AUTOMOBILE TECHNICAL SOLUTIONS AND SELECTION OF PARAMETERS FOR REBUILDING INTO ELECTROMOBILE

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Abstract. Developing an electromobile or rebuilding it from an automobile with an internal combustion motor selection of its unit technical paramneters is very important. The article analyses the possibilities for rebuilding electromobiles, a calculation algorythm has been developed for selection of electromotor parameters. The main techni cal solutions are analysed based on the internal combustion automobile Renault Clio 1.2. For the automobile 30 kW alternate current electromotor and Lithium ion batteries have been selected. The planned technical characteristics: mileage with one charging at least 100 km, battery energy capacity 25 kWh, maximal speed 120 km·h^{-1}.

Keywords: rebuilding of automobiles, rebuilding parameters, electromotor capacity, speed, mileage.

Introduction

With the decreasing oil resources the issue on development of new industrially produced electromobiles as well as on rebuilding of internal combustion engine automobiles into electomobiles becomes more topical. Development of such individually built electomobiles has got wide application in the USA and starts to become popular also in the European countries and unavoidably also in Latvia. Although in Latvia at present there is no registration of official rebuilding of internal combustion engine automobiles into electomobiles there are a lot of enthusiasts in this field.

In order to rebuild internal combustion engine automobiles into electomobiles sevaral aspects should be considered. One of them is the needs of the clients related to the expected technical parameters. The main of these parameters are:

- maximal elctromobile speed;
- motor technical parameters – power, torque, rotation frequency;
- mileage with one charging depending on the battery capacity;
- automobile mass and carrying capacity, correct axle load.

Also the constructive aspects are important that are related to legalisation of the rebuilt electromobile for road traffic. For the rebuil construction the basic units have to be chosen that have the CE compliance certificate. The choice of only such units can ensure successful registration of reb uilt electromobiles in Latvia.

Further in the analysed calculation algorythm we will use dependencies on all kinds of resistances working on the automobile and the power curves gibven by the electromobile producers.

Calculation of electromobile parameters

In order to state the power for electromobile wheel drive the power balance for an automobile with mechanical transmission will be used [1]:

$$N_k = N_f + N_\alpha + N_w + N_j, \quad (1)$$

where N_f – power for overcoming of rolling resistance, kW;
N_α – power for overcoming upgrade resistance, kW;
N_w – power for overcoming air resistance, kW;
N_j – power for overcoming inertia resistance, kW.

The motor power is higher than the power for the wheels as there are losses in transmission. The motor power and the power for the wheels are related by correlation [1]:

$$N_k = N_e \eta_T, \quad (2)$$

where η_T – transmission efficiency coefficient.

Considering the efficiency coefficient the motor power is calculated according to the correlation [1]:

$$N_e = \frac{N_f + N_\alpha + N_w + N_j}{\eta_T}. \tag{3}$$

Splitting the necessary power for overcoming every kind of resistance the power for overcoming all kinds of resistance is obtained:

$$N_i = \left(fG_a \cos\alpha v + G_a \sin\alpha v + kFv^3 + m_a\left(1.04 + 0.0025 i_k{}^2 i_0{}^2\right) jv\right), \tag{4}$$

where f – automobile rolling resistance coefficient;
G_a – automobile weight, N;
α – road upgrade angle, in degrees;
v – automobile speed, km·h^{-1};
k – air resistance coefficient;
F – automobile forehead area, m^2;
m_a – automobile mass, kg;
i_k – gear box gear number;
i_0 – gear box gear number;
j – automobile acceleration, m·s^{-1}.

Automobile movement speed can be calculated according to correlation [2; 3]:

$$v_{teor} = 0.10472 \frac{n_e r_k}{i_T} \tag{5}$$

where n_e – electromotor revolution frequency, min^{-1};
r_k – wheel kinematic radius, m;
i_T – transmission gear number.

