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To cite this article: E V Belousov *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **537** 062086

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Differential twin-engine automobile electric drive

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Abstract. This article considers work stability of a system with two-channel regulation of an autonomous electric drive's speed, where the first channel is a high-torque drive, where the engine is connected through a gear unit with reducing transfer factor; and the second – high-speed with the similar motor is directly connected. The power summation is realized by using the differential gear unit. It is shown that the stable work can be achieved by a fixation of a speed setting through one channel, and the regulation through the other channel at the same time; control algorithms are shown. Optimal values of transmission ratio of high-torque drive gear unit $j=4$ are defined, as well as a turn-on factor (rate of participation in transient process) of high-torque motor with its transient process time minimum.

1. Introduction

Autonomous (pilotless) electric transport development is a global trend. New demands determined by traffic safety have been made on tractive automobile properties. Electric drive has to provide required speeding-up, braking intensity and flexibility. The most promising variant of automobile electrical device is twin-engine electric drive, as it was shown in [1].

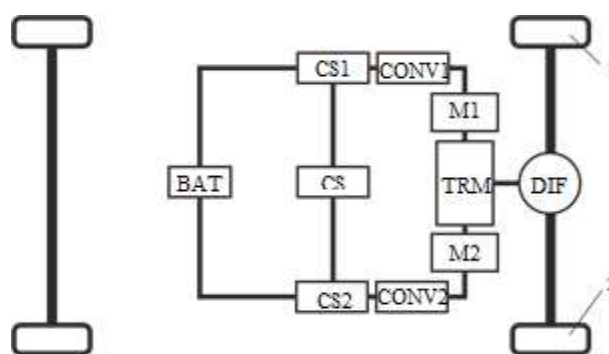


Figure 1. Electric vehicle twin-engine electric drive system.

The developers of modern electric vehicles are faced with three main problems: the first is the increase of the battery charge, the second is the increment in the vehicle's power reserve in one charge cycle, and the third is the growth in vehicle performance, often due to the safety requirements. Sometimes a fourth task is identified - an increase in the charge rate of an electric vehicle, but the solution to this problem lies in the area of improving the converter equipment and is solved by the manufacturers of charging devices.

Battery charge increases are achieved both in the course of improving their work at the level of physical and chemical processes, and by optimizing loads, in particular, depending on the environment's temperature.

The search for a solution to the second task - increment the power reserve within a single charge cycle is carried out both in the direction of improving the specific indicators of autonomous power sources and in the direction of improving the energy efficiency of the traction electric drive. In this case, the vehicle has high requirements for the dynamics of acceleration and ensuring a high maximum speed. Obviously, the second and third tasks can be solved only together.

In other words, it is required that the electric drive, working with maximum efficiency, ensure high torque both during acceleration and at high speed in the process of movement. This circumstance is due to security considerations, as it was already mentioned above. For example, highway, a driver is committing an overtaking maneuver while going on a highway, it is important to ensure fast acceleration at high speed (for example, from 90 to 130 km / h in 2 seconds).

Traditionally, this problem is solved by using a gearbox with a variable gear ratio (gearbox) instead of using the engine. The internal combustion engine is able to provide high acceleration at low gears to high speeds (the engine achieves speeds of up to $3n_n$ without a significant reduction in torque). However, the electric motor, as a rule, operates in a narrower range of speeds. Providing a speed higher than the nominal speed leads to a significant reduction in torque. Therefore, this solution is not able to provide rapid acceleration of an electric vehicle traveling on high speed.

The implementation of a two-motor electric drive (Figure 1), which sets the working unit in motion through mechanical transmission with different gear ratios via the channels "Motor 1 - Working Body" and "Motor 2 - Working Body", will ensure high acceleration dynamics when a single motor is running and high speed - at work second. In fig. 1 schematically shows an autonomous vehicle, the energy source for the movement of which is the battery of the battery. In general, motors 1 and 2 are asynchronous motors, which are powered through converters 1 and 2. The motion control system controls the coordinates of the drives through the corresponding control systems CS1 and CS2. It is important to note that motors 1 and 2 do not drive the wheels 1 and 2 separately. Both motors through the transmission and differential drive the wheel set. Details of this drive are described in [2].

