ACCOUNTING FOR LIMITATIONS OF LONGITUDINAL DYNAMICS IN REGULATION OF ELECTRIC TRAIN STARTUP MODE

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ABSTRACT

Application of non-contact soft regulation for electric train requires control of traction drive taking into account the restrictions on longitudinal dynamics, i.e. the intensity of increase in traction of train's acceleration when it starts moving. This task is solved in a control system using a master element that implements restrictions on the intensity of acceleration growth. A block diagram is shown that provides the implementation of this criterion on digital elements.

Keywords: railway, longitudinal dynamics, startup mode, electric train, traction drive.

Background. *In automation of traction drives of passenger electric rolling stock it is necessary to consider a criterion for the effects of acceleration and deceleration of the train on passengers. This is especially important for motor-car electric commuter trains and subway trains, as here a clear trend to decrease dead weight of cars and to increase the power of traction motors has been formed. Under operation mode it is possible to observe an increase in cars' filling with passengers, but at the same there is an increase in uneven filling along the length of a train, which can be taken into account by weight sensors (auto mode) mounted on each bogie.*

Objective. *The objective of the authors is to investigate limitations of longitudinal dynamics, applicable to regulation of electric train startup mode.*

Methods. *The authors use comparative method, analysis, diagram construction, evaluation approach.*

Results. *The essential point in the regulation of electric trains is provision of synchronous operation of motor cars. This occurs in case of minimum longitudinal forces* F_A *in an automatic coupler of a train, which corresponds to the criterion*

$F_{Amax} \rightarrow min(0<t<t_p)$ (1)

where t_p *is duration of transition process.*

It is possible to introduce an integral criterion

$$\int_0^{t_p} F_A(t)dt \rightarrow \min .$$

And in case of perfect synchronization both criteria become zero.

At step regulation [1] perfect synchronization is impossible. In modulating control, it is possible to debug a system of synchronous control of motor cars in such a way that each of these criteria tends to zero. Let's consider it using as an example motor-wagon train, the cars of which because of different filling with passengers have different masses M_1, M_2, ...M_N. *Then using auto mode devices it is possible to set for each car individual settings of starting or braking current* I_{31}, I_{32}, ...I_{3N}, *proportional to the mass of the car. If each car is not moving in the train, but on its own, we get longitudinal acceleration for it*

$$a_i = \frac{F_{3I} - W_I}{M_I(1+\gamma)}, \quad (2)$$

where F_{3I} *is traction force, corresponding to the current* I_{3I}; W_I *is resistance to motion;* γ *is inertia coefficient of rotating masses.*

As for electric trains $F_{3I} >> W_I$ *and* $F_{3I} \cong I_{3I}$, *then on the basis of (2) we get an equation of cars' acceleration*

$a_1=a_2=...=a_n$, (3)

that is equivalent to the minimization, i.e. both criteria introduced above, which in this case are consistent, are equal to zero. From (3) it follows that, since cars, not coupled with each other, move with the same longitudinal accelerations, then in the train the same mode will be provided, i.e. with the same acceleration forces in their automatic couplers will be zero.

Minimization of introduced criteria is provided in the quasi-stationary mode of constant current in the motor when

$I_1=I_{31}$; $I_2=I_{32}$;...; $I_n=I_{3n}$,

which should be ensured also in transient modes of changes in traction and braking forces, most characteristic of which is the switch-on mode of traction motors when a train start moving with a subsequent transition to the steady mode $I_i=I_{3i}$ *[2]. System analysis shows that there are three types of transition curves to the specified value of the current (Pic. 1a), with an exponential current rise (Pic.1b), linear rise and smoothing the transition to the quasi-steady mode exponentially (Pic.1c).*

