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SIMULATION OF THE HYDRAULICS SYSTEMS WITH CYLINDERS IN SERIES

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Abstract: *Usually, the hydraulic cylinders work independently, in parallel and, rarely, in series. This paperwork presents mathematical models that can be used for calculating and simulating the systems using two cylinders - constructively identical or not - connected in series. This type of cylinders is used by hydraulic guillotine shears. They ensure not only the cutting, but also the adjustment of the angle between the fixed blade and the actuated one.*

Key words: *machine tools, simulation, mathematical models, hydraulic cylinders.*

1. INTRODUCTION

Cylinders connected in series represent a solution rarely adopted. However, this solution can be found in some cases such as the hydraulic guillotine shears.

At the time being, such machines are subject to modernization and rebuilding [2].

The cutting blades of this machine cannot be actuated by one single centrally located hydraulic cylinder. Because of the large useful length between the columns, two hydraulic cylinders are required. They are located on both sides on the guide-ways area. They are connected in series and they ensure not only the cutting, but also the adjustment of the angle between the fixed blade and the actuated one.

The value of the angle is adjusted by bringing or removing oil from the common line of both cylinders, as shown in Fig. 1. Through line A, supplementary oil is removed or brought in and the cutting angle is modified accordingly.

2. THE MATHEMATICAL MODEL OF THE SYSTEM WITH TWO CYLINDERS IN SERIES

It is considered the calculation diagram in the Fig 2. The left-hand cylinder is fed with the flow Q_1. It moves the mass M_1 against the force F_1, with the velocity v_1 and p_1 is the pressure developed on the lower part of the piston with the surface S_1.

The oil discharged from the upper surface represents the flow Q_2 getting in the right-hand cylinder through the lower side of the piston with the surface S_2. The right-hand cylinder moves the mass M_2 against the force F_2. It is considered the oil on the upper surface of the piston S_2 goes freely to the tank. For calculation it is considered that the pressure within the common line of the two cylinders is p_2 and it has the same value on any part of the line.

The flow Q_1 and the forces F_1 and F_2 will be considered as being known. The unknown parameters are: pressures p_1 and p_2 and the velocities of the two pistons, v_1 and v_2.

Figure 3 shows the simplified calculation scheme.

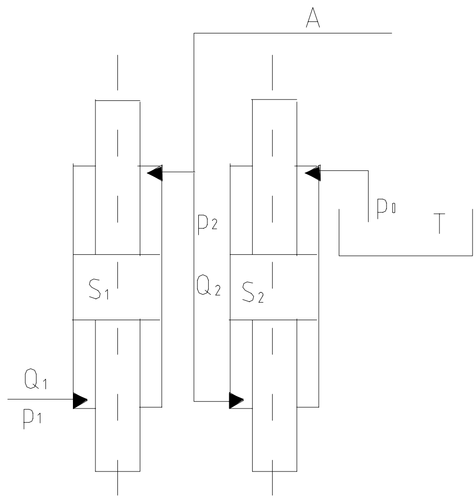

Fig. 1. The two hydraulic cylinders connected in series.

Based on this scheme, the following differential equations describing the system operation in dynamic duty can be written [1, 4]:

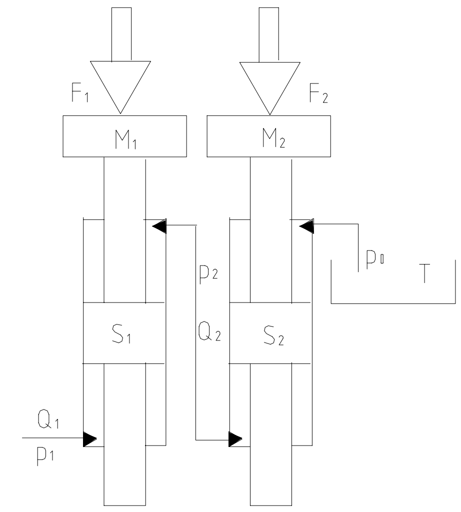

Fig. 2. The calculation diagram.

