Analysis of the effectiveness of using the block for limiting the vibrations of the load on the mechanism of movement of the bogie with various control systems

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Abstract. Damping load vibrations in an electric crane drive is an urgent topic for research. The swinging load has a negative effect on the mechanical part of the device, leading to its wear, and on the entire control system as a whole. To combat the swaying of the load, it is proposed to install a vibration damping block created on the basis of an equation describing the dependence of the change in the deviation of the load on the equilibrium position in the plane of movement of the cart. The control signals in the vibration damping unit are the parameters of truck acceleration, suspension length, and weight of the load. At the output of the vibration damping unit, a speed task is formed. A block diagram of the trolley drive control system has been developed. Both scalar systems and systems with direct torque control are used on trolley travel mechanisms. The paper analyzes the efficiency of using the vibration damping unit when using different control systems on the movement mechanism of the bridge crane trolley.

1 General information

The travel drive of the overhead crane trolley operates in intermittent mode, with frequent starts and brakes, as well as reverse.

Loads of crane mechanisms change in absolute value from nominal to idle and in direction in lifting and braking modes.

The considered crane operates indoors in the absence of wind load.

Since the reduced moment of inertia of the mechanism and the load for the mechanisms of horizontal movement of loads exceeds the moment of inertia of the rotating parts of the electric motor by 10-30 times, the starting time, and therefore, the performance of the crane as a whole, significantly depends on the dynamic capabilities of these mechanisms.

For movement mechanisms, the value of the optimal average acceleration (*a*), which is the starting point for establishing the necessary average accelerating moments, is 0,2 m/s^2. When choosing accelerations, one should keep within certain boundary conditions: for squirrel-cage asynchronous motors of all types, the maximum starting time should be less than 3 seconds. The maximum acceleration should not exceed the values at which the adhesion of the wheels to the rails is disrupted, as well as an unacceptable sway of the load occurs.

Swinging the load when starting and braking movement mechanisms is an undesirable process, since it causes additional loading of structures, is unsafe for the surrounding personnel and reduces the performance of the mechanisms. The swing of the load on the rope occurs when the mechanism is accelerated or decelerated. The swing of the load is characterized by the angle of deflection of the load rope from the vertical.

It is possible to reduce the fluctuations of the load by using a method based on the use of an intensity generator. This system will reduce the value of the dynamic moment, fluctuations of the load, and make the necessary adjustments in the specified range of the transient process.

1.1 Vibration damping unit

During the movement of the trolley, the suspended load sways, having a negative effect on both the mechanical part and the control system itself, therefore it is necessary to use devices to limit the oscillation of the load.

To develop a block system for limiting vibrations, on the basis of [1], an equation was obtained that describes the law of change in the deviation of the load from the equilibrium position in the plane of movement of the trolley.

$$\frac{d^2 \cdot x_0}{dt^2} + \frac{K_{sw}}{m_g} \cdot \frac{dx_0}{dt} + \left(1 + \frac{m_g}{m_t}\right) \cdot \frac{g}{l_p} \cdot x_0 = \frac{k_t}{m_t} \cdot M_{din.t},$$

where m_g –this is the mass of the load and the load handling device, m_t – is the sum of the masses of the mechanism and the drive of the bogie, K_{sw} – this is the aspect ratio, x_0 – is the deviation of the load from the

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equilibrium position, k_t – this is the aspect ratio, l – this is the length of the suspension, g – is the acceleration of gravity, $M_{din.t}$ – this is the dynamic moment of the cart.

The frequency of oscillations of the load, according to [1], is determined by the ratios of the weight of the load m_g, trolley weight m_t, suspension length l_p

$$\Omega_x = \sqrt{\frac{g}{l_p} \cdot \left(1 + \frac{m_g}{m_t}\right)}.$$

Vibration amplitude

$$A_x = \frac{k_t \cdot M_{din.t}}{\Omega_x^2 \cdot m_t}.$$

On fig. 1 shows a diagram of a device that allows you to limit the swinging of the load when moving the trolley.

