Position-servo electric drives (PSEDs) operating in a real-time regime can work through either an earlier set up program-time assignment of an output variable or adapt to a change in driving actions directly in the process of monitoring changes in external conditions.

Numerical control systems (NCSs), which are widely used in the electric drives of metal-cutting machine tools, robot manipulators, etc., are systems of the first type. These systems are based on preliminary “cropping” of the control program. This allows the required limits of electric drive positions at the interpolation stage of motion path of the working body to be set up.

The systems operating in conditions of unpredictable changes of external actions are systems of the second type. In this case, interpolation of driving actions is impossible. For such PSEDs—in particular, for mobile robotic platforms moving in an environment with unknown changes in spatial coordinates and equipped with machine vision systems, the task of limiting performance and accuracy of motion needs to be accomplished in real time and, moreover, in conditions of limitation of the phase variable, i.e., of speed, acceleration, and tag. This class of PSEDs also includes most operator-aided automatic control systems (ACSs), for example, ACSs of traveling or gantry cranes in which the process of dealing with a changing environment is carried out by the operator.

Position-servo electric drives operate both in regimes of small deviations of coordinates (SDCs) and in regimes of large deviations of coordinates (LDCs). The SDC regime determines the operation of the system in a linear area, which is what most synthesis methods of optimal control have been developed for. The LDC regimes that are associated with the work of the PSED are limited by at least one phase variable. As a rule, the controlling coordinates are always subject to limitation conditioned by limitation of control energy with limitation of the control equivalent to the phase variable, i.e., acceleration of an electric drive or tag that is the time derivative of acceleration. Of course, the presence of SDC and LDC modes means that they are related to a class of nonlinear control systems, for which the general methodology of synthesis is absent.

The requirement that a PSED needs to adapt to a changing external environment additionally complicates the task of synthesis of an optimal nonlinear control. Quite a large amount of research has been devoted to the solving these kinds of problems, including ones based on the principles of finite control. Quite a large amount of research has been devoted to the solving these kinds of problems, including ones based on the principles of finite control. Quite a large amount of research has been devoted to the solving these kinds of problems, including ones based on the principles of finite control.

This article proposes that the position-servo control task be divided into two subtasks:
— finite control in the traditional setting of linear control theory by a discrete–continuous PSED; and

— reference assignment of phase variables of the electric drive under conditions of arbitrary changes of increments of assignment of an output coordinate using a nonlinear adaptive reference model (ARM).

Of course, such a reference model can generally be applied, but, in adaptive electric drives with signal or parametric self-tuning [1, 2], owing to the problem of adaptation to external conditions, it is obviated in many respects.

In itself, this approach is not so new, since the use of dynamic preceding filters has long proven itself as to be an effective and simple method to restrict electric drive coordinates [3, 4]. In modern microprocessor servo-drives, this task is partly solved by programming a so-called S-ramp [5] allowing to limit the first and second derivatives of an output variable in the acceleration and brake curves of the electric drive, while limiting performance in all possible operating regimes is not implemented, as the constant parameters of S-ramps are linked to specific increments of electric drive speed and cannot be changed during operation. From this, it is clear that the systems of electric drives that are being considered must belong to the class of systems that are adaptive to external conditions.

Let us consider the specifics of the operating of PSEDs in different regimes defined first by the value of the increment of the specified position of the electric drive.

The time of transition process in the SDC regime is constant, and, in accordance with the theorem of \( n \) intervals [5–7], it is equal to \( n \) periods of digital control. In addition, it does not depend on the level of the increment of input driving action and never reaches the specified limit of \( U_{\text{max}} \) or, which is the same thing, the limitations of the main PSED phase variable.

The LDC regime that is characterized by meeting only the highest derivative is a boundary regime between the SDC and the LDC. Due to forming a variable control period \( T_i \) in the module of the control period controller (CPC), one can for this regime retain the validity of the theorem of \( n \) intervals of finite control and implement control \( U(T_i) \) with optimal performance when its limitation is at an acceptable level. In this regime, the response time on increments of driving action will change. Therefore, for parametric adaptation of the ARM to the operating regimes, it is necessary to set up a nonlinear dependence of the control period of different increments of driving actions and limitations of the control (of the PSED major phase variable).

If, during the functioning of the ARM, not only the major phase variable is satisfied, but other phase variables as well, such regimes are LDC regimes in their entirety and for finite control to be established it is needed not only to change the control period (parametric adaptation), but also to use an ARM regulator with a variable structure (structural adaptation).

The functional diagram (Fig. 1) shows the core of the proposed approach with respect to an autonomous PSED.

The adaptive reference model is represented as a closed loop nonlinear control system with variable structure adapted to the functioning of the ARM in two regimes: linear (SDC) and nonlinear (LDC).

Driving action \( X^*(t) \) of the ARM is in general a vector step function of time. However, as applied to an autonomous PSED, it is enough to have information only on the required change of output variable \( x^*_i(t) \) of PSED (of motion) at some unknown points of time:

\[
X^*(t) = X^*(t_i) = x^*_i(t_i), \quad i = 0, 1, 2, \ldots \quad (1)
\]

The control object (CO) of the ARM is a serial connection from one to three integrators to limit the required number of phase variables. The output signal of the CO of the ARM is generally (at the triple integrator; i.e., \( n = 3 \)) a vector of four PSED driving variable:

\[
X^{**}(t) = \begin{bmatrix} x^{**}(t) \\ x_2^{**}(t) \\ x_3^{**}(t) \\ x_4^{**}(t) \end{bmatrix}^T = \begin{bmatrix} \varphi^{**}(t) \\ \omega^{**}(t) \\ \varepsilon^{**}(t) \\ \rho^{**}(t) \end{bmatrix}^T,
\]

where \( \varphi^{**}(t) \), \( \omega^{**}(t) \), \( \varepsilon^{**}(t) \), and \( \rho^{**}(t) \) are given changes over time in accordance with the position, speed, acceleration, and tag formed at the PSED output.