A mathematical model of the controlled axial flow divider for mobile machines

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Abstract. The authors give a mathematical model of the axial adjustable flow divider allowing one to define the parameters of the feed pump and the hydraulic motor-wheels in the multi-circuit hydrostatic transmission of mobile machines, as well as for example built features that allows to clearly evaluate the mutual influence of the values of pressure and flow on all input and output circuits of the system.

With the stricter requirements on environmental and rising fuel prices, the problem of improving the energy efficiency of mobile machines (MM) is becoming more relevant.

Today, one of the ways to improve efficiency is a combination of a power unit with an electrodynamic, or a hydrostatic transmission. For high MM is more appropriate to use (in terms of efficiency) a hydrostatic type of transmission (based on the volume of the hydraulic drive) beyond electrodynamics in specific capacities in 2,5-3 times.

In the composition of the hydrostatic transmission are traditionally used adjustable hydraulic pump with one or more hydraulic motors, as well as guiding and regulating equipment. There are possible circuits connecting the hydraulic motors to the wheels via mechanical transmission adder, and circuits connecting directly to the wheels in which each wheel can be controlled independently by means of valves with proportional electromagnetic control [1,2,3,4,5]. It is also possible with the use of an adjustable axial flow divider, operating on the principle of axial piston hydraulic machines, which in conjunction with control system, allows significantly improve the mobility and the controllability of the vehicle, and significantly improve the efficiency of the entire power plant as a whole.

The use of unregulated volume flow divider in the cooling system of MM is considered in work [6]. This article is devoted to modeling of processes in proposed a regulated axial flow divider.

For calculation of the required pump pressure, for a known pressure drop in each line, which is connected with the working section (the direct problem), and calculation of the magnitude of the pressure in each working section at a known pressure of the pump (the inverse problem), we use the balance of the hydraulic input power and outputs of the controlled axial flow divider (see Fig. 1) [6]:
\[ Q_n \cdot P_n = \sum_{i=1}^{k} (Q_i \cdot \Delta P_i), \]  

where \( Q_n \) – pump, \( m^3/c \); \( P_n \) – the discharge pressure of the pump, Pa; \( Q_i \) – the flow passing through the \( i \)-th section, \( m^3/c \); \( \Delta P_i \) – the magnitude of the pressure drop in Magistral-th section, Pa; \( k \) – number of working sections of the divider.

Figure 1 – Scheme for the compilation of balance of the hydraulic power.

Given the fact that the average value of the flow through an axial-piston hydraulic machine according to [7], is defined as

\[ \bar{Q}_p = D \cdot \tau g(\gamma) \cdot \left( \frac{\pi}{4} \cdot d^2 \right) \cdot n \cdot z, \]

and the pump flow is fully distributed to sections of the flow divider, the balance of power, for example, for a 4-section flow divider can be written in the following form:

\[ D \left( \frac{\pi}{4} \cdot d^2 \right) \cdot n \cdot z \cdot \left[ \tau g(\gamma_1) + \tau g(\gamma_2) + \tau g(\gamma_3) + \tau g(\gamma_4) \right] \cdot P_n =
\]

\[= D \left( \frac{\pi}{4} \cdot d^2 \right) \cdot n \cdot z \cdot \left( \Delta P_1 \cdot \tau g(\gamma_1) + \Delta P_2 \cdot \tau g(\gamma_2) + \Delta P_3 \cdot \tau g(\gamma_3) + \Delta P_4 \cdot \tau g(\gamma_4) \right) \]  

(2)

where \( D \)– the diameter of the location of the axes of the plungers in the cylinder block, \( m; d \) – the diameter of the plunger, \( m; n \) – the shaft rotation frequency divider, \( \text{Rev/s}; z \) – the number of plungers in the cylinder block; \( \gamma_1, \ldots, \gamma_4 \) – the angles of inclination of the washer sections (see Fig. 1).

After mathematical transformations we get finally:

\[ P_n = \frac{\sum_{i=1}^{k} (\Delta P_i \cdot \tau g(\gamma_i))}{\sum_{i=1}^{k} (\tau g(\gamma_i))}. \]  

(3)

Equation (3) allows us to solve the “direct” problem, i.e. determine the required pump pressure, with different pressure drop in each line regardless of the number of working sections of the axial divider.

