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THE INCLUSION IN THE CALCULATION SCHEMES FOR NUMERICAL SIMULATION OF THE PRESSURES DROP ON INLET AND OUTLET OF HYDRAULIC CIRCUITS

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ABSTRACT

Numerical simulation of the operation of hydraulic systems acting on hydraulic cylinderst is based on differential equations that describe the equilibrium of forces and the continuity of the flow rate. To simplify the calculations it is assumed that the pressures on hydraulic circuits on inlet and outlet are constant. This approximation is far from reality, especially in conditions of increasing the working speeds. This paper presents a possibility to eliminate this drawback. It is considered that the variable hydraulic flows admitted and discharged from the hydraulic cylinder, will create pressure drop on each of the various components of the hydraulic system. The pressure made by the hydraulic pump is dissipating on all hydraulic resistances and on the hydraulic cylinder piston. By integrating the system of differential equation, it is possible to determine the law of motion of the piston and, implicitly, the pressure drops across each component of the hydraulic system.

KEYWORDS: hydraulic cylinders, mechanism, hydraulic excavator

1. INTRODUCTION

In determining, by computations, of the dynamic behavior of hydraulically operated mechanisms, including hydraulic cylinders, are taken into account both mechanical and hydraulic aspects.

From the mechanical point of view are taken into account:

- Forces generated by pressure;
- Inertial forces;
- The weight of the moving parts;
- Friction forces;
- Technological forces.

Figure 1 presents a mechanism in which element 3 is set in motion by the rotation by a hydraulic cylinder. The supply with hydraulic oil is achieved through a conventional hydraulic scheme, with the limitations;

- Maximum working pressure (p_S);

- Maximum pressure when the hydraulic cylinder is passive (p_m).

It is considered that element 3 has a significant mass and masses are neglected for elements 1 and 2.

Also we consider that energy is used for weight lifting element 3, which includes payload. r_Σ is a vector that describes the position of the center of mass of the driven element.

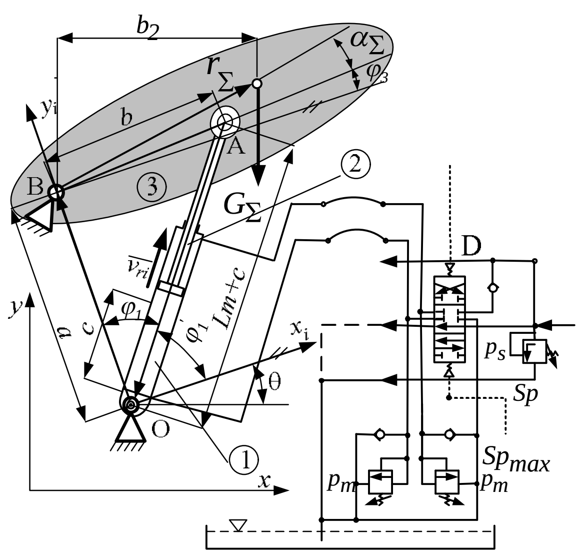

Fig. 1. Schematic diagram of the hydraulically operated mechanism

2. DESCRIPTION OF THE MODEL

On the two sides of the piston act the pressures:

- p_{in} on S_{k_1}, active surface ;
- p_{out} on S_{k_2}, passive surface.

Surfaces change their roles depending on the direction of movement of the piston-rod assembly.

Equation 1 describes the dynamic equilibrium of element 3.

The variable parameter is the stroke, $c(t)$.

From

$$\left(p_{icCH} S_{k_1} - p_{outCH} S_{k_2} - F_f\right) b \cdot \mathbf{sin}\left(\varphi_1^{'}\right) \quad G_{\Sigma} r_{\Sigma} \mathbf{cos}\left(\alpha_{\Sigma} + \theta\right) - J_{\Sigma B} \cdot \varepsilon_3 = 0 \tag{1}$$

and replacing the ties of kinetic nature, it resultings

$$\ddot{c} = \frac{\mathbf{sin}\left(\varphi_1^{'} - \varphi_3\right)}{b \cdot m_{rA}} \Big[\left(p_{inCH} \cdot S_{k_1} - p_{outCH} \cdot S_{k_2} - F_f\right) b\,\mathbf{sin}\left(\varphi_1^{'} - \varphi_3\right) - G_{\Sigma} \cdot r_{\Sigma}\,\mathbf{cos}\left(\alpha_{\Sigma} + \theta_k\right) - b^2 m_{rA} \omega_3^2 / \mathbf{tan}\left(\varphi_1^{'} - \varphi_3\right) + \frac{b \cdot m_{rA}\left(L_m + c\right)\omega_1^2}{\mathbf{sin}\left(\varphi_1^{'} - \varphi_3\right)} \tag{2}$$

The inlet and outlet pressures, p_{inCH} and p_{outCH}, are usually considered, constant. Due to increased work speeds, this approximation become far from reality. Hydraulic schemes are becoming increasingly complex, with a large number of components. An example of a hydraulic installation is shown in Figure 2.

