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THE STUDY OF HYDROMECHANICAL PROCESSES IN HYDROMACHINES OF POWER-INTENSIVE DRIVES

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Abstract: *Axial piston swash plate hydraulic machines are widely used in volumetric hydraulic drive due to their high energy performance. However, their use in a motor mode restrained a relatively small adjustment range due to high levels of minimum stable velocities hydraulic machine output link. One way of reduction APHM output unit minimum steady speed may be to provide a hydrostatic unloading in the piston-cylinder pair.*
Keywords:*mechatronics, hydraulics, power drives*

1. INTRODUCTION

Despite of high weight and size parameters of modern positive-displacement hydraulic machines the problem of their improvement and heightening the coefficient of efficiency of hydraulic machines remains rather actual. The way of perfecting of these hydraulic machines can be in their further forcing on pressure, and also in widening a range of adjustment at the expense of lowering the level of minimum stable rotating frequency.

Main objectives in studying of hydromechanical processes in hydromachines of power-intensive drives are:

1. Study the interaction of the basic link of mechanism in the variable HMTD structure, which interfaced surfaces are disjointed by an oil film.
2. Define requirements of transition to a different friction mode.
3. Create the theoretical base for a valid choosing of service conditions, possible prediction of volume change and hydromechanical losses, uses of forced operation conditions.
4. Search for new structure charts and constructions that will ensure elimination of the basic limitation in this type of hydromachines.

2. PROBLEM OVERVIEW

Traditionally the hydraulic drive is used where the fast response time, sensibility, small dimensions and automated management is required. The most widely hydrostatic power drive of cars is applied in cutting machines, presses, in control systems of aircrafts, vessels, heavy machinery, mobile road-building equipment, in automatic control systems of thermal drives, hydraulic turbines [2].

The main advantages of hydraulic drives are: ability to be organically integrated into the hydrostatic drive system, high power-intensity and long-time loading mode and, consequently, high thermal regime.However, these actuators have limitations that prevent the establishment and operation of these drives, such as: high volume and hydro-mechanical losses and durability and reliability issues.

Two types of positive-displacement hydraulic machine should be distinguished, which now can be considered as a basis for creating power-intensive drive with long-time loading conditions: hydraulic machine with tilting cylinder block (HMTCB) and hydraulic machine with tilting disc (HMTD).Hydraulic machine with tilting cylinder block have a higher volumetric coefficient of efficiency, a smaller dead space and, consequently, a wide steady range of rpm. Hydraulic machine with tilting disc have a better weight and size parameters, and also are incomparably easier in production. Their main disadvantage is a relatively bigger volume loss, especially during the start-up process, which greatly narrows a range of stable rates and increases the no reaction zone [1].

3. SCIENTIFIC RESEARCH

Scientific studies of problems listed above are conducted on the basis of the International Research and Educational Center BSTU-FESTO "Synergy".

At a preliminary research stage the load design of the piston mechanism has been done. Among kinematic pairs in the main frame of the axial-piston HMTD - piston pair is the only kinematic pair which doesn`t have hydrostatic unloading of interfaced surfaces, because of complexity of its constructive realization The complexity is determined by indeterminacy of movement of the interfaced surfaces in relation to a loading force vector. At small rates piston pair is influenced by a huge amount of forces and friction torques [5].

Unlike start-up conditions and conditions of unstable rates, the piston mechanism operation at stable hydromachine shaft rate is characterized by essential decrease of mechanical losses, in its kinematic pairs. This is caused by transition from boundary to mixed, and at the operation conditions close to a nominal, to a liquid friction. In these operation conditions, especially at a liquid friction, it is possible to have simultaneous relative movement of elements of the piston mechanism, depending on a ratio of friction forces in kinematic pairs [3]. Ratio of relative rates and friction forces in kinematic pairs of the piston mechanism in this case are interconnected and are in dependence from such factors as values and shapes of clearances between the interfaced elements, viscosity and pressure of a working fluid in them Fig. 1.

