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Dual Row Rotary Piston Hydraulic Machine with Two Pumping Units

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***Abstract* — The article reviews the possibility to improve efficiency of the cylinders block design and the pumping unit of an axial-piston hydraulic machine by means of utilization of inter-cylinder zones for installing additional chambers smaller in diameter. This design allows to building a new axial piston rotor double row hydraulic machine with two pumping units, which have not been used in hydraulic drives. It is required to increase in the outer diameter of the original cylinders block by only 10% that will provide an increase the working volume and power of the new hydraulic machine by 33%. The updated efficiency improvements do not only increase the working volume and power, but also increase the hydraulic motor acceleration without increasing the feed pulsation, angular velocity and torque on the shaft of the hydraulic machine under investigation.**

Keywords* — *double row rotary piston hydraulic machine; increased power; small feed pulsation; high power response

I. INTRODUCTION

Despite plenty of inventions, technical solutions and designs of rotary hydraulic machines, developed and widely used in practice since the middle of the last century, the research in this area continues, both abroad and in our country, for example [1-6].

Amongst the range of rotary-piston double-and multi-row hydraulic machines, only units with multi-pampers radial-piston hydraulic motors and with various control systems are widely used [7-25].

Two or more piston sets with supporting thrust bearings or rollers sliding (rolling) along the surface of a common stator during operation can be located one after another in the same rotor in different sections. This kind of design is mainly used as high-torque hydraulic motors [26-32].

Dual-row axial piston pumps and hydraulic motors with two rows of operating chambers in one cylinder block are also utilized, for example [33], but they have not found being used in hydraulic drives at all.

However, in this case, there is no purpose to update the design of such hydraulic machines.

The purpose is to improve efficiency of the cylinder block of a typical hydraulic machine with a tilting disk and to increase its operating volume and power without changing dimensions of the original block. This is the point of innovative upgrading.

Moreover, the hydraulic machine retains its versatility: it can serve as a pump and a hydraulic motor and can be supplied with/without variable capacity.

II. THE CONFIGURATION OF ROTARY-PISTON HYDRAULIC MACHINE

There machine consists of the follow parts (Fig. 1): body frame 1, drive shaft 2 with splines, mounted in bearings. The cylinder block 5 is connected to the shaft through a spline connection and its spherical end is pressed to the surface of the distributor 6 by a spring 7 through an annular stop 8.

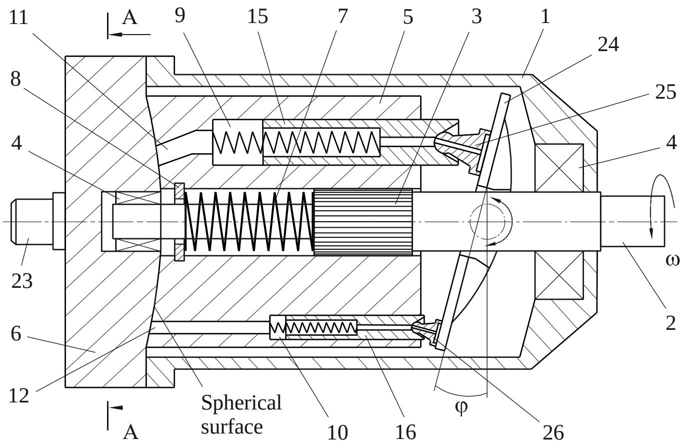

Fig. 1. Rotary piston hydraulic machine in cross section

In a modified cylinder block with an outer diameter 10% bigger than the original diameter (Fig. 2) the main cylinders 9 are made with axes along the diameter D_m and additional cylinders 10 with axes along the diameter D_{ad} (the slots in the central opening of the block are not indicated under conditions).

In the cylinders block (Fig. 1 and 3) there were eyelets 11 and 12 drilled for supplying the operation fluid to the distributor 6, fig. 4. There are main 13 and additional 14 crescent-shaped eyelets on the distributor 6, but extra eyelets 17 and 18 were added which are connected on the left and right sides of the stopper 19. There were also added eyelets 20 and 21 which are connected to the fittings by which the hydraulic machine is attached to the hydraulic system lines (one of them is in Fig. 1, pos. 23).

The swash plate 24 is installed inside the body of a rotary piston hydraulic machine. The swash plate is in fixed position for the non-adjustable type of the hydraulic machine and for the adjustable version the rotatory type of swash plate is applied where it is able to change the inclination angle φ, for example, depending on the pressure level in the hydraulic system.

The spherical heads of hydrostatic bearings 25 and 26 are rolled into large and small pistons on the right side which are supported by the swashplate. This typical technical solution allows to distribute the force from the piston over large surfaces and reduce friction [29, 30].

