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EXPERIMENTAL RESEARCH OF CHARACTERISTIC PARAMETERS HYDRODYNAMIC PROCESSES OF AXIAL PISTON PUMPS WITH CONSTANT PRESSURE AND VARIABLE FLOW

Axial piston pumps with constant pressure and variable flow have extraordinary possibilities for controlling the flow by change of pressure. Owing to pressure feedback, volumetric control of the pump provides a wide application of these pumps in complex hydraulic systems, particularly in aeronautics and space engineering. Mathematical modeling is the first phase in defining the conception of a design and it has been carried out at the beginning of the project. Next very important phase is the check-out of the characteristics at the physical model when the pump has been produced. Optimal solution to the hydropump design has been reached by thorough analysis of the parameters obtained at the physical model by means of the simulation results of the mathematical model. The paper presents the possibilities for selecting the most influential parameters, their correction for certain values, and eventually the simulation at the mathematical model which shows the change of hydropump performances. After all these analyses, appropriate changes are made in design documentation which will serve for prototype production. Finally, when all kinds of tests are done at the prototypes along with fine adjustment of design solution, the series production of hydropump will be organized.

1. Introduction

Experimental testing and recording of static characteristics and dynamic performance of the constant pressure and variable flow hydropump, represents a complicated and expensive operation. The mentioned activity necessitates the realization of a physical model on which testing is carried out,

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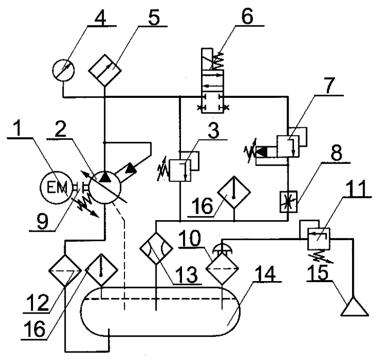
as well as applying a very complex system of data acquisition and diagram recording during the testing [1] and [2].

Thanks to great possibilities of contemporary measuring devices, used to measure non-electrical units and convert into electrical signals, all measurements can be done successfully, since all the processes may be recorded at adequate speeds.

2. Physical model and methods of testing

For examining certain characteristics of the pump, a hydraulic system shown in Figure 1. was realized. The hydraulic system is very similar to the systems of aircraft "Orao" and "G4" in which this hydropump has been applied. The difference lies in the propulsion, instead of being propelled by reducer gear shaft from the jet engine, here the pump is propelled by an electromotor. Additionally, the physical model contains far less components in comparison to the hydrosystem of the mentioned aircraft. In the physical model, the pump works in a pressurized system with volumetric regulation, so that there is little energy wasted, which is why the hydraulic fluid does not heat much. The hydraulic system tank contains around $7 \cdot 10^{-3} m^3$ of hydraulic fluid, which participates in the transformation and transmission of power that amounts to approximately 7.4 kW. During moments when the system does not need hydrostatic energy, the pump decreases the flow to around $2 \cdot 10^{-5} m^3/s$, consuming far less power compared to the case when the fluid excess, after the pressure reduction, returns to the tank. Figure 2 is the photograph of the hydraulic system realized in the hydraulics and pneumatics laboratory, where all the shown tests have been conducted. A pneumatic generator has been connected onto the hydraulic system, with the aim of maintaining a particular overpressure in the hydraulic tank. The pressure in the tank is constantly maintained within limits of 0.2 to 0.3 MPa, which is sufficient for the pump to operate in a quality manner. In these conditions, no cavitation occurs even in the fastest processes of flow alteration.

By way of selecting components in the hydraulic system, it is possible to imitate all the conditions which otherwise occur in the aeronautical hydraulic system. The system contains an electromagnetic distributor, by means of which the pump flow may quickly be brought from the maximal value to the minimal. The thrust duct contains a safety valve, which relieves the system, in the case of an unpredicted situation, up to the defined level. Indirect action pressure regulator, enables fine regulation of pressure in the thrust duct while particular small variations are effected by way of variable resistance absorber. Alongside the mentioned hydraulic components, there are a number of transducers which register changes of particular parameters, which will be



1-electromotor,
2-hydropump,
3-safety valve,
4-manometer,
5-pressure transducer,
6-electromagnetic distributor,
7-indirect action pressure regulator,
8-variable resistance absorber,
9-elastic connector,
10-inflow filter,
11-air pressure regulator,
12-suction filter,
13-flow transducer,
14-pressurized tank,
15-pressurized air source,
16-temperature transducer

Fig. 1. Scheme of hydraulic system for testing constant pressure hydropump

discussed in the chapter on parameter acquisition. It should also be pointed out that, during the entire testing process, four parameters are recorded: pressure change in the thrust duct, pump flow change, temperature of work fluid in the tank and temperature at the variable resistance absorber outlet [3] to [5].