Transmission gear number is calculated according to correlation:

$$i_T = i_k \cdot i_0, \tag{6}$$

The automobile moving speed changes depending on the chosen gear. For electromobiles due to the efficient torque and power characteristic curves not always all gears are necessary, though choosing the parameters it is useful to analyse movement in all gears.

Inserting the correlation 5 in the expression 4 we get

$$N_i = 0.10472 \frac{n_e r_k}{i_T} \left(fG_a \cos\alpha + G_a \sin\alpha + 0.011 kF \left(\frac{n_e r_k}{i_T} \right)^2 + m_a\left(1.04 + 0.0025 i_k{}^2 i_0{}^2\right) j \right) \tag{7}$$

When the automobile has reached the maximal speed it moves evenly without acceleration, due to this the part of the correlation 7 that characterises the power necessary for overcoming the inertia resistance will be equal to 0 and:

$$N_i = 0.10472 \frac{n_e r_k}{i_T} \left(fG_a \cos\alpha + G_a \sin\alpha + 0.011 kF \left(\frac{n_e r_k}{i_T} \right)^2 \right) \tag{8}$$

Most of automobile rotating components, such as power steering pump, air condition compressor and heater fan are powered by internal combustion engine, in the direct or indirect way. Direct drive uses mechanical link, for instance, belt to connect power steering pump or air condition compressor pulley to engine crankshaft pulley. Indirect drive is realized by using alternator, which creates electrical power, and electrical motor for powering mechanical components, for instance, windscreen wipers or heater fan. In case of the electrical vehicle, all such components will not be powered directly from electrical motor. Necessary amount of energy will be drawn from electrical batteries. It means that batteries will be loaded additionally. Energy, used to supply additional components of electrical vehicle can be calculated as follows:

$$N_{Ag} = N_{St} + N_{Br} + N_{Kl} + N_{Apg} + N_i , \qquad (9)$$

where N_{St} – power necessary for the driving steering booster, kW;
N_{Br} – power consumed for driving the electric brake vacuum pump, kW;
N_{Kl} – power necessary for the system ensuring the climate in the salon, kW;
N_{Apg} – power necessary for the lighting system, kW;
N_i – power necessary for other electrically driven systems, kW.

In order to determine the electromobile maximal speed with the corresponding resistance parameters it is advisable to choose at least 2 movement conditions. In the first case the planned easiest operation conditions can be considered at which the maximal speed will be achieved, for instance, for the case when the road resistance coefficient $\psi = 0.015$ [2; 4] that characterises asphalt concrete road cover in good condition. In the second case hard movement conditions can be considered when the road resistance coefficient is $\psi = 0.1$ [2; 4] that corresponds to movement on naturally trodden road. In that case maximal movement speeds will be obtained for both conditions and it will be possible to choose the corresponding gearbox gears. Other gears can be dismounted from the gearbox to decrease the influence of the gearbox mass and rotating mass.

Calculating the possible electromobile mileage the electromotor efficiency coefficient is very essential. With the electromotor operating depending on the rotation frequency in the mechanical rotation energy it can transform different amounts of energy that are characterized by the efficiency coefficient. In literature several algorithms can be found how to calculate the electromotor efficiency coefficients, but in practice it is easier to use definite motor characteristic curves that can be obtained in the electromotor specifications. This way it is possible to determine what automobile characterizing indices can be obtained with electromotors of different capacity. Simplified scheme of calculation algorithm is shown in Fig. 1.

An automobile with the average driving speed v_{vid} can cover a definite distance s in corresponding movement time. In this case the movement time or the time for discharging of the batteries can be determined according to correlation:

$$t_{iz} = \frac{s}{v_{vid}} , \qquad (10)$$

where s – desired mileage of electromobile, km;
v_{vid} – average movement speed of electromobile, km·h^{-1}.