When the shaft rotates with the cylinders block, the pistons 15 and 16 reciprocate. In the first half turn of the block, the above-mentioned pistons, moving out of their cylinders, suck up the operation fluid from the suction line through eyelets 11 and 12 and crescent-shaped windows 13 and 14.

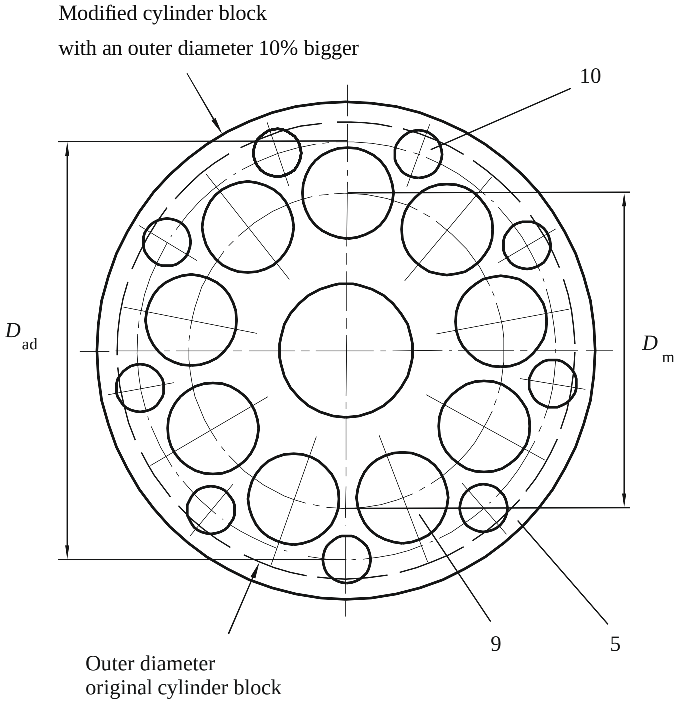

Fig. 2. View of the cylinder block from the right end

On the second half turn, the pistons 15 and 16 pass through the upper jumper 19, which cuts the suction line from the discharge line, and thus displace the operation fluid into the discharge line through the eyelets and crescent-shaped slots of the distributor 6.

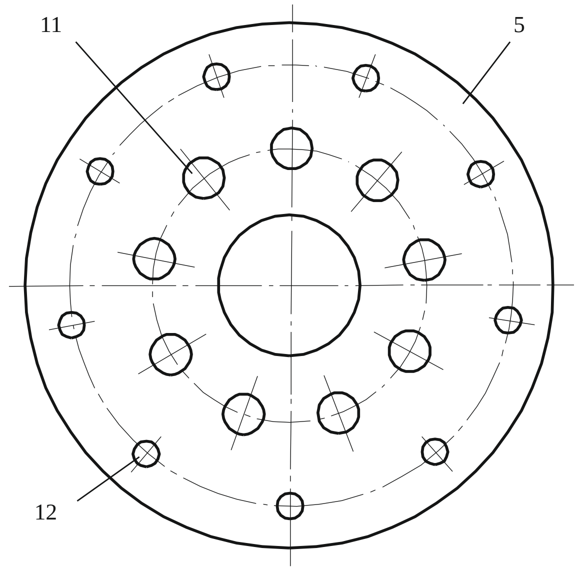

Fig. 3. View of the cylinder block from the left end

It is possible to modify block design by drilling additional slots for cylinders axis of a smaller diameter coaxially with the axis of the block if its outer diameter is increased by 10% (and cross-sectional area and volume by 21%) in the inter-cylinder zones of the main cylinders 9.

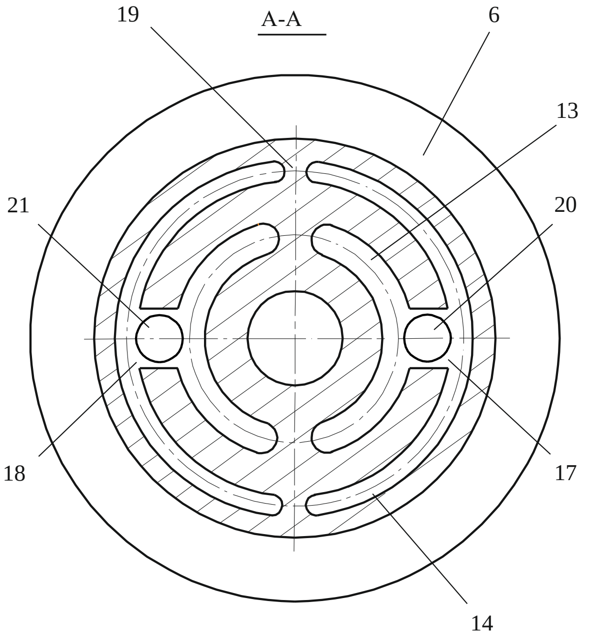

Fig. 4. Distributor section view

III. THE PERFORMANCE OF A TWO-ROW ROTARY PISTON HYDRAULIC MACHINE

After such modification of the unit, the diameters of the additional cylinders can be only two times smaller than the diameters of the main cylinders, and their area – four times smaller. In this case, the additional pistons move hдоп is determined by the equation [29] (m):