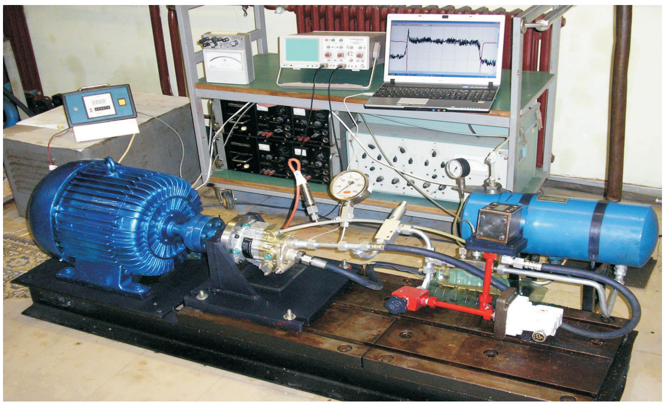


Fig. 2. Photograph of hydraulic system for hydropump testing

The hydraulic system contains mineral-base hydraulic fluid, Hidraol 15, kinematic viscosity $\nu = 15 \cdot 10^{-6} \mathrm{m}^2/\mathrm{s}$, at the temperature of 40°C. Hidraol 15 has been applied in the hydraulic system because its characteristics are most similar to those of hydraulic fluid used in aeronautics. The pump which is the subject of testing has been designed for operation with fluid "Aero Shell 40" used for temperature range from −55°C to 135°C.

3. Testing characteristics of constant pressure hydropump

3.1. Recording the flow change upon pressure change from assigned value to maximal adjusted value

When recording this characteristic, the pump is adjusted so that within the pressure from p_n = 20 MPa to $p_{\max}$ = 21 MPa the flow changes within bounds of Q_n to $Q_{\min}$. The experiment has been carried out by adjusting, in the first part, the work pressure to p_r = 3 MPa, and then with the help of electromagnetic distributor, which had been in flow-through position at the outset, momentarily closing it by an electrical command. After a certain period of time, the electromagnetic distributor was re-opened, obtaining pump characteristic in the given modes, as shown in Figure 3. on the left side. Afterwards, the work pressure was adjusted by the help of pressure regulator, pos.7, to the value of p_r = 16 MPa. By activating the electromagnetic distributor, pos.6, the pump was again compelled to effect a flow regulation, see the picture. The diagram shows two transitional modes at the jump signal of closing and opening the thrust duct. It may be observed that the flow and

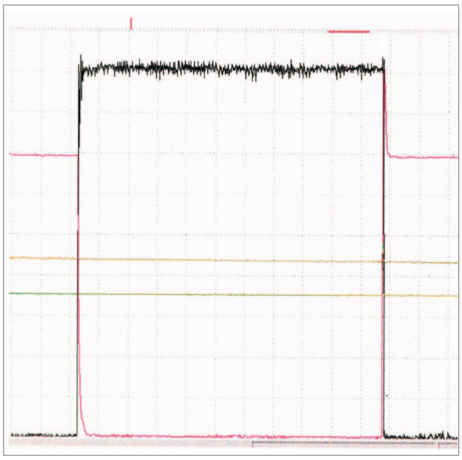


Fig. 3. Diagram of flow change upon pressure change from p_r = 3 MPa to $p_{\max}$ = 21 MPa (pressure scope 3 to 23 MPa value of each mark is 2 MPa)

