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THE EXERGETIC ANALYSIS FOR PREDICTING OF ENERGY EFFICIENCY OF THE HYDRAULIC DRIVE SYSTEMS

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Summary. In the article was analyzed the peculiarities of influence the mode of exploitation on energy-consumption of the hydrodrive. The energy efficiency was considered at the stage of circuit design of the hydrodrive. The resulted methods of assessing the effectiveness for the exergetic approach, based on the analysis of circuit design with considering modes of work.

Key words: hydro drive, hydraulic calculation, temperature, viscosity, exergetic analysis

INTRODUCTION

In engineering being used multimode drives to enhance the energy-efficiency of hydraulic systems of hydrodrive. Such hydraulic drives providing work in different exploitation modes. Arrangement of drives provides for different modes of use the hydraulic drive. This complicates the tasks of circuit design of hydraulic drives constructions and makes special demands on the assessment of their effectiveness [1-5, 16, 18].

Detection of the advantages and disadvantages of hydraulic drive is possible to carry out at different stages, from initial stages of design to experimental test of construction. The purpose of research is to explore the possibility of partial prediction of energy efficiency of the drive at the stage of scheme development. The exergetic analysis was used. It is often used to analyze processes and units, which associated with the use of energy and heat in the drive of control systems.

There is a growth of the fluid temperature during operation, the oil viscosity decreases, and the change of oil viscosity affects the pressure drop in the elements of hydrodrive. This results to a change of energy losses for the transportation of fluid and to the additional changes of power [2, 14, 17-21].

Hydraulic drives for different modes have different deadlocks, the flow channels, areas which accumulate various additives and others. They are calculated by methods, which consider changes in the physical properties of the calculated dependences.

Trends in the development and modernization of hydraulic drive are aimed at increasing of requirements, imposed on the reliability, multifunctionality and durability of engineering systems functioning. However, taking into account the increase in energy prices much attention is paid to increasing the energy efficient of hydraulic drive. There are several different methods and approaches for increase energy efficiency of automated systems of drives. For example, the structural optimization of multi-mode systems [11, 12, 15]. At the stage of the hydraulic system design the energy efficiency can be increased by selection of rational structure of the system, which is appropriate with regimes and operation conditions. Thus, taking into account changes of the input energy flow and the power consumption of drive the rational number of executive devices can be defined. Herewith, the level of their power being calculated, the effectiveness of system modes operation being assessed, or several separate systems for different modes and performance of the same production functions being developed [7-11]. At the following stages of system design the calculation of operational parameters of each mode (flow, pressure, rated power, duration of each mode) is carried out.

One of the promising approaches is the exergetic analysis of systems, which is used for modernization of existing systems and developing the new ones. The approach allows to compare the potential of energy efficiency of the physically different devices; and also, allows to find the causes of energy losses (that ones that can be removed and can't be removed). These reasons of energy losses are related with the elements of the system, operational modes or conditions of their work [16, 22]. When solving practical tasks two marked approaches can complement each other. Exergetic approach will allow extendedly estimate the potential of energy efficiency and choose the general principles of the automated system construction. Structural optimization will give algorithm of functioning and composition of the system. It will allow finding ways of their reducing, realization of which will result to the construction of a rational system.

BASIC MATERIALS

For the correct description of the hydraulic drive it is necessary to perform the local taking into account of rheological properties of fluids for individual elements of the system and for the operational cycle, such as: the coefficient of friction, coefficient of hydraulic resistance, viscosity (period of use), and etc. The principle scheme of an example of such drive is shown in Figure 1 [12, 21].

For exergetic analysis of multimode drives is used the type of exergy, which includes forms of energy (such as the internal energy of matter, energy of chemical bonds, heat flow). For each of them the exergy calculated individually depending on the presence and