M, Nm

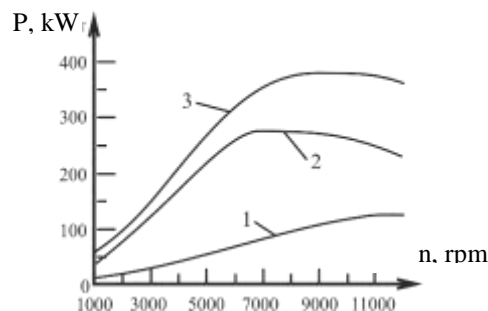
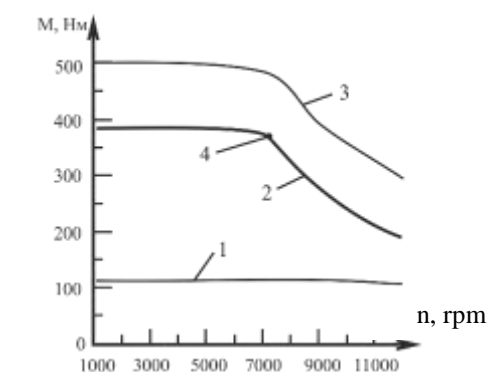


Figure 2. Static k characteristics of the torque and power 1 - the first motor, 2 - the second motor, 3 - the electric drive when two motor s work together; 4 - rated operating mode of the second motor.

It should be noted a number of advantages of such a solution. Firstly, the efficiency of the electric drive increases significantly, since each motor operates in a mode close to the nominal one. Secondly, the driving safety increases, since the use of motors with a smaller M_n leads to a decrease in the height of the axis of their rotation, which in turn helps to improve the mass distribution and increase the stability of the car during cornering.

Finally, thirdly, the use of a two-motor electric drive allows one to significantly expand the possibilities of its operation, both in the speed range and in the torque range (Figure 2). Curves 1 and 2 are optimal torque and power curves for motors 1 and 2, respectively. Curves 3 are optimal torque and power curves for a twin-motor drive. Point 4 corresponds to the nominal mode of operation of the second motor. It can be seen from the figure that the torque of the first motor is constant over the entire range of work, its power increases linearly as a function of speed. This approach allows you to compensate for the drop in torque at high speeds, characteristic of motors with limited operating voltage.

The usage of two motors, which set the front and rear axis of all-wheel automobile in motion, makes it more flexible. Meanwhile the reliability of the whole electrical device is increasing – there is an opportunity to continue motion if one of the motors is broken. Finally, energy performance of the electrical device can be reduced integrally, so each motor works in a mode close to nominal, because of the wheel axis motion made by gear units with different gear ratio.

Power summation of two motors can be provided, for example, by a differential gear unit, which is defined as a gearwheel, connecting rotary motion around Long axis with rotary motion around two axes. Thus, the transmission has three rotary degrees of freedom [3]:

$$\omega_b = \frac{1}{2}g(\omega_1 + \omega_2) \quad (1)$$

where ω_1 – angular velocity of the first motor, ω_2 – angular velocity of the second motor; g – gear-ratio of mechanical differential.

The output power equals the input shaft sum of power:

$$\omega_b M_{sh} = \omega_1 M_1 + \omega_2 M_2 \quad (2)$$

where M_{sh} - torque at the output shaft of mechanical differential, M_1 – torque at the first input shaft, M_2 - torque at the second input shaft [4].

If (2) is put in (1), it is an equation, defining power distribution at differential transfer:

$$M_B g = \frac{2(\omega_1 M_1 + \omega_2 M_2)}{\omega_1 + \omega_2} \quad (3)$$

Regulation stability is a serious problem, as it is shown in (3) – the torque at the output shaft depends on four variables. While two torque control loops work at the same time, each of them cannot provide stable system during load-on or during sharp increase of velocity signal [5].

