Conference Paper

Effect of the Mechanism Transfer Function on the Positioning Law

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Abstract

Parametric synthesis of mechanical system consisting of actuator, transfer mechanism and control device is considered. Planar and spatial mechanisms with one degree of freedom can be included in the system. Mechanism structure and the type of the actuator are considered to be given preliminary.

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1.

Drive devices consisting of engine, transfer mechanism and control systems are widely used for the automation of technological processes in various industries. These devices include transporting mechanisms (drives), which serve to move and position objects of different purposes. Transporting drives of different types are used in an autonomous mode or built into automated (including robotic) technological equipment. The engine of the transporting drive can be electric, hydraulic, pneumatic or other type. The movement from the engine to the operating element is transmitted by a mechanism with a constant or variable gear ratio. The control system is electronic, and in most cases its structure is approximately the same for engines of all types, since it depends mainly on the control algorithm. The only difference is in the parameters of the control system and the design of the devices that generate the control actions applied to the engine.

Thus, the synthesis of the transporting drive is reduced to the problem of searching the structure and parameters of a complex dynamic system consisting of three subsystems. High performance of the drive in terms of accuracy, reliability and other requirements with minimum power consumption and minimum dimensions can be ensured only if the full potential of all interacting drive subsystems is fully utilized. Due to the huge number of automated transport devices used in various industries, a rational choice of their type, structure and parameters can give a significant economic effect.

To solve this problem, a coordinated (end-to-end) synthesis of a complex dynamic system consisting of several subsystems requires special methods.

In most cases, the structure and parameters of the individual drive subsystems are selected independently with subsequent matching of their characteristics. To proceed to the end-to-end synthesis of the drive subsystems, a number of problems need to be solved. Some of them and their solutions are listed below.

The dynamics of the drive is determined by a basic mathematical model, which includes three main groups of equations:

- the motion,
- the relationship between the input control action and the driving force of the engine,
- the control system functioning.

Usually, the structure, geometrical parameters of the transfer mechanism and the type of engine (electric, hydraulic, or pneumatic) are selected beforehand and then the main engine parameters are chosen. The structure of the control system is chosen at the last stage, depending on the specific features of the problem. As a result, the synthesis process is reduced to the analysis of various combinations of engine parameters and the control system with fixed structure and parameters of the mechanism. In this paper we propose a synthesis method based on the dynamic analysis of all its subsystems simultaneously, taking into account their interaction with each other.

2.

Consider an example of solving a problem of vertical cargo moving from point A to point B (Fig. 1) for a given (or minimum) time with a specified accuracy of positioning at point B. Initial data are the mass of the object being moved, the resistance to movement, the moving time and the accuracy of stopping the object in the final position. At the same time, some constraints can be set: on the dimensions of the mechanism and the engine; on the power developed by the engine or other conditions. Thus, vectors of optimization criteria and constraints are considered to be given.

Figure 2 shows a diagram of the positioning system, which consists of subsystems: engine 1, distributor 2, control device 3 and transfer mechanism 4. A moving (positioned) object 5 is connected with the output link of the mechanism. At the first stage of the parametric synthesis of the transporting drive, it is proposed to replace the transfer mechanism 4 with some simple kinematic model – a transfer function *i* expressing

