Basis of Model of Electric Drive of Diesel Start-U

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Abstract. The article analyzes the electrical system of the diesel starting system for diesel locomotives with a constant current transmission. The dynamics of processes in electric circuits and the control model of the start-up process are based on diesel start-up. In this case, systems of second-order differential equations with variable coefficients for current fluctuations in circuits are derived. A method of approximate solution of these systems of equations has been developed using methods of integral averaging of variable coefficients and methods of operational calculation. The given system of equations was calculated and compared with the results obtained by experimental studies.

1 Introduction

The coefficient of friction of the brake pad to the bandage. The size of φ_k The main part of the diesel locomotives in use in Uzbekistan are diesel locomotives with constant current transmission. Many scientific studies have been conducted to improve the operational condition of these locomotives [1-5]. In the scientific research conducted on the electrical transmission part of locomotives [6-10] and in the studies conducted on the basis of the parameters of the systems that facilitate the process of starting the locomotive diesels [11, 12], additional tools were used to facilitate the start-up and system reserves were not used. Therefore, on the basis of previous studies and the study of the constructions of various systems, to determine the available reserves of power and control circuits necessary to facilitate the start-up of locomotives with direct current and alternating current electric transmission.

In this article, the damping oscillation of the current $i_1(t), i_2(t)$ in the electrical circuit of diesel-generator start-up of locomotives is considered. The scheme of the power circuit of the diesel engine starting of TE10M (UzTE16M) diesel locomotives is presented [13, 14].

2 Objects and methods of research

The equations of the current fluctuation model were derived taking into account the following assumptions.

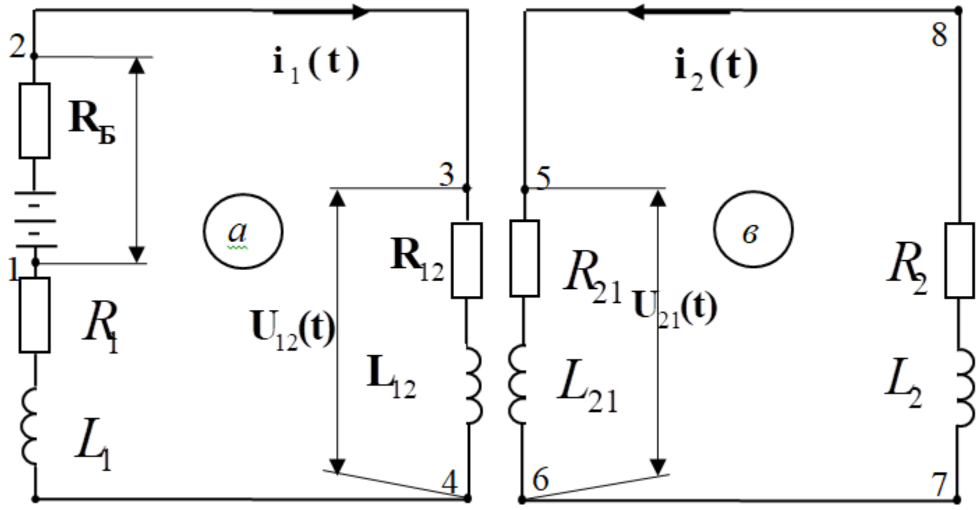

Fig.1. Option of a two-circuit scheme

1. In order to analyze the processes taking place in the diesel-generator start-up chain, we use the electric circuit of the diesel-generator start-up chain of the TE10M (UzTE16M) locomotive [13, 14],

where - $R_Б$ - the internal resistance of the accumulator battery;

L_{12}, L_{21} - inductances of starting and independent coils of torque generator operating in electric engine mode during diesel start-up;

R_{12}, R_{21} - starting and independent resistors;

L_1, L_2 - inductances of primary and secondary circuits;

R_1, R_2- resistances of primary and secondary circuits;

i_1, i_2- currents in the primary and secondary circuits;

$U_Б$ - battery voltage;

U_{12}, U_{21}- during the start-up process, the voltage drop in the circuits - between points 3, 4 and 5, 6 and independent circuits.

We adopt the following assumptions to describe the transition process.

2. Resistances $R_Б$, R_1, $R_{12}$and inductances L_1, L_2 expressed in Ohms remain unchanged when starting the DG model.

3. We assume that the voltage function of the accumulator battery between points 1 and 2 is given.

$$U_Б(t) = U_0 + A_1 t + A_2 t^2 + A_3 t^3 \qquad (1)$$

where: A_1, A_2, A_3 are the known representation of the constants for the time t calculated after the start of the battery and DG.

