FACTA UNIVERSITATIS
Series: **Mechanical Engineering** Vol.1, N° 7, 2000, pp. 863 - 869

SYNCHRONIZATION OF HYDROMOTOR SPEEDS IN THE SYSTEM OF WHEEL DRIVE

UDC 621.22:62-254

Radan Durković

The Faculty of Mechanical Engineering, University of Montenegro
Cetinjski put bb, 81000 Podgorica

Abstract. *Two parallely connected hydromotor speed synchronization applied to the mobile machine wheel drive has been solved in this paper. The speed synchronization is achieved on the principle of the hydromotor working capacity regulation.*
The regulator structure and parameters for the regulation circuit, by applying the method of technical optimum, have been determined.
By analyzing the regulating moment and by simulating the dynamic drive behaviour, the effect of the regulation system has been shown.

Key words: *synchronization, hydromotor, regulator, simulation.*

1. INTRODUCTION

In solving the problems of the motion drive of the mobile working machines with hydrostatic transmission, very important are the solutions based on the application of the constructive modulus - "hydromotor-wheel". By applying this modulus for driving the wheels, the flexible building of driving system with free wheel arrangement is made possible. The connection of the dislocated "hydromotor-wheels" can be either differential or blocking differential one.

The blocking differential connection is provided by synchronizing the driving module motion speeds, on the throttling or volume regulation principles.

From the point of view of efficiency, the solution based on the principle of the hydromotor working volume regulation, so-called secondary regulation, is of a special importance.

In Fig. 1, a simplified function scheme of the hydrostatic drive of a mobile machine with two driving module motion - "hydromotor-wheel" has been shown.

Received August 15, 2000

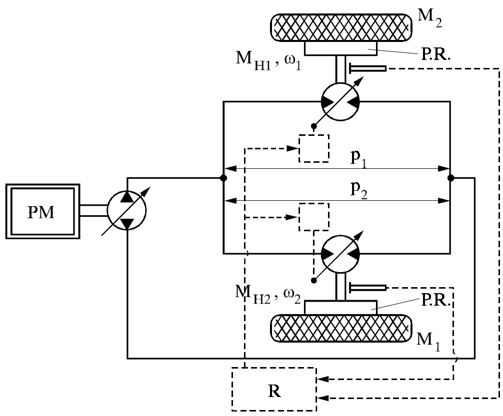


Fig. 1. Functional drive scheme

The driving modulus - "hydromotor-wheel", in Fig. 1, consists of an axial-piston hydromotor of changeable working volume, this being achieved by altering the incline angle of the cylinder block and planetary reduction gear (PR) of the transmission ratio j.

The marks of physical values in Figure 1 are as follows:

M_1 and M_2 - moments of loads on the drive wheels,

M_{H1} and M_{H2} - moments of loads on the hydromotor shafts,

ω_1 and ω_2 - angular velocity of the hydromotor shafts,

p_1 and p_2 - effective pressures of the hydromotor.

The drive module speed synchrinozation is achieved in a way that, when hydromotor speeds are different (and they are constantly measured), there is an automatic hydromotor working volume reduction, tending to accelerate till the moment the hydromotor speeds are equalized. In this way, the relative drive module motion is either regulated or prevented. With the drives having a greater number of hydromotors and the hydromotor working volume regulation, microcontrollers have been used [1].

2. THE MATHEMATICAL MODEL OF THE SYSTEM

The linearized mathematical model of dynamic behaviour of the system shown in Fig. 1, has been set out in the author's work [2]. This model, in somewhat altered survey, has been given in a block diagram in Fig. 2.

The marks of values in Fig. 2, besides the values defined in Fig. 1, are as follows:

$\Delta u_1(s)$, $\Delta u_2(s)$ and $\Delta u_3(s)$ - increment of measuring voltages,

Δu_{ref} - increment of referential voltage,

$\Delta i(s)$ - increment of electrical current,

$\Delta\alpha_1(s)$ - increment of incline angle of the hydromotor cylinder block,

$\Delta M_{\alpha 1}(s)$ - increment of the hydromotor drive moment (regulating moment),

s - complex variable,

q_M - specific volume of the hydromotor,

k_{TG} - coefficient of transmission (amplification) of the tahogenerator.

