Functional Modeling and Simulation of a Rotary Hydraulic Actuator Controlled by a Servovalve

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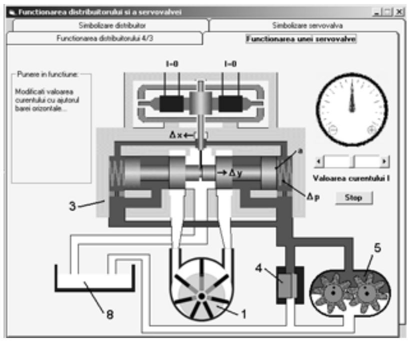
Abstract: *It is extremely important for the understanding of the functioning and control of a hydraulic actuator-servovalve system to establish a mathematical model and to transpose it to a program that could simulate the system.*

Keywords: *Hydraulic actuator, Servovalve, Modeling, Simulation*

I INTRODUCTION

The paper presents a mathematical model in order to establish a link between an input measure, which is the servovalve’s command current intensity (*i*) and an output measure which is the rotational speed of a rotary hydraulic actuator, controlled by the servovalve. (n). The actuator-servovalve assembly and the auxiliary circuits are presented in Figure 1.



Functionarea distribuitorului si a servovalvei

Punere in functiune:

Modificati valoarea curentului cu ajutorul barei orizontale...

Figure 1
Actuator-servovalve system

II MODELING SYSTEM

In order to establish the dependency for *n=n(i)* first a correlation will be expressed between the current that flows in the servovalve’s torque motor’s windings and the slide valve’s displacement *Δy*. The command current variation (*Δi*) will lead to proportional modification of the flap’s position (*Δx*) and will produce a pressure difference on the command faces of the slide valve (*Δp*):

$$\Delta x = c_1 \cdot \Delta i \tag{1}$$

$$\Delta p = c_2 \cdot \Delta x \tag{2}$$

Where c_1 is the amplification factor of the torque motor and c_2 is the amplification factor of the nozzle-flap system which is the first stage of hydraulic amplification.

The pressure force on the slide valve’s faces and the elastic forces built-up by the centering prings with *k* rigidity are in balance:

$$\Delta p \cdot a = K \cdot \Delta y \tag{3}$$

$$\Delta y = \frac{\Delta p \cdot a}{K} = \frac{c_2 \cdot \Delta x \cdot a}{K} = \frac{c_1 \cdot c_2 \cdot a}{K} \cdot \Delta i \tag{4}$$

Slide valve's displacement is proportional to the command current. The flow that passes through the servovalve is also proportional to the slide valve's displacement [1]:

$$Q = \alpha \cdot \pi \cdot d \cdot \Delta y \cdot \sqrt{\frac{2 \cdot p}{\rho}} \tag{5}$$

Where α is a flow coefficient that depends on the sectional shape of the fluid, ρ is the fluid's density, d – slide valve's diameter and p is the fluid's pressure built by the pump 5 that feeds the system.

Replacing (4) in (5) and knowing that:

$$a = \frac{\pi \cdot d^2}{4} \tag{6}$$

we have:

$$\begin{aligned} Q &= \alpha \pi d \cdot \frac{c_1 c_2 \pi d^2}{4k} \cdot \Delta i \cdot \sqrt{\frac{2p}{\rho}} = \\ &= \frac{\alpha \pi^2 c_1 c_2 d^3}{4k} \cdot \sqrt{\frac{2p}{\rho}} \cdot \Delta i \end{aligned} \tag{7}$$

This flow enters in the impeller hydraulic actuator (Figure 2).

The rotor 2 has several radial scoops where the impellers 3 are placed, having a small lateral play. These, through radial movements hold the permanent contact with the interior bore of the stator 1 and with the lateral caps 4 they define the fluid transporting chambers.

The volume variation of these chambers between a maximum and a minimum value will allow the expression for the fluid flow that empowers the actuator's rotor.

By following the notations in Figure 2b we have:

$$V_{\max} = S_{\max} \cdot R_m \cdot \theta \tag{8}$$

$$V_{\min} = S_{\min} \cdot r_m \cdot \theta \tag{9}$$

where θ is the angle between two impellers:

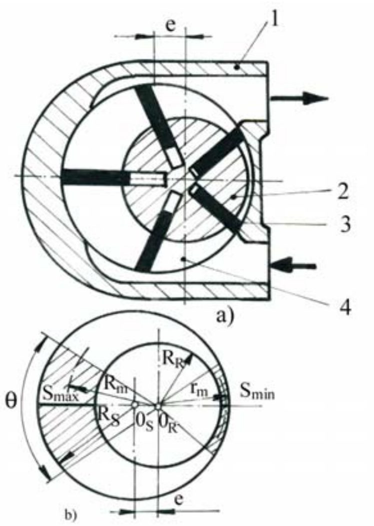


Figure 2
Impeller rotary hydraulic actuator

$$\theta = \frac{2\pi}{z} \tag{10}$$

z – represents number of impellers;

$$S_{\max} = (R_S + e - R_R) \cdot b \tag{11}$$

$$S_{\min} = (R_S - e - R_R) \cdot b \tag{12}$$

b – is the with of the impellers;

$$R_m = \frac{1}{2}\left(R_S + e + R_R\right) \tag{13}$$

$$r_m = \frac{1}{2}\left(R_S - e + R_R\right) \tag{14}$$

Replacing relations (10) ÷ (14) in (8) and (9) is obtained:

$$V_{\max} = \frac{\pi b}{z}\left[\left(R_S + e\right)^2 - R_R^2\right] \tag{15}$$

$$V_{\min} = \frac{\pi b}{z}\left[\left(R_S - e\right)^2 - R_R^2\right] \tag{16}$$

The volume variation of a fluid chamber is:

$$\Delta V = V_{\max} - V_{\min} = \frac{\pi b}{z} \cdot 4 \cdot R_S \cdot e \tag{17}$$

And the geometrical volume of the actuator:

$$V_g = \Delta V \cdot z = 4 \cdot \pi \cdot b \cdot R_S \cdot e \qquad (18)$$

The final form of the flow used by the actuator will be:

$$Q = V_g \cdot n = 4 \cdot \pi \cdot b \cdot R_S \cdot e \cdot n \qquad (19)$$

where *n* represents the rotational speed of the actuator's shaft.