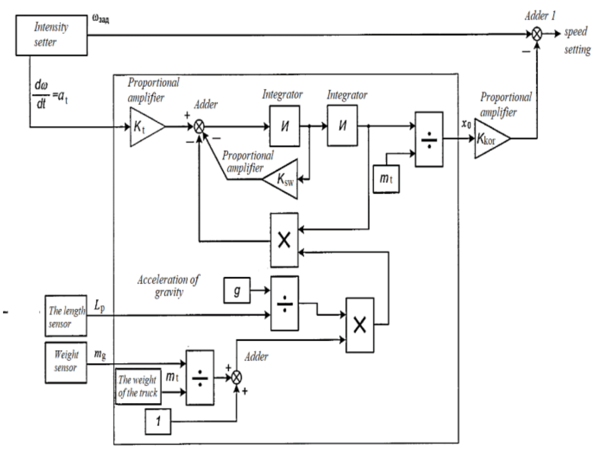

Fig. 1. Block diagram of vibration damping unit.

The input control signals of the vibration damping unit are the trolley acceleration dω / dt - the output of the intensity generator unit, the length of the suspension and the weight of the load (in practice, it is measured using sensors). At the output of the dividing unit, the value of the angle of deviation of the load from the vertical x_0 is formed, which is fed to the proportional amplifier with the scaling factor k_{kor}. The signal received at the amplifier is subtracted from the speed reference signal formed in the ramp generator, the obtained value is the input signal of the speed controller, forming the speed reference.

1.2 Bogie drive control system

In fig. 2 shows a diagram of the control system, where it can be seen that the generated speed reference is the input signal of the SC unit (speed regulator), from which the control signal goes to the current regulator CC, then through the power unit to the electric motor M. At start-up, at the initial stage, point load suspension with acceleration equal to const accelerates (depends on the value of the IS setting). Inertial forces act on the load, which leads to its deviation from the vertical. After the expiration of the time, a value appears on the totalizer 1 leading to the exit of the SC from the limiting mode, this phenomenon is observed until the drive reaches the set speed. Accordingly, at the end of the transient process, the acceleration of the drive decreases, and, as a consequence, the value of the dynamic torque on the motor shaft decreases and the load catches up with the suspension point. When the transient is complete, which happens after reaching the set speed, there is no load deflection.

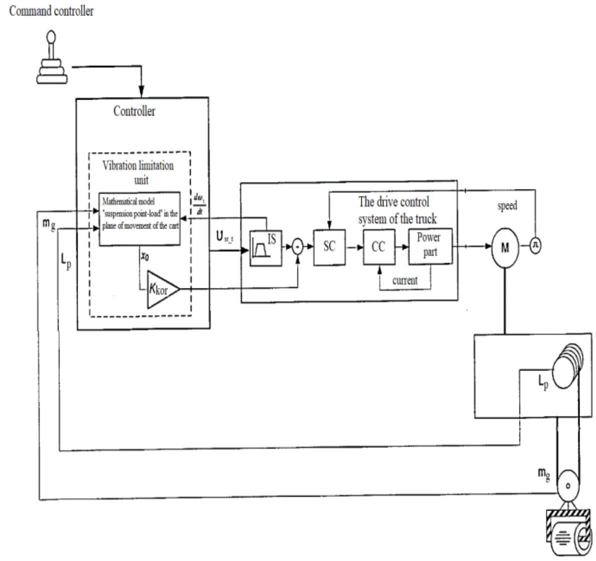

Fig. 2. Block diagram of the control system of the bogie drive.

1.3 Mathematical model of the vibration damping unit

The mathematical model in the Matlab [2-10] environment of the vibration damping unit is shown in Fig. 3.

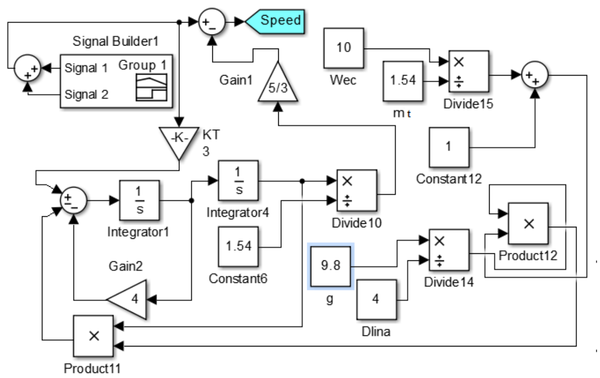

Fig. 3. Oscillation damping block in Matlab.

2 Control systems

2.1 Vector system

For the study, at the initial stage, a standard vector control system was taken, the implementation of which in the Matlab environment is shown in Fig. 4.

