The algorithm of optimization of parameters of a dual-mass electromechanical system of manipulators

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Abstract. This article deals with the optimization criteria for a dual-mass electromechanical system, the choice of which is made according to three generalized parameters: the frequency of the mechanical resonance of a single-mass system, the electromechanical time constants of the electric motor and the working mechanism. In addition, a technique was developed for selecting the gear ratio of the gearbox.

1. Introduction

The optimization of the power part of the servo drive (SD) is devoted to a large number of works, but the problem is still far from complete. As a part of a systematic approach of designing SD, a specific optimization algorithm, when a detailed structural scheme is compared and analyzed, allows substantiating the nature and level of requirements when designing mechanical parts, choosing material properties, type of kinematics, layout options and design.

The formulation of an optimization problem for an electromechanical system (EMS) can be considered correctly, if optimization parameters, optimization criteria, constraints and functional relationships are specified and proved.

2. Materials and methods

Let us select the optimization parameters: rated torque $E_D M_r$ and the gear ratio of the gear $i$. Since a series of EDs from a selected series are usually considered, for each of the electric drives, that are supposed to be used, its other parameters (power, angular velocity, moment of inertia of the armature, mass of ED, etc.) are specified.

Optimization criteria are usually ambiguous and, as a rule, in each case require substantiation. Speed, mass and dimensions of the electric drive, its efficiency and other performance standards can be taken in the capacity of such parameters. We choose the accuracy of the SD tracking by the nature of the production (regime) requirements for the SD for the optimization criterion. However, due to the huge variety of possible modes of the SD stabilization, impact loads of the working mechanism (WM) and frequent movements of the electric drive, it is not possible to use direct assessments of the processes’ quality in specific modes (for example, a regulation error). In this case, one of the indirect estimates turns out to be more appropriate and, in our opinion, the cutoff frequency of the position control loop in the SD is most convenient [1-3].

Restrictions, which are imposed on the change of parameters of the object of optimization, are determined by the design specification, standards and other directive documents, as well as geometric, physical, technical and economic relations included in the design methodology of this class of SD. The
most relevant restrictions in the object-oriented programming (OOP) of the class under consideration are usually the maximum angular velocity of the ED and the working mechanism, the maximum torque (or armature current) of the ED, the permissible RMS torque of the ED [4].

Finally, the structural diagram of a dual-mass elastic EMS (Fig. 1) and the load and velocity diagrams of the electric drive, taking into account the effect of the applied perturbations, describe the functional relationships, characterizing the properties of the optimization object.

The optimally constructed unchanged part of the SD will undoubtedly provide the best characteristics of the electric drive, so, firstly, we find out what parameters and when it is reasonable to optimize, if the unchanged part appears to be a dual-mass EMS. Secondly, we couch the optimization criterion, focusing on reducing the maximum tracking accuracy. In the further consideration, we will rely on the block diagram of a dual-mass EMS presented in Fig. 1 [5, 6].

![Figure 1. Block diagram of a dual-mass EMS](image)

Computational procedures in the course of parametric optimization of dual-mass EMS can be represented consisting of several stages:

- input of initial data;
- selection of a prototype and its parameters;
- calculation of generalized parameters: the resonance frequency of a single-mass mechanical system \( \omega_1 \), the electromechanical time constant of the electric motor \( T_m \) and the electromechanical constant time of the working mechanism \( T_{pm} \) and the choice of optimization criteria;
- calculation and minimization of the objective function.

3. Mathematical model

At the stage of inputting the initial data, the parameters of the links, forming a dual-mass EMS according to the scheme, are pointed: the parameters of the working mechanism and mechanical transmission (inertia moment \( J_{wm} \), the expected type of kinematic scheme, the stiffness coefficient of the mechanical transmission \( C \)), the parameters of electric motors intended for use (type of ED, nominal moment and angular velocity, moment of inertia of the armature, parameters of the armature chain \( R_a \) and \( L_a \)), load and speed characteristics of possible technological modes. For example, it can be stabilization of end-effector position, movements, in a given shaft or the required program, the load is applied [7, 8].

When the prototype is chosen, it can be more convenient to start computing operations. Here, the type of the ED and the gear ratio of the gear are determined. In principle, for the initial selection of the type and power of the ED, any of the generally accepted methods of selecting the power of the ED of the tracking drives are suitable [9, 10]. Since the function, characterizing the parameters of the ED, is discrete, usually given by the table for several suspected EDs from the selected series, the task of the machine selection of the ED is actually reduced to enumeration and comparison of competing options.
For the initial value of the gear ratio of gear $i$, it is more convenient to take a value, which would make it possible to change its value most conveniently by a software. This condition, obviously, satisfies the maximum possible value of the gear ratio of the gear, when the maximum speed of the working mechanism $n_{w_{\text{mmax}}}$ is reached at the maximum speed of rotation of the shaft ED $n_{s_{\text{hmax}}}$:

$$i_{\text{max}} = n_{w_{\text{mmax}}}/n_{s_{\text{hmax}}}$$  \hspace{1cm} (1)

The generalized parameters $\omega_1$, $T_{\text{ed}}$ and $T_{\text{wm}}$ are calculated based on the expressions given in [11, 12]. Depending on the ratio of the values of these parameters, the optimization criteria are also selected. It provides the simplest way to achieve the highest tracking accuracy in the SD: with a combination of the parameters corresponding to Fig. 2, the optimization criterion is taken to be the magnitude of the resonant maximum AM, which is minimized by increasing the time constant $T_{\text{wm}}$ due to a change in the gear ratio of gear $i$. In the group of cases ($\omega_1 < 1 / T_{\text{ed}}$) with very small $T_{\text{wm}}$, when the broken lines 1 and 2 do not intersect (Fig. 2.), the effect of the elastic electromechanical communication is weak, the whole EMS behaves like a system open through an external feedback channel. This case is typical, for example, for electrically driving the arm of a manipulator, for the SD of a vertical direction. Here, in the frequency range $\omega_1$, a resonant maximum is observed. In the existing SD of the class under consideration it reaches $AM = 3 \ldots 5$ and makes it very difficult to further adjust the electric drive closed in the position of the working element [13,1 4].