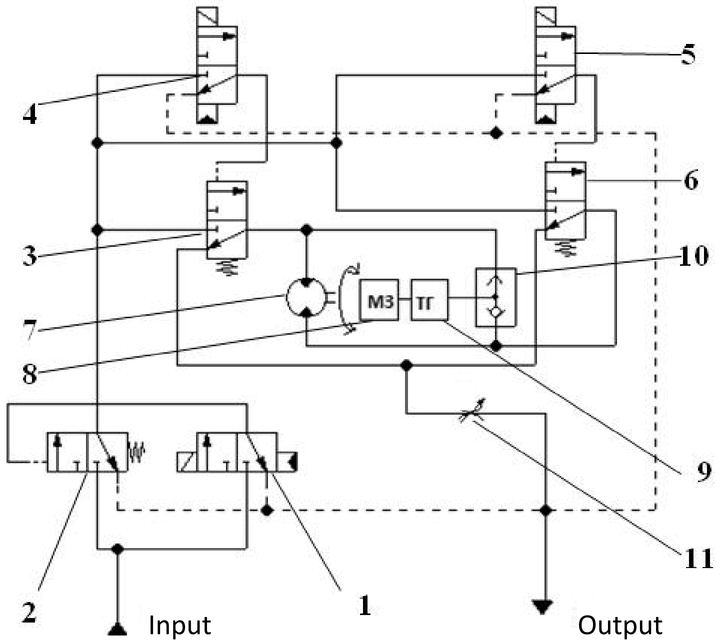

Fig.1. Principle scheme of the multimode drive:

1 – the electrohydraulic inlet valve; 2 – the hydraulic shutoff valve; 3 – the control valve of position the output shaft to «moving output link»; 4 – the electrohydraulic valve of control valve 3; 5 – the electrohydraulic valve of control valve 6; 6 – the control valve of position the output shaft to «return of output link»; 7 – the hydraulic motor; 8 – the brake coupling; 9 – the brake hydromechanical; 10 – the shuttle valve; 11 – the flow control valve

the type of material carrier – different solids or other objects. Such calculation required details on the conditions of heat exchange within the analyzed subsystem with the other subsystems of the drive [18, 22].

To define advantages and disadvantages of reduced schemes such as hydraulic drive must be performed pre-project predicting their performance in the operating modes. When comparing the energy losses in different modes of hydrodrive operation can be used exergetic method. For the current method were calculated the energy losses during the operation of hydrodrive with different working fluids in different operational modes.

During the exergetic analysis for each element in the hydraulic system were calculated pressure losses, losses of energy, and losses of power. These calculations were carried out in several stages, i.e., depending on the operating conditions of the drive, mode and with different working fluids.

To assess the effectiveness of circuit design taking into account operating modes of drive was constructed the graphic-analytical model. It is allowed to perform a distributed elementwise assessment of pressure losses and energy losses taking into account the time of each element action.

The principle of the model explained in the following example.

Hydrodrives work by successive energy transfer or streaming signal from one element to another. Let's take some section of the drive functioning (Figure 2). First, goes the signal for the «displacement of output link» – valve (1) operates, then the motor (2) starts working, what leads to the «displacement of the output link», further valve $(\bar{1})$ is disconnected and respectively, the motor $(\bar{2})$ stops – we have the lock position. Thus, we have a cycle of operation: $1-2-\bar{1}-\bar{2}$ [3].

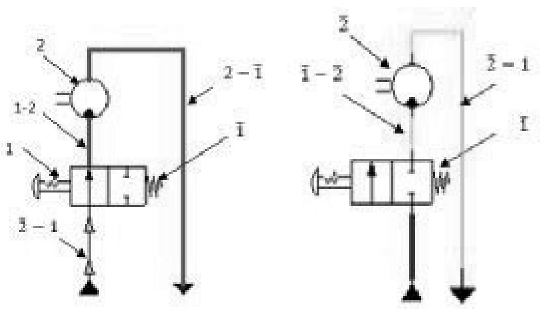

Fig.2. Application of logic-functional method on the example of the hydraulic scheme with motor

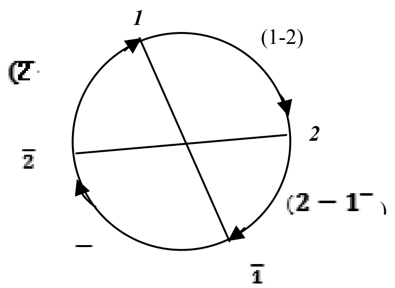

Fig.3. Example of constructing a graph

Power supply to the valve and its operation is indicated (1), disconnection – ($\bar{1}$). Sending a signal for the valve operation and completion with pressure of channels – arc ($\bar{2}-1$); arc (1 – 2) – switching of the valve and transmission of the signal from it on the motor operation; ($2-\bar{1}$) – signal transmission from the motor and the filing of pressure to the channel of valve to turn it off; arc ($\bar{1}-\bar{2}$) – transmission of the signal from the turned off valve to the turning off the motor (Fig. 2, 3).

