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The Dynamic Behavior of the Elevation Movement Mechanism of one Transfer Manipulator with Electro-Hydraulic Acting

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Abstract. The paper presents the results following the theoretical research of one vertical elevation mechanism regarding the dynamic behavior for one modern transfer systems, a manipulator or robot in cylindrical co-ordinates, which belongs to a molding technological module based on the hydraulic presses. Using the mathematical modeling and the computer simulation, it can identify the parameters with sensitive behavior and, finally, it can optimize the dynamic regimes according to the real requests of driving.

Keywords: transfer manipulators, industrial robot, dynamic behavior, mathematical modeling, simulation

1. Introduction.

The creation of one technological module for stamping components on hydraulic presses, with high performances and productivity, imply the development of some modern systems of mechanization of the transfer operations of warm components [1]. The manipulators and industrial robots tend to become some of the widespread means of mechanization and automation, these appearing in the field of forges as well since over a quarter of a century, where, despite the specific difficulties, were recorded notable progress. For creating one technological module of stamping, or even pressing flexible systems [2], it is important to have a modern transfer system, which can charge the presses with semi-finished parts and evacuate pressed parts

In the figure 1, is presented one charging and evacuating manipulator, as a part of the mechanization systems of the handling operations of one stamping technological module. The charging and evacuating manipulator consists of the 3 basic mechanisms, for the three main movements: the mechanism of rotation around a vertical axis, the elevation mechanism of the tong and the mechanism of horizontal displacement.


Fig. 1: The transfer manipulator

These 3 mechanisms give to manipulator the feature to be one in cylindrical coordinates. The working mechanisms are acted by an electro-hydraulic driving system [3]. In order to assure a great productivity of the stamping technological module is necessary to know the dynamic behaviour of all mechanisms. Having at disposal modern methodologies to research the dynamic behaviour, based on using one performant simulation softwares for the dynamic systems [4], it has started a research for finding the dynamic responses of the each mechanism..Reference [5] was the first paper which presents some of the theoretical results regarding the dynamic behavior of the horizontal translation mechanism.

Now, in this paper, are presented some of the theoretical results regarding the dynamic behavior of the elevation mechanism of the one transfer manipulator, presented in Figure 1.

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2. The Modeling Of The Elevation Mechanism

The elevation mechanism, presented in figure 2, assure the vertical movement of the tong and, usually, is a hydro-mechanical subsystems, generated by the need of lifting large loads, on large strokes. The modeling was made in more stages: physical modeling, systemic modeling, and mathematical modeling.

Fig. 2: The elevation mechanism

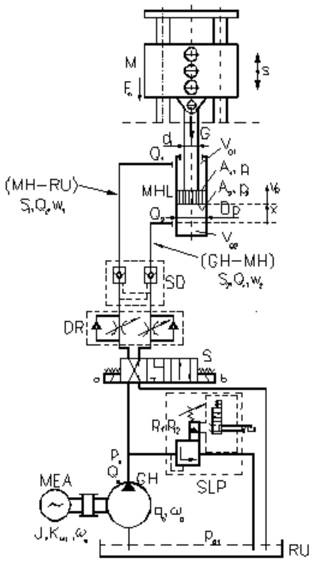

Fig. 3: The phisicall model of the elevation mechanism

2.1. The physical model of elevation mechanism

The physical model of the elevation-descent movement mechanism, presented in the figure 3, is a principal hydro mechanic schematic diagram, necessary to indicate all the physical parameters involved in the process. The physical model comprises a linear hydraulic motor MHL, with its valves and hydraulic circuits considered as concentrated parameters of resistances and hydraulic capacity. The main component elements are the following: the electric drive motor MEA, the hydraulic generator GH, the pressure restrictive valve SLP, the distribution valve S, regulation DR and safety devices SD, linear hydraulic motor MHL, oil tank RU and arm slider with *M* weight. Also, the hydraulic model comprises two other hydraulic circuits: the hydraulic drive circuit (GH-MH), from pump GH to the hydraulic motor MHL, and the discharge hydraulic circuit (MH-RU), from motor to oil tank RU.