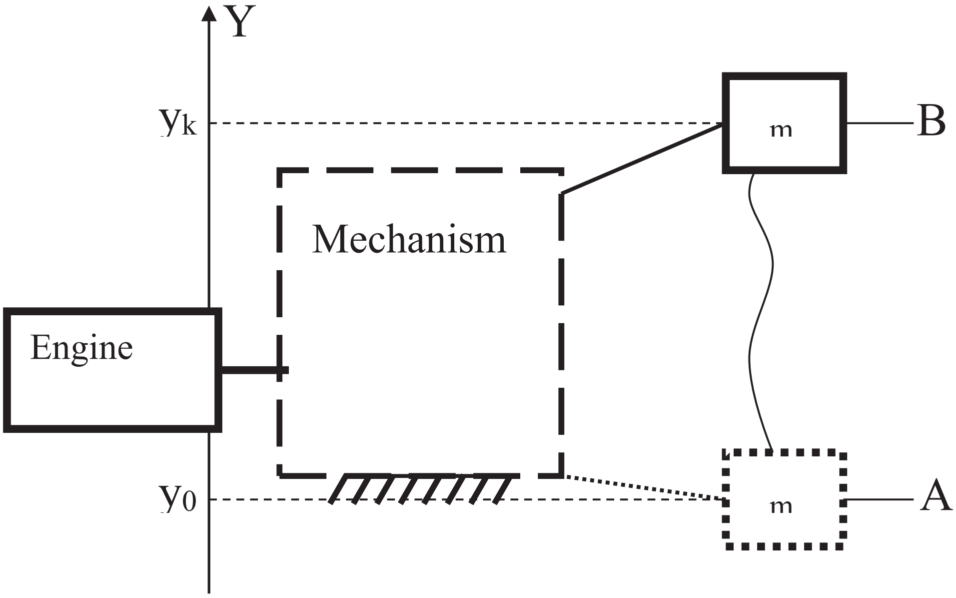

Figure 1

the law of changing the ratio of the speeds at the input and output of the mechanism. In the general case, the function *i* is a variable dependent on the position of the mechanism, and it can be specified, for example, as a function of variable *y*:

$$i = \frac{\dot{x}}{\dot{y}} = f(y). \quad (1)$$

In this example, $\dot{x}$ coincides with the speed of the engine, and $\dot{y}$ with the speed of the object being moved.

If $i = const$ (which is typical for gear, screw and other mechanisms), then the following relation holds:

$$i = x/y.$$

For a transport drive with a limited stroke of the actuator

$$i = s_x/s_y,$$

here s_x and s_y are complete stroke of the engine and the object correspondingly.

In case $i = var$, the full stroke ratio s_x/s_y characterizes the mean-integral value i, since

$$x = \int_0^y f(y) \cdot dy.$$

Therefore, the ratio s_x/s_y is hereinafter referred to as the equivalent gear ratio and is denoted by i_e.

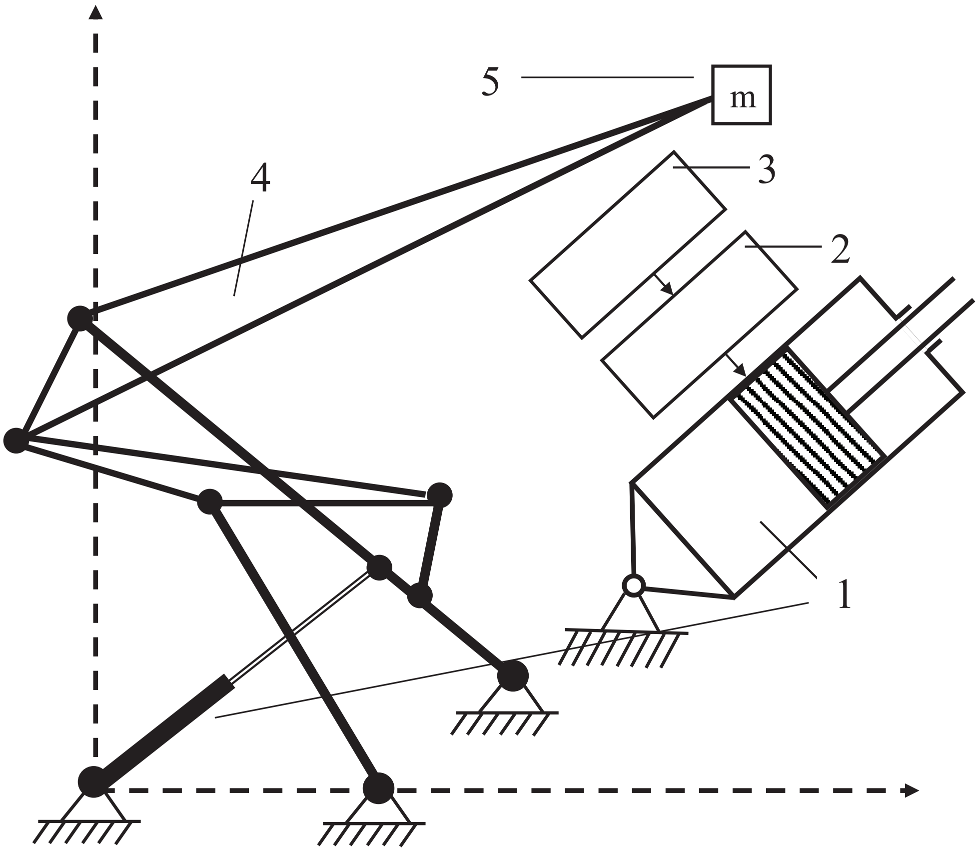

Figure 2

We represent the transfer function in the following form

$$i = i_e \cdot I, \tag{2}$$

here $I = i/i_e = f(y)/i_e$ - function i values relative to i_e. The representation of the transfer function in the form (2) allows us to divide the process of its construction into two stages. The first stage is to select the value i_e. The value of the ratio of the strokes of the engine and the actuator is determined by the design requirements for the drive. Preliminary studies have shown that a fairly wide class of functions can be used as $f(y)$, including a piecewise linear function. The main requirement when choosing the type of $f(y)$ is to provide its minimum, sufficient to overcome the applied load.