Some elements realize both energy and information function. That is at one mode the energy signal leads to a work of certain element and in another mode the same element performs only the informational function – «Off».

The calculation by such method was made individually for the process of «displacement of output link» and «return the output link» for the two schemes (Figure 1, 5).

The structure for the main process (hydraulic) mode according to the notation of scheme elements (Figure 1) consists of two sequences of system components operation:

1) «moving output link»:

$$input-1-2-\prec 12\succ-4-3-7{,}10-\prec 6\succ-9-\text{ВГМ}-$$
$$-\text{ВВ}-\bar{1},\bar{4}-\bar{2}-\bar{3}-\bar{7},\overline{10}-\bar{9}-\overline{\text{ВГМ}}-\overline{\text{ВВ}}-\prec\bar{6},\overline{12}\succ-\text{output}$$

2) «return of output link»:

$$input-1-2-5-6-7{,}10-3-9--\text{ВГМ}-\text{ВВ}-$$
$$-11-12-\bar{2}-\bar{1},\bar{5}-\bar{6}-\bar{7},\overline{10}-\bar{3}-\bar{9}-\overline{11}-\overline{12}-output.$$

Scheme of hydraulic drive with other elements, i.e. with back pressure valve and without coupling of separation presented in Fig.4.

For the example scheme (Figure 5) calculations were carried out. Heat balances was made for those of elements where the inlet of fluid at the first switch of drive was carried out. The appraisal of energy losses for each element of the system was carried out, and duration of their work.

Calculations of parameters was based on exergetic method, which takes into account the different types of energy – thermal, electrical, mechanical and determine the general costs of the process by individual elements and blocks.

The structure of the process for the scheme with an additional valve (Figure 4):

1) «moving output link»:

$$input-1{,}4-2-3-7{,}10-9{,}8-6-\prec 11\succ-\prec 12\succ-$$
$$\bar{1},\bar{4}-\bar{2},\bar{3}-\bar{7},\overline{10}-\bar{9},\bar{8}-\bar{6}-\prec\overline{11}\succ-\prec 12\succ-output,$$

2) «return of output link»

$$input-1{,}5-2-6-7{,}10-9{,}8-3-\prec 11\succ-\prec 12\succ$$
$$-\bar{1},\bar{5}-\bar{2},\bar{3}-\bar{7},10-\bar{9},\bar{8}-\bar{3}-\prec\overline{11}\succ-\prec 12\succ-output.$$

After drawing a graph perform the calculation of drives operation.

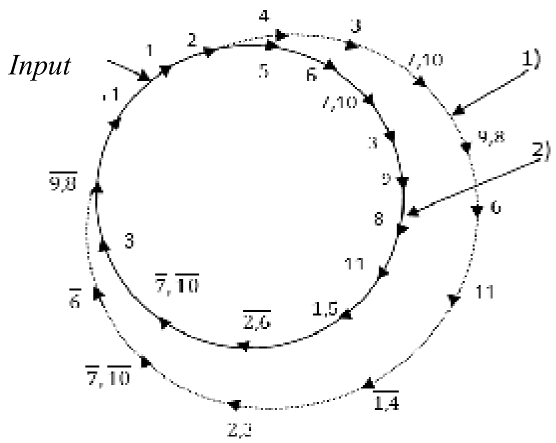

Fig.4. The graph of operating modes of hydraulic drive for modes «moving output link» and «return of output link» by the scheme Fig.1.

