E3S Web of Conferences **401**, 01072 (2023) https://doi.org/10.1051/e3sconf/202340101072
CONMECHYDRO - 2023

Torsional oscillations of armature shaft of generator of main diesel locomotive in diesel start-up mode

A. T. Djanikulov*, and *U. I.* Abdulatipov

Tashkent State Transport University, Tashkent, Uzbekistan

Abstract. The article considers a mechanical model of torsional vibrations in the starting system of a diesel generator (DG) with two concentrated mass moments of inertia and a previously unaccounted factor of torsional vibrations between the traction generator and the crankshaft of a diesel locomotive of the UzTE16M type. For this model, the Lagrange method is used to derive a system of equations for mass oscillations along the generalized coordinates of "kinematic" and elastic oscillations between the masses of the armature of the traction generator and diesel engine with a variable mass moment of inertia. For the resulting system of equations, by the method of operational calculus, solutions were made for the accepted functions of mass moments of inertia, moments of driving forces, and resistances. Based on the developed model, it is recommended to determine the angular velocity of the diesel crankshaft which is currently used.

1 Introduction

One of the expensive components of a diesel locomotive is the battery. During the operation of diesel locomotives of the UzTE16M type, cases of difficult starting of diesel engines due to a decrease in the capacity of the battery are not uncommon. Theoretical and experimental studies presented in [1, 3] showed that most of the storage batteries TPZhN - 550 diesel locomotives of the UzTE16M type have a service life at "Uzbekistan Temir Yollari" JSC from 6 to 10 years. Some of these diesel locomotives do not turn off the diesel of one of the sections to start the second one. This leads to an additional expenditure of funds to purchase fuel and oil. Therefore, research on developing and improving the conditions for launching diesel locomotives in the Republic of Uzbekistan and on the territory of the CIS countries is relevant.

Earlier, studies were carried out to justify the parameters of systems that facilitate the process of starting diesel locomotives with the electric transmission of direct and alternating current [4-6] and the operating conditions of electrical equipment of diesel locomotives [7-17]. In several such systems, new contactors and devices were used, which complicated the control and reduced the reliability of diesel locomotives as a whole. At the

* Corresponding author: axat.djanikulov.7554@mail.ru

same time, the available reserves for improving existing systems and electrical devices were not used.

Therefore, based on the study of previous studies and designs of various systems, to facilitate the launch of diesel locomotives with the electric transmission of direct current (EP PT) and alternating current (EP PPT), it is necessary to find out the available reserves of power and control circuits.

In works [20], mainly electromechanical phenomena in circuits and devices that ensure the start of diesel engines were analyzed. At the same time, the relationship between the rotational frequencies of the armature of the $\omega_y(t)$ traction generator (TG) operating in the electric motor mode and the crankshaft of the diesel $\omega_d(t)$ engine being started was not studied. This article solves the problem of torsional vibrations of the reduced masses J_i (t) of the TG armature and diesel engine in the mode of starting the diesel generator from the battery and additional devices.

The following assumptions were used to solve the problem:

The model of torsional vibrations of a two-mass elastically connected system, characterized [1], was used as a calculation model:

- functions of the reduced mass moments of inertia Jl (t) $t = t \div t_3$;
- function $\varphi_y(t)$of "kinematic" oscillations of the mass $J_y(t)$, loaded with a driving moment $\mathrm{M}_y(t)$;
- function $\varphi_d(t)$of elastic vibrations of the mass $J_d(t)$, relative to the mass $J_y(t)$), under the action of the torque of the resistance forces $\mathrm{M}_d(t)$) applied to $J_d(t)$; at the same time, the torsional rigidity of the elastic connection $\mathrm{C}_d$between $J_y(t)$and $J_d(t)$is considered constant during the time $t = 0 \div t_3$.