2. Materials and methods

Thus, during overtake realization (high speeding up) and high speed motion it is necessary to fix the current speed of the working “high speed” motor; and to provide speed control only at a “high-torque” motor’s channel. During racing rate reduce it is necessary to fix “high-torque” motor speed and to return the control over the channel with “high speed” motor [6].

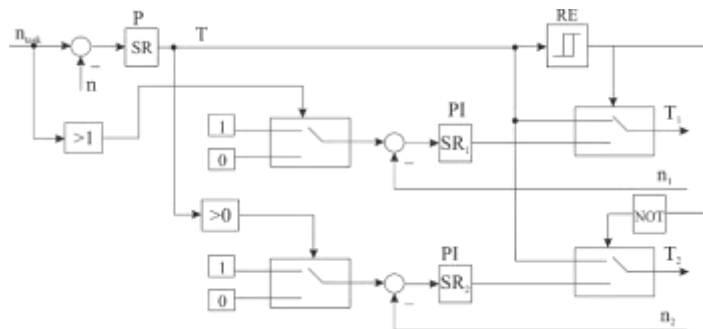


Figure 3. Functional scheme of task signal formation onto torque of motor at twin-engine system of tractive electric drive.

This approach can be used for other operating modes. Stable system can be provided, only if one of the channels is working in the fixed speed maintaining mode, and the final speed control goes in another channel. The channel of selecting control depends on required racing intensity. Besides, it is useful to switch the control onto another channel during saturation by speed of one of the channels, which is in “high-torque” channel. The objective of this article is the search of an optimal switching torque.

Functional scheme of task signal formation onto torque of motor at twin-engine system of traction electric drive, is shown in Fig.3, its mathematic model is described at [7] in details. In Figure 3 T_1 – task signal at a torque of “high-torque” channel, where the motor is connected with differential gear unit through ordinary gear unit with gear ratio j . T_2 – task signal at “high-speed” channel torque, where the motor is connected directly with differential gear unit. At every time moment speed control at task signal function is realized only by one of channels – task signal at T moment, which is coming from speed regulator SR , is fed to drive. Meanwhile motor speed in another channel is fixed and equals “0” or “1” (in question of relative units. While $n=1$, $n=n_{nl}$, where n_{nl} - no-load speed). At fixed speed of one of the channels, task signal at this channel torque is coming from regulator SR_1 in the case of first motor and from SR_2 in the second case. The basic thing is using PI-speed regulators SR_1 and SR_2 , so that the high accuracy of going to a fixed speed in each of channels influences the overshoot absence, and the work correctness. P-regulator with the gain factor k_{SR} can be used as a speed regulator SR [8, 9].

The switching between channels of signal M injection is realized by relay element RE . When $T > k_p(n_{task} - n)k_{SR}$, RE output signal equals “1”, $T_1 = T$. Here k_p – turn-on factor of “hightorque” motor while transfer process. When $T < k_n(n_{task} - n)k_{RS}$, RE output signal equals 0 and the task signal T_1 is the regulator SR_1 output signal, and the $T_2 = T$. Simultaneous inject of task signal T for both of channels is impossible.

Fixed speed choosing of the first and second channels drives can be different. For the first channel with “high-torque” motor, speed will be fixed at perfect idling speed.

Fixed speed of the second channel “high-torque” motor is determined by T signal: when the signal is positive it is 1, when it is negative or zero – 0. Speed oscillograms while researching this scheme on mathematic model *Matlab- Simulink* [10].

