

## MODELING A FLUID POWER DRIVE OF THE EXCAVATOR EQUIPMENT

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**Abstract.** *The article studies an example of simulation of complex technical systems that combine the dynamics of the excavator equipment and the fluid power drive mechanical subsystem.*

**Keywords:** *simulation model, excavator working equipment, mechanical systems, SimScape, SimHydraulics, SimMechanics.*

### Introduction

The hydraulic drive of modern construction and road machines is quite complex, and modeling the entire drive in full requires significant effort and time [1]. However, improving the quality of design with reducing time and cost becomes possible only with the use of modern technologies as well as computer hardware and software.

SimHydraulics is a special library of the Simulink package in the MATLAB environment, designed to simulate hydraulic systems using components that take into account the influence of real physical characteristics and magnitudes that connect all blocks of the model. At the same time, the main approach to modeling is based on the transfer of physical energy from block to block, taking into account physical dimensions.

### Analysis of publications

In literature [2–6], several models of the dynamics of the fluid power drive have been proposed. In a significant number of works, for example [2–3], as a rule, the sequence of modeling the working processes of a hydraulic drive implies the development of a mathematical model based on differential and algebraic equations, which are then entered into a computer by taking them from the Simulink module standardized blocks of the MATLAB program with subsequent solution by numerical methods.

In works [4–6] the modeling of hydraulic system working processes in the SimHydraulics physical simulation environment is substantiated. The examples of building the block diagrams from standard elements of the library (spool valve, pump, hydraulic cylinder, safety and reverse valves, hydraulic locks and auxiliary equipment) are given. However, these works do not consider the influence of time-varying external forces, which appear as a reaction during the transient processes in multi-link mechanical systems.

### Purpose and problem statement

The aim of the work is to develop a simulation model of the fluid power drive of the excavator working equipment mechanical system in the MATLAB & SimHydraulics package for studying the dynamics of transient processes in multi-link mechanical objects.

The following tasks are being solved in the work:

- to develop a physical simulation model of the fluid power drive for excavator working equipment in the SimHydraulics package;
- to check the performance of the developed model and find the power characteristics of the actuators using the real technical characteristics of the Borex 2201 excavator hydraulic equipment.

### Analysis of the excavator working equipment hydraulic drive

The method for constructing a block diagram of an excavator working equipment mechanical subsystem mathematical model in the terms of SimMechanics was considered in [7]. The fluid power drive of the Borex 2201 excavator (Fig. 1) consists of an open working circuit driven by a gear pump H1.

In the excavator, the working fluid is supplied from pump H1 through valve block P1–P3 (Fig. 2) to the hydraulic cylinders of the working equipment (C1 of the boom, C2 of the stick and C3 of the bucket) and then to the draining into the tank. Pressure valves KP2 and KP3 that prevent the rod ends from overloading are connected to the head ends of hydraulic cylinders C1 and C2 of the boom and stick, and throttle DP1 with the reverse valve KO1 that ensures smooth lowering of the boom, is connected to the rod end of hydraulic cylinder C1.

The safety valve KP1 adjusted to a pressure of 16.5 MPa is installed at the inlet to the hydraulic valves P1–P3.

In the SimHydraulics standard library there are no blocks for modeling monoblock and sectional multi-line (more than 4 lines of supply and removal of working fluid) hydraulic valves with pump unloading in the neutral position of three-position spools [8].

The Simulink package allows the user to create their own blocks that have the properties of standard library blocks, therefore the required element can be created from elementary hydraulic blocks of Variable Orifice adjustable throttles that are interconnected as shown in Fig. 2 in [9].

