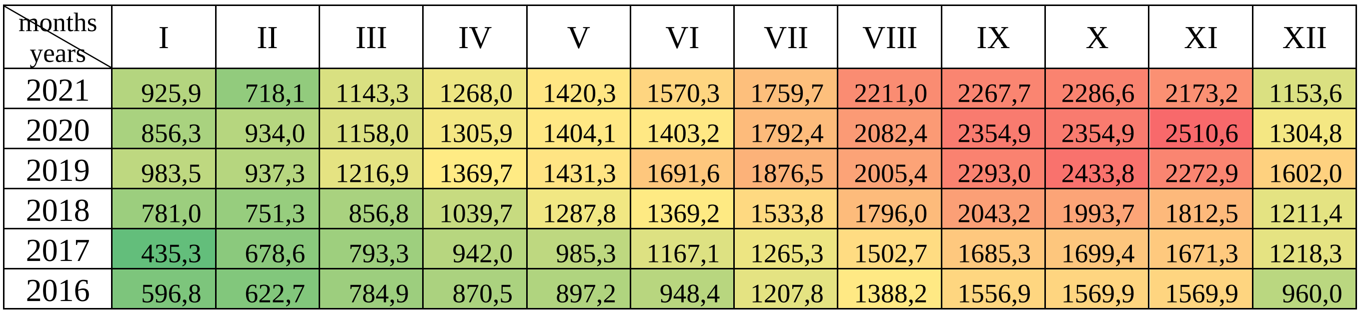
$$T_{\kappa} = \left\{ \begin{matrix} M\left(p_1, p_2, ..., p_n\right) \\ gradM \\ D_p^M \end{matrix} \right\}, \tag{1}$$

where $p_1, p_2, ..., p_n$ – indicators of transshipment of goods for the accounting period;
$M\left(p_1, p_2, ..., p_n\right)$ – an array of indicator data;
$grad\ M$ – intensity gradient of array indicators;
D_p^M – overlap distance (clustering of «distances» between array values).

The application of this model in the analysis of indicators of cargo transshipment from rail transport to sea transport will make it possible to visually assess the dynamics of transshipment over the past years (Fig. 1).



months / years	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
2021	925,9	718,1	1143,3	1268,0	1420,3	1570,3	1759,7	2211,0	2267,7	2286,6	2173,2	1153,6
2020	856,3	934,0	1158,0	1305,9	1404,1	1403,2	1792,4	2082,4	2354,9	2354,9	2510,6	1304,8
2019	983,5	937,3	1216,9	1369,7	1431,3	1691,6	1876,5	2005,4	2293,0	2433,8	2272,9	1602,0
2018	781,0	751,3	856,8	1039,7	1287,8	1369,2	1533,8	1796,0	2043,2	1993,7	1812,5	1211,4
2017	435,3	678,6	793,3	942,0	985,3	1167,1	1265,3	1502,7	1685,3	1699,4	1671,3	1218,3
2016	596,8	622,7	784,9	870,5	897,2	948,4	1207,8	1388,2	1556,9	1569,9	1569,9	960,0

Figure 1 – Chromatic map of transshipment unevenness of export cargo from railway to sea mode of transport (Chornomorsk seaport), million tons

As can be seen from the chromatic maps of transshipment volumes, there is a significant unevenness in the volume of work of sea ports for exporting goods by month of the year. First of all, this is related to the specialization of ports by cargo nomenclature, which, in turn, leads to the appearance of a seasonality factor in the volume of receipts. For example, seaports with a significant share of transshipment made up of grain cargoes have the largest loading during the harvest period and until the end of the year, and ports specialized in non-seasonal cargoes have more uniform export volumes throughout the year.

Thus, as a result of the processing of statistical data and the construction of chromatic map models, variation and analytical selection or replacement within the scope of the relevant port stations for sea ports is possible.

[1] Bessaid A., Bechar H., Fellah M. K. Image analysis and pattern recognitions tools in map interpretation. *Electronic Journal "Technical Acoustics"*. URL: http://www.ejta.org. 2003, № 15.

[2] Canny J. A Computational Approach to Edge Detection. *IEEE Transaction on Pattern Analysis and Machine Intelligence*. 1986. Vol. PAMI-8, № 6. P. 679–698.

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IMPROVING THE TRACTION PROPERTIES OF ELECTRIC LOCOMOTIVES THROUGH THE APPLICATION OF CAPACITIVE ENERGY STORES

V.P. Nerubatskyi, PhD (Tech.), D.A. Hordiienko, Postgraduate,
H.A. Khoruzhevskyi, Postgraduate
Ukrainian State University of Railway Transport (Kharkiv)

The maximum traction force of modern locomotives is usually limited by the conditions of wheel-rail coupling, therefore the critical mass of the train is determined based on the dependence of the coupling coefficient. On most load-intensive routes, the clutch load of locomotives is approaching the limit. A decrease in the coupling coefficient below the calculated value on such sections often leads to train stops on the climbs and, accordingly, to a violation of the train schedule [1, 2].

At the same time, the realization of the potential coupling coefficient is influenced by the design features of the locomotive, such as the difference in the characteristics of the traction electric motors and the diameters of the wheel pairs, the connection scheme of the traction electric motors, the rigidity of the traction characteristics, etc. [3, 4]. Therefore, improving the design of locomotives is of great importance for railway transport, aimed at the maximum possible use of their traction properties, which makes it possible to increase the stability of the implementation of the traction force and, due to this, reduce the number of cases of train stops on climbs with unfavorable coupling conditions [5, 6].