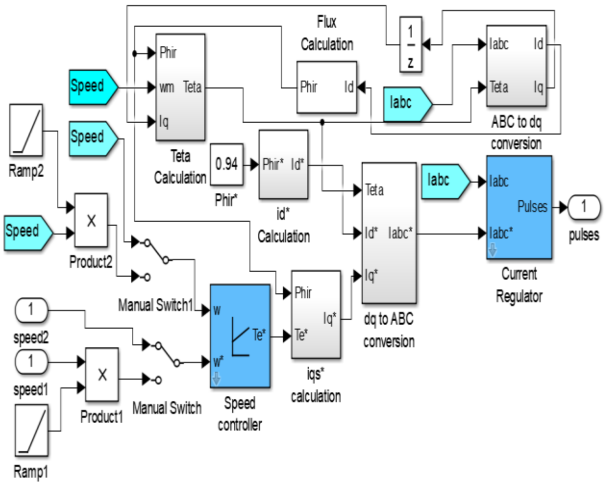

Fig. 4. Vector control system block.

2.2 Direct torque control

Further, in the Matlab environment for research, on the basis of a standard system with direct torque control, its mathematical model was presented in Fig. 5.

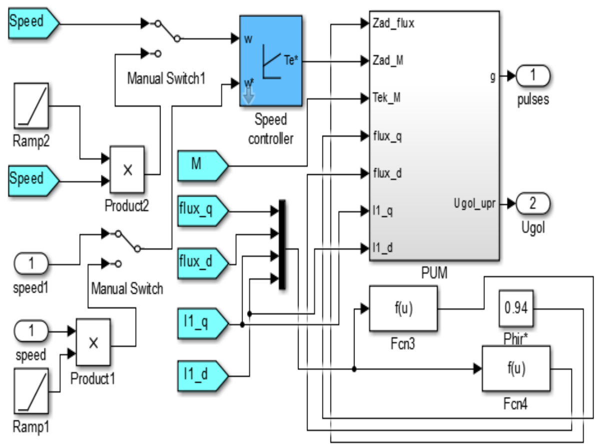

Fig. 5. Direct torque control unit.

3 Simulation results

3.1 Vector system

At the initial stage of the study, the modeling was carried out without a vibration damping unit, the results obtained in this case were compared with the results obtained at the next stage of the study in the same system, but with the addition of a vibration damping unit. In fig. 6 shows the transient process of speed formation in a vector system without a vibration damping unit and with a vibration damping unit.

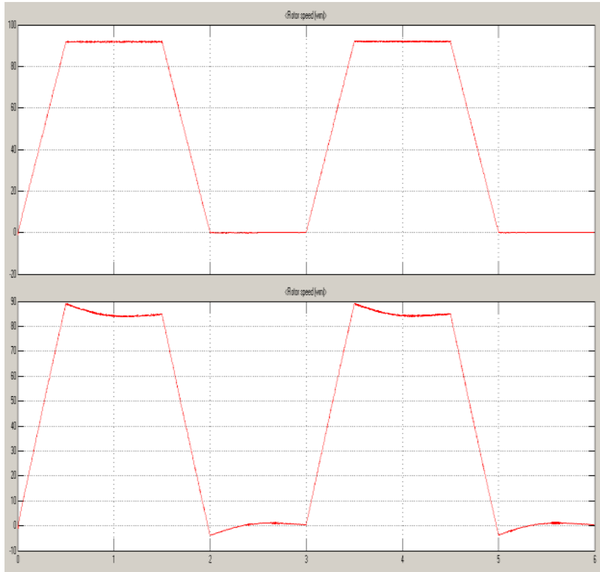

Fig. 6. Formation of motor speed.

In fig. 7 shows the transient process of the formation of the moment in the vector system without the vibration damping unit and with the vibration damping unit.

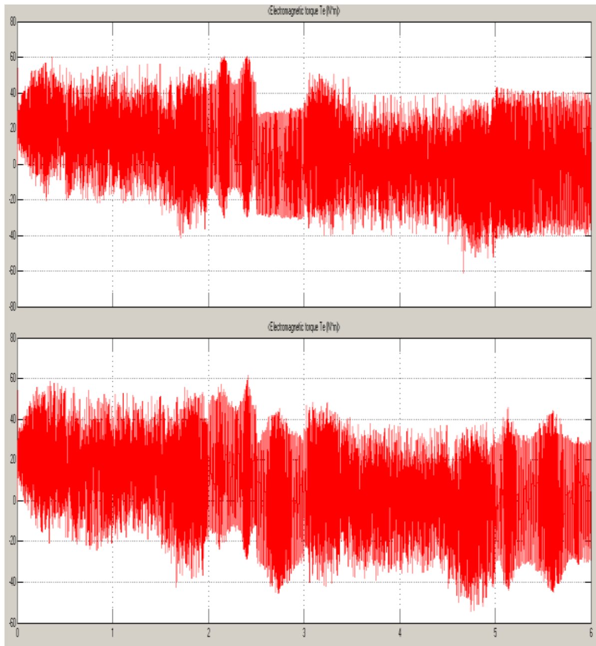

Fig. 7. Formation of engine torque.

