Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 69 (2014) 512 – 517
Procedia Engineering
www.elsevier.com/locate/procedia

24th DAAAM International Symposium on Intelligent Manufacturing and Automation, 2013

Power Analysis of an Axial Piston Hydraulic Machine of Power-Intensive Hydraulic Drive System

Ilya Larchikov*, Andrey Yurov, Sergey Stazhkov, Anastasia Grigorieva, Alena Protsuk

6th Krasnoarmeyskaya str.10-21, 190005, St.-Petersburg, Russia

Abstract

Technical characteristics of positive-displacement hydraulic machines determine the prospects of increased application for known positive properties of positive-displacement hydraulic drive to improve machines of modern technologies performance characteristics. In return, an application of positive-displacement hydraulic drive is being restrained with comparatively high value of a start and reverse inert zone and, as a consequence, comparatively low speed adjustment range. That is resulting from volumetric and mechanical high level losses comprised hydraulic machines. For removal of disadvantages, searching a new hydraulic motors structural diagram should be done.

Selection and peer-review under responsibility of DAAAM International Vienna

Keywords: Mechatronics; hydraulics; power drives

1. Introduction

Technical characteristics of positive-displacement hydraulic machines determine the prospects of increased application for known positive properties of positive-displacement hydraulic drive to improve machines of modern technologies performance characteristics.

The positive-displacement hydraulic drive has wide and varied range of application in modern technology. Traditionally, hydraulic drive is applied where the fast response, rapidity, small dimensions, large transmitted power and automated control are required.

* Corresponding author. Tel.: +7-986-180-7006.
E-mail address: ilyalar@mail.ru

Selection and peer-review under responsibility of DAAAM International Vienna
doi:10.1016/j.proeng.2014.03.020

The throttle control of high-power hydraulic drive is limited due to the low efficiency of a control process.

In return, an application of positive-displacement hydraulic drive is being restrained with comparatively high value of a start and reverse inert zone and, as a consequence, comparatively low speed adjustment range. That is resulting from volumetric and mechanical high level losses comprised hydraulic machines.

In recent times more advanced positive-displacement hydraulic drives are being constructed. This makes range of application to be extended in technology.

Global experience in the field of positive-displacement hydraulic drive allows assigning of two the most prevalent types of positive-displacement machines. These machines may be considered to be the base for engineering power-consuming drive with continuous loading conditions. These are:

- Bent axis hydraulic machines (BAH)
- Swashplate hydraulic machines (SWH)

The hydraulic machines with a bent axis (BAH) have comparatively low volumetric and mechanical level losses. As a consequence, reduced value of the start and reverse inert zone and increased adjustment range are occurred.

The hydraulic machines with swash plate (SWH) are more power-consuming, their dynamics and overall properties are higher.

Stated below research results and practical recommendations refer to the swashplate hydraulic machines. These machines are projected under a structural layout of widely known Sauer hydraulic machine type.

Given type of hydraulic machines is very promising. Primarily, because of the possibility of level operating pressure forcing.

Basic construction of swashplate hydraulic machines is being constantly improved and has suffered changes in recent years. That is allowed along with a simplification to increase level limit of operating pressure and to extend temperature span and range of regulation.

The main design concept grounds on application of hydrostatic unloaded slide bearing. Now this concept is still unchanged.

These hydraulic machines father development may be concentrate on pressure forcing, as also expansion of regulation range. This is possible as a minimum level of steady rotation frequency may be reduced.

Fundamentally, hybrid slider bearing has high alternative in design development.

The problem is to make design factors of slider bearing to meet the requirements of the operating conditions and external loading the best.

That is why the complete researches of hydromechanical processes in hybrid bearing of the swashplate hydraulic machines are necessary. The research results may be used for assessment of forced work mode, correct forecasting of losses and finding ways to reduce the losses.

