The synchronous movement of mechanisms taking into account forces of the different nature

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Abstract. In the work the method of transition to dimensionless parameters is presented on the example of movement by two synchronously working piston hydraulic engines of a heavy object with use of the theory of similarity and analogousness. Advantage of such approach is shown in limit simplification of dimensionless model, its universality and efficiency of search of an optimal solution in the choice of parameters of the real device.

Methods of dimension and the theory of similarity are successfully applied in a research of dynamic systems of various classes. The problems arising at the same time are connected generally with the choice of a rational combination of the main units of measure of physical quantities, with transition to dimensionless models and with formation basic criterion of similarity. The specified problems are solved by the researcher, as a rule, on the basis of own intuition and experience. The systematized approaches to the solution of similar problems based on a method of the theory of analogousness are meanwhile known.

1. Introduction

In technological processes operations of controlled movement of objects of big weight, large dimensions, complex geometry or other characteristics often meet. In some cases such operations should be performed by two or more robotic devices interacting with each other [1-3].

For moving especially heavy and bulky objects preference is given to hydraulic engines which are characterized by high specific power and, as a rule, do not require the inclusion in the design of additional reinforcement mechanisms. To solve such problems, it is proposed to use the approaches developed by the authors, based on the interactive procedure of dynamic systems synthesis, rationalization of their mathematical models, including forces of different nature, in particular friction forces. The complexity of this model consists in a large number of parameters introduced into the model. All these parameters have different dimensions, which greatly complicates the analysis and synthesis of the mechanisms produced on the mathematical model. This problem can be greatly simplified by moving to dimensionless parameters using the theory of similarity and analogousness [4]. However, the process of transition to dimensionless parameters has a number of features associated with the choice of dependent and independent variables.

The procedure for constructing dimensionless models of robotic systems taking into account the friction of different nature for subsequent optimization is not sufficiently developed to date.

The problem of friction forces simulation also arises in solving the task of driving systems dynamics with hydraulic and pneumatic piston engines [5, 6]. Along with the relatively simple models

of viscous and dry friction, quite complex models are used here, which take into account many additional factors: the stribeck-effect, the difference in the friction processes in the periods before and with the beginning of the slip of the sealing element, the effect of damping, hysteresis, etc. It should be noted that the introduction of complex friction laws in the model can help to find a solution in minimizing the influence of friction forces in general, rather than setting up the system to work with certain, complex laws of friction.

The problems of coordinated synthesis of complex dynamic systems, including taking into account the friction forces, have been repeatedly investigated. A detailed mathematical model of the radial piston pneumatic motor for the analysis of dynamic processes and the construction of mechanical characteristics is presented in works [7, 8]. The process of parameter selection is shown using the multi-criteria optimization program. The optimization method of the main design parameters, from the condition of obtaining the maximum developed power at the minimum consumption of compressed air and the minimum dimensions is given in work [7]. The methods of multi-criteria optimization systems with a large number of variable parameters and decision support are used.

In this paper, we consider the first part of the task, namely the transition to dimensionless parameters, using the example of moving a heavy object with two synchronously operating piston hydraulic motors. The mass load is assumed to be distributed between the engines unequally.

2. Mathematical model of a system

We consider the transition to dimensionless parameters based on the below mathematical model. The mathematical model of the system is obtained under the following conditions. The actuators are hydraulic cylinders 1 and 2, fed from a common source p_M (Fig. 1). The drives operate in synchronous mode and move the object mass m, where $m = m_1 + m_2$; $m_{1, 2}$ – the mass loads attributable to the engines. The law of motion is realized by a controlled pressure change in the lower cavities of the hydraulic cylinders, which are connected to the power source (with pressure p_M) through the control valve 3, the intermediate cavity 4 (volume V) and the distribution valve 5.

Figure 1. Figure with short caption (caption centred).
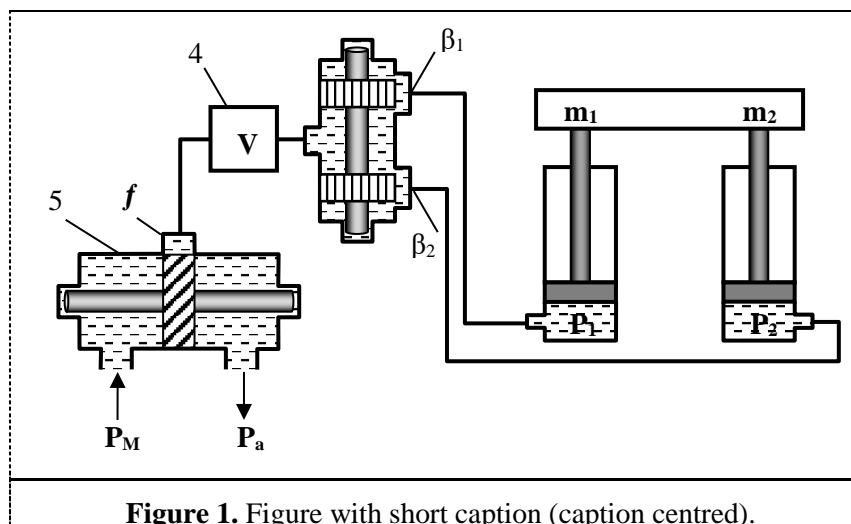
The engines motion equations are:

$$m_{1,2}\ddot{x}_{1,2} = p_{1,2}F + m_{1,2}g - \kappa_{1,2}\dot{x}_{1,2} + P_{L1,2}$$

(1)

where x is the piston displacement, $p_{1,2}$ are the pressure in the lower cavities of the hydraulic cylinders 1 and 2, F is the piston effective area, $m_{1,2}\,g$ and $P_{L1,2}$ are the weight and force loads on the rod, $\kappa_{1,2}$ are the fluid friction coefficients in the drive.

