Limiting Dynamic Loads of Electric Drive with Flexible Couplings and Variable Inertia Moment

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***Abstract*—This The paper addresses some issues of design of electric drives for mechanisms and machines with varied inertia, which are operating under severe dynamic conditions are noted. A logarithmic decrement has been taken as the most suitable limit of dynamical loads. The standard classification of electric drive designs upon criterion of mechanical impedance of the speed-torque characteristic of electric drives has been provided. It is shown that it is possible to get a marginal limitation of oscillations providing the greatest possible operational life of the machine. Missing or wrong information of a current inertia of the second mass compounds represents a problem for selection of an optimum adjustment of electric drive regulator. This paper studies different designs of electric drives to damp vibrations within the specified inertia range. The results of analysis of dynamic behavior of electric drives obtained with simulation have been provided. Recommendations for these electric drives have been elaborated. It is proven that intelligent control systems based on fuzzy controllers and artificial neuron network are most promising.**

Keywords—electric drive; elastic linkage; dynamical loads; intelligent control system

I. INTRODUCTION

Modern machines must meet strict requirements to capability, reliability and transient performance. Many of these specifications are antagonists. For example, productivity improvement requires increase of the motion speed to reduce mass and inertia moments of moving member of electric drives and in its turn to use as great as practicable loads. It involves necessity to take into account mechanical portion of electric drives that, as is known, leads to a poor accuracy of guided path and increase of dynamic loads due to elastic deflection. Most modern process machines, such as industrial robots, CNC cutting machines, lift-and-carry equipment are operated with variable parameters of mechanical portions of electric drives. These parameters change incalculably depending on a current configuration of the mechanical portion, cargo mass etc. Increase of dynamical loads results in a high wear of mechanical members and clearances in the mechanical transmission that definitely reduce reliability of the machine. In order to meet the above conflicted requirement it is necessary to reduce dynamic loads in an appropriate way to ensure a high performance of the machine within the whole parameter range of the mechanical portion of electric drives [1]-[6].

II. MATHEMATICAL DESCRIPTION OF THE ELECTRIC DRIVE WITH ELASTIC LINKAGE

Generalized schematic structure of the electric drive with elastic linkage and a clearance is shown in Fig 1. Mechanical portion of the electric drive is represented as a dual-mass, where J_1 and J_1 are inertias according to the first and the second mass; C_{12} is elasticity of the function-generating mechanism. The mechanical impedance of the speed-torque characteristic of the electric drive *β(p)* specifies the design of the electric drive [7]-[8]. Expressions for the most known designs of electric drives are given in Table 1. Thus, the design of the electric drive shown on Fig. 1 can be considered as generalized and valid for most applications.

The clearance makes the system nonlinear. The solution of this problem is divided into two parts. First, before clearance taking-up, the movement represents a single-mass; and the inertia is J_1. At that, the speed of the first mass is increased up to $\omega_{1C;}$ and the speed of the second mass is equal to zero. When the clearance is eliminated, the mechanical system is a dual-mass; and there are dynamic loads caused by elasticity. The flexible torque J_{12} applied by the spring is

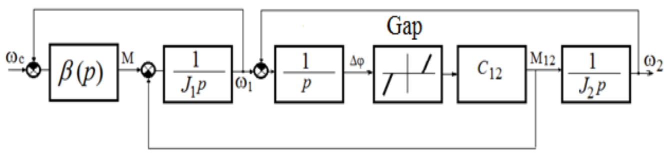

Fig. 1. Generalized schematic structure of the electric drive with elastic linkage and clearance

TABLE I. MECHANICAL IMPEDANCE FOR SOME DESIGNS OF ELECTRIC DRIVES

Electric drive providing position torque control	$\beta(p)=\beta_a\dfrac{T_1p+1}{(T_2p+1)(T_3p+1)}$
Electric drive providing static speed control	$\beta(p)=\dfrac{\beta_a}{T_1p+1}$
Electric drive providing floating speed control and position control	$\beta(p)=\dfrac{\beta_a(T_1p+1)}{T_2p(T_3p+1)}$

$$M_{12} = J_2\varepsilon - J_2\varepsilon e^{-\alpha t}\cos\Omega_{12}t + \frac{C_{12}\omega_{1C}}{\Omega_{12}} e^{-\alpha t}\sin\Omega_{12}t$$

Here, along with the useful torque, there are two oscillation components. The first component is caused by the setting, and the second is due to the speed differential ω_{1C} at the time of clearance closing. Thus, the aggregate amplitude of the elastic torque shall be

$$M_{12max} = \sqrt{(J_2\varepsilon)^2 + \left(\frac{C_{12}\omega_{1C}}{\Omega_{12}}\right)^2}$$

Possible ways of reducing dynamic loads are considered below.