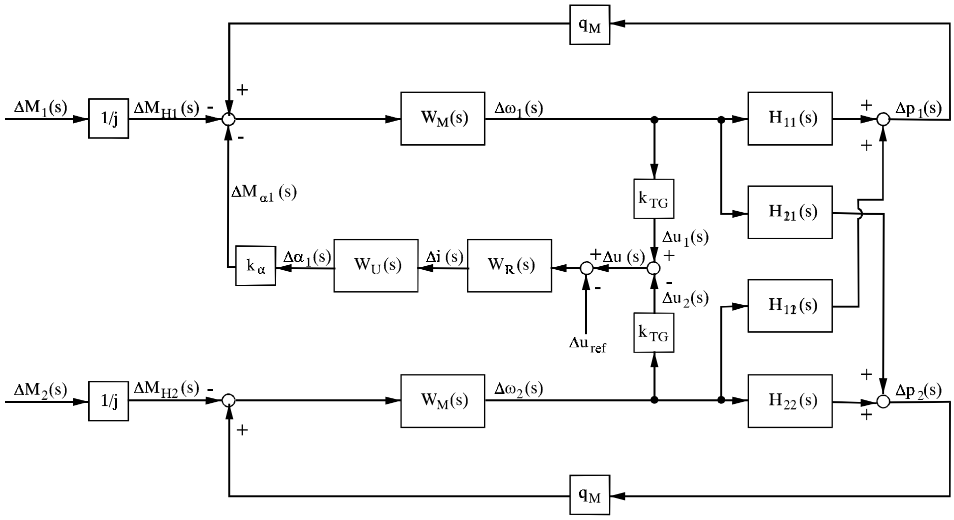


Fig. 2. The system block diagram

In the block diagram in Fig. 2, the transmission function of the hydromotor $W_M(s)$ and the device for altering the hydromotor working volume $W_U(s)$ are:

$$W_M(s) = \frac{k_M}{T_M \cdot s + 1} \tag{1}$$

$$W_U(s) = \frac{k_U}{T_U \cdot s + 1} \tag{2}$$

where T_M and T_U are time constants, and k_M and k_U are amplifications.

The transmission function of the regulator, in general case, has been marked with $W_R(s)$.

At a simplified considering the transmission lines as elements with concentrated hydraulic capacity, disregarding the hydraulic resistance and inductivity, the transmission functions of direct and cross connections of angular velocity and pressures of the hydromotor are equal:

$$H_{ij}(s) = -\frac{k_H}{T_H \cdot s + 1}, \quad i = 1,2;\ j = 1,2 \tag{3}$$

where T_H and k_H are hydraulic time constant and hydraulic amplification, respectively.

The block diagram in Fig. 2 shows that the driving module are double coupled. A differential effect is provided by the coupling through the transmission functions $H_{12}(s)$ and $H_{21}(s)$, whereas a blocking effect of the driving module connections is obtained by the regulation circuit.

3. THE SYNTHESIS OF THE REGULATION SYSTEM

On the basis of the block diagram in Fig. 2, by applying the block diagram algebra transformation, we get a block diagram of the regulation circuit of relative movement of drive module, Fig. 3.

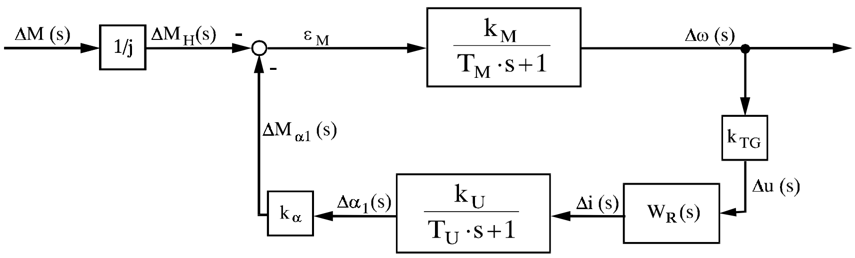


Fig. 3. Block diagram of the relative drive module movement regulation circuit

In the block diagram in Fig. 3 are:

$$\Delta M(s) = \Delta M_1(s) - \Delta M_2(s)$$

$$\Delta M_H(s) = \Delta M_{H1}(\mathrm{s}) - \Delta M_{H2}(\mathrm{s})$$

$$\Delta\omega(s) = \Delta\omega_1(s) - \Delta\omega_2(s)$$

The synthesis of the regulation system, that is the choice of structure and parameters of the regulator drive module relative movement, can be solved by applying the method of technical (modulus) optimum, [3], [4].

For the regulation circuit being considered, it is necessary to have a regulator of the proportional-integral type with the transmission function:

$$W_R(s) = k_R \cdot \frac{T_R \cdot s + 1}{T_R \cdot s} \tag{4}$$

In this regulation circuit, T_M is a high and T_U a low time constant (T_M™T_U) so, according to the technical optimum criteria, the time constant and the regulator amplification are:

$$T_R = T_M$$

$$k_r = \frac{T_M}{2 \cdot T_U \cdot k_M \cdot k_{TG} \cdot k_U \cdot k_\alpha}$$

4. THE EFFECT OF THE REGULATION SYSTEM

The regulation system effect has been analyzed analytically and illustrated by the system behaviour simulation.