Changes in the pressures $p_{1,2}$ in the lower cavity of the actuator and in the pressure p in the intermediate cavity are related by the following dependencies:

$$\dot{p} = W(\beta \operatorname{sgn}(\Delta p)\sqrt{|\Delta p|} - \beta_1 a_1 \operatorname{sgn}(\Delta p_1)\sqrt{|\Delta p_1|} - \beta_2 a_2 \operatorname{sgn}(\Delta p_2)\sqrt{|\Delta p_2|})$$

$$\dot{p}_{1,2} = W_{1,2}(\beta_{1,2} a_{1,2} \operatorname{sgn}(\Delta p_{1,2})\sqrt{|\Delta p_{1,2}|} - \dot{x}_{1,2}) \tag{2}$$

where $\quad W = (Ef/Fx_v)\sqrt{(2p_M)/\rho}$; $\quad W_{1,2} = (Ef/F(x_{01,2} + x_{1,2}))\sqrt{(2p_M)/\rho}$; $\quad \Delta p = p_M - p$; $\Delta p_{1,2} = p_M - p_{1,2}$; β, β_1 and β_2 are the opening extent of the f, f_1 and f_2 channels; E is the volume elasticity module of the working fluid; x_v is the reduced length of the intermediate cavity; ρ is the working fluid density.

Dimensionless models are recommended to use for solving complex, multi-parameter systems in which real parameters and other characteristics of the system are dimensionless complexes. This transformation reduces the number of basic parameters and allows obtaining generalized characteristics, which facilitates the analysis and synthesis of the drive (mechatronic) complex. The transition to dimensionless parameters is based on the analogousness theory method [4]. Equations (1, 2) are transformed into a dimensionless form by replacing their variables with dimensionless analogues λ, τ, σ according to the relations: $x = q_1\lambda$, $t = q_2\tau$ and $p = q_3\sigma$. As a result of this replacement, in the first approximation, as well as $m_{1,2} = c_{1,2}m$, $\varepsilon = E/q_3$ and simple transformations, we obtain a transformed system (3):

$$c_{1,2}\ddot{\lambda}_{1,2} = \sigma_{1,2} + c_{1,2}\chi_L - \kappa_{1,2}\dot{\lambda}_{1,2} + \chi_{L1,2}$$

$$\dot{\sigma} = K_V(\beta \operatorname{sgn}(\Delta\sigma)\sqrt{|\Delta\sigma|} - \beta_1\alpha_1 \operatorname{sgn}(\Delta\sigma_1)\sqrt{|\Delta\sigma_1|} - \beta_2\alpha_2 \operatorname{sgn}(\Delta\sigma_2)\sqrt{|\Delta\sigma_2|} \tag{3}$$

$$\dot{\sigma}_{1,2} = (\varepsilon/(\lambda_{01,2} + \lambda))(\beta_{1,2}\alpha_{1,2} \operatorname{sgn}(\Delta\sigma_{1,2})\sqrt{|\Delta\sigma_{1,2}|} - \dot{\lambda}_{1,2})$$

where τ is the time; λ_1 and λ_2 are the movements of the drives; σ, σ_1 and σ_2 are pressures in the cavities; $\Delta\sigma$, $\Delta\sigma_1$ and $\Delta\sigma_2$ are differential pressures between the cavities; $c_{1,2}$ is mass load distribution between the drives; χ_L is the total mass load of the manipulator, $x_L = mg/p_M F$; $\chi_{L1,2}$ are additional resistance forces, $x_{L1,2} = P_{L1,2}/p_M F$; K_V is the stiffness of the intermediate cavity, $K_V = \varepsilon/\lambda_V$; $\lambda_{01,2}$ are reduced initial volumes of the working cavities of the drives, $\lambda_{01,2} = x_{01,2}/q_1$; $\kappa_{1,2}$ are the fluid friction forces, $\kappa_{1,2} = k_{1,2}U/p_M F$, where $U = (f/F)\sqrt{2p_M/\rho}$; $\alpha_{1,2}$ is the ratio between the dimensions of the flow areas of the channels 3 and 5, $\alpha_{1,2} = f_{1,2}/f$.

The initial conditions of the obtained model are the actual time of movement τ_S of mass m and the value of its stroke x_S. Since the scale q_1 of the dimensionless displacement measurement is the stroke of the manipulator, then q_1 is assumed to be x_S.

The use of the transformed mathematical model (3) in this case is necessary for the study of a relatively little studied dynamic system with two hydraulic execution units which solve together the problem of linear displacement of an object having large dimensions and mass. Sufficiently complex mechanical and hydraulic cross-links affecting the dynamics of the system arise with the constant interaction of the drives and the external object. Accounting for these connections is also complicated by the fact that in the movement process may arise unpredictable additional disturbances in the form of random forces of resistance, instability of parameters and other factors. The system components involved in the movement are connected to each other through hydraulic and mechanical circuits which leave some mutual freedom in the movements that also affects the quality of the operation.

3. Conclusions

The process of forming a dimensionless model of a dynamic system and its similarity criteria is subject to certain rules in this work, which lead to an optimal set of basic units of a measure of physical quantities corresponding to the problem to be solved. The transformed model is characterized by high versatility in comparison with the original model, it contains a much smaller number of parameters, which makes it convenient to solve problems of both analysis and, in particular, the synthesis of the system.

Many factors specific to real systems, such as friction, other types of loads, control loop dynamics, etc., were not taken into account in the construction of the initial model for the sake of clarity.

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