The average movement speed can be calculated according to correlation:

$$v_{vid} = k_v v_{piel} , \qquad (11)$$

where k_v – driving speed correlation coefficient that evaluates the movement regime;
v_{piel} – permissible average movement speed mentioned in road traffic regulations.

In cities in the Republic of Latvia $v_{piel} = 50$ km·h^{-1}, but in traffic outside cities $v_{piel} = 90$ km·h^{-1}. The driving speed correlation coefficient shows by what the average driving speed is lower than the permissible. This coefficient can be assumed for city traffic $k_v = 0.5 – 0.7$, but in traffic outside cities $k_v = 0.7 – 0.9$.

The current consumed by the electromotor and other electric units in a definite moment of movement is calculated according to correlation:

$$I = \frac{N_{el} + N_{Ag}}{1000U} , \qquad (12)$$

where N_{el} – electromotor average momentary power, kW;
U – voltage fed to electromotor, V.

The battery theoretical capacity, Ah, considering the electromotor efficiency coefficient is calculated according to correlation:

$$C_{ak} = \frac{t_{iz} \cdot I}{3.6 \cdot 10^3} \tag{13}$$

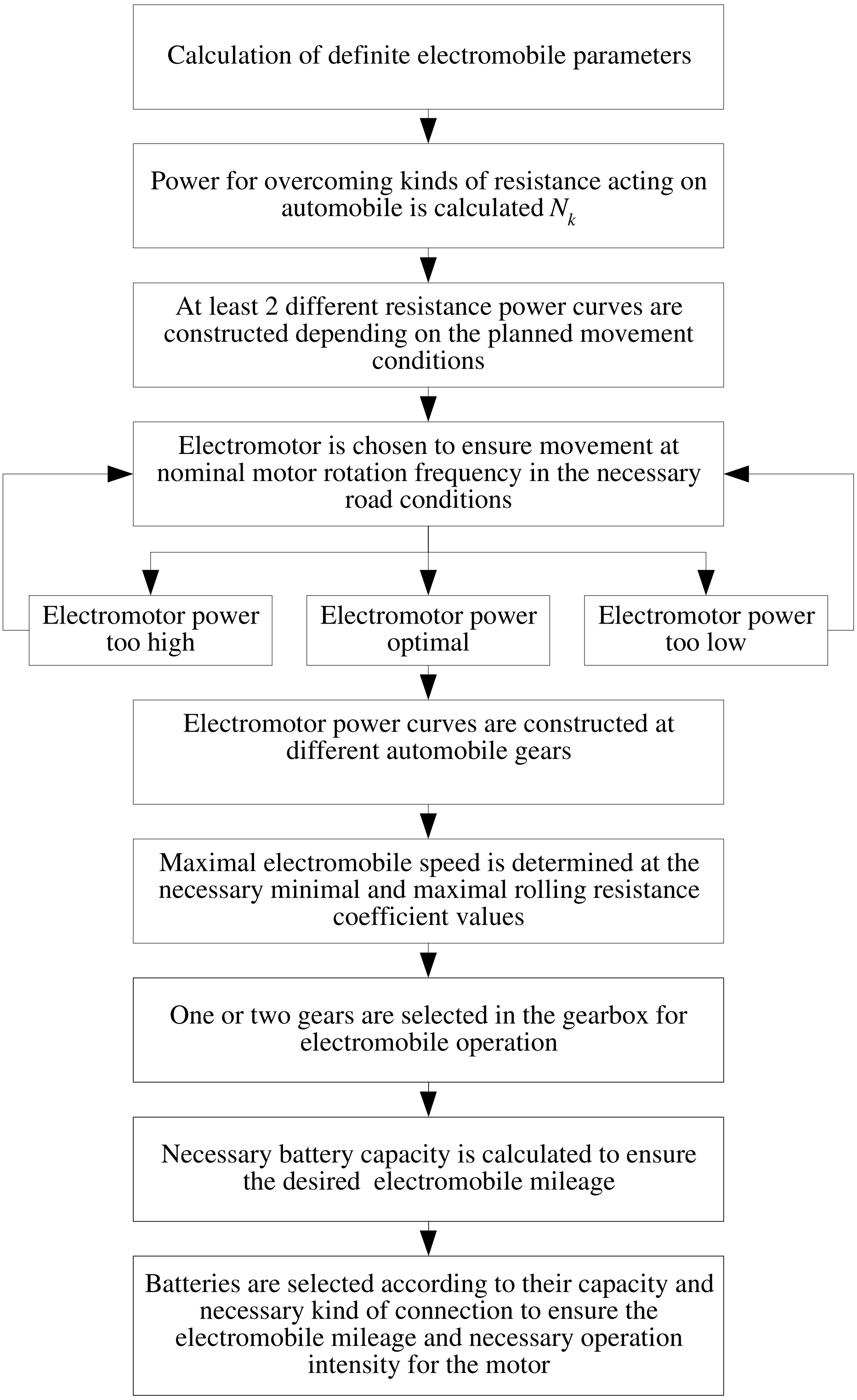