2.2. The systemic model of elevation mechanism

Starting from the physical model, shown in figure 3, on the base of the theory of automatic systems, was elaborated, a systemic model, figure 4, which comprises *5 systemic elements* with their inputs and outputs:

- *a quadripolar systemic element* "ME-GH", which is a hydraulic generator GH, rigidly coupled with the electric motor MEA, characterized by the mechanical parameters ω_p and $M_{p,}$ and the hydraulic parameters Q_p and p_p. The input parameters are ω_p and p_p (angular velocity and pressure at pump) and the output parameters are the flow Q_p and the pump shaft moment $M_{p.}$ In this hypothesis, the moment of inertia *J* is cumulated for the pump and motor, and allows approaching them as a single element.

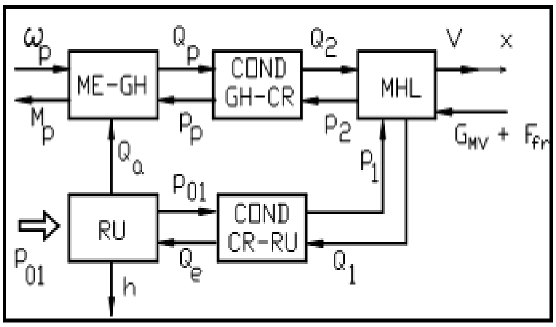

Fig. 4: The systemic model

- *a quadripolar systemic element* "COND GH-CR", *which represents a* hydraulic drive circuit (GH-MH), characterized by hydraulic parameters, Q_p and $p_{2,,}$ as input parameters, and enter flow Q_2 and p_p, as outputs.
- *a sexapolar systemic element* "MHL", which represents the linear hydraulic motor which transforms the hydraulic parameters, the enter flow Q_2 and pressure from the elevation circuit $p_{2,,}$ into mechanic parameters, the elevation speed v_r and the elevation force F_R .

The linear hydraulic motor is characterized, also, by the exit flow $Q_{1,}$ and *circuit* pressure $p_{1..}$ The resistant forces F_R is represented by the weight of the mobile parts G_{Mv}, friction force F_{fr} and inertial force F_i.

- *a quadripolar systemic element* "COND GR-RU", which represents the *discharge hydraulic circuit* (MH-RU), with the flow Q_1 and pressure p_{01}, as input, and the exit flow Q_e and pressure p_1, as output;
- *a quadripolar systemic element* "RU", representing the oil tank, with the enter flow Q_e and suction flow Q_a, as input parameters, and the pressure p_{01} and the variation of the fluid level *h*, as output parameters.