The use of the vibration damping unit makes it possible to increase the smooth movement of the trolley.

3.2 Direct torque control

In fig. 8 shows the transient process of speed formation in a system with direct torque control without a vibration damping unit and with a vibration damping unit.

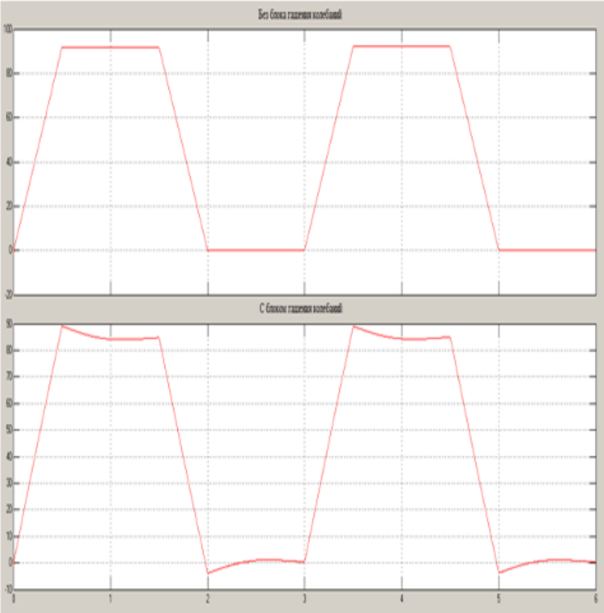

Fig. 8. Formation of motor speed.

In fig. 9 shows the transient process of the formation of a torque in a system with direct torque control without a vibration damping unit and with a vibration damping unit.

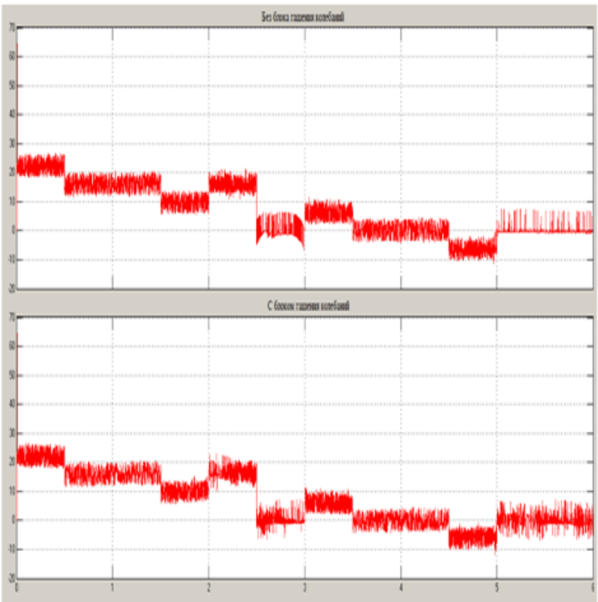

Fig. 9. Formation of engine torque.

From the graphs obtained, it can be seen that the formation of speed in a system with a block for damping load fluctuations occurs more smoothly, you can also notice some suppression of torque fluctuations.

3.3 Practical implementatoin

In the practical implementation of the proposed system, it is possible to directly measure the weight of the load on the hook by means of force meters or external force sensors installed in the crane structure, as well as indirectly determine the weight of the load based on the energy indicators of the electric drive of the lifting mechanism, but this is not necessary on the crane in question, since it is used for moving rolls of standard weight.

It is possible to determine the length of the suspension according to the data of the drum rotation angle sensor, or by recalculation, depending on the speed of the electric drive, the design data of the lifting mechanism. In this case, the accumulation of an error in determining the length of the suspension will occur, which can be corrected by using the limiter of the lifting mechanism (the load gripper is in the upper position) - when it is triggered, enter a constant equal to the minimum length of the suspension. The maximum value of the suspension length can be determined during the adjustment of the overhead crane using the formula for the oscillation period of a mathematical pendulum (valid for a physical pendulum at small oscillations). By measuring the time of the oscillation period of the load at the maximum suspension length, you can determine the suspension length.