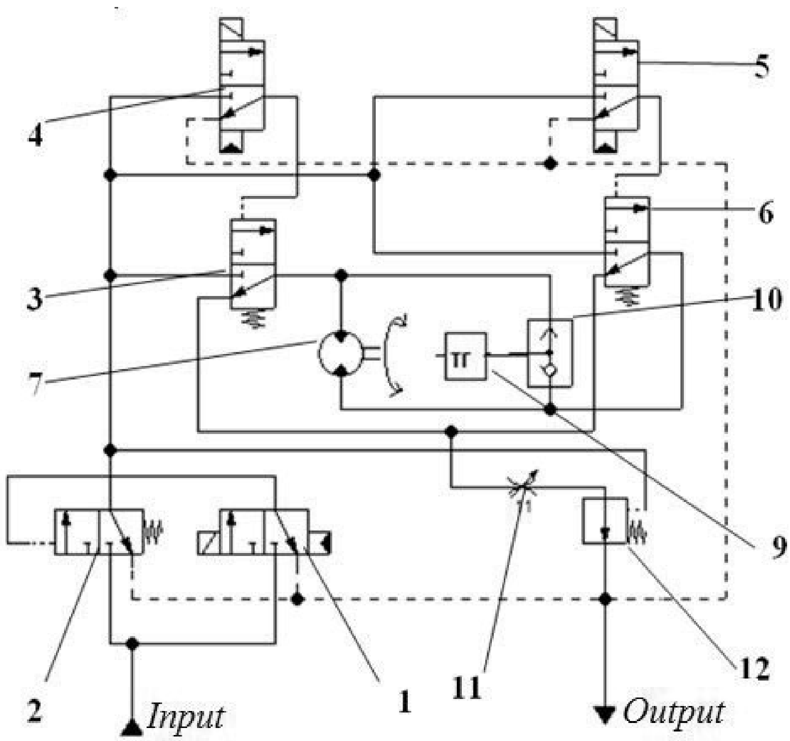

Fig.5. Principle scheme of the multimode drive with valve of retaining (12)

When calculating the exergy flow system is limited by the surface and determined its relationship with the environment. Therefore, the parameters of the environment for which the calculation is made, play a significant role [21].

The feature of the calculation is exergetic analysis of system for the most unfavorable conditions, i.e. at sub-zero temperatures of hydraulic fluid (for example, the value is – from -50° C for -70°C.

The initial data for the exergetic analysis is temperature and pressure of fluid flows at the outlet and in the inlet of each element of the scheme, flow and heat of substances at a certain temperature. For the multimode drive comparative exergy calculations performed with the use of various hydraulic fluids.

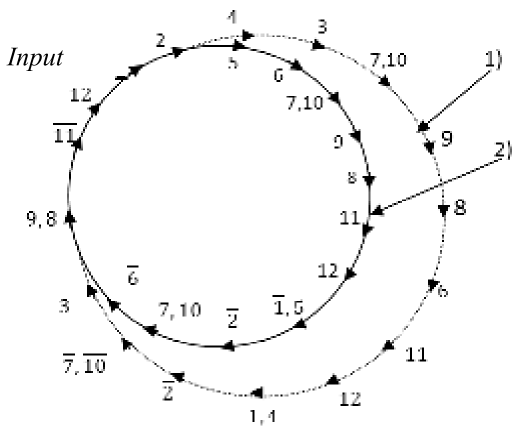

Fig.6. The graph of operating modes of hydraulic drive for modes «moving output link» and «return of output link» by the scheme Fig.5.

The power consumption of the system is determined by the product of the power and the response time for each element according to the graph in Fig. 4 and 6. Effective work of the drive does not depend on its schematic solutions. Therefore, determining the effectiveness of the scheme is based on energy consumption of elements, by which these schemes are different:

$$W_{schem\ 1} = \sum_{i=1}^{34} N_i^{`} \cdot t_i^{`};$$

$$\sum W_{schem\ 1} = N_i^{`} \cdot t_i^{`} + N_{i+1}^{`} \cdot t_{i+1}^{`} + \ldots + N_{i+33}^{`} \cdot t_{i+33}^{`},$$

wherein $N_i^{`}$ – power of the corresponding element of the system, $i$ – corresponding line of the system, $t_i^{`}$ – time on $i-th$ area of drive operation from one element to another, $\sum W_{schem1(a)}$ – the total number of energy, used in the system.

Energy losses in the system (Fig. 1) for «moving output link»:

$$\sum_{i=1}^{34} \Delta W_{Izag}^{`} = \Delta N_1^{`} \cdot t_1^{`} \cdot y_1^{`} + \ldots + \Delta N_i^{`} \cdot t_i^{`} \cdot y_i^{`} + \ldots + \Delta N_{34}^{`} \cdot t_{34}^{`} \cdot y_{34}^{`}. \quad (1)$$

The value t_i indicates the time of work of a particular element in the hydraulic system, and the logical variable y_i indicates its use. That is, if an element operates in a certain mode, the energy losses on it is take into account ($y = 1 \Rightarrow \Delta W = \Delta N \cdot t \cdot y$). If the system element is not working, the energy losses on it does not take into account ($y = 0 \Rightarrow \Delta W = \Delta N \cdot t \cdot y = 0$).