4. The influence of the secondary (v) chain on the primary (a) chain is characterized by the EP (electric power) function that occurred between points 3 and 4.

$$U_{12}(t) = K_{12}\, di_2/dt \qquad (2)$$

For him, K_{12} the coefficient of mutual inductance is a constant quantity.

5. We determine the effect of the primary (a) chain on the secondary (v) chain by the function that appeared between points 5 and 6.

$$U_{21}(t) = K_{21}\, di_1/dt \qquad (3)$$

For him, K_{21} the coefficient of mutual inductance is a constant quantity.

6. For circuits (a) and (v), the condition of equality of the sum of voltages and voltage losses $U_{\text{Б}}(t) + U_{12}(t)$ in all sections of the connected circuit between points 1, 2, 3, 4, 2, 1 and 5, 6, And between points 7, 9, the condition $U_{21}(t)$ is fulfilled.

3 Results and their Discussion

The following system of equations was obtained on the basis of the assumptions allowed under clauses 1-6.

$$i_1(R_{\text{Б}} + R_1 + R_{12}) + \frac{di_1}{dt}(L_1 + L_{12}) = U_{\text{Б}}(t) - U_{12}(t) \qquad (4)$$

$$i_2(R_{21} + R_2) + \frac{di_2}{dt}(L_{21} + L_2) = U_{21}(t) \qquad (5)$$

Taking into account clauses (1-3) of the assumptions adopted in finding the solution of the system of equations (4), (5), we present this system of equations as shown below.

$$\frac{di_1}{dt} + B_1 i_1 + B_2 \frac{di_2}{dt} = B_3 + B_4 t + B_5 t^2 + B_6 t^3 \qquad (6)$$

$$-\frac{di_1}{dt} C_1 + \frac{di_2}{dt} + C_2 i_2 = 0 \qquad (7)$$

where: $B_1 = \frac{R_{\text{Б}}+R_1+R_{12}}{L_1+L_{12}}$; $\quad B_2 = \frac{K_{12}}{L_1+L_{12}}$;

$B_3 = \frac{U_0}{L_1+L_{12}}$; $\quad B_4 = \frac{A_1}{L_1+L_{12}}$;

$B_5 = \frac{A_2}{L_1+L_{12}}$; $\quad B_6 = \frac{A_3}{L_1+L_{12}}$;

$C_1 = \frac{K_{21}}{L_{21}+L_2}$; $\quad C_2 = \frac{R_{21}+R_2}{L_{21}+L_2}$;

We find the solution of the system of equations (6), (7) using the operational calculation method [15-16] taking into account the initial conditions:

$$i_1(0) = J_1 \approx \frac{U_0}{R_{\text{б}}+R_1+R_{12}}; \qquad i_2(0) = J_2;$$

the integration constant is equal to the following,

$$i_2(\tau_C) = 0 \qquad (8)$$

It is determined based on the condition that the current is equal to zero at the end of the DG start-up period at $t = \tau_C$

To perform the calculation, we take the representation of the parameters presented in the system of equations (6) and (7).

$$\begin{array}{ll} i_1(t) \leftarrow i_1(p); & \frac{di_1}{dt} \leftarrow pi_1(p) - pJ_1; \\ i_2(t) \leftarrow i_2(p); & \frac{di_2}{dt} \leftarrow pi_2(p) - pJ_2; \\ B_3 \leftarrow B_3; & B_4 t \leftarrow \frac{B_4}{p}; \\ B_5 t^2 \leftarrow \frac{2B_5}{p^2}; & B_6 t^3 \leftarrow \frac{6B_6}{p^3} \end{array}$$

let it be;

In this case, we will have the following system of equations to describe the functions.

$$i_1(p)(B_1 + p) + pB_2 i_2(p) = p(J_1 - B_2 J_2) + B_3 + \frac{B_4}{p} + \frac{2B_5}{p^2} + \frac{6B_6}{p^3} \qquad (9)$$

$$pC_1 i_1(p) + i_2(p)(p + C_2) = -p(C_1 J_1 - J_2) \qquad (10)$$

To solve this system, we first find the determinant of the coefficients $i_1(p)$, $i_2(p)$.

$$\Delta = \begin{vmatrix} B_1 + p, & pB_2 \\ -pC_1, & p + C_2 \end{vmatrix} = (B_1 + p)(p + C_2) + p^2 B_2 C_1 \qquad (11)$$