Fig. 1. **Simplified scheme of calculation algorithm**

Results and discussion

In order to analyse more deeply the calculation algorithm should be verified. It is done using the technical data and parameters of the automobile Renault Clio. The technical data necessary for Renault Clio calculations:

- m_a = 1425 kg;
- k = 0.23;
- body-size width B = 1.377 m, body-size height H = 1.417 m, forehead area F = 1.58 m^2;
- tyres 165/70R 14, r_k = 0.283 m;
- gear numbers i_I = 3.364; i_{II} = 1.864; i_{III} = 1.321; i_{IV} = 1.029; i_V = 0.821; i_0 = 4.067.

The power graph of the electromotor used in the calculations (AC induction motor M2-AC25/4-A/L) [5] is shown in Fig. 2. The nominal power of electromotor M2-AC25/4-A/L is 25 kW at 5500 min^{-1}. Doing calculations the transmission efficiency coefficient η_T should be considered, a part of the electromotor power is used for operation of transmission units. Due to this the power driven to the wheels N_k will be lower.

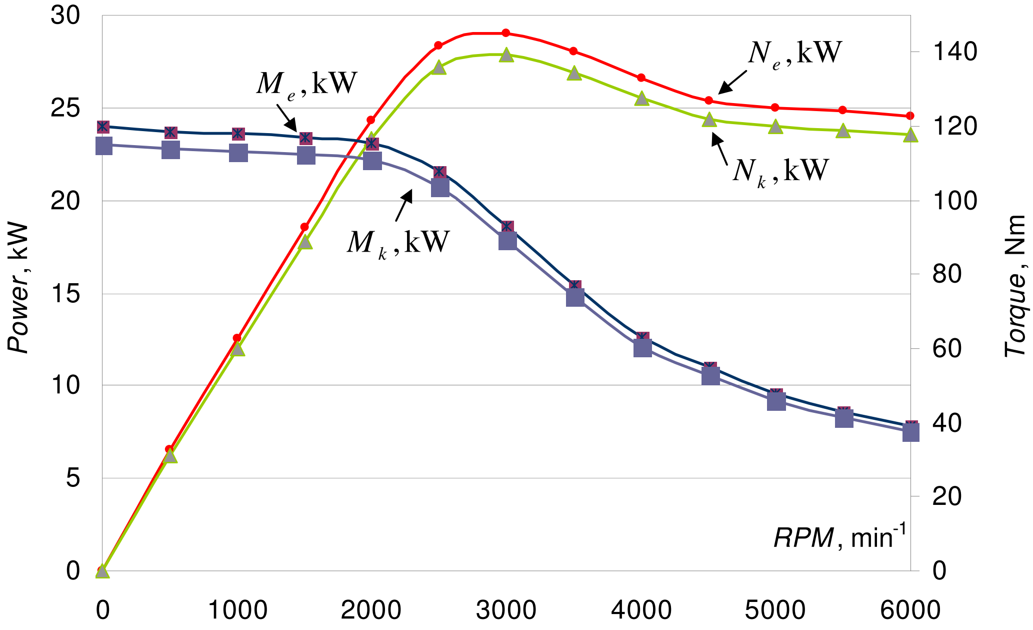

Fig. 2. **Primarily selected electromotor characteristic curves:**
AC induction motor M2-AC25/4-A/L