Schemes with rigid characteristics used on electric locomotives have disadvantages, the main of which is a significant spread of currents in parallel branches of traction electric motors. For this reason, the use of a drive with high stiffness of traction characteristics is difficult to implement without the use of devices for leveling the loads, which greatly complicates the scheme of the electric locomotive. Therefore, it is desirable that in the absence of skidding, the characteristics of traction electric motors should be soft, and when the clutch breaks, the stiffness of the characteristics increases.

The control system that ensures the transition to a rigid characteristic should be as simple as possible so as not to reduce the reliability of the electric locomotive as a whole. At the same time, a high speed of transition to rigid characteristics should be ensured. In order to improve the anti-skid properties of series-excitation traction electric motors, while maintaining its soft characteristics, it is suggested to connect a large-capacity energy storage capacitor parallel to the excitation winding of each traction electric motor, as shown in Fig. 1.

In the stable mode, when the armature current I does not change, the voltages on the excitation winding L_{ew} and on the energy storage device C_{es} are the same. There is no supply current I_{es}, therefore the excitation current I_{ew} is equal to the armature current I, as in the case of series excitation. At the same time, the energy storage does not affect the characteristics of the traction electric motor and it remains soft.

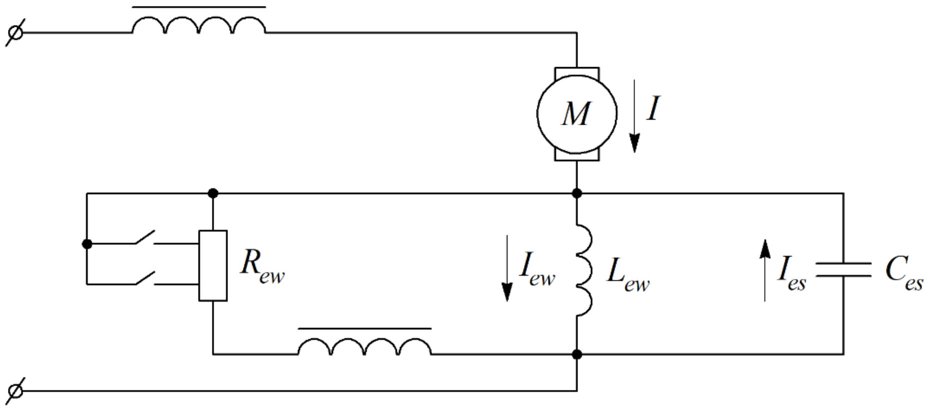

Fig. 1. The scheme of connecting the energy storage device to the excitation winding

When a pair of wheels breaks down due to skidding, its rotation frequency increases. Accordingly, the electromotive force of the motor increases and the current flowing through the windings decreases. At the same time, the voltage drop on the excitation winding becomes less than the voltage on the energy storage. The accumulator begins to discharge through the excitation winding, preventing the excitation current from decreasing. This ensures an increase in the stiffness of the traction characteristic and a short-term reset of the traction force of the traction electric motor, due to which skidding is eliminated at the very beginning. At the same time, there is no need for additional sensors and switching devices to suppress the skidding that began by switching to a rigid characteristic, and high speed of the circuit is ensured.

Due to the fact that the transition to a rigid characteristic occurs only during slippage, the spread of currents of parallel-connected traction electric motors in the absence of slippage will remain the same as with series excitation. Thus, the scheme with the energy storage does not require the use of load balancing devices.

Thus, energy storage devices have a significant potential for use in railway transport. The increase in resistance of the electric locomotive to skidding, caused by the use of the proposed scheme, leads to a decrease in the values of the generalized indicators of slippage of wheel pairs and sand consumption, which reduces the loading of the electric locomotive on the clutch. This, in turn, leads to a reduction in the damage of traction drive elements, to a reduction in tire wear of wheel pairs and, accordingly, to a reduction in the destruction of the rail track.

[1] Ishrat T., Ledwich G., Vilathgamuwa M., Borghesani P. Wheel slip control based on traction force estimaton of electric locomotives. *2016 Australasian Universities Power Engineering Conference (AUPEC)*. 2016. P. 1–6. DOI: 10.1109/AUPEC.2016.7749331.

[2] Nerubatskyi V. P., Plakhtii O. A., Hordiienko D. A., Syniavskyi A. V., Philipjeva M. V. Use of modern technologies in the problems of automation of data collection in intellectual power supply systems. *Modern engineering and innovative technologies*. 2022. Issue 19. Part 1. P. 38–51. DOI: 10.30890/2567-5273.2022-19-01-058.

[3] Nerubatskyi V., Plakhtii O., Hordiienko D., Podnebenna S. Synthesis of a regulator recuperation mode a DC electric drive by creating a process of finite duration. *2021 IEEE 3rd Ukraine Conference on Electrical and Computer Engineering (UKRCON)*. 2021. P. 272–277. DOI: 10.1109/UKRCON53503.2021.9575792.

[4] Zhang T., Wang Z. The Approximation of the Train Resistance Based on Improved PSO-RBF. *2020 Chinese Control And Decision Conference (CCDC)*. 2020. P. 1726–1731. DOI: 10.1109/CCDC49329.2020.9164359.

[5] Jia C., Xu H., Wang L. High Speed Train Modeling Based on Traction Motor Model. *2018 37th Chinese Control Conference (CCC)*. 2018. P. 1798–1803. DOI: 10.23919/ChiCC.2018.8482725.

[6] Ishrat T., Ledwich G., Vilathgamuwa M., Borghesani P. Identification scheme of maximum traction force using recursive least square for traction control in electric locomotives. *2017 IEEE 12th International Conference on Power Electronics and Drive Systems (PEDS)*. 2017. P. 1120–1125. DOI: 10.1109/PEDS.2017.8289141.