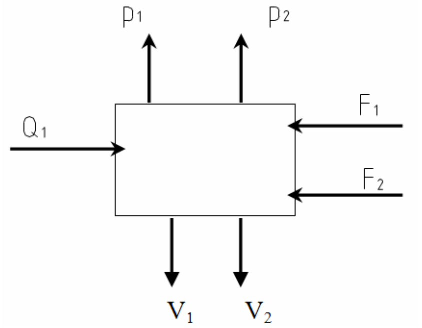

Fig. 3. The simplified calculation scheme.

$$Q_1 = S_1 \cdot v_1 + a \cdot (p_1 - p_2) + \frac{V_{M1}}{E} \cdot \frac{dp_1}{dt}. \qquad (1)$$

$$Q_2 = S_1 \cdot v_1 + a \cdot (p_1 - p_2) - \frac{V_{M1}}{E} \cdot \frac{dp_2}{dt}. \qquad (2)$$

$$Q_2 = S_2 \cdot v_2 + a \cdot p_2 + \frac{V_{M2}}{E} \cdot \frac{dp_2}{dt}. \qquad (3)$$

$$M_1 \cdot \frac{dv_1}{dt} + b \cdot v_1 + F_1 = (p_1 - p_2) \cdot S_1. \qquad (4)$$

$$M_2 \cdot \frac{dv_2}{dt} + b \cdot v_2 + F_2 = p_2 \cdot S_2. \qquad (5)$$

In the relations above the following notation has been used: t - time, a - coefficient of the flow losses in proportion with the pressure which is supposed as being the same for both cylinders, V_{M1} and V_{M2} – average volumes in the two cylinders, E - elasticity modulus of the oil used, b - linearised coefficient of the force losses in proportion with the velocity, and considered as having one single value for both cylinders.

The mathematical model, in accordance with the relations (1) … (5), can be solved by simulation.

In static duty, if the losses and the inertial effects are neglected and it is considered that $E \to \infty$, the relations above become [5]:

$$Q_1 = S_1 \cdot v_1. \qquad (6)$$

$$Q_2 = S_1 \cdot v_1 = S_2 \cdot v_2. \qquad (7)$$

$$F_1 = (p_1 - p_2) \cdot S_1. \qquad (8)$$

$$F_2 = p_2 \cdot S_2. \qquad (9)$$

In a first phase, it is considered that forces F_1 and F_2 are different and constant. Also, it is considered that the entire supplied flow Q_1 is available. We are interested on the evolution of the velocities v_1 and v_2 and the pressures p_1 and p_2, respectively.

For the values: $F_1 = 36000$ N, $F_2 = 30000$ N, $S_1 = S_2 = 60$ cm^2 for a flow $Q_1 = 6$ l/min, $M_1/M_2 = 2$, in static duty, the values: $v_1 = v_2 = 0.016$ m/s, $p_1 = 110 \cdot 10^5$ N/m^2, $p_2 = 60 \cdot 10^5$ N/m^2 are obtained.

The characteristics below are obtained as a result of the simulation in dynamic duty. Fig. 4 presents the evolution of velocity v_1, and Fig. 5 the velocity v_2.

After approximately 0.2s the two velocities get stable. The velocity v_1 has the stable value of 0.0124 m/s, while the velocity v_2 has 0.0116 m/s.

The pressures develop in time as shown in Fig. 6 - for pressure p_1 and Fig. 7 - for pressure p_2.

The stabilized values of the pressures are $p_1 = 110 \cdot 10^5$N/m^2 and $p_2 = 60.04 \cdot 10^5$ N/m^2.

If it is considered that the forces have a periodical component with the amplitude of 10% of the constant component and of $\omega_1 = 10$ rad/s and $\omega_2 = 5$ rad/s, the system behavior under the new conditions can be studied.

The velocity v_1 develops as presented in figure 8 and gets stable at the value of 0.0123 m/s. However, the influence of the oscillating component can be noticed also after the stabilization. Also, the velocity v_2 of the second cylinder is influenced by the oscillating components as shown in Fig. 9.

The halving of the pulsation, against the figure above, directly influences the development of the velocity that gets stable at $v_2 = 0.0114$ m/s.

Also, the pressure p_1 is influenced by the oscillating component and gets stable at $p_1 = 110.3 \cdot 10^5$ N/m^2 as shown in Fig. 10.

The pressure p_2 in the common line will get stable at $p_2 = 60.1 \cdot 10^5$ N/m^2, after an evolution as in Fig. 11.

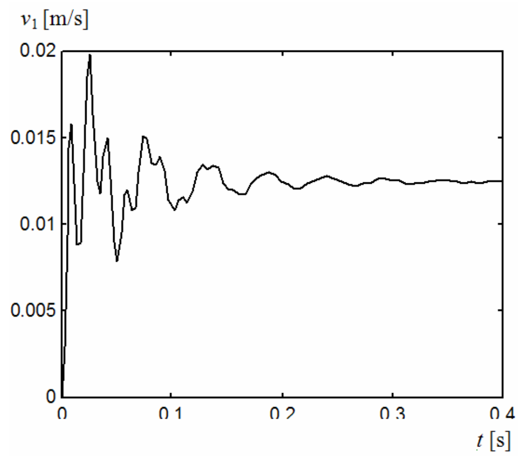

Fig. 4. The evolution of velocity v_1.