On the basis of the block diagram in Fig. 3 and the defined regulator structure and parameters, the expression for the regulating moment at non-symmetrical wheel load is obtained:

$$\Delta M_{\alpha 1}(s) = -\frac{1}{j} \cdot \frac{1}{T^2 \cdot s^2 + 2 \cdot \zeta \cdot T \cdot s + 1} \cdot \Delta M(s) \quad (5)$$

where $T = \sqrt{2} \cdot T_U$, and $\zeta = \sqrt{2}/2$.

The value of the throttling coefficient $\zeta = \sqrt{2}/2$ provides a qualitative transitional process in the regulation circuit. In the rapid alteration of the moment $\Delta M(t)$ the indicators of the transitional process of the regulating moment $M_{\alpha 1}(t)$ are:

- the jump over $\sigma = 4.3\%$,
- the time of growth till achieving the stationary state $t_p = 4.7 \cdot T_U$,
- the time of tranquillity $t_s = 8.4 \cdot T_U$.

Also, stationary error of the moment is $\varepsilon_M = 0$, that is the chosen regulator provides the astaticism of the system in relation to the disturbance moment $\Delta M(t)$.

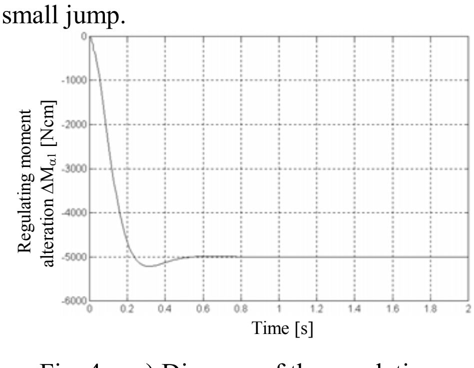
The analogue results can also be obtained for the alteration of the incline angle of the hydromotor cylinder block.

The effect of the regulator chosen is illustrated by the system behaviour simulation. It is simulated, by application of the program package "MATLAB", of the modulus "Simulink", the system shown in the block diagram in Fig. 2, with the following values of the time constants and the amplification coefficient: $j = 20$, $T_M = 1.1$ [s], $k_M = 5.6 \cdot 10^{-2}$ [$N^{-1} \cdot cm^{-1} \cdot s^{-1}$], $T_H = 0.15$ [s], $k_H = 318.5$ [$N \cdot cm^{-2} \cdot s$], $T_U = 0.05$ [s], $k_U = 0.9$ [$A^{-1} \cdot rad$], $k_{TG} = 0.01$ [V·s], $k_\alpha = 2000 \cdot 10^2$ [$N \cdot cm \cdot rad^{-1}$], $q_M = 26.48$ [$cm^3 \cdot rad^{-1}$].

We have observed and followed the case when, owing to the fall of the athesion coefficient on the wheel 1 the moment of the load falls by $\Delta M_1 = -1000 \cdot 10^2$ Ncm, and the load on the wheel 2 and the reference voltage are constant, that is $\Delta M_2 = 0$ and $\Delta u_{ref} = 0$.

In Fig. 4.a the alteration of the regulating moment $\Delta M_{\alpha 1}(t)$, and in Figure 4.b the alteration of the hydromotor cylinder block $\Delta\alpha_1(t)$ incline angle have been shown respectively.

The diagrams in Fig. 4.a and Fig. 4.b confirm the conclusions made on the base of the regulation circuit model analysis concerning the character and indications of the transition process of the regulating moment and the hydromotor cylinder block incline angle. The adjustment of the cylinder block and alteration of the regulating moment are quick with small jump.



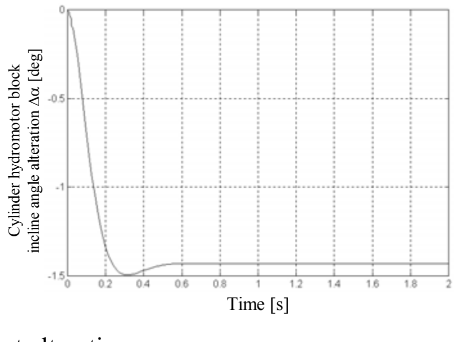


Fig. 4. a) Diagram of the regulating moment alteration,
b) Diagram of the cylinder hydromotor block incline angle alteration

In Fig. 5.a the hydromotor shaft revolution number alteration $\Delta n_1(t)$, $\Delta n_2(t)$ and the difference in revolution numbers $\Delta n(t) = \Delta n_1(t) - \Delta n_2(t)$, whereas in Fig. 5.b the effective pressure alteration $\Delta p(t) = \Delta p_1(t) = \Delta p_2(t)$, have been shown respectively.