2 Objects and methods of research

To derive the equations of torsional vibrations for the model according to claim 1, the Lagrange method was used with expressions [17] for:

kinetic energy

$$T = \frac{1}{2}[J_y(t) + \left(\frac{d\phi_y}{dt}\right)^2 + J_\partial(t) \cdot (\frac{d\phi_y}{dt} + \frac{d\phi_\partial}{dt})^2] \quad (1)$$

potential energy

$$\Pi = \frac{1}{2} C_\partial \phi_\partial^2(t) \quad (2)$$

work of external forces

$$dA = M_y(t)\partial\phi_y - M_\partial(t)(\partial\phi_y + \partial\phi_\partial), \quad (3)$$

Lagrange equations in generalized coordinates $\phi_y(t)\ and\ \phi_d(t)$:

$$[J_y(t) + J_d(t)] \cdot \frac{d^2\varphi_y}{dt^2} + \frac{d\varphi_y}{dt} \cdot [\frac{dJ_y(t)}{dt} + \frac{dJ_d(t)}{dt}] + \\ + J_d(t)\frac{d^2\varphi_d}{dt^2} + \frac{d\varphi_d}{dt} \cdot \frac{dJ_d(t)}{dt}] = M_y(t) - M_d(t) \quad (4)$$

$$J_d(t)\frac{d^2\varphi_y}{dt^2} + \frac{dJ_d(t)}{dt}\frac{d\varphi_y}{dt} + J_d(t)\frac{d^2\varphi_d}{dt^2} + \frac{d\varphi_d}{dt}[\frac{dJ_d(t)}{dt} + K_з] + c_з\varphi_d = -M_d(t) \quad (5)$$

The resulting system of equations (4) - (5) is characterized by variable coefficients and allows approximate solutions.

Let us perform approximate solutions of these equations with the introduction of assumptions.

On the constant value of J_y, equal to the mass moment of inertia of the armature and the approximate function

$$J_d(t) = J_0 e^{\beta t} \tag{6}$$

where

$$\beta = \frac{1}{t_3} \ln \frac{J_D}{J_0} \tag{7}$$

Where J_0 is the mass moment of inertia of the rotating units of the diesel engine, reduced to the angular velocity of the crankshaft and corresponding to the circular frequency of rotation $\omega_y(t)$ of the main generator armature; J_d is the reduced mass moment of inertia of all rotating and translationally moving masses of the diesel engine at the end of the time $t = t_з$ for the completion of its launch.

In this case $J_y = const$ (for all rotating masses of the shaft and armature of the main generator in the mode of its operation as an accelerating electric motor for diesel masses during the time) $t = 0 \div t_3$)

We specify the torque functions:

- Propulsive, attached to the shaft of the anchor

$$M_y(t) = a_0 + a_1 t + ... \tag{8}$$

- forces of resistance to rotation of diesel masses

$$M_d(t) = d_0 + d_1 t + ... \tag{9}$$

where a_i and d_i and - coefficients of polynomials - known constant values determined for the conditions:

$$t = 0, \text{ when } M_y(0) = a_0; M_d(0) = d_0 \tag{10}$$

$$t = t_3, \text{ when } M_y(t) = a_0 + a_1 t = M_{ym}, M_d(t) = d_0 + d_1 t = M_{dm} \tag{11}$$

Under these assumptions, we obtain the following system of equations

$$\begin{gathered}(J_я + J_0 e^{\beta t})\frac{d^2\phi_я}{dt^2} + \frac{d\phi_я}{dt}\beta J_0 e^{\beta t} + J_0 e^{\beta t}\frac{d^2\phi_д}{dt^2} + \frac{d\phi_д}{dt}\beta J_0 e^{\beta t} = a_0 - d_0 + t(a_1 - d_1), \\ J_0 e^{\beta t}\frac{d^2\varphi_y}{dt^2} + \frac{d\varphi_y}{dt}\beta J_0 e^{\beta t} + J_0 e^{\beta t}\frac{d^2\varphi_d}{dt^2} + \frac{d\varphi_d}{dt}\beta J_0 e^{\beta t} + C_3\varphi_d = -d_0 - d_1 t\end{gathered} \tag{12}$$

In this system of equations, we change functions based on and: φ_y and φ_d:

$$\frac{d\varphi_d}{dt} = \omega_d; \ \frac{d\varphi_y}{dt} = \omega_y, \ \frac{d^2\varphi_d}{dt^2} = \frac{d\omega_d}{dt}; \frac{d^2\phi_y}{dt^2} = \frac{d\omega_y}{dt} \tag{13}$$

and then we perform the differentiation of all terms of equations (4) - (5) concerning time t, taking into account conditions (6), (7), and after dividing all terms by $J_0 e^{\beta t}$ a new system of equations, we obtain