2.3. Elaboration of the mathematical model for the elevation mechanism

On the base of the physical model from figure 3 and of the systemic model from figure 4, was conceived a mathematical model, which depicts the dynamic behavior of the transfer manipulator for the elevation phase, on the base of the following symbols: D_P - piston diameter, d_t -rod diameter; G - the weight of the mobile parts; M - reduced mass; p_{01} - the fluid pressure from RU; ξ_1 - coefficient equivalent of the pressure losses on the discharge circuit; x - piston stroke; S_1 - section of the discharge pipe; w_1 - flow speed; m_1 - reduced volume of the fluid from the discharge pipe; V_{01} - the volume of fluid from the passive chamber and the discharge pipe; $x.A_1$ - the volume of fluid discharged by piston; ; A_2 - the volume created by the elevation of the piston on the stroke x; V_{02} - the volume of fluid on the active chamber and the elevation pipe; p_1 - effective pressure on the passive surface of the piston A_1; p_2 - the effective pressure on the active surface of the piston A_2; S_2 - the section of the pipe of elevation of the piston; w_2 - flow speed; m_2 - reduced volume of fluid from the elevation pipe; ξ_2 - coefficient equivalent to the pressure losses; p_{01} - fluid pressure from the aspiration recipient; Q_1/Q_2 – discharge/elevation flow, at exiting entering in the motor; Q_e - the flow on the discharge pipe; p_e - fluid pressure at the exit from the discharge pipe; $Q^{'}_p$ - momentary flow discharged by pump; q_p - the pump volume; ω_p - momentary angular speed of the pump; ω_s - angular speed of synchronization of the electric motor; F_{fg} - friction force in the slider; μ_0 - dry friction coefficient; b_M - linear coefficient of the force losses proportional with speed; a_M - linear coefficient of flow losses at piston MHL, proportional with pressure; h - height of fluid in the the oil aspiration reservoir; A_{RU} - aria section of the aspiration reservoir; vh - level variation speed; E_1/E_2 equivalent elasticity modules of the pipes; a_P - linear coefficient of the flow losses at pump; b_P - linear coefficient of the couple losses; c_{fP} - dry friction coefficient at pump; K_{ME} - slope specific for the electric motor. Taking into account the motion direction of the slider of the manipulator, which is from downwards to upwards, are written the expressions of the fluid volumes from the bottom and top chambers of the linear hydraulic motor, which are given by the sum, respectively, the difference between the initial volumes V_{02}, V_{01}, and the volumes generated by piston, $x.A_2$, respectively, $x.A_1$, which are compressed. With the symbols and hypothesis from above, in accordance with the professional specialized literature, [5] and [6], were written the corresponding equations for each of the 5 systemic elements and, finally, was obtained the mathematical model for the elevation mechanism of the transfer manipulator, compounds the next equations: This set of equations from number (1) to number (13) represents the mathematical model for the elevation mechanism.

$$Q^{'}_p = \frac{q_p}{2\pi}\omega_p - a_p p_p - \frac{q_p}{2E}\frac{dp}{dt} \qquad (1)$$

$$J\frac{d\omega_p}{dt} + b_p\omega_p + \frac{q_p}{2\pi}p_p + c_{fp}\frac{q_p}{2\pi}p_p = K_{ME}(\omega_s - \omega_p) \qquad (2)$$

$$m_2\frac{dw_2}{dt} = S_2[(p_p - p_2) - 0{,}5\frac{\gamma}{g}\xi_2 w_2^2] \qquad (3)$$

$$\frac{dp_2}{dt} = \frac{E}{S_2 l_{cond\,2}}[Q_p - Q_2] \qquad (4)$$

$$Q_2 = S_2 \cdot w_2 \qquad (5)$$

$$M\frac{d^2x}{dt^2} + b_M\frac{dx}{dt} + \mu_0\frac{\dot{x}}{|\dot{x}|}(A_2 p_2 - A_1 p_1) + F_{fg} = (A_2 p_2 - A_1 p_1) - G \qquad (6)$$

$$Q_2 = A_2\frac{dx}{dt} + a_M(p_2 - p_1) + \frac{V_{02} + xA_2}{E}\frac{dp_2}{dt} \qquad (7)$$

$$Q_1 = A_1\frac{dx}{dt} + a_M(p_2 - p_1) - \frac{V_{01} - xA_1}{E}\frac{dp_1}{dt} \qquad (8)$$

$$Q_e = S_1 \cdot w_1 \qquad (9)$$

$$\frac{dp_1}{dt} = \frac{E}{S_1 l_{cond\,1}}[Q_1 - Q_e] \qquad (10)$$

$$m_1\frac{dw_1}{dt} = S_1[(p_1 - p_{01}) - 0{,}5\frac{\gamma}{g}\xi_1 w_1^2] \qquad (11)$$

$$Q_a - Q_e = -A_{RU}\frac{dh}{dt} \qquad (12)$$

$$Q_a = Q_p \qquad (13)$$

3. The Computer Simulation Experiments

For making the simulation experiments of the dynamic behavior on computer, was elaborated on the base of the mathematical model presented above, a specialized calculating program. For this, was used a modern simulation software, tool Mat-lab with Simulink [4]. The elaborated program realizes a simulation model of the dynamic behavior of the manipulator, in the phase of elevation, on the base of the specific block from the Simulink menu and others special blocks which were created for this application.