3.

After selecting i_e, a parametric synthesis of the "engine-control" system is performed with the transfer mechanism represented by the transfer function. This problem is solved in the criterial space of dynamic similarity based on the study of the features of this space with the selection of domains of feasible solutions. The criteria for similarity obtained during the transition to dimensionless relations can be conditionally divided into two groups.

The criteria of the first group characterize the dynamic properties of the engine; the criteria of the second group characterize the features of the control system [3]. From the criteria of the first group, two basic criteria are singled out – the criterion of inertia of the engine and the criterion for the duration of the dynamic process. The forces of resistance (friction), the delay in the operation of the switchgear, the criteria for the initial and final state of the drive were used as additional criteria. The criteria of the second group include dimensionless gain factors in the feedback loops and parameters characterizing the transfer function of the mechanism.

The criterion for the duration of the dynamic process (in order to achieve a minimum response time or to obtain a minimum engine driving force for a given time), the quality criteria for final positioning, and others were considered as criteria of optimization. Multicriteria and multiparametric optimization methods were used to search the optimal (rational) solution [4].

The final goal of this stage is the selection of the criteria of the first and second groups for the subsequent transition to the determination of the real parameters of the engine, the control system and the transmission mechanism. The procedure for such a transition was described in detail in [1, 2].

4.

In conclusion, let us dwell on the process of transition from a transfer function to the determination of its parameters. This process consists in varying the lengths of the links of the mechanism, the position coordinates of the point of connection of the mechanism with the base and the points of connection of the engine to the mechanism and the initial state of the mechanism in order to approximate the actual transfer function i^* to the function i constructed in the previous stage. The numerical experiment shows that the function i^* is very sensitive even to small changes in the parameters of the mechanism, which made it possible to find an acceptable solution quickly. At the same time, the problem of providing linear motion of an object along a trajectory close to a straight line was solved.

As a function of approximation *I*, we chose rather close to each other V-shaped piecewise linear, parabolic and sinusoidal functions (Fig. 3). It was established that, for the same restriction to $I_{\min}$, the result (function i^*) depends little on the form of *I*. The numerical optimization was carried out from the condition of minimizing the objective