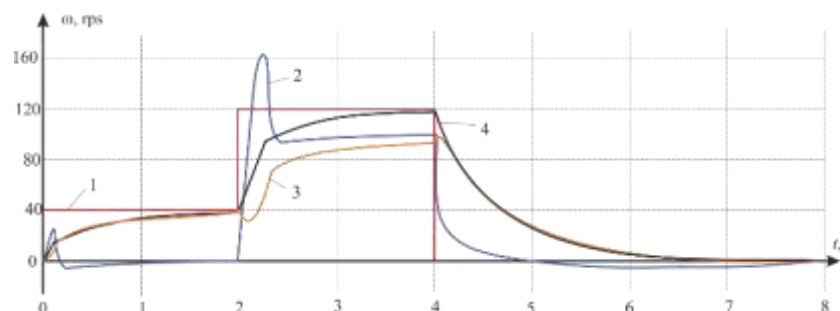


Figure 4. Speed oscillograms (2) – “high-torque” motor, connected with differential gear unit by transfer from $j=4$; (3) – “high-torque” motor, connected directly with differential gear unit; (4) – output shaft of differential gear unit and (1) – velocity signal; at $k_p=0,3$.

As it is shown in Figure 4, during the injection of velocity signal, which is less than 1 (section 0-2 s), at the first time moment the regulation goes by channel 1 with “high-torque” motor, “high-speed” motor speed is recorded at 1. Then the first motor switches off, and regulation goes by “high-speed” drive [11].

At the second section (2-4 s) the task signal is more than 1. This mode permits to simulate an intensive racing mode during speed motion. In this case “high-speed” motor task signal equals 1. “High-torque” motor switches on at the first moment, and after that it continues to work at speed and equals 1.

At the third section (4-8 s) braking mode is imitated. In this case “high-torque” motor task signal resets and the braking process is organized by high-speed motor. There is a variant, when high-torque motor begins reverse rotation at the start of braking, braking tempo is increasing by that. It is enough to give a signal T onto RE input, which is taken by a module. In other words, speed regulation by the first high-torque motor with a second channel fixed speed can be carried out when $T < -k_P(n_{task} - n)k_{RS}$, and also when $T > k_P(n_{task} - n)k_{RS}$. But the set up of the scheme gets complicated with this algorithm because of the overshooting at the second channel [12].

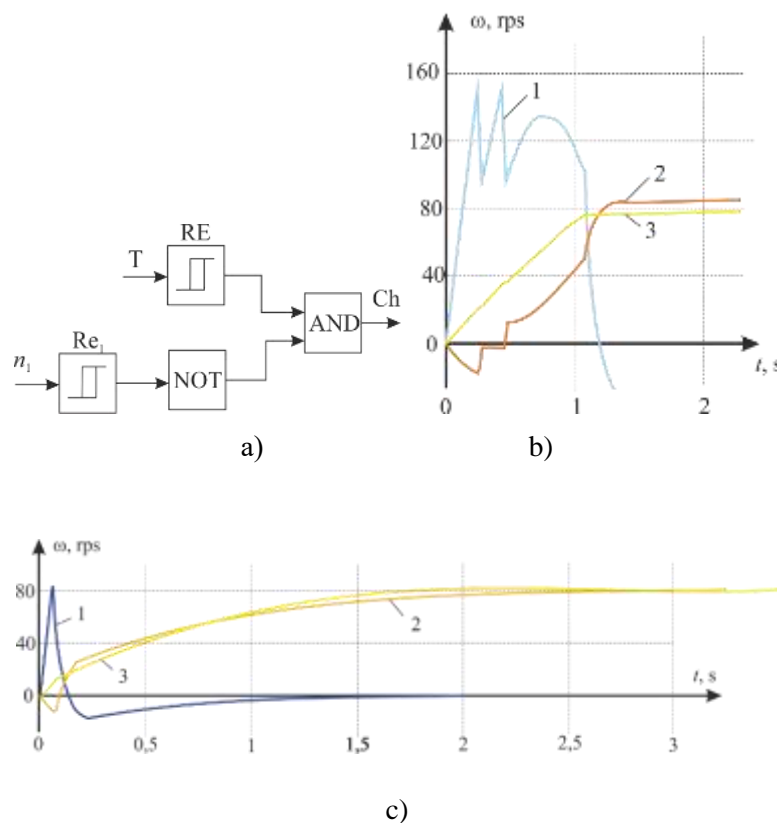


Figure 5. a) – functional scheme of velocity signal limit of high-torque motor and speed oscillograms of the first motor (1), second motor (2) and differential gear unit output shaft (3) while racing mostly at high-torque drive b) and mostly at high-speed motor (c).