$$\frac{d^2\omega_я}{dt^2}\left(\frac{J_я}{J_0}e^{-\beta t}+1\right)+2\beta\frac{d\omega_я}{dt}+\beta^2\omega_я+\frac{d^2\omega_д}{dt^2}+2\beta\frac{d\omega_д}{dt}+\beta^2\omega_д=\frac{a_1-d_1}{J_0}e^{-\beta t}=в_1e^{-\beta t} \quad (14)$$

$$\frac{d^2\omega_я}{dt^2}+2\beta\frac{d\omega_я}{dt}+\beta^2\omega_я+\frac{d^2\omega_д}{dt^2}+2\beta\frac{d\omega_д}{dt}+\beta^2\omega_д+\frac{C_3\omega_д}{J_0}e^{-\beta t}=-\frac{d_1}{J_0}e^{-\beta t}. \quad (15)$$

We perform additional averaging of functions over a period of time t_3

$$A_y=\frac{1}{t_3}\int_0^{t_3}\left(\frac{J_y}{J_0}e^{-\beta t}+1\right)dt=1+\frac{J_y}{J_0}\ln\frac{J_d}{J_0}\left(1-e^{-\ln\frac{J_d}{J_0}}\right) \quad (16)$$

$$P_d^2=\frac{1}{t_3}\int_0^{t_3}\left(\frac{C_3}{J_0}e^{-\beta t}dt=\frac{C_3}{J_0}\ln\frac{J_d}{J_0}\left(1-e^{-\ln\frac{J_d}{J_0}}\right) \quad (17)$$

For systems (16), (17), we accept the initial conditions as zero $\frac{d\varphi_d^2}{dt^2}=0$ and $\frac{d\varphi_d}{d_t}=d\varphi_y/dt$. Let's solve the solution by the method of operational calculus [13] and get the images of the solution:

$$\omega_y(p)(A_y p^2+2\beta p+\beta^2)+\omega_d(p)(p^2+2\beta p+\beta^2)=\frac{в_1 p}{p+\beta} \quad (18)$$

$$\omega_y(p)(p^2+2\beta p+\beta^2)+\omega_d(p)(p^2+2\beta p+P_d^2)=-\frac{d_1 p}{p+\beta} \quad (19)$$

To solve this system, as an algebraic one concerning images, we first compose the determinant from the coefficients at $\omega_y(p)$ and $\omega_y(p)$

$$\Delta_2=\begin{vmatrix} A_я p^2+2\beta p+\beta^2 & p^2+2\beta p+\beta^2 \\ p^2+2\beta p+\beta^2 & p^2+2\beta p+P_д^2) \end{vmatrix}= \quad (20)$$
$$=(A_я p^2+2\beta p+\beta^2)(p^2+2\beta p+P_д^2)-(p^2+2\beta p+\beta^2)^2.$$

Denote $A_y p^2+2\beta p+\beta^2=c_1$; $p^2+2\beta p+P_d^2=c_2$; $(p^2+2\beta p+\beta^2)^2=c_3$

To find the last function, we solve the equation $\Delta_2=0$. In doing so, we consider the conditions that $c_1>c_3$ and $c_2>c_3$, a $c_1c_2>>c_3^2$. Therefore, we obtain an approximate solution in the form

$$\Delta_2\approx A_y(p^2+2\beta_1 p+{\beta_2}^2)(p^2+2\beta p+P_d^2)=0 \quad (21)$$

whose roots look like

$$p_{1,2}=-\beta_1\pm i\alpha_1=-\beta_1\pm i\sqrt{\beta_2^2-\beta_1^2} \quad (22)$$

$$p_{3,4} = -\beta \ \pm i\alpha_3 = -\beta \ \pm i\sqrt{P_\partial^2 - \beta^2} \tag{23}$$