Investigations of piston arrangements show, that hydromotors have high minimum level of steady rotation frequency at the start under the load. The reason for that is an interface seal leaks up to the breaking force. That is due to the significant friction load of piston mechanisms before motion start.

Because of the stated above feature of swashplate hydraulic motors, the inert zone of positive-displacement drive increases appreciably. The value of zone goes up then the operating pressure does. Here the inert zone shall be understood to mean a range of inclination of pump swash plate, by which hydraulic motor shaft is fixed.

This demerit is evident especially in the reverse mode and during the start under the load. By increasing inert zone the smooth running characteristic and accuracy of regulation process suffer.

For removal of disadvantages, searching a new hydraulic motors structural diagram should be done. The diagram has to save design and energy characteristics of the swashplate hydraulic machines. But alternatively, should improve force closure of the main part, providing reduction of superficial friction factor in a piston block.

Development a force diagram of running gear SWH and reducing friction forces in running gears simultaneously allow to solve hydraulic drive current problems concerning with pressure forcing and rotation frequency for machines, operating in condition of short-term overloads.

As can be seen from the above, researches for designing method of computation and construction of power-consuming axial piston hydraulic machine with high fast response and rapidity are extremely relevant.

2. Research

An idea of researching involves theoretically and experimentally integrated approach. The subject is hydromechanical processes in main kinematic pair of SWH influenced with unsettled work kinematics of hydraulic machines running gears.

In addition it is necessary to determine and study interaction of main members of SWH variable structure mechanism, meeting surfaces of whose are divided with oil film; to define conditions that make type of friction changes; to found a choice of operation conditions, forecasting capabilities of volumetric and hydromechanical losses, using an forced operation conditions, along with searching the new structural diagram and construction that would improve characteristics of given type hydraulic machines [2].

For these purposes have been done:

- Structural, kinematic and power analysis of SWH mechanism. The hydraulic drive was considered to be of variable structure as to define possible structure diagrams, requirements of its implementation and conversion
- Analysis of SWH kinematic pairs operation in liquid friction in a wide range of temperature, velocity and pressure
- Analysis of SWH piston blocks operation in boundary and mixed friction
- Analysis of structural diagrams and construction of main members of SWH that are provide liquid friction and low volumetric losses during the zero and creep speeds
- Analysis of pressure forced SWH

For structural diagrams analysis and systematization of running gear spatial mechanism of the swashplate hydraulic machines for different mode and condition of its operation the main methods of mechanism and machines structural analysis were practiced.

Power analysis of piston mechanism was made basing on the method of superficial friction factor computation and others tribological characteristics.

For mathematical model design of hydromechanical processes in kinematic pairs of hydraulic machine running gears was used N. A. Slezkin’s method. For numerical solution was used one of the most efficient numerical method for solution elliptic equation - the relaxation method.

Experimental researches were made with specially designed test-bench equipment and based on the inversion method of main observed members of hydraulic machines running gears.

As a result of SWH running gears mechanism studying (mechanism was considered to be of variable structure, depending on conditions and modes of drive application) the methodology of structural analysis, synthesis and structural classification of mechanism was engineered; different modes and conditions of drive application structural diagrams were investigated. Given methodology of structural analysis and synthesis is an evolution of Assur’s method, was used for spatial mechanism analysis.

The next step of investigation was dedicated to analysis of microkinematics special feature of SWH variable structure mechanism. They depend on conditions and modes of application. The kinematic of main cycle of operation and the one for mechanism with redundant degree of freedom were studied. Cycle of operation is a cycle, by which mechanism operates as the first degree mechanism does (without involving a passive links). A special focus was on microkinematic investigation – relatively shifting of meeting surfaces of hydraulic machines running gears within the gap filled with a working fluid. Based on analysis of a macro- and microkinematic of meeting surfaces relatively shifting, the mathematical relations of every kinematic pair of SWH running gear were derived. These are a foundation for creating a mathematical model of hydromechanical processes in gaps for liquid friction.

