem by adding two additional cells. As shown in Fig. 2, b, the total voltage of the battery, consisting of 18 cells, also decreases during discharge. However, when the capacity is reduced by up to 15%, the maximum speed does not decrease, since the total battery voltage does not fall below 48 V. This way we get a smooth speed shelf. If the discharge is less than 15%, the charge monitoring system disables the drive, since reducing the voltage of each of the cells below 2.1 V is unacceptable based on the operating conditions of this type of battery. This shutdown occurs in the same range of operation of all machines, which allows you to achieve absolute identity of their performance characteristics [16].

The maximum charge current was 30 A. The BMS system with a nominal balancing current of 60 mA was chosen as the charge control system, which allowed to achieve a balancing time with a voltage spread of no more than 5% of the order of four minutes. The balance voltage in the specified system is provided at the level of 3.5 In each cell, with an acceptable deviation of 0.05 V. There is protection against overcharging at the level of 3.85 V and excess discharge at the level of 2.1 V. The permissible deviation for these modes is also 0.05 V.

Copper cables were used to connect the batteries located on different sides of the drive. Since the maximum current at the time of acceleration can be 120 A, the VVG copper cable with a cross section of 25 mm kV was chosen.
3. Results

The test runs were conducted in an open area with speed detection by the chassis rpm sensor and using the GPS system. Figure 3 shows screenshots of the screens of both systems.

Figure 2. Charge level of battery, %.
The accuracy of the measurements was indirectly confirmed by the fact that both systems gave a maximum speed of arrival equal to 61.2 km/h. The average speed of arrival is 30.9 km/h. The video of the test tests is available on the website [1].

The power reserve on a single charge is 45 minutes, or about 30 ... 35 km, depending on the driving style. This was achieved, including a fairly low weight of the car, equal to 116 kg. In this mass: the mass of the drive is 11 kg, the voltage inverter is 2.5 kg, the total mass of the electric drive is 13.5 kg, the mass of the battery block is 24 kg (one cell is 1.5 kg).

4. Discussion

For six trips of 10 minutes, or an hour of continuous driving, the electric car consumes 6 kW*h. If the average cost of electricity is 3 rubles per kWh, an hour of operation, the cart will cost the owner 18 rubles. For comparison, a gasoline car based on a Honda drive consumes 1.8 liters of gasoline per hour of driving, which in terms of rubles is 58 r.

Table 3. The cost of operation.

| Model of the most famous manufacturer of carts in Europe based on lead-acid batteries | Developed cart based on lead-acid batteries | Developed electro-carts based on LiFePO4 batteries |
|---|---|---|
| Cost, thousand rubles | 420 | 220 | 280 |
| Battery replacement cost for 4 years of operation, thousand rubles | 164 | 164 | 0 |
| Total, the cost of the battery together with operation for 4 years, thousand rubles | 584 | 384 | 280 |
Comparison of maps that have the same traction characteristics (acceleration time, maximum speed, presence of reverse, power reserve) is made.

The cost of renting an electric car for 10 minutes can be set at 30...40% more than the cart with the internal combustion drive. Due to the large hardware resource, maps can be actively used for up to 4 years or more without replacing the equipment. The number of battery charge cycles 5 thousand One charge is enough for three full-fledged races. Therefore, the electric car is designed for 15 thousand trips of 10 minutes. E-Cart, losing in design, but not losing in driving characteristics, will cost the consumer 2.2, 5 times cheaper than foreign analogues.

So what is cheaper to operate-a petrol or electric car? As we defined above, "refueling" an electric car is cheaper. But as is the case with depreciation of equipment? In petrol carting, the drive serves a maximum of two years. Operation of an electric car will be cheaper. This is achieved due to a greater resource of electrical equipment. In the range of ten years, of course, the battery will need to be replaced, since the number of charges is limited by the manufacturer at the level of 6000 cycles. Table 3 shows the calculation of the cost of operation, taking into account the replacement of the battery. The comparison also involves Western developments that are available for purchase and have a more attractive design.

5. Conclusions
The E-Cart, developed by teachers and undergraduates of the Department of "Automated electric drive" of the South Ural state University, has high performance characteristics. The technical solutions made it possible to achieve high acceleration dynamics and a range of 30 km. on a single charge, the "evenness" of the machines – the range of speed and torque when the battery charge level is from 15 to 100%.

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