$$h_{ad} = D_{ad} \cdot \mathrm{tg}\varphi, \tag{1}$$

where D_{ad} is the diameter along the axes of the additional cylinders) is greater than the hосн main pistons move with their diameters along the D_m axis, determined by the same equation:

$$h_m = D_m \cdot \mathrm{tg}\varphi \tag{2}$$

With an increase of 10% in the outer diameter of the cylinder block, the diameter D_{ad} is 1.32 times larger than D_m, therefore, with the same angle φ, the ratio of the move additional h_{ad} and the main h_m pistons will be equal to the ratio of the indicated diameters – 1.32.

The volume capacity, determined by the formula [29] (m^3):

$$V_0 = f \cdot z \cdot h, \tag{3}$$

where f is the piston area, m^2; z is the number of pistons, for the considered rotor piston hydraulic machine will be determined by the sum of:

$$V_0 = V_{0m} + V_{0ad}, \tag{4}$$

which can be represented as:

$$V_0 = f_m \cdot h_m \cdot z + 0.25 \cdot f_m \cdot 1.32 \cdot h_m \cdot z \tag{5}$$

and after transformations, determine the volume capacity of the new rotor hydraulic machine:

$$V_0 = f_m \cdot h_m \cdot z \cdot (1 + 0.25 \cdot 1.32) = 1.33\ V_{0m}, \tag{6}$$

which increases by 33%.

Thus, the additional cylinders of smaller diameter were placed into cylinder zones of the main cylinders which outer diameter was slightly enlarged, that gave a significant increase of the volume capacity of the rotary-piston hydraulic machine and its theoretical supply and power by 33%.

But there is another, even more drastic way of solving this problem. If outer diameter is not enlarged then a seven-cylinder block is used, which has larger inter-cylinder zones.

Figure 5 shows a typical cylinder block 1 with a piston diameter of 25 mm from a series of hydraulic machines 310 [34].

To the left of the axis O – there is the original unit with seven cylinders 2 (measurements are taken from the product); on the right there is a modified block with added seven cylinder 3 with a diameter of 11 mm (all dimensions of the modified block are obtained according to a drawing made on a 1:1 scale).

It is possible to increase the total area S_Σ of all fourteen cylinders to a value equal to mm^2, by placing the additional operating chambers the inter-cylinder zones

$$S_\Sigma = S_1 + S_2 = 490.625 + 94.985 = 585.61, \tag{7}$$

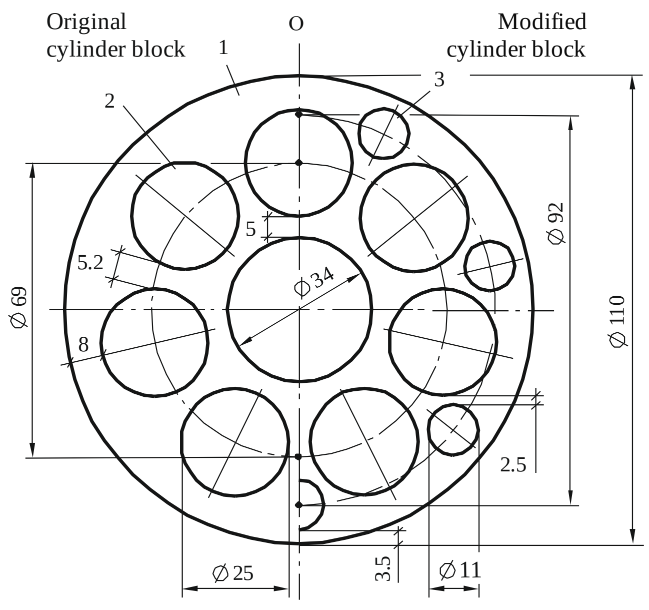

Fig. 5. Standart seven-cylinder unit for hydraulic machines from the 310 series

which is 19.36% more than the area of S_1 – the main cylinders with the area of S_2 – additional cylinders. However, the volume capacity increases somewhat more due to the larger stroke of the additional pistons.

Calculations show that in this case the volume capacity obtained in the modified design is 26% larger and this is a very significant increase, especially considering that it was achieved without changing the diameter of the cylinder block.