Since $\Delta = 0$, in the mode of resonance vibrations, we calculate the equation based on this condition.

$$p^2 + (B_1 + C_2)p + B_1 C_2 + p^2 B_2 C_1 = 0$$

Expressing the constants of the equation with coefficients, we bring the equation to the following form.

$$p^2 + 2\psi_1 p + \lambda_1^2 = 0 \qquad (12)$$

where: $2\psi_1 = \frac{B_1 + C_2}{1 + B_2 C_1}$, $\qquad \lambda_1^2 = \frac{B_1 C_2}{1 + B_2 C_1}$

Equation (12) can be solved in two ways:

The first option is when $\psi_1^2 > \lambda_1^2$;

in this case, equation (12) will have roots as follows.

$$p_1 = -\psi_1 + \sqrt{\psi_1^2 - \lambda_1^2} \qquad (13)$$

$$p_2 = -\psi_1 - \sqrt{\psi_1^2 - \lambda_1^2} \tag{14}$$

(11) the equation will have the following form.

$$\Delta = (p + p_1)(p + p_2) \tag{15}$$

in the second option when $\psi_1^2 < \lambda_1^2$;

In this case, the roots of equation (12) take the following form.

$$p_{21} = -\psi_1 + i\theta_1 = p_1 = -\psi_1 + i\sqrt{\lambda_1^2 - \psi_1^2} \tag{16}$$

$$p_{22} = -\psi_1 - i\theta_1 = p_1 = -\psi_1 - i\sqrt{\lambda_1^2 - \psi_1^2} \tag{17}$$

Equation (11) will have the following form.

$$\Delta_{12} = (p + \psi_1 - i\theta_1)(p + \psi_1 + i\theta_1) \tag{18}$$

Preliminary calculations for a simplified version of the electrical circuit of the starting system presented in the figure showed that $i_2(0) = J_2 = 0$ can be used in the formulas due to the absence of external current sources (except for U_{21}) in the secondary circuit when carried out by formulas (12-14). Therefore, we will use this system of equations for further solution representations.

$$i_1(p)(B_1 + p) + pB_2 i_2(p) = pJ_1 + B_3 + \frac{B_4}{p} + \frac{2B_5}{p^2} + \frac{6B_6}{p^3} \tag{19}$$

$$pC_1 i_1(p) + i_2(p)(p + C_2) = -pC_1 J_1 \tag{20}$$

We consider the solution of formulas $B_4 = B_5 = B_6$ (19), (20) according to the second solution option of formula $\psi_1^2 < \lambda_1^2$ (12) and when the eigenvalue polynomial coefficients are equal.

$$\Delta_{12} = (p + \psi_1 - i\theta_1)(p + \psi_1 + i\theta_1).$$

In this option, it is necessary to use a "large" storage battery to start the DG. The system of equations for this solution option.

$$i_1(p)(B_1 + p) + pB_2 i_2(p) = pJ_1 + B_3 \tag{21}$$

$$pC_1 i_1(p) + i_2(p)(p + C_2) = -pC_1 J_1 \tag{22}$$

and we get the following images of solutions:

Primary circuit current.

$$i_1(p) = \frac{1 + B_2 C_1}{(p + \psi_1 - i\theta_1)(p + \psi_1 + i\theta_1)} \begin{vmatrix} pJ_1 + B_3 & pB_2 \\ -pC_1 J_1 & p + C_2 \end{vmatrix} =$$

$$= \frac{1+B_2C_1}{(p+\psi_1-i\theta_1)(p+\psi_1+i\theta_1)}[(pJ_1+B_3)(p+C_2)+p^2B_2C_1J_1] \qquad (23)$$

Secondary circuit current.

$$i_2(p) = \frac{1+B_2C_1}{(p+\psi_1-i\theta_1)(p+\psi_1+i\theta_1)}\begin{vmatrix} p+B_1 & pJ_1+B_3 \\ -pC_1 & -pC_1J_1 \end{vmatrix} =$$

$$= -\frac{1+B_2C_1}{(p+\psi_1-i\theta_1)(p+\psi_1+i\theta_1)}[(p+B_1)pJ_1C_1 - pC_1(pJ_1+B_3)] \qquad (24)$$

We perform the transition to the originals of some functions.

