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ALGORITHM AND SIMULATION OF ACCELERATED ANGULAR MOVEMENT OF THE STEPPER MOTOR ROTOR

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Abstract. *Among the indicators of efficiency of electromechanical systems, the drive of which is a stepper motor (SM), one of the main ones is smoothness of movement and reliability. These indicators are significantly influenced by the acceleration/ deceleration modes of the SM rotor. The work analyzes the most used acceleration/ deceleration modes, compares them and proposes new ones.*

Key words: *acceleration, braking, S-curve, stepper motor*

Introduction

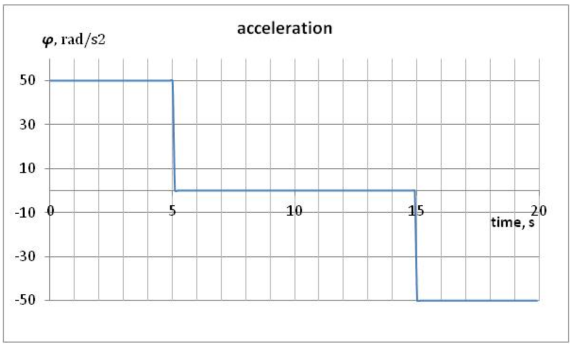
A sudden change in acceleration (velocity) at the beginning and at the end of the movement can cause shocks that can seriously affect the stability and accuracy of the reproduction of the given movement mode. These sudden overloads can also affect the service life of the mechanical system elements. In order to eliminate these undesirable consequences and increase the reliability of operation, various acceleration/ deceleration algorithms of the drive of electromechanical systems are usually used. These algorithms are known as S-shaped curves and can be described by various mathematical relationships, the graphical representation of which is similar to the shape of the letter S.

Traditional types of acceleration/braking

The reason for the limitation of the starting speed of the stepper motor is the inertial properties of the SM rotor and the limitation in the magnitude of the electromechanical moment. However, for practical tasks, an increase in rotor rotation speeds is required, for example, for tasks of rapid positioning of the carriage of an electromechanical system. To solve this problem, the following algorithm is used: start the movement from a low speed; then increase the speed to the desired value; movement at a constant speed; reducing the speed to zero. The use of acceleration/ deceleration algorithms allows you to achieve high rotation speeds and move to a given position in the shortest possible time interval. The speed change parameters during acceleration/braking depends on the inertia of the mechanical system: with the increase of inertia, the acceleration of the rotation of the SM rotor should be reduced.

The simplest method of acceleration/ deceleration is a linear change of speed in the areas of acceleration and braking (Fig.1). This is the so-called trapezoidal type of acceleration/deceleration formation [1].

The entire time range occupied by the movement for the given example consists of three segments: 1 – acceleration (0 – $t1$), 2 – uniform movement ($t1$ - $t2$), 3 – braking ($t2$ – $t3$). Acceleration and braking is provided by a linear change in angular velocity. Despite the simplicity of calculations, this method of implementation of acceleration/ deceleration has a significant drawback associated with the instantaneous change of acceleration at the moments of time $t0$ = 0, $t1$ = 5, $t2$ = 15 and $t3$ = 20 s. In electromechanical systems using stepper motors, at times of sudden changes in acceleration values, loss of control is possible due to the fact that the SM does not have time to process the commands in time.



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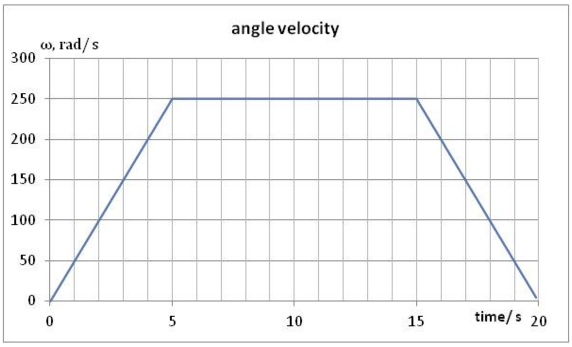

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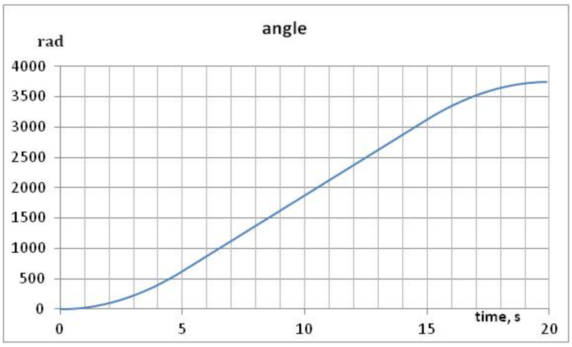


c

Fig.1. Diagrams of the trapezoidal type of acceleration/ deceleration.