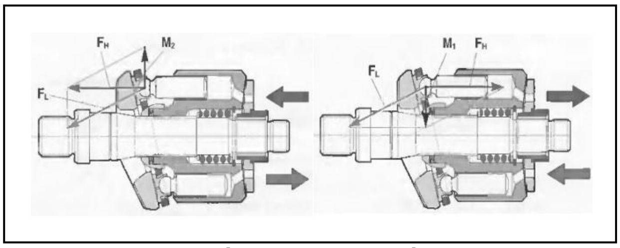

Fig. 1. Forces in pump and motor operating mode

As a result of the load design of HMTD piston mechanism the generalized dependence for friction force calculation in piston pair depending on a coefficient of friction and the geometrical sizes of piston pair has been received. The analysis of the received dependence displays that the spherical joint offset contrariwise to a direction of the transversal force vector acting on the piston essentially reduces value of a friction coefficient in piston pair [6].

Physically this explained by the fact that as a result of this offset, the moment from the transversal force, is partially, or completely compensated by the moment from the axial force acting on an arm equal to the offset value. This will result in absence of tipping moment on the piston. Based on the results of the study a new design of piston mechanism was developed. This modified piston design compensates the break out force and provides mechanism with additional oil film Fig. 2.

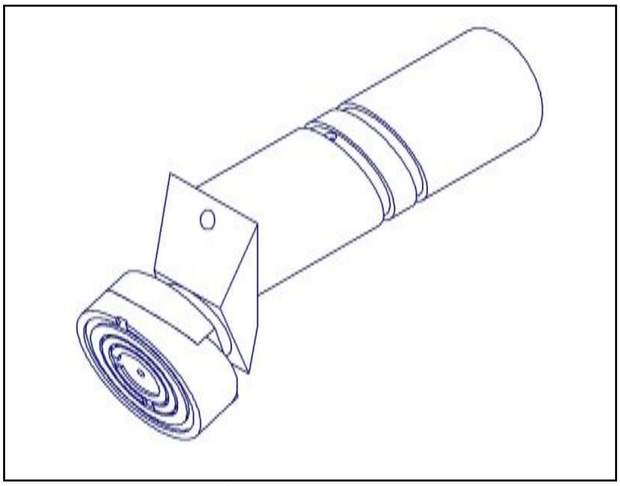

Fig. 2. Improved design of piston mechanism

In the continuation of the study the more detailedpower analysiswas conducted. The purpose of the analysis was to establish relationships between the external forces and internal forces (reactions of the bearing surfaces of the kinematic pairs and friction forces in them) and, consequently, derived dependencies for the friction coefficient [4]. Dependence was obtained for the motor and pump operation mode of piston mechanism. The resulting dependence is shown in Tab. 1.

Pump mode	$T^{н} = \frac{F_{р}}{(\frac{1}{f_{пр}^{н}\, tg\gamma} - 1)}$
Pump mode	$T^{н} = \frac{F_{р}}{(\frac{1}{f_{пр}^{н}\, tg\gamma} - 1)}$
Motor mode	$T^{м} = \frac{F_{р}}{(\frac{1}{f_{пр}^{м}\, tg\gamma} + 1)}$

Tab.1. Total friction force

Based on data obtained in the course of the experiment, was calculated magnitude of the forces of friction and the coefficient of friction and, as a result, their overall reaction shown in Tab. 2.

Pump mode	$R^{н} = (F_{р} + T^{н}) \cdot [\left(2\frac{l_{ca}}{l_{ab}} + 1\right) tg\gamma + \frac{1}{l_{ab}}(d_{п} \cdot f \cdot tg\gamma - 2r_c)]$
Motor mode	$R^{м} = (F_{р} - T^{м}) \cdot [\left(2\frac{l_{ca}}{l_{ab}} + 1\right) tg\gamma + \frac{1}{l_{ab}}(d_{п} \cdot f \cdot tg\gamma - 2r_c)]$

Tab 2. Total friction force in piston kinematic pair

Analysis of the dependences shows that for small values of the friction coefficient the friction force in the piston pair in motor and the pump modes are almost equal in magnitude.

When friction coefficients are corresponding to the mode of mixed and boundary friction, frictional force in the piston pair in pump mode can greatly exceed the frictional force in motor mode.