The simulation experiments were performed using as input data constructive functional parameters of the transfer manipulator of 100 N, shown in figure 1, from which are done: nominal load = 100 N; max. mobile weight =1400 N; max. Stroke = 0.250 m; max. elevations velocity 0.150-0.200 m/s; piston diameter =.0.050 m; Rod diameter= 0.030 m; Pump displacement = 0.014 x 10^{-3} m^3/rot; Power/rotation of Elevtric Motor= 4 kW /1435 rot/min; Nominal diameters of circuits pipes = 10 mm.

By using the simulation programs, was acquired the variation of all parameters of interest, in graphical form, their evolution being in accordance with the known data.

In figure 5, is shown the variation of the elevation stroke, which has a lower evolution in the first part, motivated by the presence of inertial forces in the system, and, then, an almost constant variation. From the diagram may be found that the maximum elevation stroke of 0,250 m is made in about one second and half.

The elevation speed has an evolution characterized by a rapid increase, then stabilization at a value of aprox 0,165 m, according to figure 6, which is in the range of admitted speed values of 0,150 - 0,200 m/s. In the first part of the elevation stroke, the acceleration varies very abrupt (3,5 m/s^2), then, according to figure 7, when the speed is stabilized, the acceleration is annulled. By knowing this evolution may be appreciated the values of the inertial forces from the system at the start of the elevation stroke being possible to take the necessary measures for eliminating their effects. The variation of the fluid flow which enters the linear hydraulic motor MHL, shown in figure 8, is affected by the evolution of the elevation speed and corresponds with the theoretical flow of the pump. The pressure required for elevation, at the linear hydraulic motor MHL, varies like in figure 9, where is noticed that although for operation in stabilized mode, is required a pressure of 9-10 bar, appear pressure exceeding values of over 70 bar, and the pressure oscillations are powerful enough, but are damped in the end. This oscillations highlights that it is required to be taken certain measures for alleviating pressure oscillations, which may lead to strong vibrations in the transfer system. The diagram from figure 10 shows the evolution of the necessary moment at the pump shaft and the figure 11 shows the rotation of the shaft. The diagram from figure 12 shows the power variation at the of pump shaft. On the base of these diagrams of the operational cycle, may be chosen precisely the suitable electric motor. Figure 13 shows the variation of energy consumption in elevation stroke, and allows evaluating of the energy efficiency of the elevation mechanism of the manipulator.

From the figure 11, may be understood that the max power required at the electric drive motor may be less, depending on the real operational mode. Also, on the base of this diagram from figure 11, may be drawn the conclusion that the power of the electric motor of 4 kW, specified in the project, is too high, and that it should be provided a motor with less electric power, about. 2.2 kW. This scientific study was finalized with interesting results which may constitutes the groundwork for future research regarding the transfer systems.