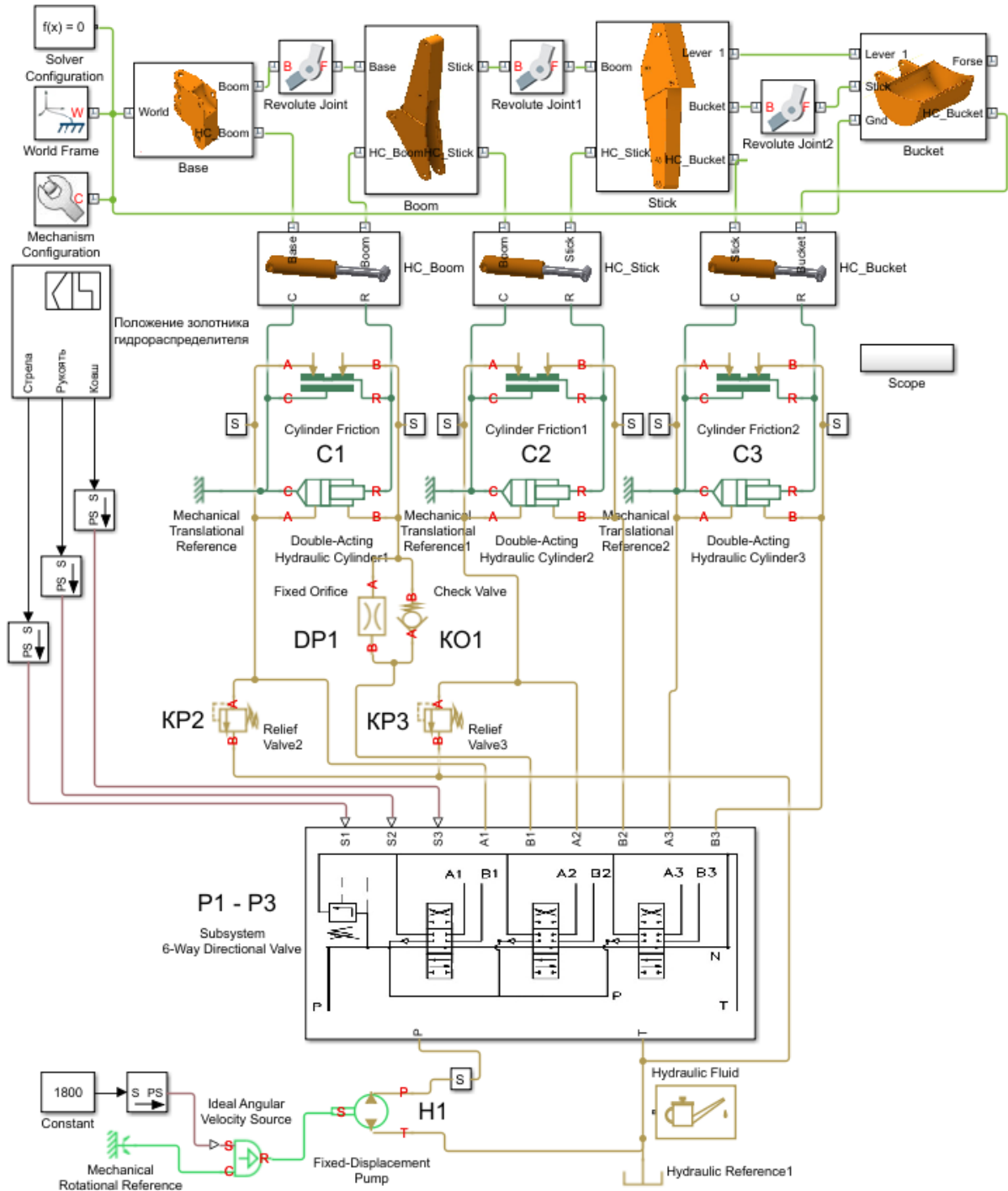


Fig. 1. Simulink-model of the excavator working equipment hydraulic drive

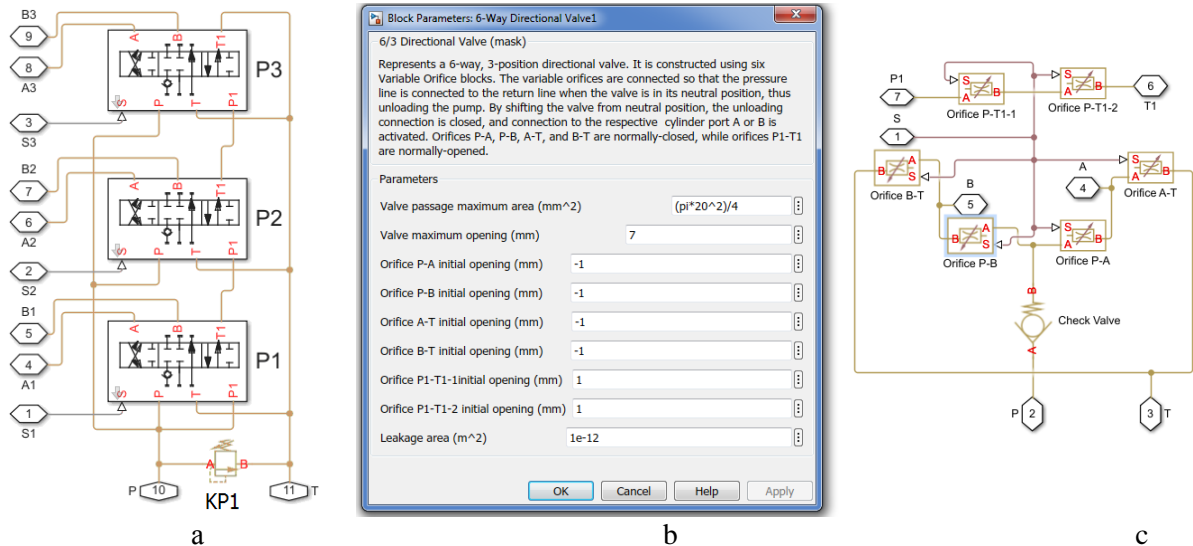


Fig. 2. Masked user subsystem of the hydraulic valve P1 - P3: a – the subsystem window after performing «Look Under Mask» action; b – the settings window of the block P1 (mask); c – the structure of a separate section of the hydraulic valve

The mathematical models of the hydraulic control valve spool and the safety valve are represented by the models of fluid flow through the orifice of the adjustable diameter. Taking into account the assumption of flow turbulence, we can write down:

$$Q = \mu \cdot S \cdot \sqrt{\frac{2}{\rho} |\Delta p|} \cdot \text{sign}(\Delta p), \quad (1)$$

where  $Q$  – rate of the liquid flow through the section under consideration;  $\mu$  – coefficient of consumption;  $\rho$  – density of the liquid;  $\Delta p$  – pressure difference at the throttle;  $S$  – sectional area of the throttle.

The pressure difference is calculated according to the selected positive direction of the fluid flow, and this determines the sign of the flow rate. With the negative values, the liquid flows in the opposite direction.

The cross-sectional area of the spool passages is determined as:

$$S = S_{\max} \frac{|h_{\text{control}}|}{h_{\max}}, \quad (2)$$

$$h_{\text{control}} = h_0 + z_{\text{control}}, \quad (3)$$

where  $h_{\max}$  – maximum valve displacement (Valve maximum opening);  $h_{\text{control}}$  – current displacement of the spool, which looks like a non-linear dependence on the control signal  $z_{\text{control}}$  to be regulated;  $h_0$  – spool overlap (Ori-