And now, we get the images of functions by an approximate method

$$\omega_я(p) = \frac{1}{\Delta_2}\frac{p}{p+\beta}\begin{vmatrix} в_1 & p^2+2\beta p+\beta^2 \\ d_1 & p^2+2\beta p+P_\partial^2 \end{vmatrix} \approx \frac{pв_1}{(p+\beta)(p+\beta_1-i\alpha_1)(p+\beta_1+\alpha_1)}, \tag{24}$$

$$\omega_Д(p) = \frac{1}{\Delta_2}\frac{p}{p+\beta}\begin{vmatrix} A_я p^2+2\beta p+\beta^2, & в_1 \\ p^2+2\beta p+\beta^2{}_1 & -d_1 \end{vmatrix} \approx \frac{pd_1}{(p+\beta)(p+\beta_1-i\alpha_3)(p+\beta_1+\alpha_3)}, \tag{25}$$

then the originals of the approximate solutions

$$\omega_я(t) = \frac{в_1 e^{-\beta t}}{A_я\left[(\beta-\beta_1)^2+d_1^2\right]}\left[1+\left(\frac{(\beta-\beta_1)}{\alpha_1}\sin\alpha_1 t_3 - \cos\alpha_1 t_3\right)\cdot e^{(\beta-\beta)t}\right] \tag{26}$$

$$\omega_\partial(t) = -\frac{d_1 e^{-\beta t}}{P_\partial^2-\beta^2}\left[1-\cos\alpha_3 t\right] \tag{27}$$

At the end of the diesel $t = t_3$ start time, we obtain from (26), (27) the values of the angular velocities.

$$\omega_я(t_3) = \omega_{я3} = \frac{в_1 e^{-\ln\frac{J_Д}{J_0}}}{A_я\left[(\beta-\beta_1)^2+\alpha_1^2\right]}\left[1+\left(\frac{(\beta-\beta_1)}{\alpha_1}\sin\alpha_1 t_3 - \cos\alpha_1 t_3\right)\cdot e^{\ln\frac{J_Д}{J_0}-\beta_1 t}\right] \tag{28}$$

$$\omega_\partial(t) = -\frac{d_1}{P_\partial^2-\beta^2}e^{-\ln\frac{J_Д}{J_0}}\left[1-\cos\alpha_3 t_3\right] \tag{29}$$

To estimate the average values of the function$\omega_{ys}(t)$

$$\frac{\partial\omega_{YS}}{dt} = \frac{M_{YS}-M_{DS}}{J_{DS}} \tag{30}$$

where M_YS-M_DS is the arithmetic mean values of the driving moments and resistances for the time t=0÷t_3 , and we get

$$\omega_{YS}(t) = \frac{M_{YS}-M_{DS}}{J_{YS}}t, \tag{31}$$

The resulting function of the angular velocity of the engine acceleration model is represented by the equation

$$\omega_Y(t) = \omega_{YS}(t) + \omega_Y(t_3) \tag{32}$$

3 Results

We accept [2] that during the start, after 3-5 seconds of the process, flashes begin in certain cylinders. And we're looking at the first 5 seconds $t_3 = 0 \div 5$. Computational studies of changes in angular velocity and driving moment for two variants of electrical circuits, existing and recommended in the time interval from 0-5 seconds, were carried out. The calculated values of the angular velocities of the anchor are given in Table 1.

Table 1. The calculated values of the angular velocities of the anchor.

t, c	J_d, kgms^2	serial scheme				recommended scheme			
		$\omega_{yc}(t)$, c^{-1}	$\omega_{y1}(t)$, c^{-1}	$\omega_y(t)$, c^{-1}	$M_d^c(t)$, Nm	$\omega_{yc}(t)$, c^{-1}	$\omega_{y1}(t)$, c^{-1}	$\omega_y(t)$, c^{-1}	$M_d^p(t)$, kgm
0.8	3	0.	-0.01	0.01	2800	0.8	0.2	1.0	2200
1	6	0.5	-0.06	0.44	2600	1.5	0.25	1.75	2500
2	11.7	3.2	-0.25	2.95	1800	5.1	0.36	5.46	2700
3	17	5.8	- 0.56	5.24	1200	8.7	0.6	9.3	1700
4	23	8.5	-0.99	7.41	950	12.3	0.72	13.02	1000
5	30	11.7	-1.51	10.19	800	15.9	0.65	16.55	750

4 Conclusion

1. The diesel start-up scheme on diesel locomotives of the UzTE16M type is characterized by the functions of the reduced mass moment of inertia of the diesel engine $J_d(t)$, the driving moment $M_d^c(t)$and the function of the angular velocity $\omega_y^c(t)$.).

2. The solution obtained makes it possible to calculate the driving moment $M_d^p(t)$) and the range of change in the angular velocity $\omega_y^p(t)$when starting the diesel generator set of diesel locomotives UzTE16M for comparison with experimental data.