III. Proposed Solutions

Analysis of the expression for the elastic torque has shown that dynamic loads of the mechanical equipment of the electric drive with elastic linkages and a clearance can be reduced as follows:

- increase of damping capacitance of the electric drive, i.e. α increase;
- reduction of rate of clearance closing, i.e. reduction of ω_{1C};
- smooth loading, or reduction of ε.

In order to determine the damping capacitance of the electric drive, the logarithmic decrement term has been introduced [7]

$$\lambda = \frac{2\pi}{\Omega_{12}}$$

Investigations have shown that the logarithmic decrement essentially depends on static stiffness of the speed-torque characteristic of the electric drive. Fig. 2 shows the dependence between logarithmic decrement and static stiffness of the speed-torque characteristic of the electric drive.

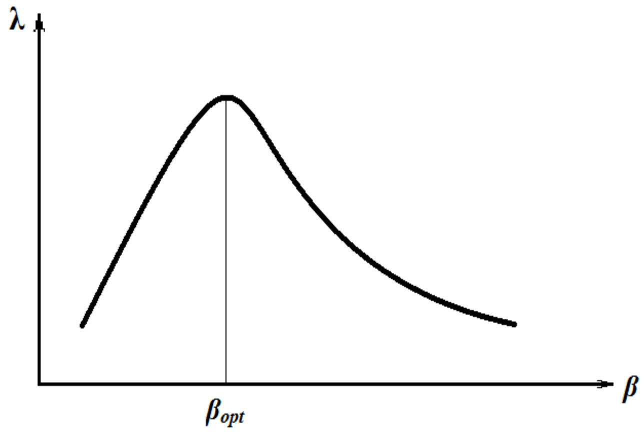

Fig. 2. Function of the logarithmic decrement

The efficient stiffness enables selection of parameters for speed and current configuration of the electric drive. Unfortunately, parameters of mechanical equipment of the most electric drives vary during operation. Thus, regulator settings of a classical electric drive design shall be changed too. It is often impossible because these changes are unpredictable and occur within a wide range according to the law sophisticated and unknown in advance.

The second way of reducing dynamic loads is to decrease the speed differential at clearance closing. It can be implemented by selection of a power-up sensor operating as per the law shown in Fig. 3. This law ensures the speed differential within ω_1 at clearance closing. The only thing that matters is clearance closing within t_1, and t_1.

A power-up sensor operating in conformity with the law shown in Fig. 4 demonstrates good results too. Under these conditions, the first oscillation component is also reduced due to smooth loading. This method is efficient for small clearances only. With the clearance increasing, closing takes place at the increased speed differential, which results in gain of the second component.

Classical methods fail at designing the electric drive with variable parameters of the mechanical portion that can provide a high dynamic behavior. Intelligent control systems are used to solve this problem [9]-[17]. The example of the intelligent control system based on the artificial neural network is given in Fig. 5.

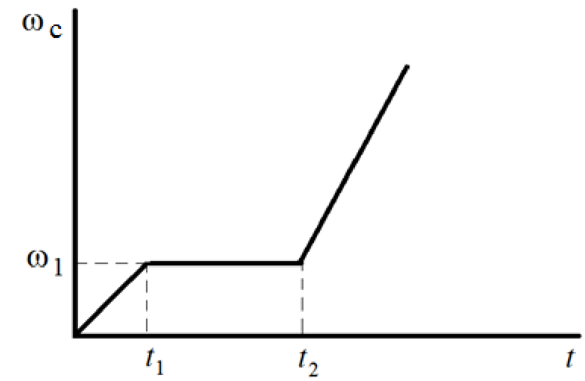

Fig. 3. Rate setting

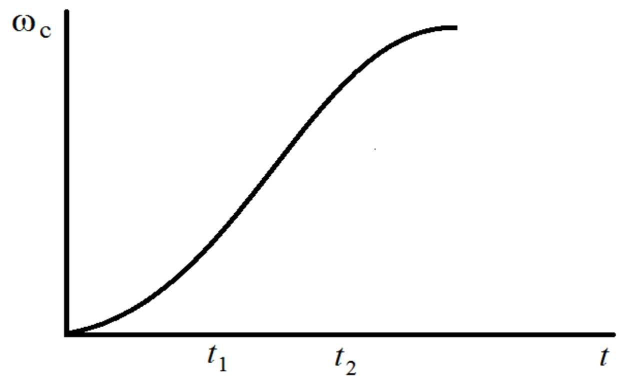

Fig. 4. Smooth rate setting

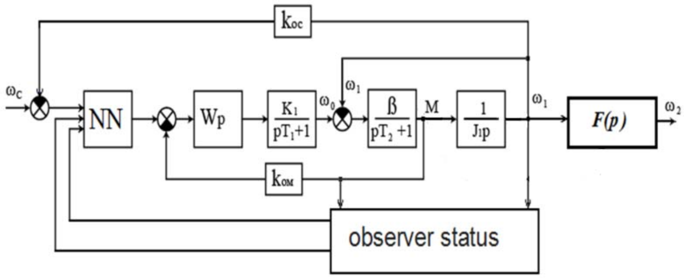

Fig. 5. Intelligent control system

IV. CONCLUSIONS

Dynamic loads of the electric drive with elastic linkage and clearance can be best limited when:

- a power-up sensor with a smooth setting is selected;
- the electric drive is adjusted to provide an optimum stiffness of the speed-torque characteristic;
- a design involving an intelligent control system is selected for the electric drive with variable parameters of the mechanical portion.