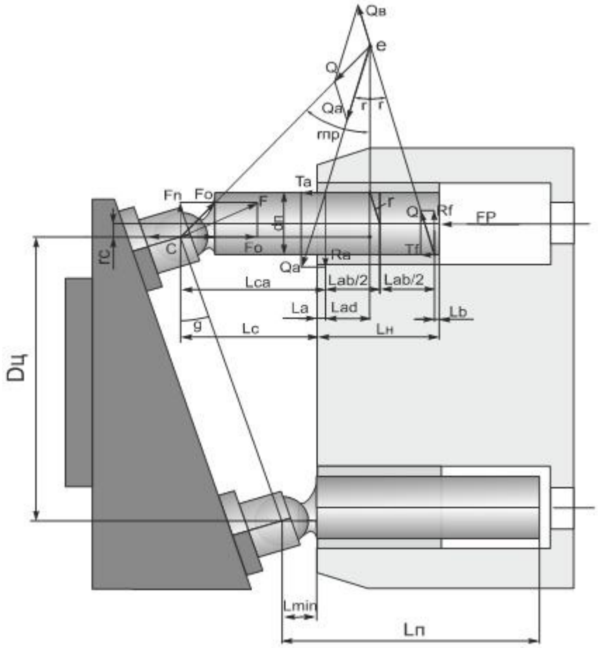

Fig. 1. Forces profile in pumping mode of SWH.

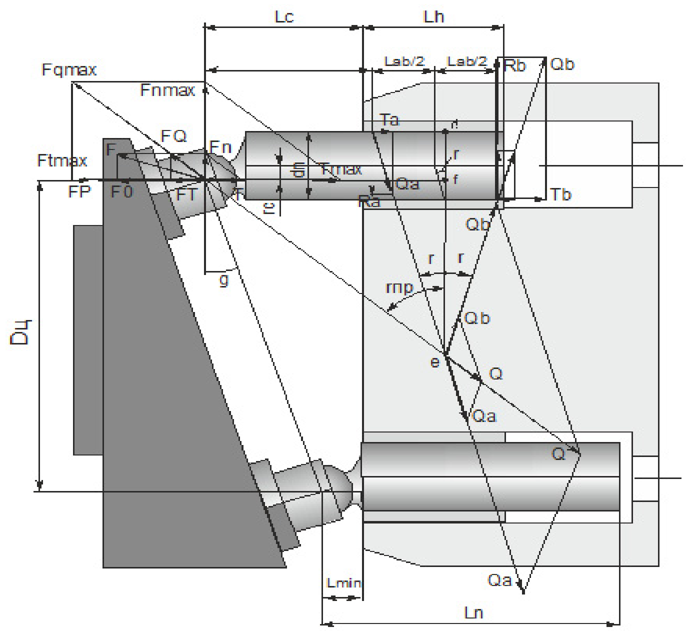

Fig. 2. Forces profile in motor mode of SWH.

2.1. Power analysis

Based on power analysis (Fig. 1, 2) the relations for friction force computation in piston pairs were derived for hydraulic machines operated in pumping and motor mode in wide variety conditions of applications, including the extreme one.

$$T^{p} = \frac{F_p}{\left(\frac{1}{f_s^{p} \cdot tg\gamma} - 1\right)} \tag{1}$$

$$T^{m} = \frac{F_p}{\left(\frac{1}{f_s^{m} \cdot tg\gamma} + 1\right)} \tag{2}$$

where:

$$f_s^{p} = \frac{\left(2\overline{\ell}_{ca} + \overline{\ell}_{ab}\right) \cdot f + f^2}{\overline{\ell}_{ab} - 2\overline{r}_c \cdot f} \tag{3}$$

$$f_s^{m} = \frac{\left(2\overline{\ell}_{ca} + \overline{\ell}_{ab}\right) \cdot f - f^2}{\overline{\ell}_{ab} + 2\overline{r}_c \cdot f} \tag{4}$$

