Choice of the Traction Motor for the Electric Racing Car “Formula Student”

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Abstract

The choice of an electric racing car traction motor is one of the main tasks while designing the electric racing car because it is the motor that specifies dynamic and high-speed characteristics. Besides, the electric drive must be within the regulations of the competition. When comparing some electromechanical characteristics of electric motors used in the electric racing car, it is necessary to prefer electric drives with more hardening characteristic, despite the fact that it will result in the increase of expenses for copper as well as upgrade technical requirements for the choice of storage batteries, but the “hardening” characteristic will provide the model with the required dynamics. The most widely-spread motors with the “hardening” characteristic are a direct current motor with a separate excitation. However, this motor has some disadvantages related to its specific structure. The analysis of different versions of electric drives has shown the prospects of the use of synchronous motors on constant magnets.

Keywords: Electric racing car; Formula student; Traction electric motor; Electric vehicles

1. Introduction

“Formula Student” is the international competition the purpose of which is to motivate students’ teams for working out their own bolide to take part in the race [1]. The competitions are divided into following kinds of races: Formula SAE (racing bolide with an internal-combustion engine); formula hybrid (hybrid power unit); formula electric (racing bolide on electric traction).
Formula Electric is a young and dynamically developing class of Formula Student competition directed to the creation of ecologically safe cars. The great attention in this class is paid to control algorithms, to decrease the car mass, to the electric transmission efficiency and to the problems of electrical active and passive safety [1].

On the designing electric racing car, it is important to keep the technical requirements according to the regulations of SAE competitions. The main requirements to the electric part of the electric racing car are presented in Table 1.

Table 1. Main requirements to the electric racing car according to the regulations of Formula student competition.

<table>
<thead>
<tr>
<th>“Formula Student” competition</th>
<th>Max. admissible difference of potentials between any two points of the bolide power system (Volt).</th>
<th>Motor of traction drive (kWatt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>International</td>
<td>300 V</td>
<td></td>
</tr>
<tr>
<td>Brazil</td>
<td>300 V</td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td>600 V</td>
<td></td>
</tr>
<tr>
<td>Italy</td>
<td>600 V</td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td>600 V</td>
<td>Total peak power of 80 kW motors</td>
</tr>
</tbody>
</table>

2. Propulsion calculation of electric racing car

In order to determine the electromechanical characteristics of the bolide motor, it is necessary to do its propulsion calculation. According to the previous dynamic characteristics of the above electric racing car model based on the A.Sh.Khusainov’s procedure for the car propulsion calculation [2], we can determine the electric drive characteristics.

First it is necessary to determine the drive capacity according to the formula:

\[ P = \frac{M_a \cdot g \cdot f_k \cdot V_{max}^3 + 0.5 \cdot c_s \cdot \rho_{air} \cdot A \cdot V_{max}^3}{\eta_{tr} \cdot K_p} \]  (1)

\[ M_a = 300 \text{ kg} \] – mass of an equipped car;

\[ g = 9,8 \frac{m}{s^2} \] – acceleration of gravity;

\[ f_k = f_{k0} \cdot \left(1 + A_f \cdot V_{max}^2 \right) \] – Coefficient of rolling resistance of a strained wheel on the unstrained surface [3, 4];

\[ f_{k0} = 0.015 \] – for the smooth asphalt accordingly;

\[ A_f = 5.1 \cdot 10^{-4} \frac{s^2}{m^2} \] – the coefficient of efficiency of speed on the force of rolling resistance [4].

\[ V_{max} = 150 \text{ km/h} \] – previously specified maximum speed for the car;

\[ c_s = 0.5 \] – car drag coefficient;

\[ \rho_{air} = 1.202 \frac{kg}{m^3} \] – air density under normal conditions;

\[ A = 1.6 m^2 \] – car midlength section;

\[ \eta_{tr} = 0.9 \] – the coefficient of efficiency of an electric vehicle transmission;

\[ K_p = 0.95 \] – compensation coefficient of capacity, in this case it is an electric power operation factor (coefficient) [5].

Substituting the known data in formula 1, we get the following power value of the electric motor:
Another important factor when choosing the electric racing car motor is its maximum torque, as the acceleration time and dynamic characteristics of the bolide depend on it.

As a whole, the time of uniform motion of motor transport is not usually much. Even in a town/a city cars and usual motor transport move uniformly only 15-25% of the total traveling time [6], this time is less on the race circuits, and the electric racing car movement on the race circuit is characterized by its quick acceleration and braking. So for a racing car it is very important such a factor as acceleration capability [6] that is characterized by the time of acceleration to the preset speed.

