Elasticity Influence on Properties of Electromechanical Scanner

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Abstract: Elasticity influence on static and dynamic characteristics of electromechanical scanner of the telescope scanning axis is discussed. It is shown, that the controller algorithm, which provides specified scanner behavior, could be synthesized in spite of elasticity of mechanical part of scanner.

The modeling of system of control for electromechanical scanner was performed for two cases, when position sensor is installed on the first mass and when it is on the second mass. It is proved, that if possible, position sensor should be placed on the second mass of two-mass system.

The results obtained are recommended for use in high-precision electric drives of precision observations complexes. The article may be helpful for developers of precision electric drives of telescopes.

Key-words: electromechanical scanner, elasticity, discrete control law, precision electric drive.

1 Introduction

The synthesis of the control algorithms usually neglects elasticity links between the motor and the load in scanning electromechanical devices, when precision and speed of scanning is not required. If electromechanical scanner is a part of telescope axis, it is necessary to get high accuracy and good dynamics of scanning process. Disregard the elasticity links may be the cause of inability to provide the required system characteristics [1] - [3].

It is necessary to get a mathematical model of the electromechanical scanner with a magnetic spring as an actuator, taking into account the elastic connection between the motor and load.

2 Mathematical model

As it is known, the torque of the DC motor with a limited angle of rotation is equal to

$$M = K_i i - K_\alpha \alpha_1 \qquad (1)$$

In (1) i is anchor current, α_1 is rotor angle (rotation angle of first mass), K_i is stiffness of speed-load curve or current sensitivity, K_α is stiffness of speed-load curve or current sensitivity or stiffness of magnetic spring. Opposing torque for first mass is

$$M_{op1} = J_1 \frac{d\omega_1}{dt} + c_u \delta + M_{c1} \qquad (2)$$

In (2) J_1 is reduced moment of inertia of the first mass, ω_1 is rotor velocity, c_u is coefficient of flexibility between rotor and load, α_1 - α_2 = δ is twist angle, M_{c1} is external resistance moment, e.g. friction torque. If assemble (1) and (2), one can get

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$$\frac{d\omega_1}{dt} = \frac{K_i}{J_1} i - \frac{K_\alpha}{J_1}\alpha_1 - \frac{c_u}{J_1}\delta - \frac{1}{J_1} M_{c1} \quad (3)$$

The differential equation for the twist angle is

$$\frac{d\delta}{dt} = \omega_1 - \omega_2\,, \quad (4)$$

where ω_2 is angular velocity.
The equation of motor wingding is

$$\frac{di}{dt} = -\frac{R}{L} i - \frac{K_e}{L}\omega + \frac{1}{L} u \quad (5)$$

In (5) R is winding resistance, L is leakage inductance of the control winding, K_e is coefficient of back EMF [4] - [6].

The moving moment of force for second mass is twist moment, and opposing torque is moment of inertial forces and external load torque, from which equation of motion of the second mass could be obtained

$$\frac{d\omega_2}{dt} = \frac{c_u}{J_2}\delta - \frac{1}{J_2} M_{c2} \quad (6)$$

In (6) J_2 is reduced moment of inertia of the second mass.

Equations (3) - (6) give the standard state-space model of electromechanical scanner with elasticity

$$\begin{aligned} \dot{x} &= A_r x + B_r u + B_{vr} M_c \\ y &= C_r x \end{aligned} \quad (7)$$

In some systems position sensor could be placed on the first mass, or on the second mass. Consider these two cases separately. When position sensor is on the first mass, then state vector if model (7) is equal to $x = [i \;\; \omega_1 \;\; \delta \;\; \omega_2 \;\; \alpha_1]$, and state-space matrices are

$$A_r = \begin{bmatrix} -\frac{R}{L} & -\frac{K_e}{L} & 0 & 0 & 0 \\ \frac{K_i}{J_1} & 0 & -\frac{c_u}{J_1} & 0 & -\frac{K_\alpha}{J_1} \\ 0 & 1 & 0 & -1 & 0 \\ 0 & 0 & \frac{c_u}{J_2} & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \end{bmatrix},$$

$$B_r = \begin{bmatrix} \frac{1}{L} \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix},\; B_r = \begin{bmatrix} 0 & 0 \\ -\frac{1}{J_1} & 0 \\ 0 & 0 \\ 0 & \frac{1}{J_2} \\ 0 & 0 \end{bmatrix},\; M_c = \begin{bmatrix} M_{c1} \\ M_{c2} \end{bmatrix}.$$

When position sensor is on the second mass, then state vector if model (7) is equal to $x = [i \;\; \omega_1 \;\; \delta \;\; \omega_2 \;\; \alpha_2]$, matrix A_r is changed

$$A_r = \begin{bmatrix} -\frac{R}{L} & -\frac{K_e}{L} & 0 & 0 & 0 \\ \frac{K_i}{J_1} & 0 & -\frac{c_u + K_\alpha}{J_1} & 0 & -\frac{K_\alpha}{J_1} \\ 0 & 1 & 0 & -1 & 0 \\ 0 & 0 & \frac{c_u}{J_2} & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \end{bmatrix},$$

matrices B_r, B_{vr} and vector M_c stay same.