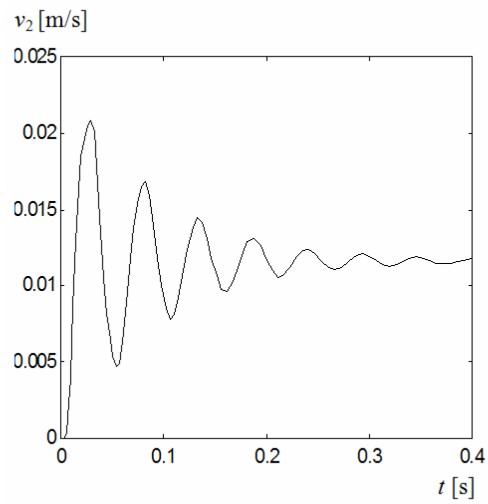

Fig. 5. The evolution of velocity v_2.

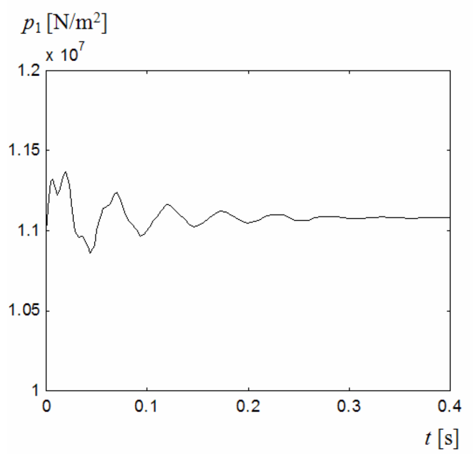

Fig. 6. The pressure p_1 in time.

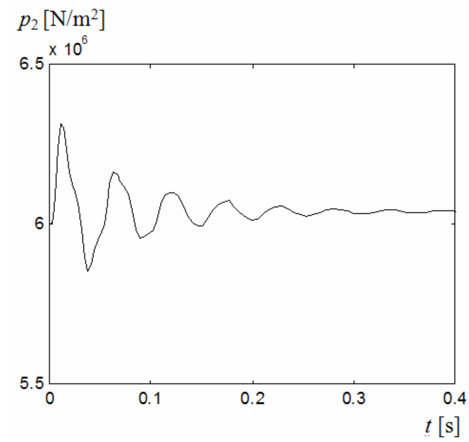

Fig. 7. The pressure p_2 in time.

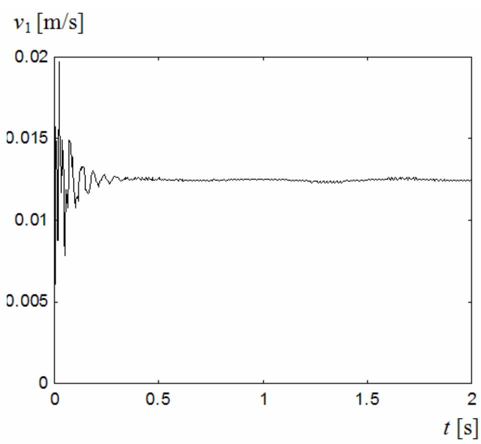

Fig. 8. The velocity v_1.

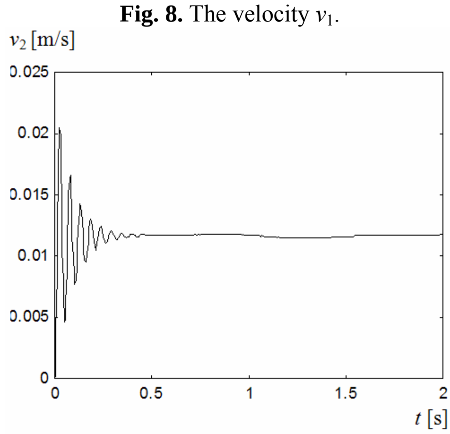

Fig. 9. The velocity v_2.