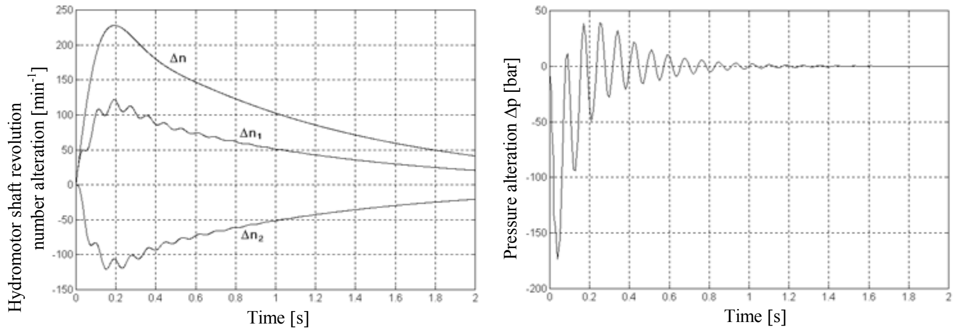


Fig. 5. a) Diagram of the hydromotor shaft revolution number alteration
b) Diagram of the pressure alteration

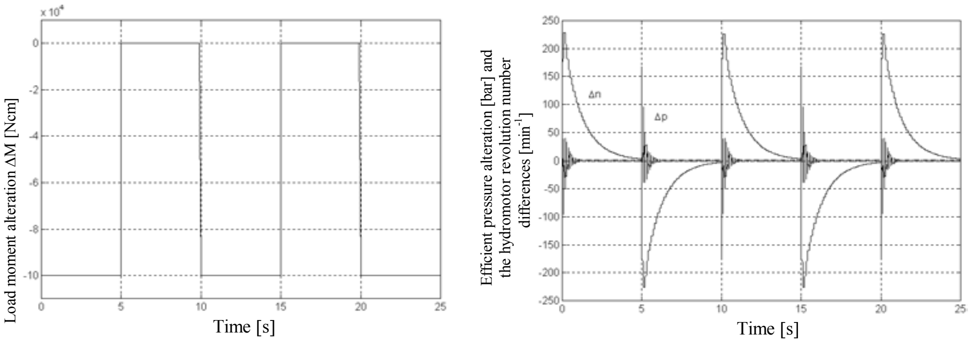


Fig. 6. a) Diagram of the load moment alteration
b) Diagram of an efficient pressure alteration and the hydromotor revolution number differences

The diagram in Fig. 5 shows that by applying the PI regulator of appropriate parameters, we provide the astaticism of difference in revolution numbers, followed by a small deviation in the transition process. In the final effect, this prevents the pressure fall in the system and the drive power loss at the coefficient adhesion fall on one drive wheel, Fig. 5.b.

Also, when operating at unfavorable conditions, at the stepping alteration of a loading moment of relatively high intensity and frequency, Fig. 6.a, there has been achieved a qualitative process of drive module speed synchronization maintaining the pressure level in the system, Fig. 6.b.

5. CONCLUSION

The problem of two paralelly connected hydromotor speed synchronization has been solved in this paper.

By applying the method of technical optimum, the proportional-integral regulator was chosen for the regulation circuit and its parameters were determined.

By analysis of the regulation circuit and by the dynamic system behaviour simulation, it was confirmed that the chosen regulator provides a qualitative transition process of regulation and astaticism of the system in relation to the disturbing moment on the wheels.

As the final purpose, the designed system of regulation prevents the fall of pressure in the system and loss of hauling power owing to the fall of adhesion coefficient on one drive wheel.

REFERENCES

1. Vonnoe, R., (1992). *Programmgesteuerte und geregelte hidrostatiche Mobilantriebe*, Ö + P "Olhydraulik und Pneumatik", No 4, pages 206÷221.
2. Durković, R., (1994). *Modeliranje i analiza dinamičkog ponašanja hidrostatičkog blokirajućeg diferencijala sa regulacijom radne zapremine hidromotora*, Naučno-tehnički pregled, Vol. XLIV, No. 10, pages 3÷7.
3. Garnov, V. K., Rabinović, V. B., Višneveckij, L., (1971). *Unificirovanie sistemi avtoupravlenija elektroprivodom v metalurgiji*, Izdateljstvo "Metalurgija", Moskva.
4. Pašalić N., Pašalić H., Hodžić M., (1988). *Sinteza sistema regulacije rudničkog izvoznog stroja*, Automatika, No. 3-4, pages 103÷107.

SINHRONIZACIJA BRZINA HIDROMOTORA U SISTEMU POGONA TOČKOVA

Radan Durković

U radu se rješava zadatak sinhronizacije brzina dva paralelno vezana hidromotora primjenjena za pogon točkova mobilne mašine. Sinhronizacija brzina se ostvaruje na principu regulacije radne zapremine hidromotora.

U radu su za krug regulacije, primjenom metode tehničkog optimuma, određeni struktura i parametri regulatora.

Analizom regulišućeg momenta i simulacijom dinamičkog ponašanja pogona prikazano je dejstvo sistema regulacije.