Linear current change is characterized by constancy of derivative $\frac{di}{dt}$, *and hence,* $\frac{dF}{dt}$, *which is equivalent to constancy of intensity of acceleration rise. The minimum allowable time of transition to the given current is equal to*

$$\Delta t_{OA} \cong \frac{F}{Mh} = \frac{a_s}{h}, \quad (4)$$

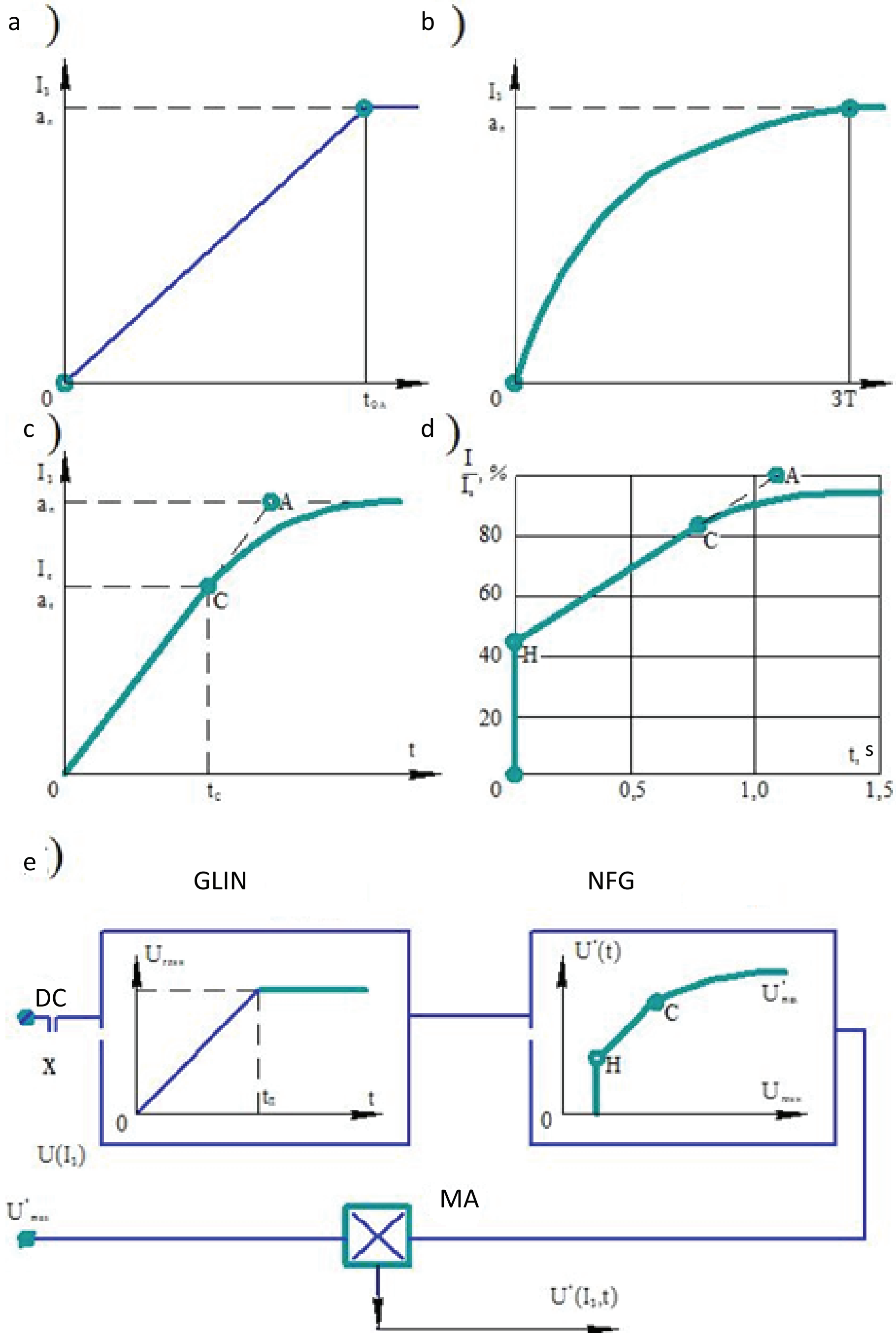
where a_s *is startup acceleration of a train (usually 0,8-1,2* m/s^2*);*

h is maximum permissible value of intensity of acceleration change, and

$h \leq (0,5 \div 0,7)$ m/s^3. (5)

The disadvantage of a linear law is a sharp transition to a quasi-stationary mode at point A, where $\frac{dh}{dt} = \infty$. *At the same time in a number of works on the longitudinal dynamics it is proposed to normalize the second derivative of acceleration, restricting its limiting value:*

$$h' = \frac{dh}{dt} \leq (1 \div 1,5)\ m/s^4. \quad (6)$$



Pic. 1. The curves of a given transition process of current control, where a, b, c – linear, exponential and combined laws of changes in the current; d – a curve of change in current for electric train ED6; e – a device to generate a given curve of change in current.