From relations (19) and (7) results that:

$$4bR_s en = \frac{\alpha\pi c_1 c_2 d^3}{4k} \cdot \sqrt{\frac{2p}{\rho}} \cdot \Delta i \qquad (20)$$

and so:

$$n = \frac{\alpha\pi c_1 c_2 d^3}{16kbR_s e} \cdot \sqrt{\frac{2p}{\rho}} \cdot \Delta i \qquad (21)$$

III FUNCTIONAL SIMULATION SYSTEM

In the sequence presented in Figure 1, is represented the operation of a hydraulic circuit composed of a gear pump (5), a safety valve (4), a servovalve (3), an impeller rotary actuator (1), an oil tank (8) and the necessary connection pipes. The oil is represented using conventional colors, dependent to its pressure levels [2].

The operation of this sequence is as follows [3]: by modifying the scroll bar's value will be simulated a change in the torque motor winding's current (Δi), which will lead to the inclination of the armature and the flap (Δx) due to magnetic fields interaction.

This inclination leads to the obstruction of one nozzle and displacement of the slide valve (Δy) under the action of the pressure difference (Δp) that acts on the faces of the slide valve.

The displacement of the slide valve (Δy) is proportional to the current's value in the windings.

Due to the displacement of the slide valve an oil channel is opened between the pump and one of the intake/outlet chambers of the rotary actuator. The rotational speed of the actuator will be proportional to the slide valve's displacement.

To rotate the actuator the opposite way (still with variable velocity) one must modify the scroll bar's value contrarywise passing through the stop position (cursor in the middle of the scroll bar).

The sequence disposes of a 'Stop' button which brings the servovalve in the neutral position and stops the actuator.

For the presentation of the servovalve's operation to be more suggestive the color of the torque motor's coils modifies from tile-color to crimson red. The circular gauge placed in the upper-right corner of the window suggests the sense and the value of the current in the coils.

The safety valve will be open when the servovalve is in the neutral position to allow the high pressure oil flow to the tank. If the servovalve is in an operational position, the safety valve is closed.

By pressing the 'Q=f(i)' button a new form is opened which presents two particular cases of servovalves: positive coverage and negative coverage.

The positive coverage servovalve has the particularity that the axial dimension of the slide valve is bigger than the oil intake. When a low current is applied to the torque motor the slide valve will translate but not enough to open the intake (Figure 3).

The negative coverage servovalve has the particularity that the axial dimension of the slide valve is smaller than the oil intake. When a low current is applied to the torque motor, the slide valve will translate but not enough to close the oil flow in one sense (Fig. 4).

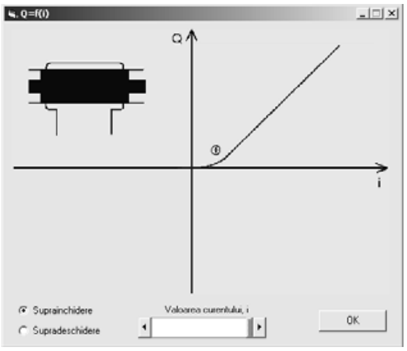


Figure 3
Flow function of current (positive coverage)

Due to these facts, this servovalve will have a permanent oil flow; the use of this type presumes connecting of driven sense valves to ensure the position lock of the hydraulic receptors.

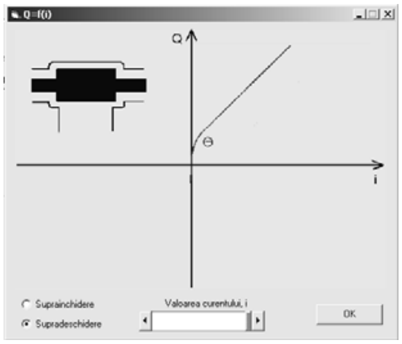
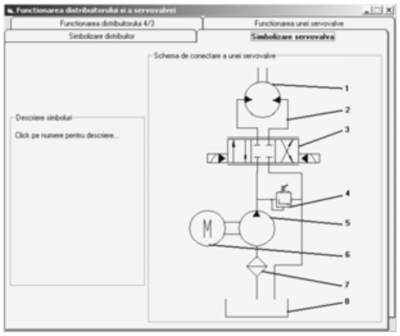


Figure 4
Flow function of current (negative coverage)

This sequence also has a tab called ‘System schematics’ that presents the schematic of the circuit presented above (Figure 5). Identification of the elements in the schematic is done in a similar way in the one described at distributor operation.



Click pe numere pentru descriere...

Figure 5
System schematics

Conclusion

The model presented leads to the conclusion that the rotational speed of the hydraulic rotary actuator is in direct ratio to the command current’s intensity of the servovalve. The other measures composing the final relation (21) are either constructive values of the two components of the actuator-servovalve system (*d, b,* R_s*, e*), coefficients and amplification factors (α, c_1, c_2, k), either fluid parameters (p, ρ), that for a certain constructive type, a certain fluid and a certain adjustment remain constant. This allows for a simplified simulation of the system functioning in given conditions.

References

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