**Optimization of Excitation Attenuation Scheme for TE10 Diesel-Electric Locomotives**

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**Abstract.** Worldwide, significant attention is being devoted to improving the technical condition of mainline diesel locomotives, determining the magnetic field parameters of traction electric motors (TED) in their traction tranWFission, identifying the impact of these parameters on the tractive force and fuel consumption of diesel locomotives, increasing the efficiency of the existing locomotive fleet, and enhancing the performance and efficiency of mainline diesel locomotives. In this context, conducting research on the application of modern methods for determining the parameters that affect the tractive force and technical condition of diesel locomotives is of particular importance. Simultaneously, reducing costs by improving the TED magnetic field weakening system in DC electric transmission mainline diesel locomotives is considered one of the crucial and urgent tasks. Analysis of the locomotive's efficiency (FIK) revealed that a decrease in the locomotive's efficiency occurs when the traction generator has low values of Rg and Ne, and MK=const on the direct start-stop diagrams in the non-hyperbolic external characteristic zone. By changing (reducing) the value of the magnetic field damping resistance of the traction generator, it was possible to alter the magnetic field damping time of the traction generator. A recommended improvement for the transient process of magnetic field attenuation in traction generators of diesel locomotives with DC transmission has been developed. An electrical circuit diagram for installation has been designed. Based on the developed system of equations for the magnetic field attenuation circuit and the analysis of the processes occurring in it, the current flowing through the power circuit during the magnetic field attenuation process was calculated**.**

**Keywords*:***Train contactors VSH, TED, contactor KV, voltage of traction generator

# Introduction

Due to the significant costs associated with experimental research on rolling stock dynamics, special attention is given to developing theoretical approaches.

Currently, modern software requires the creation of mathematical models that allow for sufficiently accurate modeling to theoretically study the dynamic qualities of rolling stock.

In diesel locomotives, the voltage U is continuously adjusted by changing the resistance to motion (load current) and regulating the traction generator voltage according to its external characteristics. Additionally, a method of voltage conversion by altering the connection circuit of traction motors, known as the starting-shutdown circuit of traction motors, is also employed [1, 2, 3].

Let us assume that the locomotive has six traction electric motors. When all electric motors are connected in series, each electric motor receives UG/6 voltage, and the current of each electric motor equals the current of the source (traction generator). When two parallel groups, each containing three electric motors, are formed, the voltage in them doubles, but the source current also increases twofold. In three parallel circuits, a further increase in voltage and source current in electric motors is observed. Such connection arrangements are called series-parallel connections. The connection circuit is referred to as a parallel connection. The change in voltage supplied to the traction electric motor as a result of starting and shutting down provides suitable conditions for altering the rotational speed of its armature [4, 5].

In locomotives with DC electric drive, there is a device for weakening the magnetic field of the traction generator with an independent excitation winding. Traction electric motors are connected to this generator in parallel through electro-pneumatic contactors with power contacts that have a delayed disconnection time. To protect the diesel generator unit, a magnetic field damping resistance is connected parallel to the power contact of the generator excitation winding's starting contactor. Additionally, the blocking contacts of VSH contactors, which connect magnetic field weakening resistances parallel to the excitation winding of traction electric motors, are connected to the current and voltage coils of differential relays that implement the first and second stages of magnetic field weakening. To prevent the burning of power contacts of group power contactors during transient processes in the power circuit of traction motors, normally closed blocking contacts of contactors that introduce resistances into the excitation winding of the traction motor are included in the coil circuits of contactors connecting the excitation winding. This prevents quick and automatic shutdown of the traction generator's excitation. Thus, at the zero position of the driver's controller, if the contactors connecting the resistances for reducing the magnetic field of the traction motor are activated, the power supply circuit of the contactor coil connecting the generator's excitation circuit remains activated until the group contactors VSH1 and VSH2 are de-energized. Furthermore, a circuit has been implemented where the VSH1 and VSH2 group contactors remain activated until de-energized, preventing the burning of power contacts of group contactors that add resistance for weakening the magnetic field of traction electric motors. This occurs in case of rapid non-automatic load removal from the diesel generator unit or activation of protection systems.

The disadvantage of these two methods is the potential for uncontrolled locomotive movement when forcibly connecting the group magnetic field weakening contactors to check their operation while the diesel is running, or the burning of power contacts when the diesel generator unit's protection system is activated.

During the transient process in the magnetic field resulting from the deactivation of the traction generator of TE10 type locomotives [6]:

- When the VSh contactors are engaged throughout the entire transient process, the armature current expression consists of 4 attenuation indicators, while when operating in the TED FF mode, it consists of three;

- As the resistance Rsh value increases, the maximum value of the reverse current decreases; as the resistance Rsh value decreases, the current increases;

- At Rsh = ∞, the current does not enter the negative range. This corresponds to the transition process when operating in TED FF mode;

- When the VSh contactors are switched on and off, arc ignition limits the amount of reverse current;

- Reducing the Rsh value decreases the maximum value of the reverse current. At a certain value (close to the   
Rsh = ∞ value), the current does not enter the negative range. An increase in the Rsh value has the same effect on the transition process;

- When the contactor's contact groups are simultaneously switched on and off, if the TED transition process is the same as when the contact groups were switched on and off earlier, the magnetic field weakening system then returns to traction mode.