Each of the diagrams depicts the change over time of one of the parameters of motion (rotation): angular acceleration (a), angular velocity (b) and total angular displacement (c).

Another way of implementing acceleration/ deceleration uses exponential dependence (Fig. 2). At the acceleration interval, the angular velocity is described by the expression:

$$\omega = \omega_0\,(1 - e^{-t/\lambda}), \tag{1}$$

where ω_0 corresponds to a fixed value of the angular velocity (time interval: $t1 - t2$); $\boldsymbol{\lambda}$ is a time constant that determines the shape of the curve. In the braking section ($t2 - t3$), the speed is described by another equation:

$$\omega = \omega_0\,(e^{-t/\lambda}) \tag{2}$$

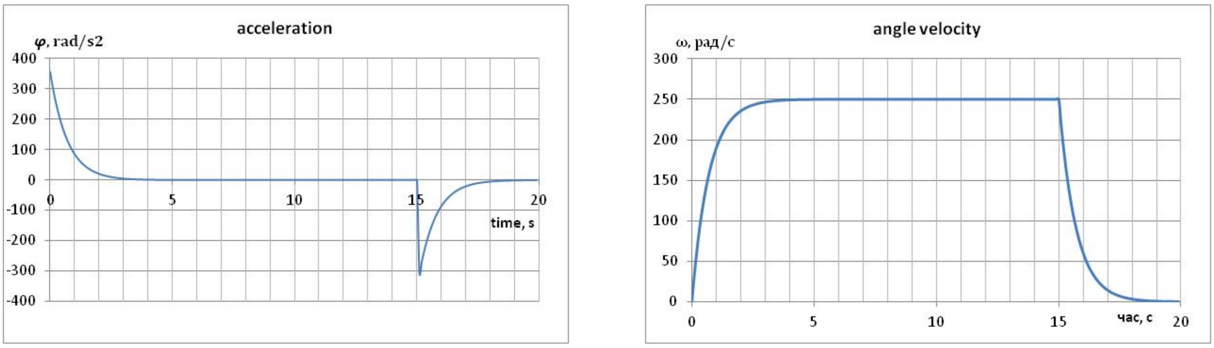
Another formula describing the third section of movement - braking is proposed in [2]. This third segment was the parabola with a smooth transition point. According to the comparison with the S-curve acceleration in the aspects of speed, acceleration, angular displacement, and number of steps, the proposed acceleration curve reduced accelerating time.

As for the trapezoidal type, the dependence graph for acceleration (Fig. 2,a) has breaks at the initial moment of time and $t2$ = 15s. The graph for the angular velocity (Fig. 2,b) also changes sharply at the time $t2$.

In order to eliminate the shortcomings of the above traditional methods of implementation of acceleration/ deceleration, in [3] a "flexible S-curve method" of implementation of acceleration/ deceleration is proposed. The main idea was that the speed curve is represented in the form of a cubic polynomial function of the following form:

$$\omega(\alpha) = (a_1 + 2a_2\alpha + 3a_3\alpha^2 + 4a_4\alpha^3)/t_n \quad (3)$$

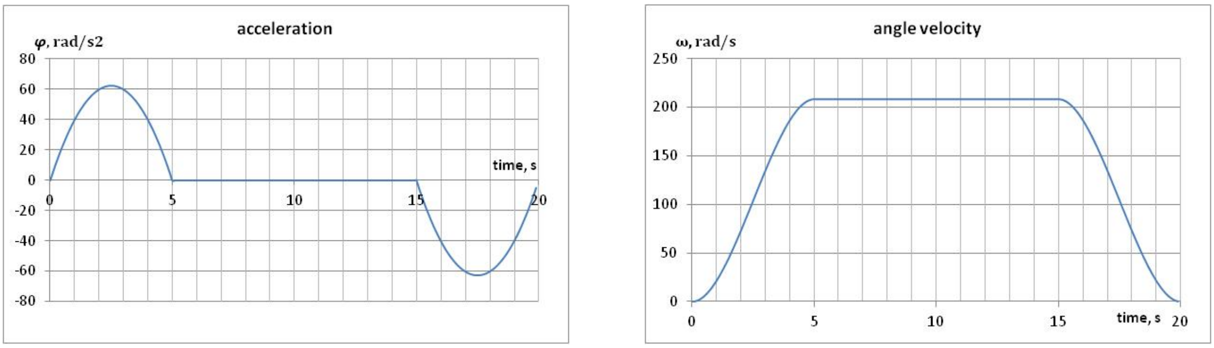
where $\alpha = t/t_n$; t_n – time required for acceleration/ deceleration.