Considered the influence of the fluid temperature on the losses in hydraulic system:

$$T°C \Rightarrow \begin{cases} \rho \\ \nu \end{cases} \Rightarrow \begin{cases} t \\ \Delta p \Rightarrow \Delta N \Rightarrow \Delta W \\ U \end{cases} .$$

Taking into account the influence of the fluid temperature variation, energy losses at a certain element can be determined by the formula:

$$\Delta W = \Delta N_{(\nu)} \cdot t \cdot y .$$

Relative energy efficiency of the schematics is determined by (2). The value B – ratio of the difference of the total energy losses of one system and another to the total energy loss of one of them, namely:

$$B = \frac{\sum_{i=1}^{34} \Delta W^{`}_{Itotal} - \sum_{i=1}^{34} \Delta W^{``}_{Iotal}}{\sum_{i=1}^{34} \Delta W^{``}_{Iotal}} . \quad (2)$$

According to initial data and geometrical parameters the calculation of pressure losses in the system based on rheological dependences of working fluids AMG-10 and Skydrol. Received by the formula (2) value of the relative energy efficiency is estimated indicator of circuit solutions with additional element and without it (Table 1).

Energy efficiency of two schemes of the drive about was designed for two working fluids AMG-10 and Skydrol. It takes into account various operating conditions, their duration and the operating time at a certain temperature. For normal operating conditions, the following indicators of energy efficiency were obtained:

- for the working fluid AMG-10:

$$B_{T=-20°C} = \frac{\sum_{i=1}^{34} \Delta W^{`}_{Iзаг} - \sum_{i=1}^{34} \Delta W^{``}_{Iзаг}}{\sum_{i=1}^{34} \Delta W^{``}_{Iзаг}} = 8,05\%$$

$$B_{T=+20°C} = \frac{\sum_{i=1}^{34} \Delta W^{`}_{Iзаг} - \sum_{i=1}^{34} \Delta W^{``}_{Iзаг}}{\sum_{i=1}^{34} \Delta W^{``}_{Iзаг}} = 7,09\%$$

$$B_{T=+60°C} = \frac{\sum_{i=1}^{34} \Delta W^{`}_{Iзаг} - \sum_{i=1}^{34} \Delta W^{``}_{Iзаг}}{\sum_{i=1}^{34} \Delta W^{``}_{Iзаг}} = 6,95\%$$

- for the working fluid Skydrol:

$$B_{T=-20°C} = \frac{\sum_{i=1}^{34} \Delta W^{`}_{Iзаг} - \sum_{i=1}^{34} \Delta W^{``}_{Iзаг}}{\sum_{i=1}^{34} \Delta W^{``}_{Iзаг}} = 7,71\%$$

$$B_{T=+20°C} = \frac{\sum_{i=1}^{34} \Delta W^{`}_{Iзаг} - \sum_{i=1}^{34} \Delta W^{``}_{Iзаг}}{\sum_{i=1}^{34} \Delta W^{``}_{Iзаг}} = 6,96\%$$

$$B_{T=+60°C} = \frac{\sum_{i=1}^{34} \Delta W^{`}_{Iзаг} - \sum_{i=1}^{34} \Delta W^{``}_{Iзаг}}{\sum_{i=1}^{34} \Delta W^{``}_{Iзаг}} = 7,79\%$$

The distribution of energy losses for elements of the scheme in Figure 1 was obtained. The energy W_2, obtained at the output of the system, also takes into account the energy losses from effect of changes in temperature $\Delta W_{(T°)}$ (Fig.7):

$$W_2 = W_1 - \sum \Delta W_i - \Delta W_{(T°)} .$$

Table 1. The relative effectiveness B_{syst}

	B_{syst}	
Temperature, ^{0}C	AMG-10	Skydrol
-20	0,0805	0,0771
+20	0,0709	0,0696
+60	0,0695	0,0779