The stages of comparing obtained results with experimental test data and adjusting the model are extremely important. To verify the results, it is crucial to have a large array of experimental test data. Only in this case can numerous features of the process be taken into account, allowing for subsequent adequate refinement. For the purpose of this analysis, losses in efficiency and power of diesel engines, generators, traction electric motors (TEMs), and auxiliary machines are considered separately, taking into account the following factors:

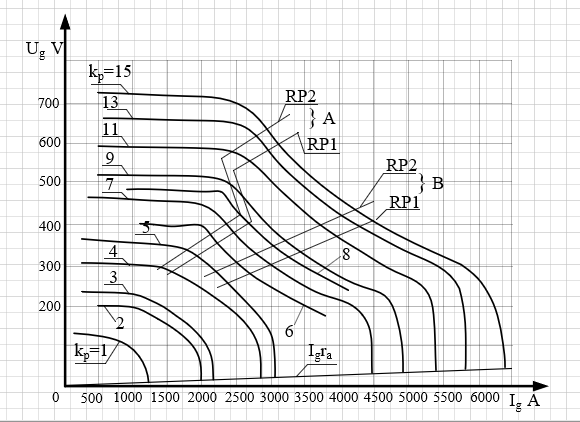
- A decrease in the power of the diesel-generator unit (DGU) occurs in the weakened field due to the non-hyperbolic nature of the external characteristic at each considered position of the locomotive controller in the start-stop zone [7, 8, 9];

- Depending on the connection of RP1 and RP2 in the non-hyperbolic part of the external characteristic, the connection moment corresponds to a higher speed of the locomotive and a lower power of the TEM compared to operation at constant generator excitation (Rg=const);

- When weakening the magnetic field of the TEM in the operation of the FF→WF1 and WF1→WF2 systems, it has been observed that the voltage of the traction generator decreases faster than the counter-electromotive force of the TEM's magnetic field. This occurs as a result of shunting the power contact of the contactor with a parallel connected resistance of RSVG=51 Ohm when the KV contactor of the generator excitation system is de-energized. It has been determined that this leads to the system transitioning to a short-term braking mode and the separation of the magnetic field weakening contactors' contacts at current and voltage values several times greater than their nominal values.



**FIGURE 1**. Graph in the magnetic field circuit



**FIGURE 2**. Graph of the state after a change in the magnetic field circuit

# Related Work

Only the first stage of TED magnetic field excitation was triggered.

According to the traction classification, at position 7 of the driver's controller, the second stage of the magnetic field system activation reaches a speed of 85 km/h (a deficiency in the operation of this relay was observed).

The magnetic field circuit is implemented according to the commutation principle: the lower the position of the driver's controller, the higher the speed of direct switching, which contradicts the conditions for implementing traction.

Direct commutation is adjusted at position 15 of the driver's controller at current values during rheostat testing:

FF-WF1 3100A;

WF1-WF2 2900 A.

Therefore, in the driver's controller positions below 9÷10, the WF1-WF2 transient processes fall into the voltage limiting zone.

Due to the possibility of self-oscillation in the automatic control system, relay tuning to low currents is not performed.



**FIGURE 3**. Diagram of the magnetic field weakening assembly for the torque generator and practical traction electric motor, connecting the power contactor. Contactors P1-P6 and magnetic field weakening contactors VSH1, VSH2

Traction-economic characteristics of mainline diesel locomotives of the TE10M type with DC drive without a microprocessor control system in the activation-deactivation zone of the transition relay. Based on the methodology presented in the literature, the calculation of the traction-economic characteristics of the relay's current coil in serial circuits in the direct activation-deactivation region was carried out, and their experimental connection to the circuit of the task-setting winding of the amplistat was performed. At the same time, the correction diagram was adjusted by adding additional resistances to the current coil circuit.

In the further process of improving the circuit, the current coil circuit was later connected to the output of the amplistat control winding, eliminating the SRPT resistance and its regulation.

Effective efficiency of diesel:

(1)

here; Ce - effective fuel consumption, g/e.h.p.; Qn - lower calorific value of fuel, kcal/kg.

Calculations show that for a 10d100 diesel engine, with a decrease in power at constant h\_e, N\_e efficiency sharply decreases due to an increase in ηe and Ce. Therefore, in a diesel engine, when the traction generator operates on the non-hyperbolic part of the external characteristic, ηt -efficiency decreases.

It is known that the efficiency of a traction generator depends on magnetic, electrical, and mechanical losses. If the voltage is limited due to the saturation of the magnetic field circuit, magnetic field losses can be assumed to be constant.

Mechanical losses in each control position are also constant. Electrical losses vary, but calculations have shown that total losses remain almost constant, and the efficiency of the generator decreases due to a decrease in the useful power of the machine.