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REFERENCES

[1] A.K.M. Azad, and M.O. Tokhi, *Flexible Robot Manipulators. Modelling, simulation and control*, Control Engineering Series, 68, 2008.

[2] A.K.M. Azad, M.O. Tokhi, "Modelling of a single-link flexible manipulator system: Theoretical and practical investigations", *IET Digital Library,* 2008. DOI 10.1049/PBCE068E.

[3] S. Mogberg, "Modeling and Control of Flexible Manipulators", *Linköping studies in science and technology*, Dissertations №1349, 2010.

[4] D.A. Blagodarov, A. A. Kostin, A. M. Reznikovskiy, Yu. M. Safonov and S.Yu. Chernikov, "Development of Control Systems of Electric Drives with Flexible Mechanics", Russian Electrical Engineering, 2015, vol. 86, no. 1, pp. 18-21.

[5] D.A. Blagodarov, L.O. Gosteva, Yu. M. Safonov, and A.M. Reznikovskiy, "Mechanical portion of electric drive with distributed parameters as an object for control", Potential of modern science, 2015, no. 8, pp. 12-15.

[6] D.A. Blagodarov, D.D. Grigorian, and Yu.M. Safonov, "Approach to Design Control System for the Electric Drive with Flexible Mechanics", *Procedia Engineering*, 2017, vol. 206, pp. 540-545.

[7] V.I. Kluchev, "Electric Drive Theory", Energoatomizdat, 2002, 704 p.

[8] Y.M. Safonov, "Mechanics of the Drive", MPEI Publishing House, 2015, vol. 52.

[9] L.C. Lin and C.C. Chen, "Rigid model-based fuzzy control of flexible-joint manipulators", *J. of Intelligent and Robotic Systems*, 1995, 13, pp. 107-126.

[10] H. Chaoui, W. Gueaieb, M. Yagoub, and P. Sicard, "Hybrid neural fuzzy sliding mode control of flexible-joint manipulators with unknown dynamics", *Proceedings of the 32nd Annual Conference of the IEEE Industrial Electronics Society (IECON-2006)*, 2006, pp. 4082-4087. DOI: 10.1109/IECON.2006.348032.

[11] V. Zeman, R.V. Patel, and K. Khorasani, "Control of a Flexible-Joint Robot Using Neural Networks", *IEEE Transactions On Control Systems Technology*, 1997, vol. 5, no. 4. DOI 10.1109/87.595927.

[12] H.A. Talebi, R.V. Patel, and M. Wong, "A Neural-Network Based Observer For Flexible-Joint Manipulators", *15th IFAC World Congress on Automatic Control*, Barcelona, Spain, 2002.

[13] Yu.M. Safonov, D.A. Blagodarov, A.A. Kostin, and S.V. Ozerov, "Implementation of electric drive with fuzzy controller in systems with variable moment of inertia", *Electric drive and control system, Proceedings of MPEI*, 2012, vol. 688, pp. 47-53. (in Russian)

[14] D.A. Blagodarov, S.V. Ozerov, and Yu. M. Safonov, "Fuzzy position controller of an industrial robot type "Tripod" with flexible mechanics", *XXI International Scientific Workshop "Modern Technologies in Control, Automation and Information Processing*", MPEI Publishing House, Ukraine, Alushta, 2012, pp. 77-78. (in Russian)

[15] S.V. Ozerov, Yu. M. Safonov, and D.A. Blagodarov, "The use of fuzzy logic and state observer in electric drive of a drilling rig", *XI International Scientific Conference "New Ideas in Science and about the Earth"*, RGGRU, Moscow, 2013, pp. 152. (in Russian)

[16] A.Yu. Sologubov, and V.R. Khramshin, "Influence of elastic couplings at simulating twin-engine electric drive of main hoist of casting crane", *Lift and Transportation Engineering*, 2016, no. 1-2, pp. 20-24. (in Russian)

[17] A.A., Radionov V.R. Khramshin, V.R. Gasiyarov, and A.Yu. Sologubov, "Analysis of the rational use of the elastic properties of the system of ropes and blocks for modeling the electric main lift bridge foundry crane with two drive motors", *in 11th. International Congress on engineering, design and Manufacturing. Sustainability and resilience approach (ICEDM2016)*, 2016, pp. 7-13.