f_s^m and f_s^p are superficial friction factors in motor and pumping mode respectively;

$$\overline{r}_c = \frac{r_c}{d_n} \qquad \overline{\ell} = \frac{\ell}{d_n} \tag{5}$$

where:

f - coefficient friction in piston - cylinder unit (PCU),
l_{ca} - piston extension (distance between center of piston spherical joint and fairlead bush external surface)
l_{ab} - length of fairlead bush
r_C - center of piston spherical joint shift relative to piston longitudinal axis
γ - swash plate displacement angle
F_P - axial force operated upon a piston
$d_п$ - piston diameter

This relations between tangential and axial component of friction PCU depending on SWH mode of application, results of experimental research and energy characteristics of PCU – the main source of mechanical losses - were a basis for father calculations. That is allowed to determine bounds for variation of design factors range of SWH running gears mechanism whereby a locking of kinematic pair is ruled out.

By using the methods of theoretical hydromechanics was found a solution for problem of hybrid loading capacity for bearing surfaces of running gear mechanism members of hydraulic machines.

The mathematical models of hydromechanical processes in arbitrary shaped gaps that divide the surfaces of kinematic pairs are given below. They were derived by using the base of research results of meeting surfaces relatively shifting of running gear members of hydraulic machines.

The computations were based one of the most efficient numerical method for solution elliptic equation - the relaxation method. The results are the pressure profiles in kinematic pairs gaps of SWH running gears. The profiles depend on characteristics that identify a shape of gap, speed of relative movement of meeting surfaces of links and also viscosity of hydraulic fluid.

The nature of results, which were derived by means of calculation, perfectly well corresponds with H. Regenbogen's profile [1], which was a result of experience with the same characteristics of gaps, speeds and temperatures. A disarrangement of maximum value for pressure in both relations is no more than 10%.

3. Conclusion

As a result, were derived the relations for load bearing and power (loss of power, coefficient of performance) characteristics for kinematic pairs of hydraulic machines running gears in under graded operation.

The mechanical loss evaluation allow to assert that in this case the kinematic pairs of hydraulic machines running gears mechanisms are mostly operated in liquid friction.

Mentioned characteristics that were derived by integrating the fields of pressure in gaps of kinematic pairs make possible to elaborate recommendation at the design stage for choosing the size and design for main mounting surfaces of mechanism running gears members. That allows to expand the range of application modes of hydraulic machines wherein the kinematic pairs are in liquid friction.

References

[1] Regenbogen H. (1978) *Das Reibungsverhalten von Kolben und Zylinder in hydrostatischen Axialkolbenmaschinen*. - VDI - Forschungsheft.
[2] Kanarchuk, V. (2008). *Durability and engine wear under dynamic operating conditions,* Naukova Dumka, Kiev.
[3] Kistochkin E. (2007). *Volumetric hydromechanical transmission. Calculation and design,* Mashinostroenie, St.-Petersburg.
[4] Mikhaylov, M.; Larchikov, I.; Yurov, A.; Cvetkov, V. & Stazhkov, S. (2011). Hydromechanical constant speed drive forwind-driven generators, *Proceedings of the 22nd International DAAAM Symposium,* Katalinic, B. (Ed.), pp. 0235-0236, ISBN 978-3-901509-83-4, Austria Center Vienna, Vienna, Austria, October 2011, DAAAM International Vienna, Vienna.
[5] Larchikov, I.; Stazhkov, S.; Mikhaylov, M.; Yurov, A. & Cvetkov, V. (2011). Study of Hydro Mechanical Processes in Hydro Machines of Power-Intensive Drives, *Proceedings of the 22nd International DAAAM Symposium,* Katalinic, B. (Ed.), pp. 0875-0876, ISBN 978-3-901509-83-4, Austria Center Vienna, Vienna, Austria, October 2011, DAAAM International Vienna, Vienna.