a b

Fig. 2. Diagrams of the exponential type of acceleration/ deceleration.

The acceleration/ deceleration equation is obtained by time differentiation of equation (3) and corresponds to an equation of the quadratic type. A graphic representation of a typical dependence of acceleration/ deceleration is shown in Fig. 3,a in the form of two parabolas.



a b

Fig. 3. Diagrams of the polynomial type of acceleration/ deceleration.

The graph for acceleration has no breaks (the function is continuous), which, according to the authors, significantly improves the stability of the system. The graph of the speed change has a clearly emphasized S-likeness (Fig. 3,b). But the graph of the derivative of the acceleration over time is a “jerk” curve, it is not continuous. At times 0, 5, 15, and 20, the function describing this curve has breaks. In [4], the method for calculating seven acceleration/ deceleration intervals and the corresponding speed values by numerical methods with the involvement of the iteration method and the use of an additional parameter - the maximum jerk value (acceleration time derivative) is considered. Due to the complexity of calculations for parameter selection, the practical use of the method raises doubts.

Proposed new types of acceleration/ deceleration

Further improvement of the acceleration/ deceleration algorithm is related to the search for such functions, the time derivatives of which would not have discontinuities, that is, would be smooth. Among them, the following functions were considered:

$$F(x) = 1/ch^2(x) \quad (4)$$

$$F(x) = e^{(1-x^2)} \quad (5)$$

$$F(x) = 1 - \cos(x) \quad (6)$$

In the presented work, it is proposed to use trigonometric functions that are infinitely differentiable, continuous and simply calculated. (6) was chosen as the simplest for calculations and application. Moving from one position to another consists of three sections: acceleration $L1$, uniform movement $L2$ and deceleration to zero speed $L3$. The simplest case is considered, when the acceleration time is equal to the braking time $t1$ - $t0$= $t3$ - $t2$, and the corresponding displacements are equal to each other. Fig. 4 shows graphs describing the dependences of acceleration (a) and speed (b) for the cosine type of acceleration/ deceleration. The analysis of accelerated movement according to equation (6) showed the following form of dependence for movement:

$$L_1(t_1) = 0.5 * \varphi * t_1^2 \quad (7)$$

$$L_2(t_1, t_2) = \varphi * t_1 * t_2 \quad (8)$$

where is an acceleration amplitude.

To calculate the minimum time of moving from one position to another, we can use the following sequence of actions:

1. We determine (experimentally or from operational documentation) the maximum acceleration $\boldsymbol{\varphi}_m$ and the speed ω_m of rotation of the rotor of the SM, taking into account the inertia and load moment, in further calculations we use $\boldsymbol{\varphi}_0 = \boldsymbol{\varphi}_m/2$;

2. From the equation for velocity $\omega_m = \varphi_0 \int_0^{t_1} (1 - \cos(2\pi x/t1))dx$ at the end of acceleration/ deceleration, we calculate the time for acceleration (braking)

$$\boldsymbol{t_1} = \boldsymbol{\omega}_m/\boldsymbol{\varphi}_0; \quad (9)$$

3. According to the formula (7) we calculate L_1, after L_0 should be subtracted the distance 2* L_1;

4. We divide the result obtained by the speed $\boldsymbol{\omega}_m$ and get the time of uniform motion t_{L2}.

Thus, the minimum time required to move the distance L_0 is:

$$t_{min} = (L_0 - \boldsymbol{\omega}_m^2/\boldsymbol{\varphi}_0)/\boldsymbol{\omega}_m + 2\boldsymbol{\omega}_m/\boldsymbol{\varphi}_0 = L_0/\boldsymbol{\omega}_m + \mathbf{2}\boldsymbol{\omega}_m/\boldsymbol{\varphi}_m \quad (10)$$

The following situations are possible:

1 - L_1<0,5*L_0. L_1 is the displacement of accelerated motion.