Anchor current and angle of rotation are measured independently from position sensor placement, therefore, measurement vector is $y = [i \;\; \alpha_p]^T$, $p = 1 \vee 2$. Measurement matrix in both cases is

$$C_r = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}.$$

Note that the object with the angle sensor located on the second mass is better conditioned, it is farther from the border of the degeneracy in comparison with the case of the sensor is located on the first mass. This follows from a comparison of the condition numbers of the degeneracy matrices for the two cases. When the object is better conditioned, the higher quality performance can be achieved in the control system of that object.

The reduced model of object is

$$\begin{cases} \frac{di}{dt} = -\frac{R}{L} i - \frac{K_e}{L}\omega + \frac{1}{L} u \\ \frac{d\omega}{dt} = \frac{K_i}{J} i - \frac{K_\alpha}{J}\alpha - \frac{1}{J} M_c \\ \frac{d\alpha}{dt} = \omega \end{cases}.$$

But control system for this reduced object has bad results when used for full object. If this controller is used with object (7), it could track only a very slow reference task, but with unacceptably large errors, both in position and speed. Therefore, elasticity links must be taken into account in controller synthesis algorithm.

Focusing on the implementation of digital controller, the transition from a continuous state model (7) to the discrete model of the object is provided using the *c2d* command of MATLAB.

A number $\eta = \frac{3}{t_n}$ is chosen, where t_n is desired step response time. Radius of a circle centered at the origin, inside which the roots of the characteristic equation of a discrete system must lie is $r = e^{-\eta T}$, where T is discretization period. The auxiliary matrices $A_n = \frac{A_d}{r}$, $B_n = \frac{B_d}{r}$ are formed and identity penalty matrices Q_s and R_s are chosen with respective size. As a result of solving the discrete matrix Riccati equation using the MATLAB command *dlqr*, feedback matrix K of control law (8) is found.

$$u_m = -Kx_m \qquad (8)$$

The expression (8) provides a specified transient time for object (7). This control cannot be realized in the pure form for the reason that only two of five state variables are measured. Missing information could be obtained using a reduced discrete observer of the third order. In this case, the (8) takes the form (9).

$$\begin{aligned} w_{m+1} &= (a_n + b_n N_2) w_m + (b_n N_1 + r_n) y_m \\ u_m &= N_2 w_m + N_1 y_m \end{aligned} \qquad (9)$$

In (9) vector $w_m = [w_{1m}\ w_{2m}\ w_{3m}]^T$, matrix $a_n = diag([0.1r\ \ 0.2r\ \ 0.3r])$, matrix r_n is chosen to provide controllability of pair (a_n, r_n), e.g.,

$$r_n = \begin{bmatrix} 0 & 1 \\ 0 & 1 \\ 0 & 1 \end{bmatrix}.$$

The rest parameters of (9) are evaluated as follows:

$$T_n = lyap(a_n, -A_d, r_n C_d),$$

$$N = -K \begin{bmatrix} C_d \\ T_n \end{bmatrix}^{-1}, \ N_1 = N(1:2),\ N_2 = N(3:5),$$

$$b_n = T_n B_d .$$

3 Modeling of system

Calculations were done for some specific object with location of position sensor on the first mass. The same method could be used for case, when position sensor is located on the second mass, only state-space matrix A_r of model (7) changes.

The modeling of system was performed using these calculations. This system consists of a digital drive signal generator, a discrete controller (9) and continuous object (7) in the case of the position sensor is located on the first mass [7] - [9].

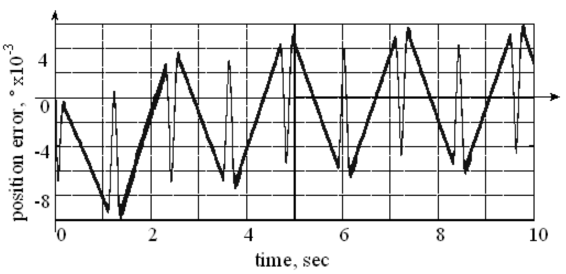

Figure 1. Position error of the second mass. Sensor is on the first mass.

Figure 1 shows a graph of position error of the second mass (actuator) when position sensor is installed on the first mass. The graph shows that the position error of the second mass in the work area does not exceed 0.0068 that is 1.2% of the maximum of position reference signal. There are oscillations with the amplitude of the second mass 0.00038 and period T, equal to the sampling period of the controller.

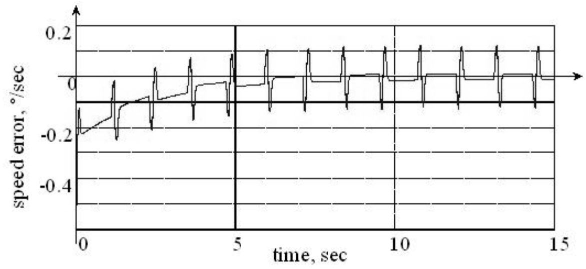

Figure 2. Speed error of the second mass. Sensor is on the first mass.