It's a hydraulic installation on an excavator. And this is only a part of the complete installation. Hydraulic oil has to travel a complex path and encounter hydraulic resistances on each component. This happens on both paths, the intake and the exhaust. Intake and exhaust paths may be different, depending on the technology cycle executed.

In Figure 3 is presented the variation of pressure drop across the intake and exhaust paths. Pressure drop in hydraulic cylinder, Δp_{CH}, is the highest.

The pressure generated by the hydraulic pump, p_P, is variable, depending on the dynamics of the system and its own control system. Pressure drop across the inlet and outlet paths depends on the pump flow and the hydraulics components geometry. For the estimation of the pressure drop the following possibilities exist:

A - analytical

- Pressure drop linear (Darcy)

$$\Delta p_{di} = \lambda_i \cdot \frac{l_i}{d_i} \cdot \frac{\rho}{2} \cdot w_i^2 \tag{3}$$

- Local pressure drops (Weissbach)

$$\Delta p_{loci} = \xi_i \cdot \frac{\rho}{2} \cdot w_i^2 \tag{4}$$

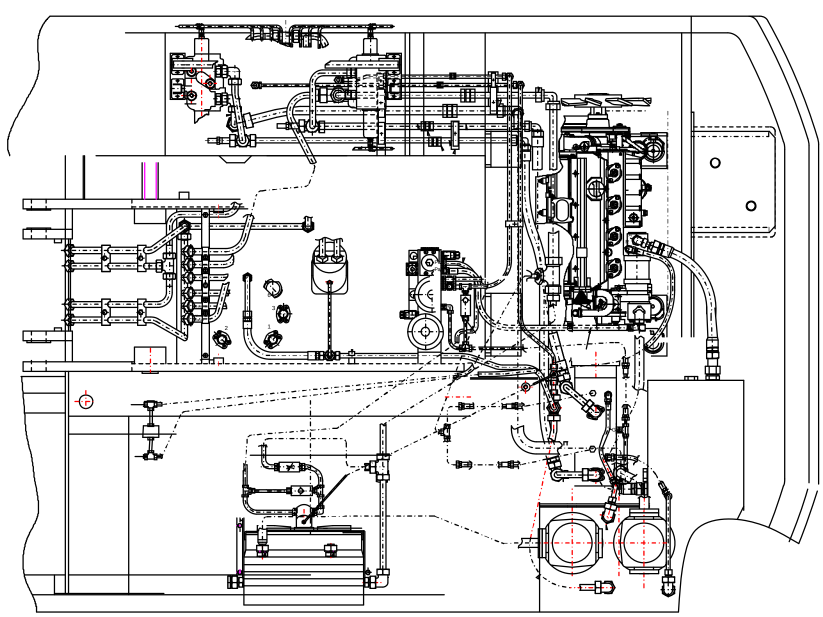

Fig. 2. The hydraulic installation on upper carriage of an excavator

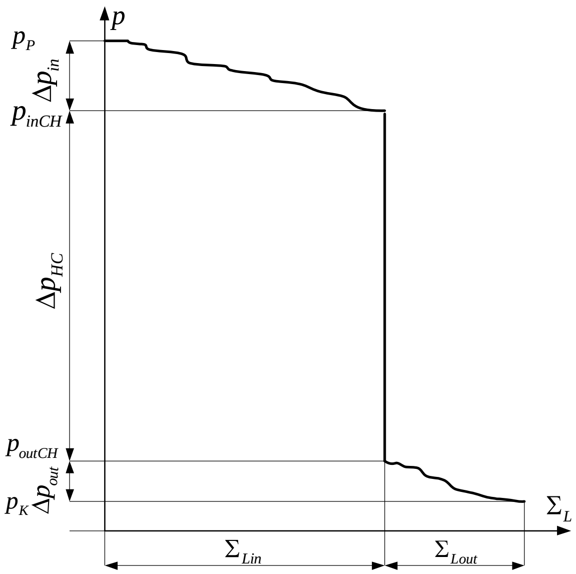

Fig. 3. Pressure drop across the whole route of the hydraulic oil

Hydraulic pump creates a pressure that is summing up all the pressure drops on the intake and evacuation of hydraulic circuit.