For calculations two rolling resistance coefficients are assumed f_1 = 0.015 and f_2 = 0.1. Calculations are done also for the third case when the automobile will move along a good quality asphalt concrete cover with f_1 and ascend with 5° upgrade angle. In calculations for ensuring uniform movement of the automobile correlation 8 is used. Calculating the power driven to the wheels according to correlation 2 the transmission efficiency coefficient is considered that is assumed to be η_T = 0.96. As a result of the calculation s the graph in Fig. 3 has been developed.

In Fig. 3 it can be seen that moving along a horizontal good quality road with gear 4 or 5 it is possible to develop the maximal speed ~130 km·h^{-1}. In the first gear the maximal movement speed is 46 km·h^{-1}, in the second gear – 84 km·h^{-1}, but in the third gear – 119 km·h^{-1}. Depending on what the desired maximal speed is, it is possible to select the most appropriate gear. In order to ensure the necessary maximal speed for the Latvian conditions, it is possible to choose the geras 3, 4 or 5 depending on whether the automobile is planned to be used in the city or in traffic outside cities. Choosing a lower gera we will get better dynamic characteristics at low and average movement speeds, but lose at the maximal speed (120 km·h^{-1}). Selecting the highest gear we will get higher possible maximal speed as well as improved dynamic characteristics of the automobile at the maximal speed.