To calculate the maximum torque for acceleration, we use the equation of force balance:

\[ F_u = F_{roll} + F_{up} + F_{air} + F_{in} \]

where \( F_u = \frac{\eta_r \cdot M \cdot i0 \cdot i1}{r} \) – is tractive force on the driving wheels, in the formula \( M \) is torque on the motor shaft (Hm) (desired quantity), \( i0 \) and \( i1 \) – gear ratios of main gear and first gear;

\( F_{roll} = f_k \cdot m \cdot g \cdot \cos \alpha \) – rolling friction force under \( \cos(\alpha) = 1 \);

\( F_{up} = m \cdot g \cdot \sin(\alpha) \) – resistance force to climbing (in the above case it is equal to 0, because it is the movement on the horizontal surface), under a=0;

\( F_{air} = 0.5 \cdot c_f \cdot \rho_{air} \cdot A \cdot V_{max}^2 \) – force of air resistance;

\( F_{in} = m \cdot a \cdot \sigma_r \) – resistance force to acceleration (force of inertia) under acceleration \( a \) and compensation factor of rotating masses.

So, formula (2) looks like this:

\[ \frac{\eta_r \cdot M \cdot i0 \cdot i1}{r} = f_k \cdot m \cdot g \cdot \cos \alpha + m \cdot g \cdot \sin \alpha + 0.5 \cdot c_f \cdot \rho_{air} \cdot A \cdot V_{max}^2 + m \cdot a \cdot \sigma_r \]

Based on formula (3), we get maximum torque for the electric motor:

\[ M = \frac{(f_k \cdot m \cdot g \cdot \cos \alpha + m \cdot g \cdot \sin \alpha + 0.5 \cdot c_f \cdot \rho_{air} \cdot A \cdot V_{max}^2 + m \cdot a \cdot \sigma_r) \cdot r}{\eta_r \cdot i0 \cdot i1} \]

Since there is no transmission in the electric racing car as well as in most standard electric cars [7], in formula (4) the gear ratio of main gear is equal to 1 and gear ratio is determined by selection from the electric motor electromechanical characteristic. The value of the driving wheel radius is equal to \( r = 0.25m \) [1].

In order to calculate the motor speed on the shaft under max. speed, we use the following formula:

\[ \omega = \frac{V_{max} \cdot i1}{r} \]

Changing gear ratio values of the reducer with the help of program MathCad, we get the values of desired quantities of maximum torque and angular velocity on the motor shaft (Fig. 1).
3. Choice of the traction motor

The analysis of traction motors with capacity up to 80 kW often used in electric racing car has shown the following results (Fig. 2). Emrax-207 electric motor of Enstroj Company has the most optimal characteristics. Moreover, we have discussed the versions of the traction drive of electric racing car and hybrid bolides for the teams including State Technical University—MADI team. For today this team has got two electric car with two direct current motors Lemco [8].

Emrax-207 motor of Enstroj Company is a synchronous alternating current motor with constant magnets. It is significant that the interest to such motors has been rising recently [9-13].
Table 2. Results of the calculation of the electrobolide dynamic factors with the use of EMRAX-207 motor.

<table>
<thead>
<tr>
<th>Preset characteristics of the electrobolide model</th>
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<tbody>
<tr>
<td>Mass of equipped car with a pilot, kg</td>
<td>Bolide max. speed, km per hour</td>
</tr>
<tr>
<td>300</td>
<td>125</td>
</tr>
</tbody>
</table>

Electric motor design parameters

<table>
<thead>
<tr>
<th>Motor peak capacity, kW</th>
<th>Rotor speed, rev. per minute</th>
<th>Maximum motor torque, Nm</th>
<th>Gear ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>6000</td>
<td>140</td>
<td>4.5</td>
</tr>
</tbody>
</table>

4. Conclusions

Thus, the comparison of the electric racing car dynamic factors of Moscow Automobile and Road Construction University team, where they use two commutator direct current motors, with the designed electric racing car with one synchronous commutator less motor on constant magnets shows that the use of synchronous motors on constant magnets as a traction motor is long-range development of electric racing car. In addition, the use of this type motors reduces loss and overflow in the cells of storage batteries due to power high voltage. However, for more true analysis of the use of the above electric motor in the racing car, it is necessary to do modeling in program Simulink that will allow to reduce the error during natural tests.

References