fice P-A initial opening);  $S_{\max}$  – maximum area of valve passage.

The cross-sectional area for the safety valve is defined as:

$$S = \begin{cases} 0 & \text{as } p_A \leq p_{\text{set}} \\ S_{\max} \cdot \frac{(p_A - p_{\text{set}})}{(p_{\max} - p_{\text{set}})} & \text{as } p_{\text{set}} < p_A < p_{\max} \\ S_{\max} & \text{as } p_A \geq p_{\text{set}} \end{cases}, \quad (4)$$

where  $p_{\text{set}}$  – value of pressure at which the valve starts to open (Valve pressure setting);  $p_{\max}$  – value of pressure at which the valve is fully open (Valve regulation range);  $S_{\max}$  – maximum passage area of the safety valve.

The P input of the «6-Way Directional Valve» subsystem is connected to the pump, T – to the drain line, and the control signal to the spools is set by the signal from the S1–S3 input. The outlets A1–A3 and B1–B3 are connected to the chambers of the hydraulic cylinder.

The windows for setting the parameters of the Fixed-Displacement Pump units and Double-Acting Hydraulic Cylinder are shown in Fig. 3 and 4.

The pump creates a fluid supply depending on the rotation speed of its shaft (control signal). This supply is expressed by the formula:

$$Q_A = D_p \cdot n, \quad (5)$$

where  $D_p$  – working volume of the pump (Displacement);  $n$  – current pump rotational rate.

Shaft speed is fed to the port S using Constant, the Simulink-PS Convert adapter, and Ideal Angular Velocity Source.