The efficiency of TED depends on the same losses as the traction generator. Only losses during the transition process are added. Electrical and magnetic losses change similarly to the losses of a traction generator. Mechanical losses increase with increasing speed. In general, when operating on the non-hyperbolic part of the external characteristic of the traction generator, efficiency decreases slightly.

Thus, when correcting the commutation diagram, the following rules should be taken into account:

- feasibility of the traction characteristic;

- optimality of using the external characteristics of the traction generator;

- impractical characteristic of transition point commutation;

- fluctuations of current I g (t) and voltage u g (t) during commutation

**TABLE 1.** Analysis of locomotive partial operating modes in commutation zones

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| № t/r | K. P. | Transition process  FF -> WF 1  WF 1-> WF 2 | V | Pr | Pr | Ce | ŋe | ẞ | hr |
| km/s | kVt | o. k. | g/e.o.k.s | - | - | - |
| 1 | 7 | PFF  FF -> WF 1  WF 1-> WF 2 | 21  32  73 | 115  730 460 | 1880  1136  728 | 62  166  184 | 0,382 0,373 0,335 | 0,085 0,117 0,22 | 0,23  0,2  0,15 |
| 2 | 9 | PFF  FF -> WF 1  WF 1 -> WF 2 | 29  34  63 | 1350 1050  780 | 2160  1645  1260 | 162  165  173 | 0,381 0,375 0,356 | 0,083 0,109 0,143 | 0,25 0,23  0,2 |
| 3 | 11 | PFF FF -> WF 1  WF 1 -> WF 2 | 28  32  50 | 1545  1330  1090 | 2480  2130  1760 | 164  165  173 | 0,377 0,374 0,365 | 0,085 0,1  0,12 | 0,25 0,24 0,23 |
| 4 | 13 | PFF  FF -> WF 1  WF 1 -> WF 2 | 33  33  50 | 1735  1735  1545 | 2770 2770  2 480 | 166  166  167 | 0,373 0,373 0,370 | 0,098 0,1  0,11 | 0,27 0,27 0,27 |

# Results and Discussion

Calculation of the technical and economic efficiency of the scheme developed according to the excitation reduction diagram for TE10 type DC-powered locomotives.

The probability of locomotives operating in positions 5-7 and 7-9 at speeds of 40-50 km/h is Fpk=0.0042. This indicates operation in the FF→WF1 transition zone. When moving at speeds of 50-60 km/h, the probability of operating in positions 5-7 and 7-9 is Fpk=0.0036, respectively.

If we assume that a locomotive operates for 300 days throughout the year, it functions in traction mode for 150 days. Thus, the operating time of the locomotive in the FF→WF1 transition zone is determined as follows.

hours per year

hours per year

hours per year;

hours per year

When comparing experimental and serial schemes, the economy of relative fuel consumption in the transition zones is determined as follows:

;

The table provided shows the locomotive power in the transition zones FF→WF1 and WF1→WF2 of the locomotive section:

horse-power

horse-power

horse-power;

horse-power.

tons per section

If the average fuel price for 2024 is 5,285,217.39 soums per ton, then the economic efficiency from the modifications introduced to the scheme for a 50-section TE10M diesel locomotive is as follows:

E = 45∙5285217.39 = 237,834,783 soums

**TABLE 2.** Specific effective fuel consumption in the start-up and shutdown zones of serial and experimental schemes of the 2TE10M locomotive series

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| № S.N. | Controller Position | Specific effective fuel consumption, | | | |
| FF→WF1 power on/off | | WF1→WF2 power on/off | |
| Serial circuit | Experimental circuit | Serial circuit | Experimental circuit |
| 1 | 2 | 3 | 4 | 5 | 6 |
| 1 | 15 | 167 | 167 | 167 | 167 |
| 2 | 13 | 166 | 166 | 168 | 167 |
| 3 | 11 | 165 | 164 | 174 | 164 |
| 4 | 9 | 165 | 162 | 176 | 162 |
| 5 | 7 | 166 | 162 | 182 | 172 |

Based on the calculations, the changes made to the electrical circuit in the transition zones FF→WF1 and WF1→WF2 allow for comparing the resulting profit against the funds spent on the developed experimental circuit and determining the overall economic benefit [10, 11, 12].

# Conclusions

By modifying (reducing) the value of the magnetic field damping resistance of the traction generator, it became possible to alter the magnetic field damping time of the traction generator. An improved transition process for attenuating the magnetic field of traction generators in diesel locomotives with DC tranWFission has been developed and recommended.

A system of equations for the magnetic field attenuation circuit has been developed, and based on the analysis of the processes occurring within it, the current flowing through the power circuit during the magnetic field attenuation process has been calculated.

The technical and economic efficiency of the developed circuit for DC locomotives has been calculated according to the excitation attenuation diagram in the transition zones FF→WF1 and WF1→WF2. Based on these calculations, the economic efficiency of the modified circuit in the transition zones FF→WF1 and WF1→WF2 has been evaluated.

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