Oscillograms shown in Figure 4 demonstrate working principle with no limits. But while seeking for optimal moment of regulation switching between channels in this model one should take into account an opportunity of saturation of high-torque motor by speed. For searching working scheme modes, when velocity signal of high-torque motor does not exceed 1,5 speed of perfect idle, it is necessary to enter additional elements into the model [13].

Structural scheme of velocity signal limitation is shown in Figure 5 a. Here Ch is a signal of selecting a channel of control equals 1 (i.e. control goes by a channel with high-torque drive) if only the signal

equals 1 at the RE output, and at the RE₁ it equals 0. RE 1 is activated while the motor speed n_1 exceeds the speed which is 1.5 of flitting speed and is switched off when it equals $0.95 n_{nl}$ [14].

3. Results and discussion

Oscillograms of selection extreme case k_P and j where racing goes most of the time only during control at one of the channels are shown in Figure 5 b, c. If k_P and j vary, the minimum of transfer process time is available (the dependence is shown in Figure 6).

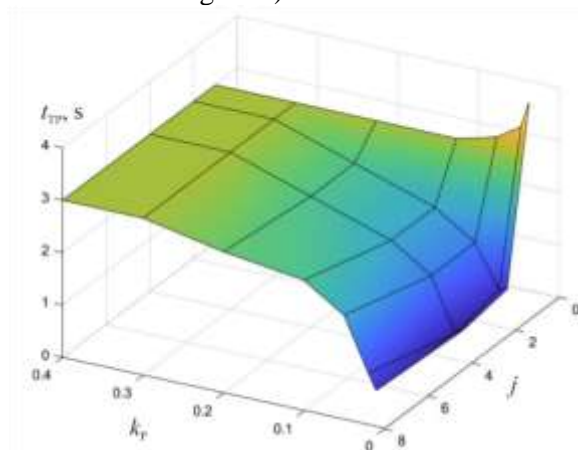


Figure 6. The dependence of transfer process time t_m on gear ratio “high torque” drive reducer j and turn-on-ratio of “high torque” motor k_P .

When $j=1$, the effect of the second motor usage levels, irrespective of its work part, transfer process time is not reduced, and even increases during short-time switching on. When $j=8$, time of transfer process is higher in comparison to $j=4$ and $j=2$. This happens because of “high-torque” drive fast saturation by speed. It was expected that while reducing k_P , factor which is responsible for switching “high-torque” motor on in dependence of $(n-n_{task})$, transfer process time is also getting reduced because the high-torque motor is working most of the time. But reducing k_P to values less than 0.01 does not result in the reducing of transfer process time. This happens due to overshooting processes during switching regulation at high-speed motor. Minimal transfer process time is at $j=4$, $k_P=0.02$. But notably there are some cases with non-standard proportion of motor inertia moment and reduced inertia moment of movable object J_{D1} , J_{D2} and J_{WB} when the optimum point can shift, where J_{D1} , J_{D2} – moments of inertia of drives 1 and 2, J_{WB} – moment of inertia of the working body.

4. Conclusion

Simplified mathematic model, presented in this article, demonstrates potentialities of using a two-channel drive at autonomous transport vehicles. Work combination of two drives makes it possible to reduce transfer process time compared to single-engine electrical installation, especially during high-speed racing.

These results suggest that developed methods allow us to achieve stable work of a twin-engine electric drive. Optimization of switch moment between two engines conducted in a view of an optimal reducer gear-ratio of «high-torque» engine allowed us to minimize transfer process time of automobile racing.

Further, the author is going to specify the mathematic model of each of the two asynchronous motors in order to enhance regulation capability – individual torque task and flow for each of the motors will make it possible to increase drive effectiveness, thus it will be possible to work in the field reduction mode.

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