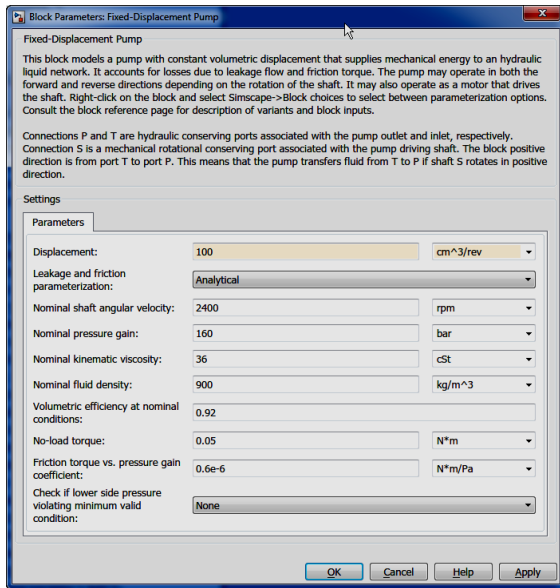


Fig. 3. Windows for setting parameters of hydraulic pump units [10] Fixed-Displacement Pump

The hydraulic cylinder consists of two volumes of hydraulic fluid, the pressure in which creates a force acting on the piston. For intermediate positions, this can be expressed by the equation:

$$F = p_p S_p - p_r S_r \quad \text{as } 0 < x_r < x_r^{\max}, \quad (6)$$

where  $p_p$  and  $p_r$  – pressure in the head and rod ends;  $S_p$  and  $S_r$  – area of the head (Piston area A) and rod ends (Piston area B);  $x_r$  and  $x_r^{\max}$  – current position of the rod and its maximum extension (Piston stroke).

The volume of these ends is set by the initial position of the hydraulic cylinder rod (Piston initial distance from cap A) and the speed of its movement.

For the extreme positions of the hydraulic cylinder piston, the force is represented by viscoelastic connections:

$$F = k(x_r - x_r^{\max}) - \dot{x}_r b \quad \text{as } \begin{cases} x_r < 0 \\ x_r > x_r^{\max} \end{cases}, \quad (7)$$

where  $k$  and  $b$  – reduced coefficients of elasticity (Contact stiffness) and viscosity (Contact damping) in the extreme position of the hydraulic cylinder piston, respectively.

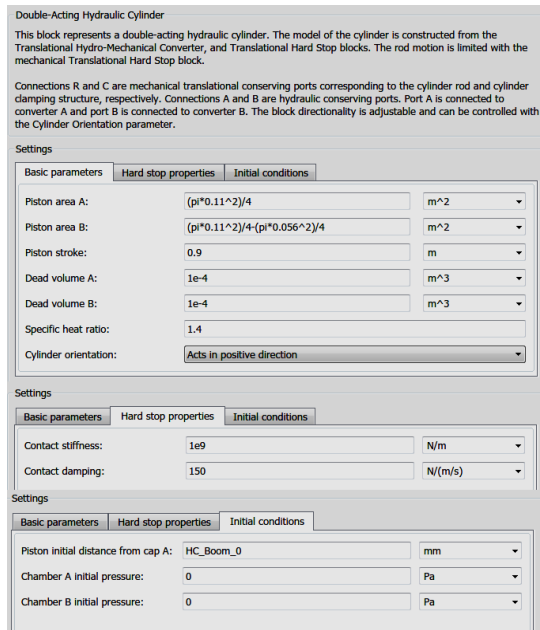


Fig. 4. Windows for setting the parameters of the power hydraulic cylinder blocks [11] Double-Acting Hydraulic Cylinder

To take into account the dissipative component, Cylinder Friction block was used (Fig. 5) which describes the forces of viscous friction, static friction and sliding friction:

$$F_D = F_p + f_{VF}(p_p + p_r) + f_{CF} \cdot \dot{x}_r, \quad (8)$$

where  $F_p$  – force of static friction (Preload force);  $f_{VF}$  – coefficient of viscous friction (Viscous friction coefficient);  $f_{CF}$  – coefficient of dry friction (Coulomb friction force coefficient).

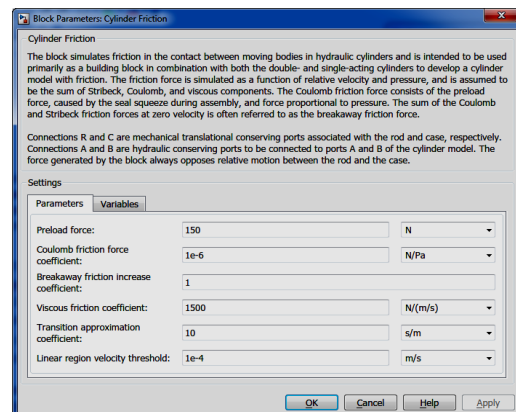


Fig. 5. Windows for setting parameters of Cylinder Friction blocks

### Conclusions

1. Thus, using the blocks of the Simulink package, a simulation model of the interaction

of the excavator working equipment mechanical system with its fluid power drive was built.

