Coordinated interaction of two hydraulic cylinders when moving large-sized objects

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Abstract. The problem of the choice of parameters and the control scheme of the dynamics system for the coordinated displacement of a large mass object by two hydraulic piston type engines is considered. As a first stage, the problem is solved with respect to a system in which a heavy load of relatively large geometric dimensions is lifted or lowered in the progressive motion by two unidirectional hydraulic cylinders while maintaining the plane of the lifted object in a strictly horizontal position.

1. Introduction
At present, the problem associated with the uniform elevation of a heavy object by two or more drives is quite relevant. This problem occurs in various situations, where it is necessary to move the load evenly up or down with a minimum skew (see Figure 1: 3 - table, 1 - drives, 2 - base) [1, 2]. For example, in 3D Printing Tools the object (product), which is produced using “printing”, is installed on the position table and moved in the vertical direction. Today quite large objects are “printed”, for example, the objects with the size of 1500mm x 1500mm x 1500mm and with maximum weight up to 200 kg. There are several implementations where the position table is moved by means of two stepping engines with the transfer of the screw-nut (ball couple). Synchronization is carried out with the help of a control system, where a displacement sensor is an optical rotating encoder on each engine. The synchronization accuracy in the displacement of the engines is approximately 0.1 mm. But in many problems this accuracy is not enough and the power of the stepper engine may not be enough.

Figure 1.
2. Movement scheme

It is proposed to use hydraulic drives that are controlled by the redistribution of fluid flows between them, including (if it is possible) introducing reverse flows.

Figure 2 shows a diagram using two hydraulic drives. A distinctive feature of the system under consideration is the adopted control scheme. It uses three hydraulic switchgears \((\beta, \beta_1, \beta_2)\). The first of them performs the function of regulating the overall speed of elevating (and lowering) the object; the other two support the horizontal position of the object within the specified accuracy in the presence of disturbing factors of different nature - changes in the resistance forces, pressure in the system, consumption characteristics of regulators, and others.

![Diagram of hydraulic drives](image)

Figure 2.

The second feature of the system is the scheme of turning on hydraulic devices. The total flow of fluid consumed by both drives passes through the first device, where it is simultaneously divided into two identical flows. The pressure created in the system and the first and second hydraulic cylinders are \(P, P_1, P_2\), correspondingly.

3. System equations

The dimensionless equations of motion of the drives

\[
\begin{align*}
\ddot{\xi}_1 &= \sigma_1 - \chi_{k1} - \kappa_1 \dot{\xi}_1 \\
\ddot{\xi}_2 &= \sigma_2 - \chi_{k2} - \kappa_2 \dot{\xi}_2
\end{align*}
\]

The derivation and analysis of these equations is given in [3-5]. Here \(\xi\) and \(\dot{\xi}\) are dimensionless variables characterizing the motion of the first and second drives.

The equation of pressure variation in the intermediate cavities

\[
\dot{\sigma} = \frac{E}{\xi_0} \Lambda \left[ \beta \ \text{sgn}(1 - \sigma) \sqrt{|1 - \sigma|} - A_1 - A_2 \right]
\]

\[
A_1 = \beta_1 \alpha_1 \ \text{sgn}(\sigma - \sigma_1) \sqrt{|\sigma - \sigma_1|}
\]

\[
A_2 = \beta_2 \alpha_2 \ \text{sgn}(\sigma - \sigma_2) \sqrt{|\sigma - \sigma_2|}
\]

\[
\Lambda = \frac{f_1}{f} \sqrt{\frac{2m}{Fs^* \rho}} \ ; \ \text{here} \ m \ - \ \text{weight of the object being moved}; \ f \ - \ \text{effective area of the channel cross-section at the entrance to the system}; \ F \ - \ \text{piston area}; \ \alpha_1 = f_1/f; \ \alpha_2 = f_2/f \ \text{here} \ f_1 \ \text{and} \ f_i \ - \ \text{effective areas of feed channels for working cavities of drives}; \ \beta, \beta_1, \beta_2 \ - \ \text{the relative areas of opening of the corresponding channels}.
\]
Equations of pressure changes in working cavities of drives

\[
\dot{\sigma}_1 = \frac{\epsilon}{\xi_{01} + \xi_1} [\beta_1 \alpha_1 \text{sgn}(\sigma - \sigma_1) \sqrt{\sigma - \sigma_1} - \dot{\xi}_1],
\]

\[
\dot{\sigma}_2 = \frac{\epsilon}{\xi_{02} + \xi_2} [\beta_2 \alpha_2 \text{sgn}(\sigma - \sigma_2) \sqrt{\sigma - \sigma_2} - \dot{\xi}_2].
\]

The control system equations \(\beta = \lambda \gamma_1\); \(\gamma_1\) – constant control signal at the first stage;

\(\beta_1 = \beta_0 + \lambda_2 \Delta \xi; \quad \beta_2 = \beta_0 - \Delta \xi\);

Using the Painlevé test one can study the analytical properties as was suggested in reference [6-8].

4. Conclusions

As a result of a numerical experiment, it was shown that it is possible to achieve a minimum deviation of the operation of the two drives to 0.01 mm. A sign of the deviation of the object from the horizontal position is the difference in the movements of the hydraulic actuator rods from some initial (basic) position at a given time, determined from the difference in the signals of the corresponding impulse-type position sensors. Additionally, a physical level sensor, whose positive property is independence from the current load position, can be used. Movement of the whole system is stable, deviations in the system are compensated by control. In the numerical experiment, it is proposed to carry out further multicriteria optimization as shown in [9].

This work was supported by the Russian Foundation for Basic Research, in the framework of a research project 16-29-04401 “Development of methods and algorithms for the synthesis of drive complexes (robots) working in different environments, taking into account the interaction of two or more robots.

This work was supported by the MEPhI Academic Excellence Project (agreement with the Ministry of Education and Science of the Russian Federation of August 27, 2013, project no. 02.a03.21.0005).

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