$$\frac{p^2}{(p+\psi_1-i\theta_1)(p+\psi_1+i\theta_1)} \to \frac{(-\psi_1+i\theta_1)}{2i\theta_1}[e^{(-\psi_1+i\theta_1)t} +$$

$$+\frac{(-\psi_1-i\theta_1)}{2i\theta_1}e^{(-\psi_1-i\theta_1)t}] = e^{-\psi_1 t}(\cos\theta_1 t - \frac{\psi_1}{\theta_1}\sin\theta_1 t) \qquad (25)$$

$$\frac{p}{(p+\psi_1-i\theta_1)(p+\psi_1+i\theta_1)} \to \frac{1}{2i\theta_1}[e^{(-\psi_1+i\theta_1)t} -$$

$$-e^{(-\psi_1-i\theta_1)t}] = \frac{e^{-\psi_1 t}}{\theta_1}\sin\theta_1 t \qquad (26)$$

$$\frac{1}{(p+\psi_1-i\theta_1)(p+\psi_1+i\theta_1)} \to \frac{e^{-\psi_1 t}}{\psi_1^2+\theta^2}(\theta\sin\theta t - \psi_1\cos\theta t) - \frac{\psi_1}{\psi_1^2+\theta^2} \qquad (27)$$

$$\frac{1}{p(p+\psi_1-i\theta_1)(p+\psi_1+i\theta_1)} \to \frac{1}{\psi_1^2+\theta^2}\{t + \frac{e^{-\psi_1 t}}{\psi_1^2+\theta^2}[\frac{\psi_1^2}{\theta}\sin\theta t +$$

$$+2\psi_1\cos\theta t + \theta\sin\theta t] + \frac{2\psi_1}{\psi_1^2+\theta^2}\} \qquad (28)$$

considering (25-28), we get the originals of functions (23) and (24).

I know the original contour current

$$i_1(t) = (1+B_2C_1)\{[J_1(1+B_2C_1)e^{-\psi_1 t}(\cos\theta_1 t - \frac{\psi_1}{\theta_1}\sin\theta_1 t) + (J_1C_2 +$$

$$+B_3)\frac{e^{-\psi_1 t}}{\theta_1}\sin\theta_1 t + B_3C_2(\frac{e^{-\psi_1 t}}{\psi_1^2+\theta^2}(\theta\sin\theta t - \psi_1\cos\theta t) - \frac{\psi_1}{\psi_1^2+\theta^2}) \qquad (29)$$

The origin of the secondary circuit current

$$i_2(t) = (1+B_2C_1)C_1(B_1J_1 - B_3)\frac{e^{-\psi_1 t}}{\theta_1}\sin\theta_1 t \qquad (30)$$

The obtained solutions indicate that the oscillations of the currents $i_1(t)$ and $i_2(t)$ are damped with the rotation frequency θ_1 when starting the DG.

Let's divide the calculation into two phases:

- $t = 0 – 0.4$ seconds (from the moment of connection of the D2 contactor power contact to the excitation moment of the torque generator armature) due to the occurrence of a jump in the starting current,

- $t > 0.4$ sec. The time from to the next 3 seconds is the rotation time of the diesel crankshaft until the fire appears in the diesel cylinders. We take this time as approximately $t = 5$ s, depending on the state of the equipment DG.

The calculation of the current value $i_1(t)$ for the first and second phase intervals was brought into the programming language and the values of $i_1^{x}(t)$ calculated for the given circuit variant were compared with the given experimental $i_1^{э}(t)$ results.

The comparative results of calculation results and experimental results values are shown in the table 1.

The table 1. shows the values of the calculated and experimental results of the starting current.

Table 1.

t, seconds	0,4	1,0	2,0	3,0	4,0	5,0
Calculated $i_1^{x}(t)$, A	1662	1317	947	807	721	668
Experimental $i_1^{э}(t)$,A	1665	1320	950	810	720	660

4 Conclusions

The model of the dynamics of processes in the power and control electric circuits in the operation of the DG is based on, for which systems of differential equations of second-order current fluctuations with variable coefficients are derived. For these systems of equations, an approximate calculation method has been developed, which uses the methods of integral averaging of variable coefficients and operational calculation. The obtained results show that the oscillatory movement of the current $i_1(t)$, $i_2(t)$ in the electrical circuit of diesel-generator start-up of locomotives is damping.

As can be seen from the table, the results of the calculated work correspond to the results obtained by the experimental method, and it allows to calculate the changes made to the chains through the sequence of calculations and the processes that take place in the chains through these changes

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