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DYNAMICS OF SLOW HYDRAULIC UNITS WITH RECURRENT CAM AND VARIABLE CAPACITY

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ABSTRACT

The paper presents a study of slow hydraulic unit with radial pistons, two recurrent cams and variable capacity, designed in the frame of a research program in faculty. For this apparatus it was developed a mathematical model which was able to supply numerical analysis for transitory and permanent regime of such a device. For simulation it was used a mathematical model derived from experimentally tested physical model, for which it was assigned the permanent regime characteristics and it was compared to the theoretical diagrams. The mathematical model coefficients have cross-correlations with unit geometrical characteristics and with the hydraulic agent used into the driving system. The analysis provides useful information especially regarding the low rev regime when functional instability becomes very pronounced and the working state was limited at a stable minimum value. This research is very useful for designers of hydrostatic devices and equipments.

KEYWORDS: hydraulics, slow motor unit, dynamic model, sine profile cams, variable capacity

1. INTRODUCTION

The slow hydraulic motors are units with a great functional stability for very low speeds. The minimum stable values of speed for these units can reach 1...2 rpm. In the same time the maximum values of stable speeds can reach a few hundred rpm. The usual torque of these units has a few hundred Nm, assigned for high pressures of 250...300 bar.

The radial pistons motors, which frame the basic theme of this article, are similar to speedy units, but have geometrical capacities in a range of 200...10000 cm^3/rot. These hydraulic motors can provide 0...500 rpm rev values for power range between 3...200 kW, in respect with serviceable capacity.

An original structure of slow hydraulic unit is the radial pistons motor with recurrent sine profile cams. In this paper the authors try to analyze the latest variant of radial pistons units fully designed at the Research Center where affiliated. This motor has two parallel cam devices thus so the capacity can be continuously adjusted through the relative rotation of the cam devices in the range of quarter of cam profile. Sectional and spatial views of this motor are presented in Fig.1-a, b.

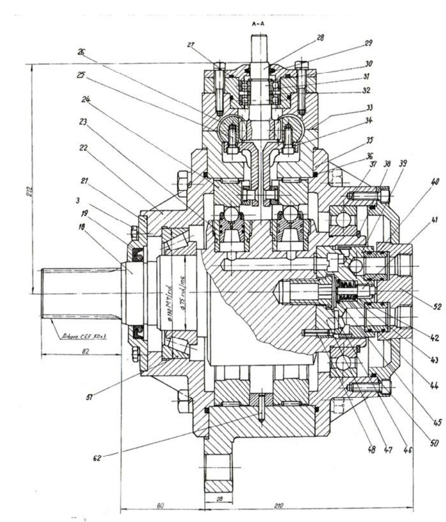

Fig.1a. Slow hydraulic motor with recurrent cams and variable capacity

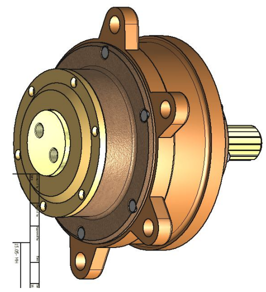

Fig.1b. Slow hydraulic motor with recurrent cams and variable capacity

2. THE ANALYSIS MODEL

The model for analysis was made according to the schematics in Fig.1, with structural and functional main characteristics in Tab.1.

Table 1. Structural and functional characteristics

No.	*Characteristic parameter*	*Symbol*	*UM*	*Value*	*Comments*
0	*1*	*2*	*3*	*4*	*5*
1	Piston diameter	d	mm	15	
2	Absolute shift value of the cam	c	mm	8	
3	Cams number	$\aleph$	-	2	
4	Cam profile number	k	-	5	sine profile
5	Number of pistons for a single cam	z	-	7	
6	Medium radius for the cam profile	R_o	mm	120	
7	Sealed length of the piston	b	mm	15	covering
8	Absolute spiel value of piston	j	mm	0,005	
9	Piston area	A	cm^2	1,767	
10	Maximum capacity of the motor unit	V_o	cm^3/rot.	100	(98.9)

The characteristics of the hydraulic agent used for the driving system respect the values as follows: doped mineral oil type H46A with density $\rho = 850$ kg/m^3; kinematic viscosity $\upsilon = 45$ cSt; dynamic viscosity $\eta = 40{,}94$ kg/m.s and modulus of elasticity E = 15.9 10^3 bar.

3. THE MATHEMATICAL MODEL OF THE MOTOR UNIT

The mathematical model of the proposed slow hydraulic motor unit can be fully described by the equations [3,4,5] presented as follows:

$$\begin{cases} c_1.(q_M - k^*).n + c_2.\alpha_M^*.p^2 + c_3.\beta^*.\dot{p} = Q; \quad [l/min] \\ c_4.J_{SM}.\dot{n} + c_5.(q_M - k^*).\delta_M^*(n - n_s)^2 + M_e = c_6.(q_M - k^*).p; \quad [daNm] \end{cases}; \tag{1}$$

where $q_M -$ denotes the motor hydraulic capacity [cm^3/ rad], k^* is the correction coefficient of the motor capacity [cm^3/rad]; α_M^* – denotes the flow losses into the motor interstices [cm^5.s^3/kg^2]; β^* is the compression coefficient of the hydraulic agent [cm^5/daN]; J_{SM} denotes the moment of inertia for the rotor and the working body driven by the motor [kg cm^2]; n_s denotes the speed coefficient of the motor unit [rpm]; $\delta_M -$ is the torque losses coefficient due to internal friction into the motor unit [daN/cm^2.s^2]; c_1 and c_6 denote the homogeneity dimensional coefficients for numerical model expressions.

The variables of the numerical model with respect to equations (1) are presented as follows: n denotes the motor velocity [rpm] and p is the pressure into the motor unit [bar].