In the pump mode, the friction force and technological force have the same direction, which leads to an increase in the reaction force of the support disc and, in particular, its transverse component.

In the motor mode, the friction force aimed in the opposite direction in relation to the technological force, which consequently leads to a reduction of the transverse (fracture) reaction force of the supporting disc Fig. 3.

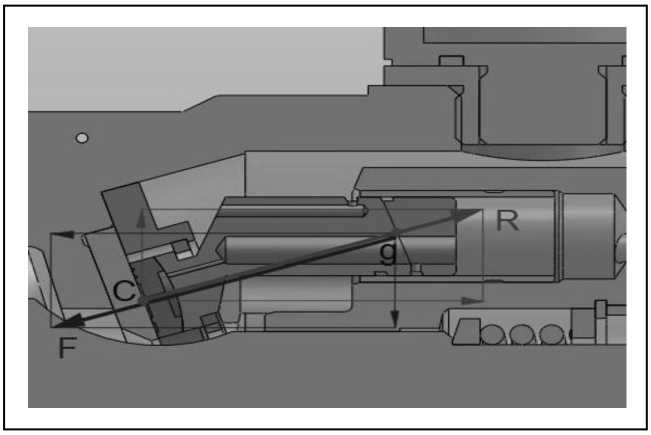

Fig. 3. Forces in the piston pair

Special software was developed in order to find the best solution on the basis of the calculations was developed that allows dynamicallydetermine the value of the eccentricity at which the overall reaction in the piston pair is the smallestFig. 4.

Moreover, it can be used to study the two hydraulic modes: pump and motor, and plot the dependence overall reaction from concentricity.

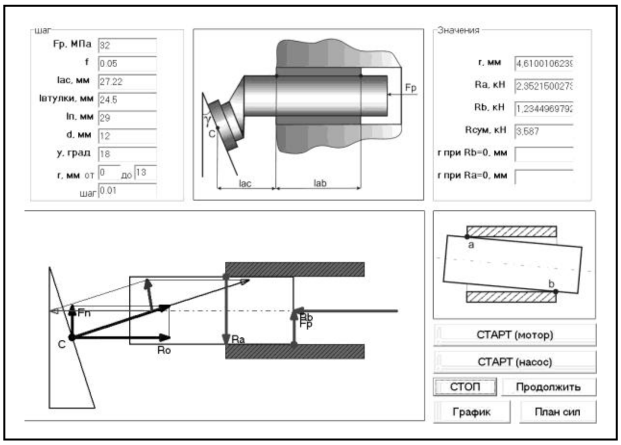

Fig. 4. Main screen

Being able to calculatethe value of friction force and the coefficient of friction in the piston pair it is possible to determine the reactions of the piston pair.Tab. 3.shows the total friction force at maximum operating pressure of 32 MPa for a piston diameter of 12 mm and a length of 29 mm while changing angle of support disc.

Disc angle	**Total friction force, kN**	
	Motor mode	***Pump mode***
16°	1.971	1.31
17°	1.608	1.09
18°	1.237	1.157
20°	1.294	1.294

Tab. 3. Total friction force

According to the calculation results use of the hydraulic machine with a maximum angle between the axes of the cylinder block and the swash plate at 18 ° is fully justified. As a practical recommendation for improving the constructive elements of the modified piston pair is to perform two longitudinal grooves parallel to the supporting disc to achieve the full hydrostatic relief.

4. EXPERIMENTAL RESEARCH

The process of the experimental research of new piston mechanism started with a production of pistons with different angles. Based on the calculation results it was decided to produce pistons and discs with angles from 15° to 16° degrees with 1° degree step Fig. 5.