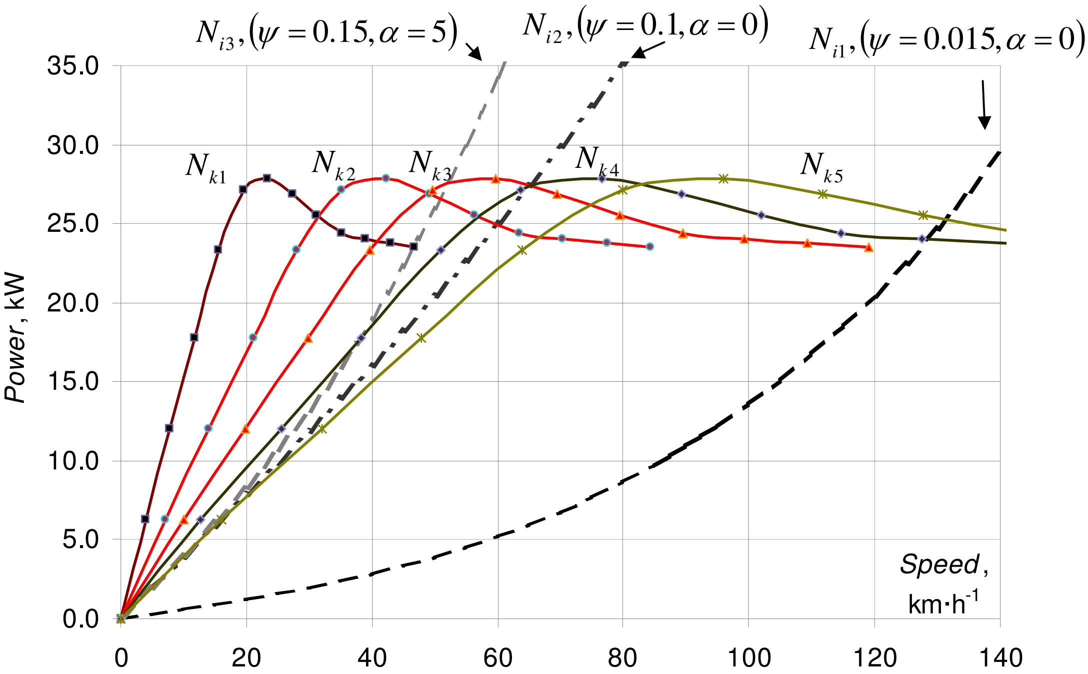

Fig. 3. **Automobile power balance**

Nevertheless, considering that in the Latvian condiotions there are also many hilly areas as well as lower quality road coverage it should be forseen that for driving along these roads the most part of the power developed by the motor will be consumed. It can be seen in Fig. 3 that with the gear 5 it is not possible to drive along low quality roads with high road resistance coefficient ($\psi = 0.1$), in turn, with the gears 3 and 4 it is possible to drive but the maximal speed possible to be developed will be ~66 km·h^{-1}. Selecting the gear 3 in this situation we will get better automobile dynamic characteristics.

Considering that the automobile will have to ascend up to 5º, also the gear 4 is not exactly appropriate. In this gear the automobile dynamic characteristics are very limited as well as the maximal mov ement speed does not exceed ~36 km·h^{-1} at higher road resistances.

Due to the above con siderations, for the automobile to show good dynamic characteristics on low quality roads and upgrades as well as to develop the necessary maximal speed and dynamics at high speed, it is useful to select a gearbox with two gears. In this definite case it is efficient to select the gears 2 and 4. The gear 2 will ensure the automobile movement possibilities on upgrades that exceed 5º, but the gear 4 will ensure a possibility to drive with higher speed at the same time maqintaining good dynamic characteristics at average and high speed.

Besides the above mentioned, it must be considered that the power developed by the electromotor and with it also the dynamic characteristics depend on the battery discharging level. At larger electromobile mileage and more empty batteries the dynamics of the automobile will worsen.

In case if the car owner need electromobile only for usage in city conditions, it is possible to choose an electromotor with lower power, for instance, 10 – 15 kW. In this case the electromobile maximal movement speed will not excede 80 km·h^{-1}, but a smaller number of batteries will be possible to choose this way decreasing the electromobile mass and rebuilding costs.

Conclusions

1. The elaborated electromobile motor selection algorithm has been verified with calculations and approved as able to operate.
2. The input parameters necessary for calculations c an be found in the technical data of definite automobiles and electromotor power curves at the producers ar dealers of these components.
3. The electromotor selection algorithm can be corrected and specified after actual rebuilding of the definite electromobile and experimental investigation.

4. For the chosen prototype Renault Clio it is optimal to choose the gears 2 and 4 driving it with the speed up to 100 $km \cdot h^{-1}$. In case if the automobile is planned for operation also at higher speeds the gears 3 and 4 can be selected.
5. To simplify the construction the gearbox can be disassembled and the non-used gear couples can be dismounted. This way it is possible to reduce the influence of the revolving masses in the process of acceleration and increase the transmission efficiency coefficient.
6. In the planned construction it is possible not to use the standard clutch and flywheel so decreasing the revolving masses.
7. In separate operation cases also usage of the investigated prototype only with one gear, for instance, the gear 3, is possible. In this case the total gearbox mass and the inertial masses decrease.

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References

1. Pommers J., Liberts G. Theory of automobiles. Riga: Zvaigzne, 1985. 248 p.
2. Berjoza D. Theory of automobiles. Methodic guidelines for development course paper, objectives and lecture notes. Jelgava: LLU, 2007. – 54 p
3. Berjoza D. Theory of automobile. Jelgava: LLU, 2008. – 200 p.
4. Automotive Handbook 7th Edition. Robert Bosch GmbH, July 2007. 1196 p. ISBN 978-0-470-51936-3.
5. AC Induction Motor M2-AC25/4-A/L [online] [12.03.2012]. Available at: http://www.electro-vehicles.eu/public/file/Motore_25kw.pdf