The conditioning parameters of the model have the significance presented as follows: Q are the supply flow of the motor unit [l/min] and M_e is the resistant moment at the motor unit shaft [daNm].

The values of the coefficients of the basic numerical model designated for dynamical analysis are presented in Tab.2.

Table 2. Specifical values for the basic numerical model

No.	Coefficient	Definition	UM	Value
0	1	2	3	4
1	$c_1\ q_M$	$= c_1.\aleph.A.c.z.k$	l/rot	0,216
2	$c_1\ k^*$	$= c_1.\ q_M.\lambda_j / 2z$	l/rot	0,001
3	$c_2\ \alpha_M^*$	$= c_2 \dfrac{2\pi}{3} \dfrac{\lambda_j^3}{\lambda_c^2.\lambda_b}.q_M \dfrac{1}{dg\rho\eta}$	$l^7/daN^2.min$	$2{,}6.10^{-5}$
4	$c_3\beta^*$	$= c_3.\dfrac{V_o}{E}$	l^5/daN	5.10^{-7}
5	$c_5\delta_M^*$	$= c_5.8\pi.\dfrac{\lambda_b}{\lambda_j}\lambda_R.\eta$	$daN.min^2/dm^2$	0,32

With the help of coefficients defined in Tab.2 the mathematical model of the hydraulic motor unit proposed by the authors becomes as follows:

$$\begin{cases} 0{,}215.n + 2{,}6.10^{-5}\,p^2 + 5.10^{-7}\,\dot{p} = Q \\ 0{,}9.10^{-4}.\dot{n} + 0{,}32.(n-16)^2 + M_E = 0{,}215.p \end{cases} ; \qquad (2)$$

The inputs into the model differential equations (2) are the parameters of flows Q with the values (5; 10; 15; 20; 25) [l/min] and resistant moment M_E with the specific values (10, 30, 50, 70, 90, 110) [daNm].

Through numerical integration of the mathematical model (2) using the Matlab 2008 software result useful information about the system behaviour during the transitory working regime.

4. THE RESULTS OF THE NUMERICAL SIMULATIONS

Using the Matlab software package for numerical solving of differential nonlinear system (2) it results a set of diagrams which reveal the variance shapes of the two variables of the model as rotational velocity n [rpm] and pressure p [bar]. The Figs.2 and 3 show the diagrams of main parameters evolution according to the case of time period between 0...0.85 s.

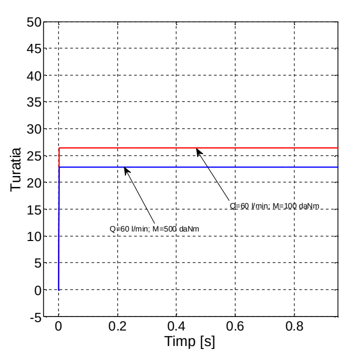

Fig.2. The evolution of the velocity at the motor shaft with in respect the parameter M

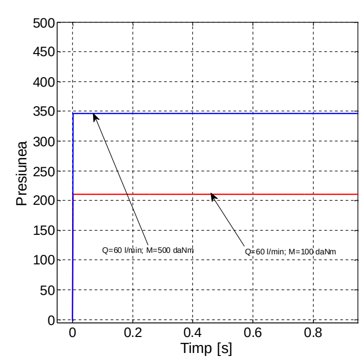

Fig.3.The evolution of the pressure into the motor unit with respect to the parameter Q

For the case when the integration time is reduced into the range of 0...0.01 s the resolution of the final solutions become better and the two analyzed parameters acquire proper evolutions presented in Fig.4.

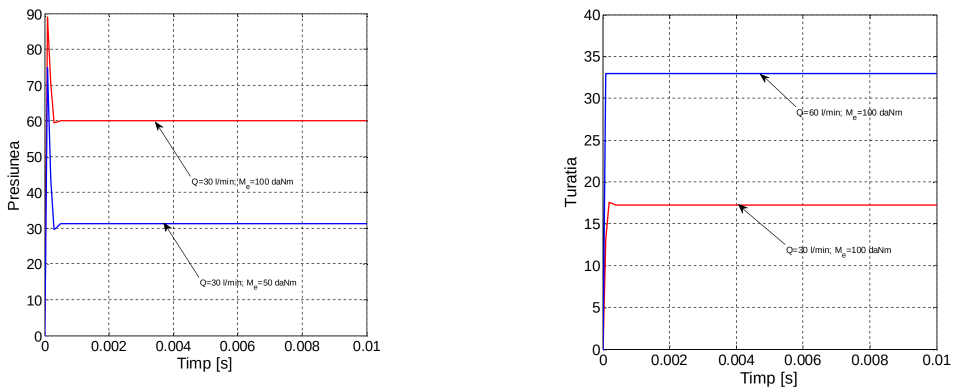

Fig.4. The evolution of the main parameters for the transitory regime

5. CONCLUSIONS

From the analysis of the simulation results, briefly presented into this paper, compared to the experimental data results the main conclusions can be drawn:

1. The proposed model allows complete and complex analysis of the transitory regime for the motor into the design phase, as a function of adopted structural and functional parameters (diameters, surfaces, spiels, coverings, volumes, etc.), of hydraulic agent used into the driving system (density, viscosity, modulus of elasticity, etc.) and of the exploitation conditions (supply flows, resistant torque, environmental temperature, etc.);
2. The paper briefly presents a case study for a single design size, for which results a very good functional stability of transitory working state, for the regime with respect to the maximum design hydraulic capacity of the motor unit;
3. As future trends, it has to investigate the transitory regime for the other adjustment values of the motor unit capacity, even for the case of continuous changing of this parameter.

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