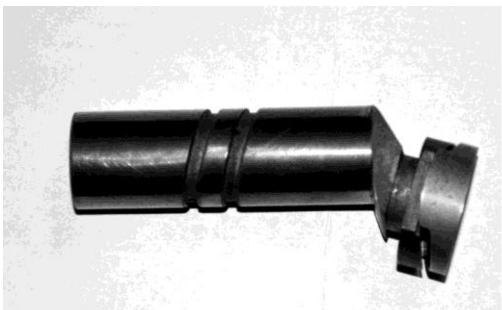
Fig. 5. Modified piston for 15°

The experimental assembly consists of three main parts Fig. 6:

1. Test module, which is a hard massive base with quick release fixing elements, with which it attached to the removable cylinder blocks (modules) and block with interchangeable rotating swash plate.
2. Auxiliary pump unit that provides hydraulic fluid supply to the cylinder block of the experimental setup.
3. Rotary drive supporting the swash plate.

The cylinderblock is amassive bodywith two "floating" cylindersin the ball bearings. They contain exchangeablecylinders,whichin turnare used to mountthe studiedreciprocatingmechanisms.Friction forceresultingin a pair of"piston-cylinder" is perceivedby rigidslottedsprings.Springs compression is recordedby inductivedisplacement sensors.Cylinder chamberhydraulically connectedthrough channelsin floatingtransitionalsupports andremovableflangeon whichthey rely.

Operating fluidis suppliedto the channelsthroughthe flangeconnectionof thehigh-pressurepumping station. Pumping station provides operatingfluid pressure in thecylinderenough tocompensatevolume lossesthrough gapsin the pumpgroupandtransitionalfloatingpiers.Operating pressureis set by pumping station relief valve.The pumping stationis supplyinghydraulic fluidin a constantpressureusing a specialfeedback.

The support block is a rigid massive body, in which shaft is mounted on bearings. One end of the shaft through the coupling is connected via a transmission with an auxiliary motor hydrostatic drive, which provides the steeples adjustment speed of the swash plate in the range of 10 to 350 rad/s. At the other end of the shaft removable swash plate is mounted. Removable swash plate has different supporting surface angles and each of them is statically balanced.

Cylinderand bearingblocksare mounted on thebasecoaxially. The working areais protected bycoverwithviewing windows. Working fluidflowingthrough the gapsin thepiston mechanismis collected ina special trayandreturned to the pumping station tankby gravity.

Experimental assembly has the following algorithm of work. From the pump station hydraulic fluid by pressure flows through the channels in the support flange and floating bearings, enters the under-piston cavity of studied reciprocating mechanisms. When the swash plate is rotated piston generally both reciprocate and rotate about its own axis.

Piston mechanisms have a reversed phase motion to each other, so when the assembly is in the constant pressure mode, one of thereciprocating mechanisms will implement the pump mode during half-cycle, and at the same time another piston mechanism will work in a motor mode.

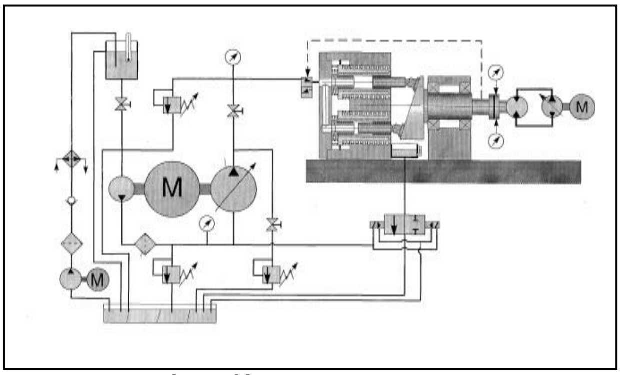

Fig. 6. Experimental assembly

The comparative assaying of results of experimental researches of the regular and modified piston mechanism in a pump mode has displayed essential reduction of friction forces in piston pair of advanced mechanism in a wide range of rotation speeds and operating pressures.

Comparative experimental researches of motor mode in a static load condition have displayed the diminished breakaway moment in advanced mechanism and higher the torque acting on a shaft within an identical range of pressure. Using obtained results it is possible to create a forced version of HMTD by only changing its piston mechanism with an improved one Fig. 7 and Fig. 8.