Obviously, the increase of number operation chambers will affect the pulsation degree of the pump feed and the angular velocity of the hydraulic motor.

The pulsation of piston pumps feed is estimated by the coefficient of irregularity of the feed, determined by an odd number of pistons by the formula [29]:

$$\sigma_Q = 2\cdot\mathrm{tg}^2\left(\frac{0.25\pi}{z}\right). \tag{8}$$

For a hydraulic machine with an initial unit with seven cylinders, it is equal to 0.025, which is considered as acceptable value [25].

In the hydraulic machine under consideration, the number of cylinders is increased to fourteen, and with an even value of working chambers, the irregularity of feed increases significantly and is determined by a different formula [29]:

$$\sigma_Q = 2\cdot\mathrm{tg}^2\left(\frac{0.5\pi}{z}\right), \tag{9}$$

which gives the value of the feed unevenness coefficient $\sigma_Q = 0.0254$, but this is despite the fact that the diameters of the cylinders are the same.

In this case, the additional operation chambers give an increase in feed of only 33%, so they are less efficient and the pulsation is lower than the acceptable value.

One of the advantages of rotary hydromotors is their high power response. This indicator is especially high in axial-piston machines.

The best hydraulic motor will be the one with the maximum coefficient k value [35] from the acceleration of external inertial load point of view:

$$k = \frac{M}{\sqrt{J}} = \frac{M}{\sqrt{0.5\cdot m\cdot R^2}}, \tag{10}$$

where M is the torque on the hydraulic motor shaft which is proportional to the operation volume N·m, J is the inertia moment of the cylinders block and all rotating masses, kg·m^2, m is the mass of the block with pistons, kg, R is the outer radius of the block, m.

To evaluate the change in power response of the new hydraulic motor, let's take the ratio of the coefficients for the modified k_2 and the original k_1 of cylinders blocks:

$$\frac{k_2}{k_1} = \frac{1{,}33M \,/\left(0{,}5m\cdot(1{,}1R)^2\right)^{\frac{1}{2}}}{M\left(0{,}5m\cdot R^2\right)^{\frac{1}{2}}} \tag{11}$$

and after transformations and shortcut we get the relation:

$$\frac{k_2}{k_1} = 1.21,$$

where 1.33 is the coefficient of increase of the volume capacity, 1.1 is the coefficient of increase of the external radius of the modified cylinder block).

Thus, an increase of volume capacity of the rotary-piston machine also leads to an increase in the power response of hydraulic motor – by 21%.

IV. SYMBOL AND SCHEME OF INTEGRATION INTO THE HYDRAULIC SYSTEM

Figure 6 shows a diagram of the pump connection to the hydraulic system.

The hydraulic machine 1 in the pump mode can supply the operation fluid as to different hydraulic lines (left position of the hydraulic distributor 2) as to the common one (right position). Valves 3 connected to their channels of the pump 1, perform a safety function when switching the positions and must have quick response.

If machine is used as a hydraulic motor, both its channels, top and side, are connected into one hydraulic line, while valves 3 and the hydraulic distributor 2 are not required.

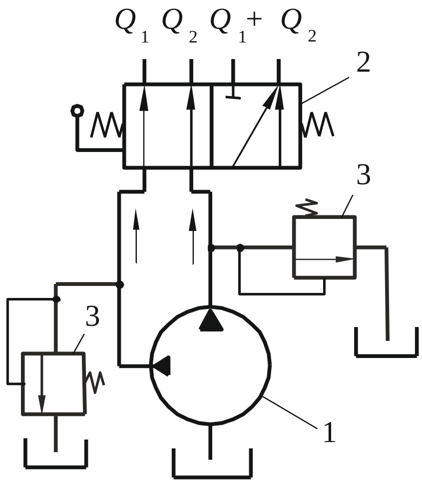

Fig. 6. Connection diagram of the rotary piston pump to the hydraulic system

V. Conclusion

The obtained results convincingly demonstrate that the efficient use of a cylinders block of a standard hydraulic machine with a swash plate (as well as with an tilt block) allows to increase its volume capacity, supply and power with almost unchanged dimensions of the original block and the same rotational frequency ω.

At the same time, the new hydraulic machine does not increase the feed pulsation, the angular velocity and the torque as compared to the initial one, and if it operates in the hydraulic motor mode, it also has a higher power response.

All this allows us to conclude that the new rotary-piston hydraulic machine with a double-row pumping unit is an advanced technical solution, while the design change does not cause serious complication.

The next stage of further development of the idea is stated idea the upgrading of the hydraulic machine with the possibility of additional phase control of the feed according to the principle set forth in [26, 27] using the example of a radial-piston hydraulic machine.

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