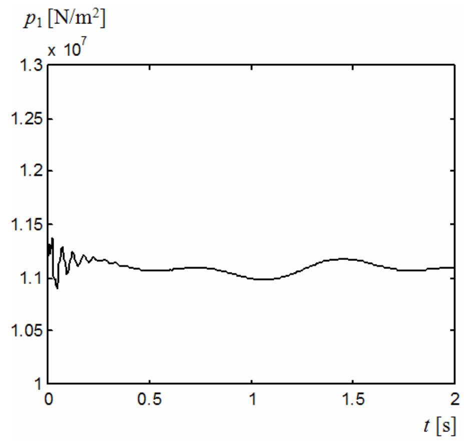

Fig. 10. The pressure p_1.

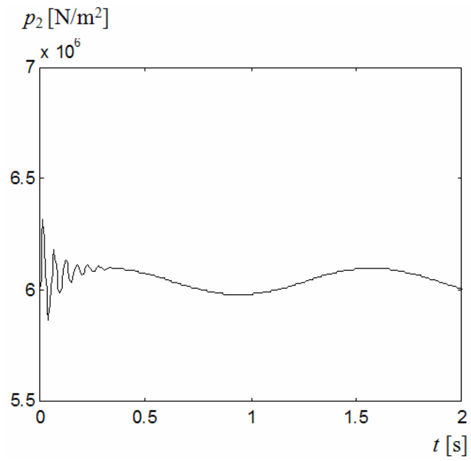

Fig. 11. The pressure p_2.

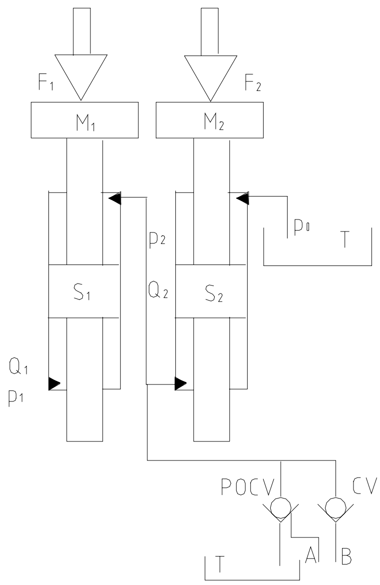

Fig. 12. The generic diagram.

3. ADJUSTMENT OF THE OIL QUANTITY IN THE COMMON LINE

If a modification of the oil quantity in the common line, at the pressure p_2, is required, the flow getting from the left-hand cylinder can be increased or decreased with the generic diagram in Fig. 12.

If pressured oil is brought through the way A, the check valve POCV is opened and the oil discharges to the tank (T). Through the check valve CV, on the way B, the flow Q_2 is supplemented by introducing oil in the common line. The elements above can be found in the actual diagram as shown in Fig. 1.

There are also electro-hydraulic systems that can ensure a synchronous movement of the two cylinders [6].

4. CONCLUSIONS

For the hydraulic cylinders in series, due to losses, inertial effects and oil compressibility, the dynamic calculation becomes more than necessary. The cylinders can be constructively identical or not. To make a calculation as real as possible, it is recommended the usage of some specific programs of simulation. These programs and their results provide useful information for designing, which can prevent possible errors or modifications during the prototype phase. The values of the specific coefficients - such as "*a*" and "*b*" above - have a significant importance for obtaining results as closer as possible to the real ones. Usually these coefficients are determined experimentally.

The operating mode of the cylinders connected in series is influenced by the distribution of the forces, the differences between them, but also by their variation.

These systems are completed with elements necessary for the real operation. The principle of modification of the oil in the main line is the same with the one presented in Fig. 12.

The cutting machines named hydraulic guillotine shears are representative example for this type of driving. A closed "system" is obtained by connecting the two hydraulic cylinders "in series".

When adjusting the machine, the cutting angle of the blades is established depending on the thickness and quality of the metal sheet. This angle is the angle between the horizontal line and the line of the hydraulic cylinders connected "in series". A system containing directional control valves, a check valve and a pilot operated check valve helps modifying the quantity of the oil in the common line, increasing or decreasing the cutting angle.

The proper working is ensured only if there is no leakage. Usually, the sealing system of the cylinders and pistons causes the leakage.

Replacing the sealing elements is recommended when repairing such machines.

For machines like FG 825, "in series" cylinders work at high pressures and flows, depending on the phase. For this reason the pumps are equipped with power regulators and electrically piloted pressure valves.

Auxiliary operations, such as blades withdrawing, semi-finished material clamping on the machine table, as well as the adjustment of the angle are accomplished by means of a separate line supplied by a constant flow pump through a system with accumulator.

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