To solve the “inverse” problem, i.e. determining the pressure in any of the trunk at a known pressure pump, we can express from the equation (3) for example, \( \Delta P_i \) :

\[ \Delta P_i = P_n \cdot \frac{\tau g(\gamma_i) + \tau g(\gamma_2) + \tau g(\gamma_3) + \tau g(\gamma_4)}{\tau g(\gamma_i)} - \frac{\Delta P_2 \cdot \tau g(\gamma_2) + \Delta P_3 \cdot \tau g(\gamma_3) + \Delta P_4 \cdot \tau g(\gamma_4)}{\tau g(\gamma_i)}. \]  

(4)

On the basis of (4), we obtain the generalized equation of pressure drop for any \( i \)-section:

\[ \Delta P_i = \left( P_n \sum_{j=1}^{k} (\tau g(\gamma_j)) - \sum_{j=1}^{k} \left( \Delta P_j \cdot \tau g(\gamma_j) \right)_{\text{run, j, i}} \right) / \tau g(\gamma_i). \]  

(5)
The shafts of the sections of the flow divider are rigidly interconnected, so the frequency of rotation and costs, passing through the sections can be determined by the following relationship:

$$Q_i = Q_n \cdot \tan(\gamma_i) \sum_{j=1}^{k} \tan(\gamma_j).$$  \hspace{1cm} (7)

For the numerical simulation of allocation process of expenditures $Q_i$ and pressure drops across the sections $\Delta P_i$ in the volume of the flow divider at different angles of regulation, we use the software package «MathCad v.15». Thus, for clarity and ease of analysis of results let us set the following conditions:

- all sections of the divider have the same diameter of piston $d_i = 10$ mm, the same diameter of the location of the axes of the plungers in the cylinder $D_i = 80$ mm, the same largest angle regulation $\gamma_m = 30^\circ$; all sections of the divider have the same diameter of piston $d_i = 10$ mm, the same diameter of the location of the axes of the plungers in the cylinder $D_i = 80$ mm, the same largest angle regulation $\gamma_m = 30^\circ$;

- the magnitude of the pressure drop $\Delta P_i$ in the output highways of the sections (see Fig. 1) depends on pressure drop in a power hydraulic motors of the motor-wheels, due to the fact that hydrostatic actuators pressure loss in the piping, usually, much less than the pressure drop in the hydraulic motor, accept: $\Delta P_1 = 30$ MPa, $\Delta P_2 = \Delta P_3 = \Delta P_4 = 5$ MPa;

- pump flow $Q_n = 0.5$ m$^3$/min, volumetric efficiency of the hydraulic machines is not considered.

![Figure 2](image)

*Figure 2 – Dependence of pressure $P_n$ pump from the corners of $\gamma$ adjustment in sections.*

1- adjustment $\gamma_1$; 2- adjustment $\gamma_1$ and $\gamma_2$; 3- adjustment $\gamma_1$, $\gamma_2$ and $\gamma_3$; 4- adjustment $\gamma_2$; 2- adjustment $\gamma_2$ and $\gamma_3$;

The simulation results are presented in the form of the dependence of the pump pressure, cost through the section and possible pressure drop for any section of the divider from the corners of adjustment (see Fig. 2, 3 and 4) obtained by the equations (3), (5) and (7) respectively.

Dependencies show (see Fig. 2) that the pressure $P_n$ in the system of hydraulic transmissions is less than the pressure in the loaded circuit $\Delta P_i$, except when lightly loaded in three sections 2, 3 and 4 the angles of inclination of the washers is equal to 0 (not shown). Moreover, the decrease in the angle...
γ1 in highly loaded sections, the pump pressure is reduced until the load of the remaining sections (curves 1, 2 and 3), and when the angle is decreased in the lightly loaded sections, the pump pressure increases (curves 4 and 5).

The change of the adjustment sections of the flow divider pump flow \( Q_n = \text{const} \) causes a redistribution of costs through section (see Fig. 3), i.e., when the angle is decreased, the flow through the adjustable section is reduced (curves 1, 3 and 5), and using the unregulated section- increases (curves 2, 4 and 6) is proportional to the number of unregulated sections and angles of inclination of the washers.

At constant pump pressure (see Fig. 4, straight 7) reduction of the angle adjustment section increases the amount of pressure in the circuit after the flow divider adjustable sections (curves 1 and 5) and to decrease the pressure in the circuit after the flow divider unregulated sections (curves 2, 3 and 6). Curve 4 shows that a decrease in the angle control in high-load section leads to a slight increase in pressure in the low-load circuits of unregulated sections.

Thus, the use in hydrostatic transmission MM of an adjustable axial flow divider gives the ability to redistribute power flow of the working fluid. This will allow us to extend the adjustment range of traction-dynamic characteristics of MM, which will significantly improve the mobility and the controllability of the vehicle without increasing the capacity of the power plant as a whole.
Figure 4 – Dependence of pressure drop $\Delta P_i$ in the contours from the angles of $\gamma$ adjustments in the sections of the divider:

1 - $\Delta P_1=f(\gamma_1)$; 2 - $\Delta P_1=f(\gamma_2)$; 3 - $\Delta P_1=f(\gamma_2,\gamma_3)$; 4 - $\Delta P_2=f(\gamma_1)$; 5 - $\Delta P_2=f(\gamma_2)$; 6 - $\Delta P_2=f(\gamma_3)$; 7 - $P_n$.

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