$$p_P = \Delta p_{in} + \Delta p_{HC} + \Delta p_{out} \, . \tag{5}$$

Pressure drop across the intake

$$\Delta p_{in}\left(Q_{in}\left(p_p\right)\right) = \sum_{j=1}^{n} \lambda_j \cdot \frac{l_j}{d_j} \cdot \frac{\rho}{2} \cdot w_j^2 + \sum_{k=1}^{m} \xi_k \cdot \frac{\rho}{2} \cdot w_k^2 \tag{6}$$

and for evacuation

$$\Delta p_{out}\left(Q_{out}\left(p_p\right)\right) = \sum_{i=1}^{t} \lambda_i \cdot \frac{l_i}{d_i} \cdot \frac{\rho}{2} \cdot w_i^2 + \sum_{p=1}^{v} \xi_p \cdot \frac{\rho}{2} \cdot w_p^2 \tag{7}$$

Pressures acting on the two sides of the hydraulic cylinder

$$p_{inCH} = p_p - \Delta p_{in}$$
$$p_{outCH} = p_k + \Delta p_{out} \tag{8}$$

B - 3D modeling and virtual simulation of the flow using simulation environments.

The process involves achieving 3D drawings for all hydraulic system components.

They are assembled in specialized programs. After processing we obtain fluid bodies.

On these fluid bodies these can be achieved virtual simulations for various flow rates, under conditions close to reality.

The data obtained can be used to achieve approximate functions describing the flow.

The theoretical flow rate depends on the hydraulic pump geometry and on the type of regulator used.

$$Q_{tHP} = Q_{tHP}\left(p_P\right) \tag{9}$$

To calculate the flow rate on the face of the hydraulic cylinder piston, Q_{tHP} diminishes with:

- The influence of the compressibility of the hydraulic oil,

$$Q_{comp} = \frac{V_0 + \frac{\pi \cdot d_C^2}{4} \cdot c}{E_C} \cdot \dot{p} \, ; \tag{10}$$

- The loss of flow rate through the pressure valve set to p_S ,

$$Q_{SP} = \frac{p - p_S}{C_S} \, ; \tag{11}$$

- Losses due to internal clearances from the hydraulic pumps,

$$Q_{lHP} = Q_{tHP} \cdot \left(1 - \frac{p_P}{p_{nP}} \cdot \left(1 - \eta_h\right)\right) . \tag{12}$$

The flow rate, in the active side of piston, is

$$Q_{in} = Q_{tHP} - Q_{comp} - Q_{SP} - Q_{lHP} \, . \tag{13}$$

The flow rate, at the level of the passive face of the piston, is

$$Q_{out} = Q_{in} \frac{S_{k_1}}{S_{k_2}} \, ; \tag{14}$$

Considering the continuity of the flow rate provided by a hydraulic pump with variable flow, it resultings the ecuation

$$\dot{p}_P = f\left(p_P, c\right) . \tag{15}$$

From the dynamic equilibrium of mechanism components and from flow rate continuity equations, results a system of differential equations that can be solved by numerical methods.

3. CONCLUSION

The assessment by calculation of the behavior of hydraulically driven mechanical systems is a complex problem. Performing complex calculations is justified by major implications in terms of energy and manufacturing issues. The calculation method chosen depends largely on the moment when the calculation is performed.

The calculations performed before design are made exclusively with analytical models.

There are a couple disadvantages:

- Greater complexity;
- Calculation relationships are valid in certain conditions of functioning of hydraulic components;
- There are reciprocal influences between the hydraulic devices in terms of operating conditions and parameters.

Making virtual experiments implies the existence of 3D designs for all hydraulic components.

The times to perform the simulations are high and require significant computing power.

From the results of the simulation these can be obtained functions to approximate with good accuracy the behavior of the hydraulic system according to the work flow rate.

These results can then be embedded in differential models, solved numerically, allowing for simulation of machine operation.

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