![Figure 2. Approximated log magnitude](image)

The calculation of the objective function is not difficult because of the simplicity of mathematical expressions that describe it in different cases. For example, we can suggest the following sequence of calculations to determine the desired ED and the optimal gear ratio of the gear for the case (Fig. 2).

First, for each of the EDs of the selected series, we construct as a function of the magnitude of the gear ratio $i$ the graph of the objective function (curve AB in Fig. 3 a).

$$C = \frac{1}{T_{\text{WM}}} = (i \cdot Ce)^2 / (J_a \cdot R_a)$$  \hspace{1cm} (2)

Then we impose a restriction on the variables. Firstly, we take into account that there is no special need to increase the TWM value above the value that guarantees eliminating the resonant maximum AM, since in this case the rms loading of the ED increases. Therefore, it is advisable to introduce a restriction on the range of possible changes in the time constant $T_{\text{wm}}$ in accordance with the equality.

$$\frac{1}{T_{\text{WM}}} = (0,5 \ldots 1,0) \cdot \omega_1$$  \hspace{1cm} (3)
This equality corresponds to the horizontal line 1 in Fig. 3 a. Secondly, we should take into account the maximum value of the gear ratio of the gearbox, which is selected based on the specified maximum speeds of rotation of the shaft ED and the working mechanism (curve 2 in Fig. 2):

\[ i_{\text{max}} = \frac{n_{\text{wmax}}}{n_{\text{shmax}}} \]  

Finally, we indicate the maximum allowable value of the rms moment for the ED (the straight line 3 in Fig. 3), being checked in accordance with the equation.

\[ M_{\text{rms}} = M_N \cdot i \]  

Where MN - the nominal moment of the checked ED.

![Figure 3. Curves, explaining the optimal gear ratio](image)

4. Conclusion

To know which of the constraints (curve 1 or 3) determines the minimum allowable gear ratio of the gearbox, we construct a graph of the function \( M_{\text{rms}} = f(i) \) for a given load diagram. In fig. 3 b is represented by the CD curve.

Since the graph of the objective function is monotonic, the optimal value of \( i \) is reached at the end of the allowable range of its change. The clarification of the fact which of the restrictions turns out to be active is made by comparing the abscissas values of the points D and C: the active limitation is taken from that of curves 1 or 3, the point of intersection of which with the curves AD and CD is to the right.

Then the calculation is repeated for other ED of the selected series.

References

[1] Klyuchev V I, Kolubaev N V 1985 Theory of electric drive: A textbook for universities (Moscow - Energoatomizdat)

[2] Ratner N I 1969 Calculation of electric drives in random modes (Leningrad – Energy)

[3] Chemodanov B K 1976 Tracking drives. In 2 books (Moscow: Energy)
[4] Schonfeld R, Habiger E, Bortsova Yu A 1985 *Automated electric drives: Trans. with him*, (Leningrad – Energoatomizdat)
[5] Wang M, Ren X and Chen Q 2018 Cascade Optimal Control for Tracking and Synchronization of a Multimotor Driving System *IEEE Transactions on Control Systems Technology* **99** 1–9
[6] Usynin U S 1994 *Differential servo drives of autonomous objects* (Chelyabinsk: South Ural State University)
[7] Wang Q and He F 2016 *The synchronous control of multi-motor drive control system with floating compensation* *The synchronous control of multi-motor drive control system with floating compensation*
[8] Ren X, Zhao W and Wang Sh 2017 Parameter Estimation-Based Time-Varying Sliding Mode Control for Multimotor Driving Servo Systems *IEEE/ASME Transactions on Mechatronics* **22** (5) 2330–2341
[9] Bedi A S and Rajawat K 2018 Asynchronous Incremental Stochastic Dual Descent Algorithm for Network Resource Allocation *IEEE Transactions on Signal Processing* **66** (9) 2229-2244
[10] Ozan E C, Kiranyaz S and Gabbouj M 2018 Competitive Quantization for Approximate Nearest Neighbor Search *IEEE Transactions on Knowledge and Data Engineering* **28** (11) 2884-2894
[11] Michael C and Safacas A 2007 Dynamic and Vibration Analysis of a Multimotor DC Drive System With Elastic Shafts Driving a Tissue Paper Machine *IEEE Transactions on Industrial Electronics* **54** (4) 2033-2046
[12] Perez-Pinal F J, Cervantes I and Emadi A 2009 Stability of an Electric Differential for Traction Applications *IEEE Transactions on Vehicular Technology* **58** (7) 3224-3233
[13] Nam P M, Thanh P T and Tinh T X 2017 Output feedback controller using high-gain observer in multi-motor drive systems *System Science and Engineering (ICSSSE), 2017 International Conference*
[14] Vodovozov V, Gvorkov L and Raud Z 2016 Multi-motor pressure management system with minimal energy consumption *Industrial Informatics (INDIN), 2016 IEEE 14th International Conference*