4 Conclusion

Based on the analysis of the simulation results, it can be concluded that the vibration damping unit is operational when both control systems are used. Smooth speed formation occurs when using both a vector control system and a system with direct torque control. However, torque fluctuations are initially smaller in a direct torque control system. The use of the vibration damping block will allow you to drink some damping of the torque fluctuations.

References

[1] V.V. Kolmykov, S.A. Serikov, Mathematical model of load rocking in the electrical system of a bridge crane, Automated control systems in production, Materials of the III international scientific and practical conference, Dnepropetrovsk, 110-116 (2006)

[2] V.A. Podobed, Mathematical modeling of wind loads on the mechanisms of movement of portal cranes with a straight arrow, Vestnik MSTU: proceedings of the Murmansk state technical University 9, 318-331 (2006)

[3] Y.I. Gracheva, N.A. Alimova, Calculating Methods and Comparative Analysis of Losses of Active and Electric Energy in Low Voltage Devices, International Ural Conference on Electrical Power Engineering (UralCon), 361-367 (2019)

[4] Y.I. Gracheva, O.V. Naumov, Estimation of Power Losses in Electric Devices of the Electrotechnical Complex, International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM), 6 (2019)

[5] V.N. Meshcheryakov, V.V. Danilov, Sh.R. Khasanov, S. Valtchev, Minimization of the

stator current in induction motor with defined load on the shaft by maintaining optimum absolute slip, Kazan, SES 2019, E3S Web of Conferences, 01036 (2019)

[6] V.N. Meshcheryakov, D.V. Lastochkin, Z.M. Shakurova, S. Valtchev, Kazan, SES 2019, E3S Web of Conferences, 01037 (2019)

[7] A.M. Abakumov, D.G. Randin, Research of Dual-Mass Oscillation System with Linear Motor, International Conference on Industrial Engineering, Applications and Manufacturing (ICIEM), Sochi, Russia, 1-5 (25-27 March 2019)

[8] T.V. Sinykova, E.V. Sentsov, A.V. Sinyukov, Neural Network Speed Observers, Proceedings 2019 1st International Conference on Control Systems, Mathematical Modelling, Automation and Energy Efficiency (SUMMA), Lipetsk, Russia, 288 (2019)

[9] T.V. Sinykova, V.E. Gladyshev, A.V. Sinyukov, Methods for Reducing Electromechanical Oscillations in Conveyor Control Systems, Proceedings 2019 1st International Conference on Control Systems, Mathematical Modelling, Automation and Energy Efficiency (SUMMA), Lipetsk, Russia, 435 (2019)

[10] R.T.Y. Thien, Y. Kim, Decentralized Formation Flight via PID and Integral Sliding Mode Control, Aerospace Science and Technology, Elsevier Science Publishing Company, Inc. **81**, 322-332 (2018)

[11] V. Meshcheryakov, T. Sinykova, A. Sinyukov, A. Boikov, R. Mukhametzhanov, Modeling and analysis of vector control systems for asynchronous motor, High Speed Turbomachines and Electrical Dreves Conference 2020 (HSTED-2020), Prague, Czech Republic, 01001 (9 July 2020)

[12] O. Rabiaa, B. Mouna, D. Mehdi, S. Lassaad, Scalar speed control of dual three phase induction motor using PI and IP controllers, International Conference on Green Energy Conversion Systems (GECS), Hammamet, Tunisia, 1-6, 23-25 (March 2017)

[13] A. Pugachev, Efficiency increasing of induction motor scalar control systems, International Conference on Industrial Engineering, Applications and Manufacturing (ICIEM), St. Petersburg, Russia, 1-5 (16-19 May 2017)

[14] P. Verma, R. Saxena, A. Chitra, R. Sultana, Implementing fuzzy PI scalar control of induction motor, IEEE International Conference on Power, Control, Signals and Instrumentation Engineering (ICPCSI), Chennai, India, 1674-1678 (21-22 September 2017)

[15] J. Peña, E. Diaz, Implementation of V/f scalar control for speed regulation of a three-phase induction motor, IEEE ANDESCON, Arequipa, Peru, 1-4 (19-21 October 2016)