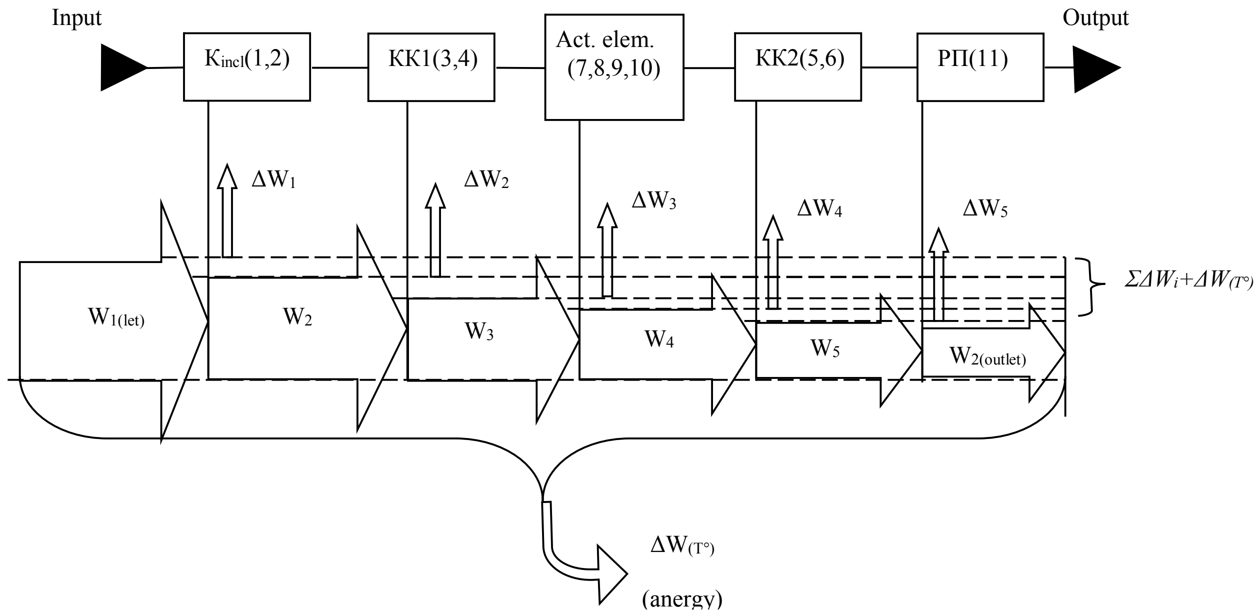

Fig.7. Scheme of distribution of energy losses in a hydraulic drive accordingly to the scheme in Fig.1

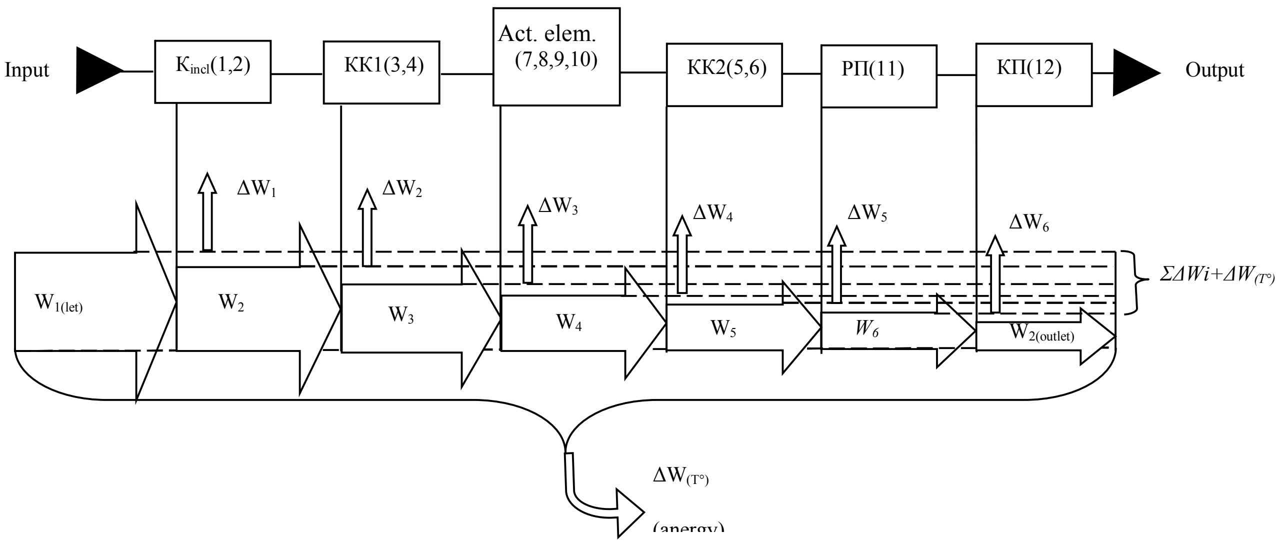

Fig.8. Scheme of distribution of energy losses in a hydraulic drive accordingly to the scheme in Fig. 6