3. When using the recommended scheme, an increase in the driving moment $M_d^p(t)$ according to column 10 and the angular velocity of acceleration $\omega_y^p(t)$ of the movement of column 9 of Table 1 is achieved.

References

1. Djanikulov A.T. Modeling of dynamic phenomena in the mechanisms of starting diesel main locomotives. Tashkent. p. 21, (2006).
2. Klinachev N.V., Voronin S.G. Simulation of the process of starting an internal combustion engine with an electric starter. The Journal "Bulletin of South Ural State University. Series "Power Engineering", No.2, Vol. 15), pp. 49-56. (2015)
3. Anikeev I.P., Kornev A.N. Improved scheme of the condenser system of diesel start-up. Lokomotiv - The journal Locomotive, No.4, p. 29. (2000)
4. Kasimov O. T., Djanikulov A. T., and Mamayev S. I. Modeling the bending of the tire surface by pads during braking. In AIP Conference Proceedings, Vol. 2402, No. 1, p. 070030. (2021).
5. Djanikulov A. T., Mamayev S. I., and Kasimov O. T. Modeling of rotational oscillations in a diesel locomotive wheel-motor block. In Journal of Physics: Conference Series, Vol. 1889, No. 2, p. 022017. (2021).
6. Kasimov O., Fayzibayev S., Djanikulov A., and Mamayev, S. Numerical studies for estimation of temperature fields in bandage material during locomotive braking. In AIP Conference Proceedings, Vol. 2432, No. 1, p. 030025. (2022).
7. Valiev M., and Kosimov, K. Diagnosing the technical condition of the diesel cylinder-piston group. In E3S Web of Conferences, Vol. 264, p. 04061. (2021).
8. Yusupov D. T., Kutbidinov O. M., Samadov S. A., and Abdullaev, E. S. Investigation of winding faults of traction transformers. In IOP Conference Series: Earth and Environmental Science, Vol. 868, No. 1, p. 012026, (2021).
9. Ablyalimov O., Khamidov O., and Domanov K. Determination of Locomotive Traction Efficiency on the Section of Marokand-Kattakurgan of Uzbek Railway. In

Networked Control Systems for Connected and Automated Vehicles: Vol. 1, pp. 671-680, (2022).
10. Khamidov O., and Udalova D. Technical and Economic Efficiency of Intelligent Data Analysis on the Railways of the Uzbekistan Republic. In International Scientific Siberian Transport Forum TransSiberia-2021: Vol. 1, pp. 230-239. (2022).
11. Khamidov O. R., and Grishchenko A. V. Locomotive asynchronous traction motor rolling bearing fault detection based on current intelligent methods. In Journal of Physics: Conference Series, Vol. 2131, No. 4, p. 042084. (2021).
12. Grishchenko A. V., Kruchek V. A., Kurilkin D. N., and Khamidov O. R. Diagnostics of the technical condition of rolling bearings of asynchronous traction motors of locomotives based on data mining. Russian Electrical Engineering, Vol. 91, 593-596. (2020).
13. Ablyalimov O., Petrochenko S., and Kodirov N. Analyzing the Movement of a Freight Train at Stops on Flat Sections of the Railway. In Networked Control Systems for Connected and Automated Vehicles: Vol. 2, pp. 165-171. (2022).
14. Petrochenko, S., Ablyalimov, O., Kodirov, N., and Rakhmaev, R. Determining Optimal Electrical Discharge Machining Modes for the Disc Tab Grooves of Small-Size By-Passengine. In Networked Control Systems for Connected and Automated Vehicles: Vol. 2, pp. 261-269. (2022).
15. Khamidov O., Yusufov A., Jamilov S., and Kudratov S. Remaining life of main frame and extension of service life of shunting Locomotives on railways of Republic of Uzbekistan. In E3S Web of Conferences, Vol. 365, p. 05008. (2023).
16. Khamidov O., Yusufov A., Kudratov S., and Yusupov, A. Evaluation of the technical condition of locomotives using modern methods and tools. In E3S Web of Conferences, Vol. 365, p. 05004. (2023).
17. Romanov V.I. Improvement of diesel locomotive start-up systems. Interuniversity collection of proceedings. Bulletin of Tashkent Institute of Railway Engineers, Vol.9(161), pp.37-42, (1980).