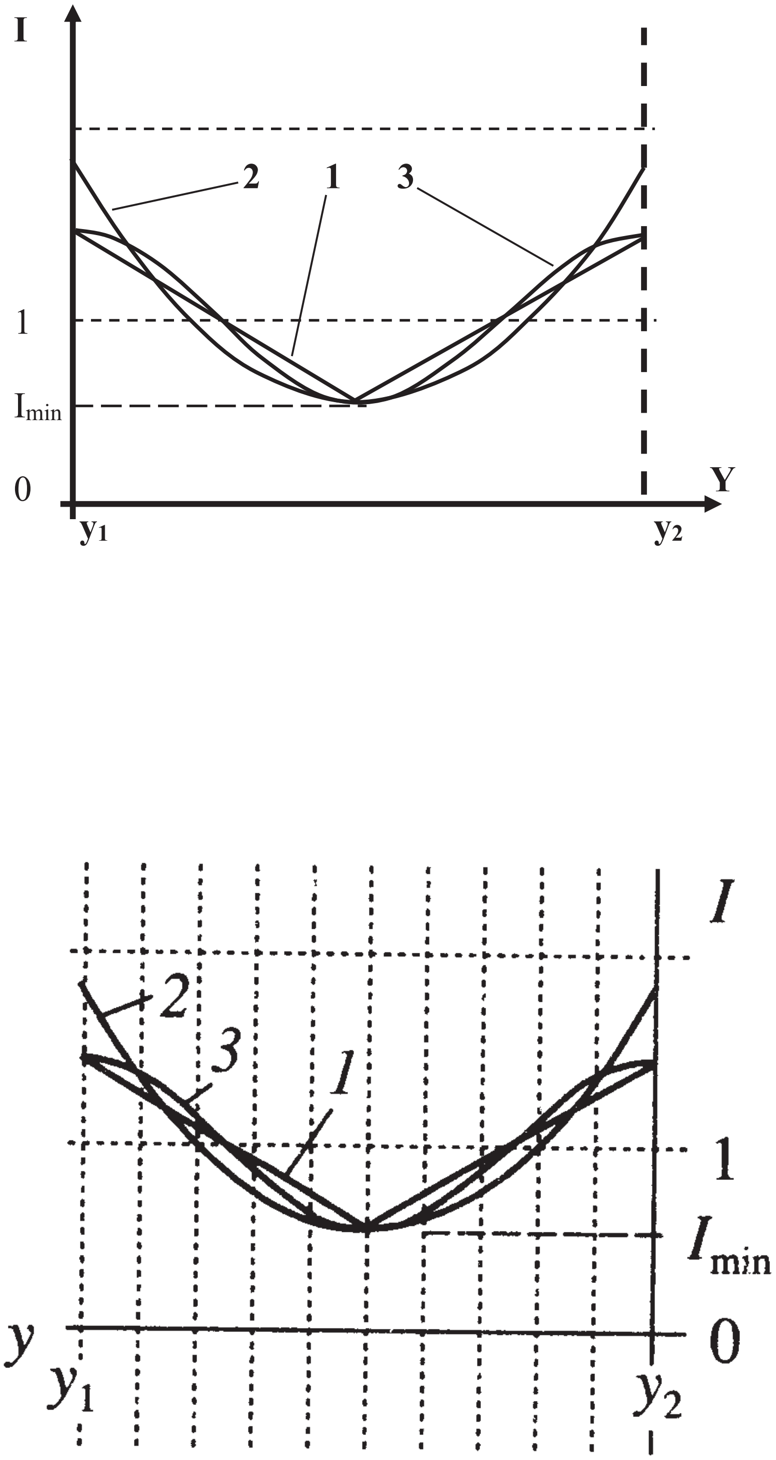

Figure 3: Function $I(y)$ of gear ratio change depending on the movement of the object: 1 – piecewise linear; 2 – parabolic; 3 – sinusoidal.

function *L*, subject to the constraints on the mechanism (the constraint vector). The

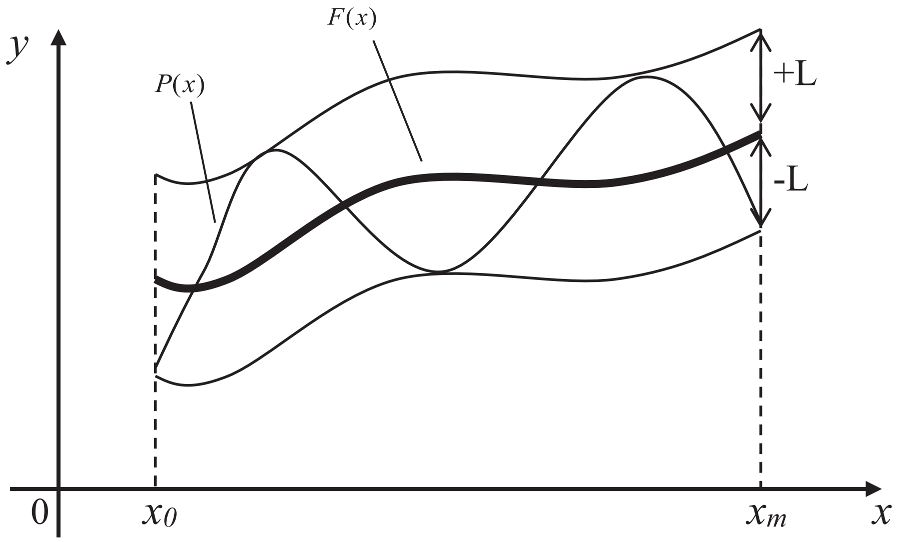

Figure 4

most convenient in this case is the "best approximation" method. Geometrically, this means that the graph of the approximating function $P(x)$ is enclosed between two curves that are at a distance $\pm L$ from the graph of the given function $F(x)$ (Fig. 4). The approximation is uniform, since deviations from a given function uniformly reach their limiting values.

References

[1] Kreinin G.V., Misyurin S.Yu., Yashina M.A. On synthesis of the positional system with hydrodrive and motion transfer mechanism with variable transmission ratio // Journal of Machinery Manufacture and Reliability, 2002, No. 5, pp. 17-23.

[2] Kreinin G.V., Misyurin S.Yu., Yashina M.A. Synthesis of positional system with hydrodrive, motion transfer mechanism with variable transfer ratio and combined loading // Journal of Machinery Manufacture and Reliability, 2004, No. 5, pp. 3-10.

[3] Kreinin G.V., Krivts I.L. Misyurin S.Yu., Yashina M.A. Pneumatic positioning drive: Evaluation of possibilities and prospects for application // Journal of Machinery Manufacture and Reliability, 2007, 36(1), pp. 20-26.

[4] Sobol I.M., Statnikov R.B. Selecting Optimal Parameters in Multicriteria Problems, 2nd Edition, Drofa, Moscow, 2006, 170 p.