This is possible with an exponential current rise

$$I(t) = I_3(1 - e^{-\frac{t}{T}}) . \qquad (7)$$

Thus the time constant T of the exponential function can be determined from a condition

$$T \geq \frac{I_3}{M_h} \cdot \frac{dF}{dI_0} . \qquad (8)$$

Although the transition to a quasi-stationary mode is performed smoothly, the disadvantage of an exponential law is manifested in the very long duration of the transition process, which is ceteris paribus approximately 3-fold greater than with the linear law. The disadvantage can be eliminated with the use of combined law (Pic.1c), which at the initial stage of the transition process is linear, and at the final – exponential. To determine the coordinates of the coupling point t_C and constant exponential function we will use the condition (5) and (6), resulting in a system of equations which solution gives

$$\begin{cases} a_C = a_{\Pi} - \dfrac{h^2}{h^{'}} \\ T = \dfrac{h}{h^{'}}. \end{cases} \qquad (9)$$

Thus, the transition curve of Pic.1c with the parameters of expression (9) should be used as a given curve of the transition process, implemented by a system of auto regulation of a motor car. With its implementation using the power actuator – autonomous inverter or pulse converter we encounter difficulty in regulation of current in the initial moment, since usually power converters are limited in the lower range of voltage control (about 4%).

However, there is no need for regulation of traction from the ground up, because when an electric train starts moving with pulse control initial step of traction force and acceleration can be admitted, roughly corresponding to the shunting position of an electric train with contactor- rheostat control.

Therefore, we can assume the initial acceleration step

$$a_0 = (0,2 \div 0,25) \text{ м/s}^2, \qquad (10)$$

which corresponds to the initial traction force of a motor car

$$F_0 = M(1+\gamma)a_0 + W_0 \approx M(1+\gamma)a_0. \qquad (11)$$

Taking this into account given curve of the transition process takes the form of Pic.1d, and its parameters can be calculated by the formula

$$\begin{cases} T = \dfrac{h}{h^{'}} \\ I_c = I_3 - \dfrac{hTM(1+\gamma)}{\dfrac{dF}{dI}} \\ t_c = \dfrac{\dfrac{dF}{dI}\left(I_3 - I_O\right) - hTM(1+\gamma)}{h'TM(1+\gamma)} \end{cases}. \qquad (12)$$

Pic. 1d shows this curve, calculated for the electric train ED6.

When using curves of the considered type in any moment of the transition process proportionality of traction force values of certain motor cars remains to their masses, due to which in transient conditions the implementation of synchronization is achieved. That is, in transient modes of synchronization regulation of cars' control is provided by selecting the same duration of transition to a quasi-stationary mode. From the condition of similarity of transition processes times in all train cars, it follows that the definition of parameters of the curve according to Pic. 1d should be conducted as follows:

– in advance during designing of the system a curve of the transition process is calculated for nominal values of car's mass;

– in every switching on of traction motors in accordance with the actual weight of the car, indirectly measured by indications of weight sensors in central spring suspension, proportionally change parameters I_a, I_c and t_{nc}.

Computing device for the generation of this curve is shown in Pic. 1e. It contains a generator of linearly changing voltage in a function of time (GLIN), a control course of which receives a startup signal from the contact of the driver's controller driver (DC) closed at all positions except zero. The output signal of GLIN goes to the nonlinear function generator (NFG) modeling a curve according to Pic. 1d. The output value of NFG, that is u*(t) is multiplied in a multiplier with a value $u(I_3)/U^*_{\max}$ proportional to the set starting (braking current) I_3, and U_{max} is a limit value of the output voltage of NFG, i.e. u*(t) at $t \to \infty$. The output value of the multiplier is proportional relative to the curve according to Pic. 1d taking into account the weight of the car.

Conclusions. Considered device shown in Pic. 1e is recommended to be used as a part of a driving element in the system of automatic control of traction drive of an electric train [4]. It can be manufactured using electronic chips of analog type but now digital implementation principle [5, 6] is more expedient, particularly using software for onboard microprocessor.

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