2. With the help of this model, it is possible to obtain values characterizing transient processes, including changes in the value of the generalized coordinates of the particular points of the working equipment, the rate of their change, and the effort in the hydraulic cylinder. A visual representation of the manipulator movement can be obtained using the built-in SimScape visualization function.

3. The resulting model makes it possible to solve the problems of analysis and synthesis of the excavator operation control systems, which will be studied in the following articles.

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### Моделирование об'ємного гідропривода экскаваторного обладнання

**Анотація.** Гідравлічний привід сучасних будівельних і дорожніх машин досить складний, і моделювання всього привода в повному обсязі потребує значних зусиль і витрат часу. Однак підвищення якості проектування в разі одночасного скорочення термінів і витрат можливе тільки за умови використання сучасних технологій, комп'ютерної техніки та програмного забезпечення. Наявні моделі робочих процесів гідравлічних сис-

тем в середовищі фізичного моделювання SimHydraulics, є компонуванням блок-схем зі стандартних елементів бібліотеки (золотниковий розподільник, гідронасос, гідроциліндр, запобіжні та зворотні клапани, гідрозамки тощо). Однак в них не визначено вплив змінних у часі зовнішніх сил, які є реакцією під час перехідних процесів у багатоланкових механічних системах. **Мета роботи** – розроблення імітаційної моделі об'ємного гідропривода механічної системи (робочого обладнання екскаватора) в пакеті MATLAB & SimHydraulics для дослідження динаміки перехідних процесів багатоланкових механічних об'єктів. У статті наведено приклад розроблення фізичної імітаційної моделі об'ємного гідропривода робочого обладнання екскаватора в пакеті SimHydraulics. Використовуючи реальні технічні характеристики гідроапаратури екскаватора Борекс 2201, перевірена працездатність розробленої моделі та визначено силові характеристики виконавчих механізмів. Використовуючи проаналізовані в статті блоки, можна побудувати імітаційну модель взаємодії механічної системи робочого обладнання екскаватора з його об'ємним гідроприводом. За допомогою запропонованої моделі можна отримувати значення, що характеризують перехідні процеси, зокрема зміни значення узагальнених координат характерних точок робочого обладнання, швидкості їхньої зміни, зусилля гідроциліндра. Наочне уявлення щодо руху маніпулятора можна отримати за допомогою вбудованої функції візуалізації SimScape. Отримана модель дозволяє вирішувати завдання аналізу та синтезу систем керування роботою екскаватора.

**Ключові слова:** імітаційна модель, робоче обладнання екскаватора, механічні системи, SimScape, SimHydraulics, SimMechanics.

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### **Modeling a fluid power drive of the excavator equipment**

**Abstract. Problem.** The hydraulic drive of modern construction and road machines is quite complex,

and it takes a lot of time and effort to model the entire drive in full. However, improving the quality of design with reducing terms and costs becomes possible only with the use of modern technologies, computer hardware and software. The existing models of hydraulic system working processes in the physical modeling environment SimHydraulics are presented by block diagram layouts from standard library elements (slide valve, hydraulic pump, hydraulic cylinder, safety and reverse valves, hydraulic locks, etc.). However, they do not consider the influence of time-varying external forces, which are a reaction during transient processes in multi-link mechanical systems. **Goal.** The aim of the work is to develop a simulation model of the fluid power drive of the excavator working equipment mechanical system in the MATLAB & SimHydraulics package for studying the dynamics of transient processes of multilink mechanical objects. **Methodology.** The article describes an example of developing a physical simulation model of the excavator working equipment fluid power drive in the SimHydraulics package. Using the real technical characteristics of the hydraulic equipment of the Borex 2201 excavator, the performance of the developed model was checked and the power characteristics of the actuators were determined. **Originality.** Using the blocks described in the article, a simulation model of the interaction of the excavator working equipment mechanical system with its fluid power drive can be created. **Practical value.** The model proposed makes it possible to obtain values characterizing transient processes, including changes in the value of the generalized coordinates of the characteristic points in the working equipment, the rate of their change, and the effort in the hydraulic cylinder. A visual representation of the manipulator movement can be obtained using the SimScape built-in visualization function. The resulting model allows solving problems of analysis and synthesis of excavator operation control systems.

**Key words:** simulation model, excavator working equipment, mechanical systems, SimScape, SimHydraulics, SimMechanics.

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