2 - L_1=0,5*L_0. The displacement will consist of acceleration and braking only.

3 - L_1>0,5*L_0. In this case, we set the displacement of accelerated motion and braking L_{1n} equal to 0.5*L_0. The new value of time t_{1n} found by formula (7) will be less than for the previous cases. Therefore, the angular velocity achieved during this time interval will be less than ω_m. Its value can be found using relation (9).

The calculation algorithm for implementing the proposed type of acceleration/ deceleration is shown in Fig. 5. The main parameters taken into account in speed (path) calculations are: L_0, ω_m and $\boldsymbol{\varphi}_m$. First, the time $t_1 = \omega_m/ \boldsymbol{\varphi}_0$ required for acceleration to the maximum speed ω_m is calculated, then this value is used to calculate the distance (angle) by which L_1 will be moved. If $L_1 \le 0.5L_0$, one branch of the algorithm is used, otherwise - the second. In the first case, we find the section of uniform movement $L_2 = L_0 - 2*L_1$ and the time required to overcome it $t_{L2} = L_2/\omega_m$ and the total time $t_3 = 2t_1 + t_{L2}$. Then, knowing the three time intervals and using the conditional operator, we calculate the value of the speed (denoted as y) according to the corresponding equations. For the second branch, when $L_1 > 0.5L_0$, we calculate the new value of the movement section with acceleration $L_{1n} = 0.5L_0$, calculate the corresponding time $t_1 = (L_0/\,\boldsymbol{\varphi}_0)^{0.5}$, then $t_2 = t_1$, and $t_3 = 2t_1$. Due to the absence of a section of uniform movement, conditional operators are used only for two time intervals.

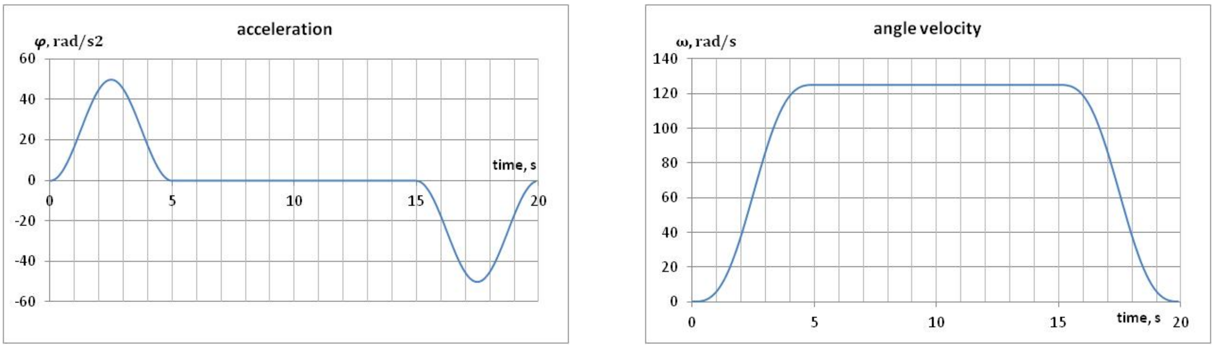


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Fig. 4. Diagrams of the cosine type of acceleration/ deceleration.