Figure 2 shows a graph of the speed error of the second mass (actuator) when position sensor is installed on the first mass. The graph shows that after the transient process is finished, speed error in the work area does not exceed 0.01 8/sec, which is 1% of the speed reference in the work area. It is clear from Figure 2, that process of is very long and speeding up of it can't be implemented due to saturation of the engine control unit.

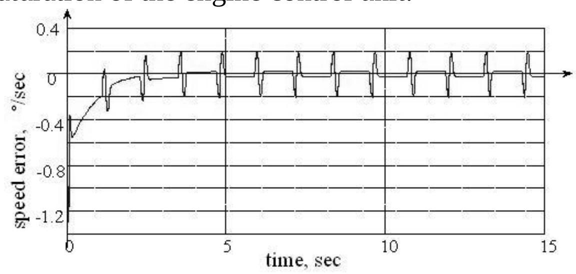

Figure 3. Speed error of the second mass. Sensor is on the second mass.

When position sensor is installed on the second mass the higher level of quality of scanning system could be achieved. As an example, Fig. 3 shows a graph of the speed error of the second mass, when position sensor is installed on the second mass. As can be seen from the graph, the transient process is significantly accelerated in this case [10], [11].

4 Conclusion

It could be said, that elasticity links are not critical for electromechanical scanner. It is only necessary to carry out the synthesis of controller algorithm using an object model that takes into account the elastic link.

The best results could be achieved when position sensor is installed on the second mass,

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directly on the actuator. This recommendation should always be used when design of electromechanical scanner allows the installation of the position sensor on the second mass. However, if it is not available, it is also possible to construct a working system, with only a few worse properties. The results obtained are recommended for use in high-precision electric drives of precision observations complexes.

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References:

[1] Sarhan, H.S. , Issa, R.H., Alia, M.A., Al-Abbas, I.K. Precision speed control of DC motor drive system, *International Review of Automatic Control*, Volume 5, Issue 5, September 2012, pp. 673-676.

[2] Balkovoi, A.P., Kostin, A.V., Myagkikh, A.S., Tolstykh, O.A., Tsatsenkin, V.K., Yakovlev, S.F. Design of direct linear drives for manufacturing, *Russian Electrical Engineering*, 2013, Vol 7(84), pp. 363-369.

[3] Yu. P. Filyushov, V. Yu. Filyushov. Control of a synchronous machine under minimization of heat losses in conditions of minimal reactive power, *Russian Electrical Engineering*, December 2013, Volume 84, Issue 12, pp. 712-717.

[4] S. G. Voronin, D. A. Kurnosov, A. S. Kul'mukhametova. Vector control of permanent-magnet synchronous motors, Russian Electrical Engineering, October 2013, Volume 84, Issue 10, pp. 581-585.

[5] Worthington, M.S., Beets, T.A., Beno, J.H., Mock, J.R., Murphy, B.T., Southa, B.J., Good, J.M. Design and development of a high precision, high payload telescope dual drive system, *Proceedings of SPIE - The International Society for Optical Engineering*, Vol. 7733, Issue PART 1, 2010.

[6] Ren, C., Liuzhao, Songlibin, Yiqiang, Chen, K., Zhang, Z. Design and simulation of the direct drive servo system, *Proceedings of SPIE - The International Society for Optical Engineering*, 2010.

[7] Tomasov V.S., Lovlin S.Ju., Tushev S.A., Smirnov N.A. Output voltage distortion of pulse width converter of precision electric drive, *Ivanovo: Vestnik IGEU*, Vol. 1, 2013.

[8] Sadovnikov Mikhail A., Tomasov Valentine S., Tolmachev Valery A., Precision Electric Drive for Optical Space Control Systems, *Scientific and Technical Journal «Priborostroenie»*, Vol. 54, No. 6, 2011, pp. 81-86

[9] Terec, R., Chindris, V., Szabo, L., Rafajdus. Position sensing system for switched reluctance motor control, *Proceedings of 9th International Conference*, *ELEKTRO 2012*, pp. 266-269.

[10] Chen, M.-Y. , Lu, J.-S. High-precision motion control for a linear permanent magnet iron core synchronous motor drive in position platform, *IEEE Transactions on Industrial Informatics* Volume 10, Issue 1, February 2014, Article number 6461410, pp. 99-108.

[11] Drozdov V.N., Tushev S.A. Ship motions influence on the range of possible coordinates of object observed by telescope on the deck, *Vestnik IGJeU*, Ivanovo 2013, Volume 4, pp. 54-58.

[12] Subbotin D.A., Lovlin S.Y., Tsvetkova M.H. Two-mass mathematical model of magnetoelectric converter for reversible scanning device // Manufacturing Engineering, Automatic Control and Robotics: Proceedings of the 14th International Conference on Robotics, Control and Manufacturing Technology (ROCOM '14) - 2014, No. 32/1/1, pp. 11-14

[13] Subbotin D.A., Lovlin S.Y., Tsvetkova M.H. Identifying dynamic model parameters of a servo drive // Manufacturing Engineering, Automatic Control and Robotics: Proceedings of the 14th International Conference on Robotics, Control and Manufacturing Technology (ROCOM '14) - 2014, No. 32/1/1, pp. 50-57