In the calculation were taken into account parameters and operation modes of the drive. In each mode were taken into account which elements work and which channels are involved. It was found that at the different modes and operating conditions the energy losses is much different. This can be explained by an example. At the mode to «move the output link» operate elements 1, 2, 4, 3, 10, 9, 11 and partly involving channels of elements 6 and 10, and the valve 5 and the channel that connect it to the valve 6 – unused. And by «return of output link» – conversely, partially operate channels of elements 3 and 10, the valve 4 and the channel that connects it to the valve 3.

According to the results of modeling of two schemes in calculated operation modes and considering the proposed standards for accuracy and efficiency of operation, we can conclude the following.

Unused elements provide additional energy losses in the system, while negative temperature of working fluids even more losses in reaction time of the system (because of deadlock areas in which the viscosity is very high). Calculation of pressure losses according to the graph is made by the formulas:

$$\Delta p_{\left(\overline{11}-2\right)} = \Delta p_{(lin.)} + \Delta p_{(inp.velv.stop)};$$

$$\Delta p_{(2-1)} = \Delta p_{(lin.)} + \Delta p_{(out.velv.stop)} + \Delta p_{(input.vl.1;)};$$

$\Delta p_{(1)} = \Delta p_{(vl.1)}$; etc.

$$\Sigma\Delta p_{(system)} = \Delta p_{(input)} + \Delta p_{(2-1)} + ... + \Delta p_{(output)}.$$

It was found that the change in the rheological properties of the fluid (AMG-10 and Skydrol) in different operating modes affect the energy losses almost equally (±1%) [12].

By the results of research was determined the relative effectiveness factor B_{syst} of circuit solutions of multimode hydraulic drives, based on energy efficiency of elements by which these schemes are different. There was obtained that the scheme of hydrodrive in Figure 1 by the operating temperatures -20^{0}C on ~ 7%, at +20^{0}C on ~ 8%, at 60^{0}C on 7% more effectively than the scheme with valve of retaining (Figure 5). These values are valid for fluid AMG-10 and for Skydrol.

The exergetic analysis made it possible to determine element of the scheme, which reduces the energy efficiency by increasing the proportion of anergy. It is necessary to view the valve of retaining, its design parameters and the appropriateness of use. Because it operate less than 3% of the time, and all the rest absorbing a significant amount of energy forming component of anergy, which can expect the developer in the design and modernization drive with the goal of improving its efficiency.

CONCLUSIONS

Analyzing the existing hydraulic models, along with advantages in their design should take into account their disadvantages. It is mainly caused by the properties of the working medium (fluid). These include leaks of the fluid, changing parameters of the working fluid viscosity due to changes of operating temperature range, quite low efficiency of mechanical transmission, the formation of abrasives, isolation of the system from the air, fire danger [21]. Before specialists-designers must be presented certain tasks to the solution which can include energy analysis.

The observed method of efficiency evaluation can be used at the stage of the multimode hydraulic drive circuit design for options that provide the same control functions on «moving the output link» and «return of the output link».

Method of exergetic analysis for multimode hydraulic drives lets you to calculate the system when choosing the design parameters, working fluid according to its rheological properties.

It is proposed to combine branched elementwise hydraulic and thermal calculations to determine the hydraulic characteristics of the drive. This will increase the accuracy of calculations of transition modes, and predict performance indicators and performance of drive.

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23.

ПРОГНОЗИРОВАНИЕ ЭНЕРГОЭФФЕКТИВНОСТИ СИСТЕМЫ ГИДРОПРИВОДА НА ОСНОВЕ ЭКСЕРГЕТИЧЕСКОГО АНАЛИЗА

Аннотация. Проанализированы особенности влияния режимов эксплуатации на энергопотребление гидро-приводов. Рассмотрена энергетическая эффективность на этапе формирования схемных решений привода. Приведена методика оценки эффективности с помощью эксергетического подхода, который базируется на анализе схемных решений с учетом режимов работы.

Ключевые слова: гидропривод, гидравлический расчет, температура, вязкость, эксергетический анализ