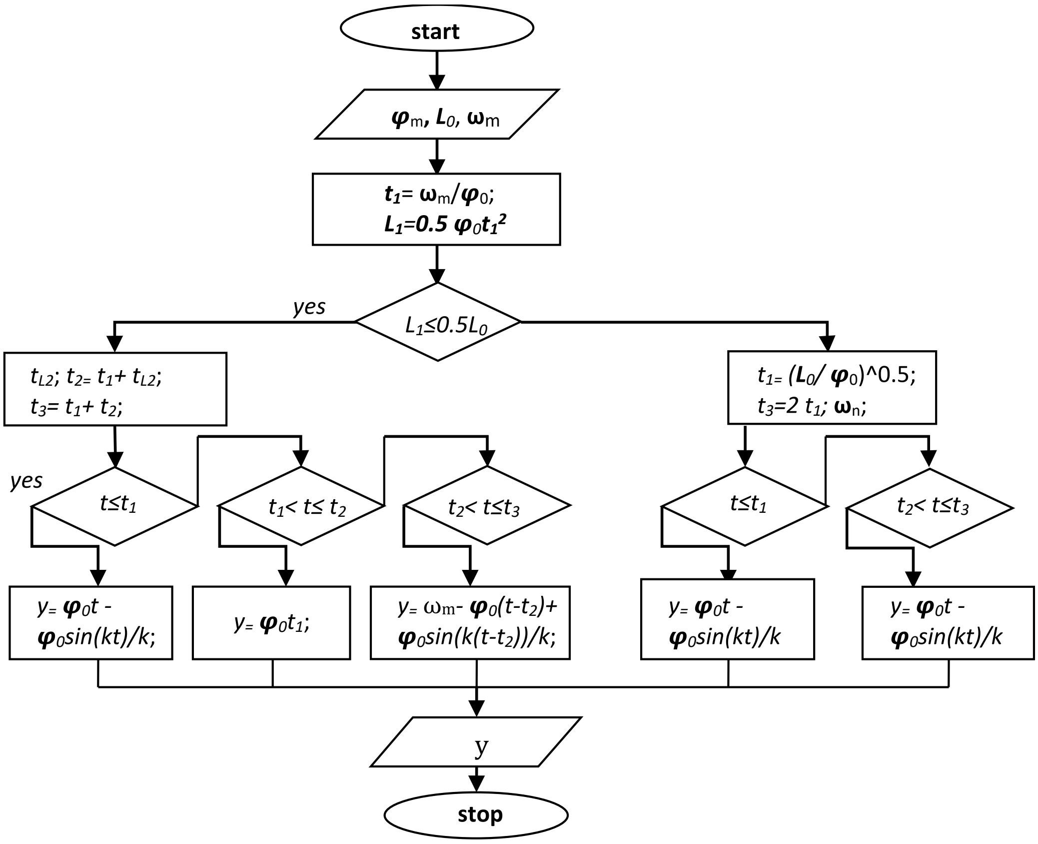

Fig. 5. Flow chart for speed calculations of cosine acceleration/ deceleration type.

To illustrate the operation of the algorithm described above, a Simulink model (Fig. 6) was developed in the simulation programming environment MatLaB/Simulink, which contains a MatLab Function block for implementing the algorithm and auxiliary elements: a meter and fixator of a given displacement, a displacement setter, an integrator, and a Scope block for display of simulation results. The displacement setter is configured to cover all typical situations described in the algorithm. The SM parameters are recorded in blocks with corresponding designations (the maximum acceleration $\boldsymbol{\varphi}_{\mathrm{m}}$ is marked in Fig. 6 through *Fm*). Fixation of the displacement value L_0 of the displacement encoder occurs synchronously with the leading edge of the pulse (Pulse control block). The additional DIR output signal of the MatLab Function block takes into account the sign or direction of the specified movement. After multiplying the two output signals, we get a signal that reflects the change in the speed of movement over time. Accordingly, the Integrator unit integrates this signal to obtain a signal that reflects the time change of displacement. An important condition for the adequate operation of the model is the synchronization of the transfer write signal and the completion of the previous command: the L_0 write must occur only after the completion of the previous move. The indicator of the completion of the movement can be equal to zero of the speed signal (output of the product block).