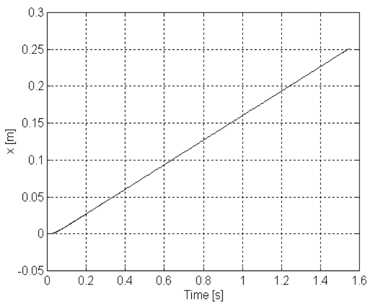

Fig. 5: The elevation stroke

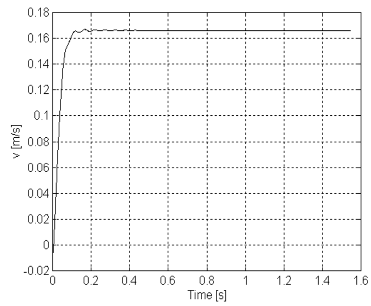

Fig. 6: The elevation speed

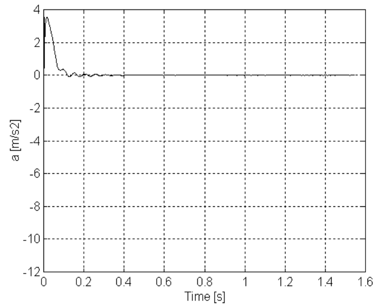

Fig. 7: The elevation acceleration

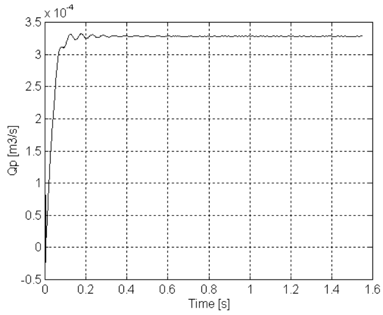

Fig. 8: The pump flow

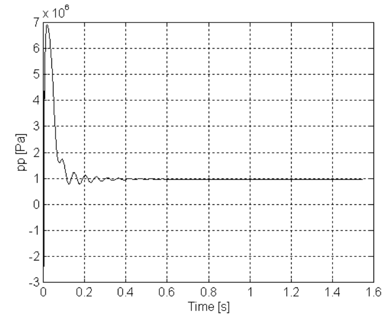

Fig. 9: The pump pressure

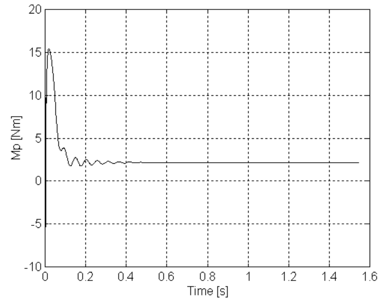

Fig. 10: The pump moment

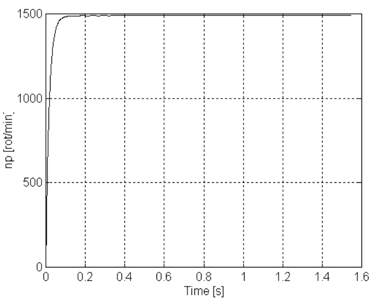

Fig. 11 The pump shaft rotation

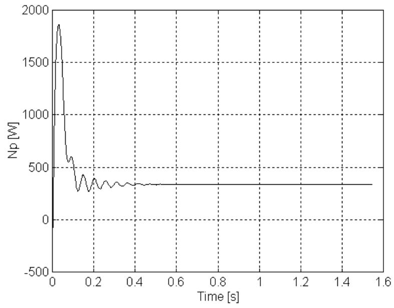

Fig: 12: The pump power

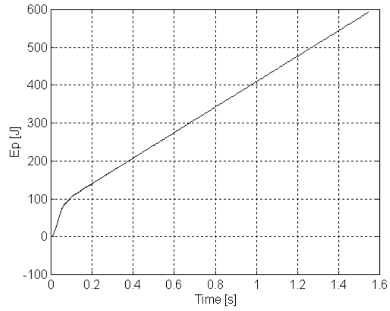

Fig. 13: The energetic consumption

4. Conclusions

The study of the dynamic behavior of the modern transfer manipulation was made by using the modern method of analysis and synthesis, by mathematical modeling and computerized simulation. The mathematical models, simulation programs and the graphical results are the main contributions of the authors. Although the results were validated logically and dimensionally, on the base on the known data, it is important to develop an experimental research which can offer the comparative data, in order to obtain a complete validation of the mathematical models, or for improving the capability of description of them.

By interpreting the graphical evolutions of the parameters, may be acquired significant knowledge in what regards the dynamic behavior of the manipulator of transfer, which cannot be revealed by old methods.

The simulation methods achieved offer the possibility of optimizing the dynamic modes, on the base of detecting the parameters with behavioral sensitivity, for obtaining prompter and more accurate responses, in complete accordance with the drive requirements related to a certain technological model of manufacture, in the conditions of minimum energetic consumption, precisely quantified and controlled in their development.

5. References

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