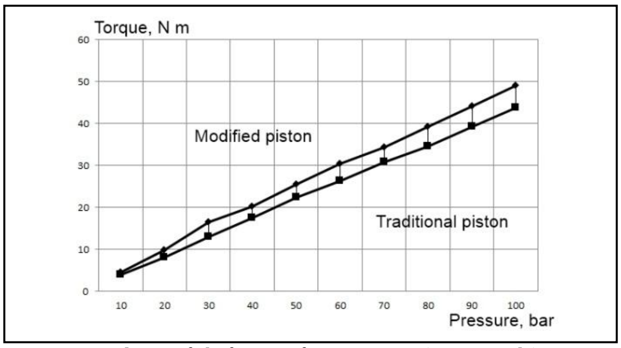

Fig. 7. Dependence of shaft torquefrom pressure (motor mode)

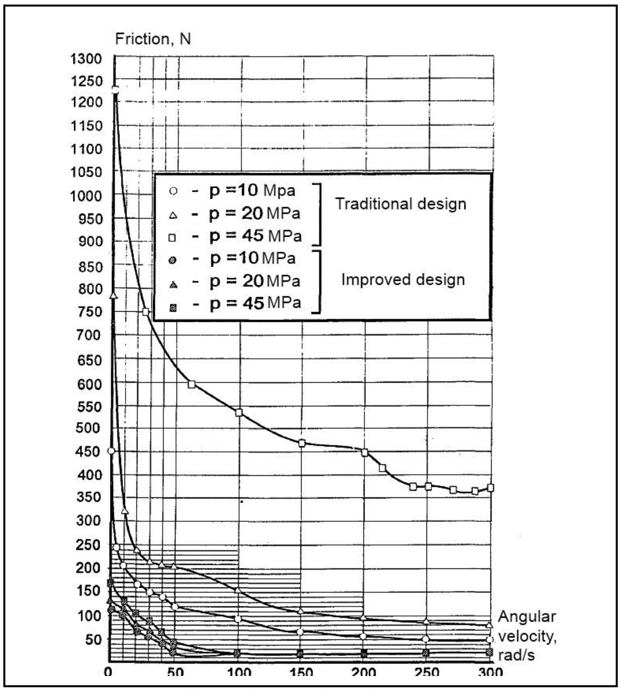

Fig. 8. Dependence of axial friction force from angular velocity (pump mode)

Deeper study of power analysis results showedthat forces created by performed longitudinal grooves parallel to the supporting discmay not properly oppose the effect from concentricity. The comparative results assaying of experimental researches of the modified pistonmechanism with two longitudinal groovesand modified piston mechanism without them in a static motor mode has displayed higher torque acting on a shaft within an identical range of pressureFig. 9.

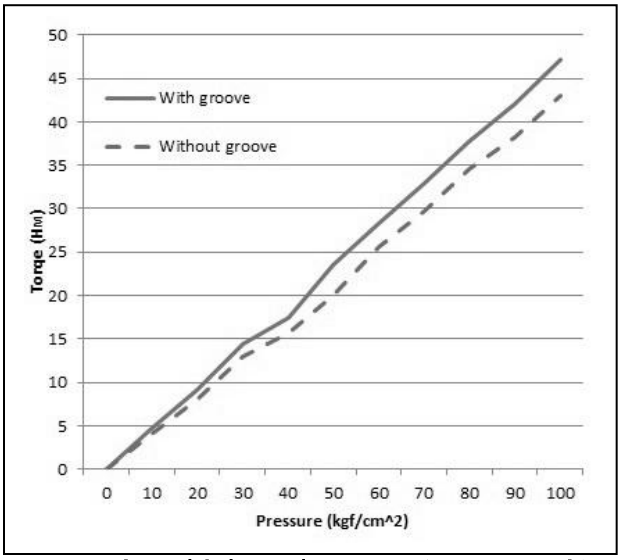

Fig. 9. Dependence of shaft torquefrom pressure (static motor mode)

5. CONCLUSION

Improvement of characteristics of hydraulic machines as a widely applied component is a very urgent direction of development. In general, application of this technology may have the following results, such as an increase of efficiency, reduce of weight and size and reduce of production, installation and operation costs of hydraulic machines that will lead to cheaper production of the system it is integrated in.

Developed HMTD with new piston mechanism has a high practical value. Preserving its weight and size parameters and having minor structural changes this machine may show better performance than drives of traditional design.

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