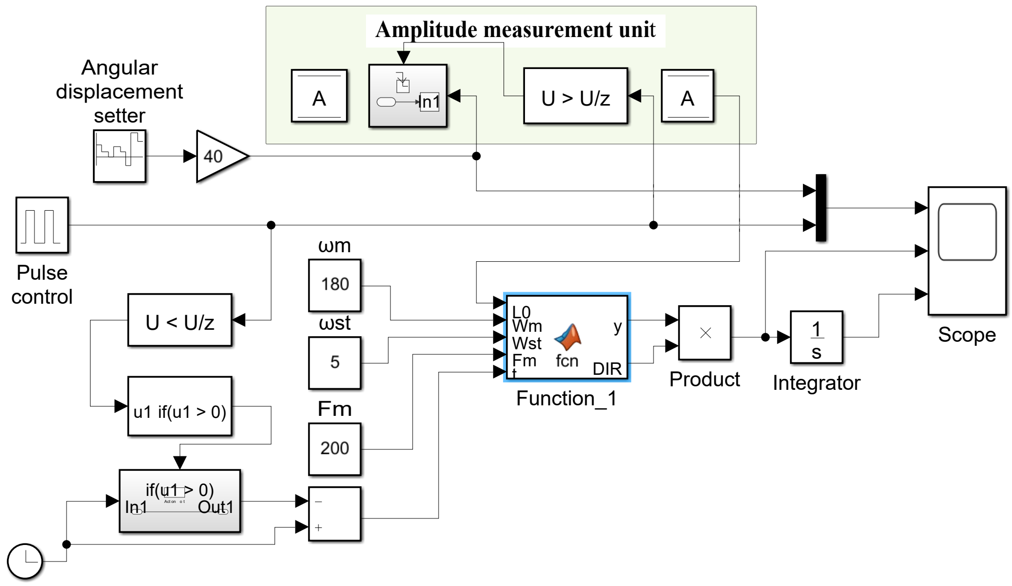

Fig. 6. Simulink model of the cosine acceleration/ deceleration type.

Diagrams of changes over time of the main calculated initial parameters of the model are shown in Fig. 7. The upper graph shows the step change in the value of the given displacement and the reading pulses of these values for further calculations.

The value of the read displacement must not change during the duration of the read pulse. The second graph shows the change in speed in accordance with the algorithm described above. The bottom graph shows the change in displacement over time, which corresponds to the time change in velocity shown in the previous graph. The distance along the vertical axis between the horizontal sections of adjacent sections, taking into account the sign, corresponds to the corresponding specified displacement values.

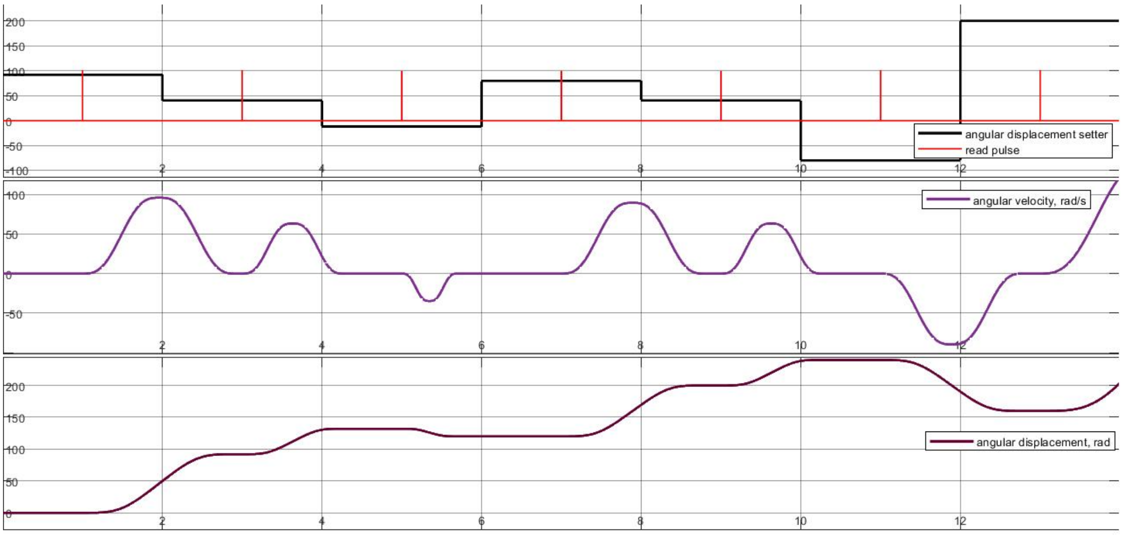

Fig. 7. Diagrams of changes in speed and displacement according to Simulink model of the cosine type of acceleration/ deceleration.

Conclusions

An algorithm and software for cosine-type smooth acceleration/ deceleration have been developed. A Simulink model was used to explain the operation of the algorithm. Using this type of acceleration/ deceleration S-curve eliminates sudden changes in speed and acceleration - jerks. This can improve the operational modes of equipment where SM, DCs (and other controlled electric drives) are used. Unlike known types of acceleration/deceleration, the proposed type has no discontinuities in the time derivative of the angular acceleration. The proposed algorithm for forming a new type of acceleration/ deceleration S-curve can be applied to implement "soft" accelerated angular (linear) movement.

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