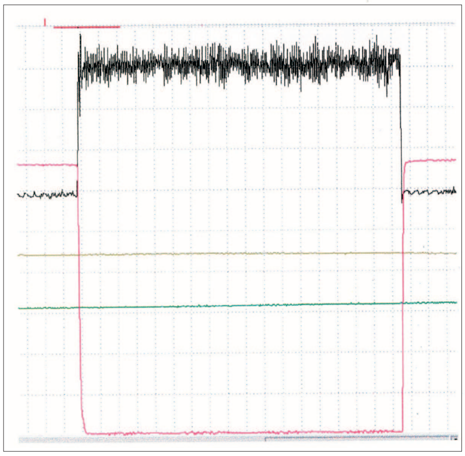


Fig. 4. Diagram of flow change upon pressure change from p_r = 16 MPa to $p_{\max}$ = 21 MPa (pressure scope 6 to 23 MPa value of each mark is 1.7 MPa)

pressure changes are strongly interdependent, so that the change of one value elicits a precise and rapid change of the other value, regardless of the level of the work pressure which is taken as the start.

3.2. Recording the pump parameter change upon work with two different values of maximal pressure

The aim of this test was to check the stability of pump work with somewhat greater maximal pressure. By adjusting the HPT, the maximal pressure has been increased to the value $p_{\max}$ = 23 MPa. The change has been carried out by way of changing the pre-tension of HPT coil by a certain value, which caused the increase of maximal pressure, while the denominated pressure amounted to p_n = 22 MPa. All the remaining operations have been carried out as in item 2.1, while the diagram recorded on that occasion is shown in Figure 5. The left side of Figure 5 also shows a diagram of when the pump is adjusted to the customary work mode, which means that the pump is working with the denominated pressure of p_n = 20 MPa, whereas the maximal pressure is $p_{\max}$ = 21 MPa.

3.3. Recording the temporal constant of the pump

For recording the temporal constant, the hydropump has been prepared so as to work with the denominated pressure of p_n = 20 MPa and maximal pressure of $p_{\max}$ = 21 MPa. By way of the indirect action pressure regulator, pos.7, the value of denominated pressure has been adjusted. Using the electromagnetic distributor, pos. 6, the pump receives a command to

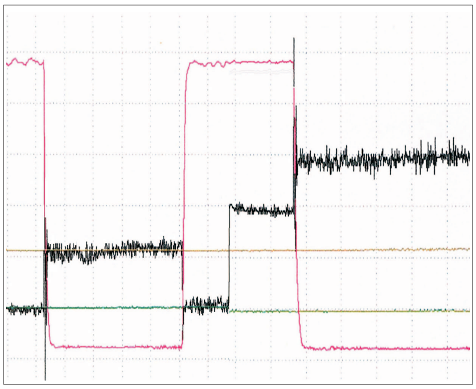


Fig. 5. Diagram of flow change upon pressure change in two levels, from 20 MPa to 21 MPa and from 22 MPa to 23 MPa (pressure scope is from 13 to 23 MPa, value of mark on the diagram is 1 MPa

work in two modes, as follows: with the denominated flow and pressure ($Q_n = 3.7 \cdot 10^{-4}$m^3/s, $p_n = 20$ MPa), then with minimal flow and maximal pressure ($Q_{\min} = 2 \cdot 10^{-5}$m^3/s, $p_{\max} = 21$ MPa) and again with denominated flow and denominated pressure. The described changes are shown in diagram presented in Figure 6. Alongside the pressure and flow, in this case the temperatures t_1 and t_2 have also been recorded in the earlier described places. Figure 7 and Figure 8 show considerably zoomed-in details of the transitional process in the first and second case. From the diagram, temporal constants t_1 and t_2 have been read, which are within allowed limits, below 50 ms. In this case, the temporal constant t_1, is somewhat lower than the temporal constant t_2, although both are within the required limits.

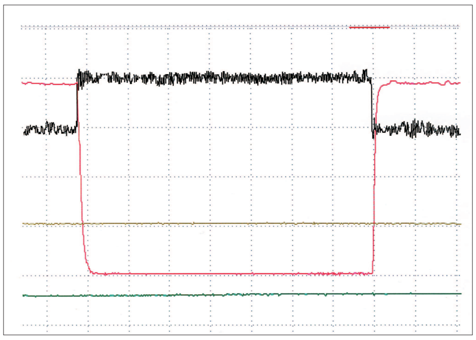


Fig. 6. Diagram of pressure change upon flow hange from Q_n to $Q_{\min}$ and vice versa ($Q_n = 3.7 \cdot 10^{-4}$m^3/s, $p_n = 20$ MPa); ($Q_{\min} = 2 \cdot 10^{-5}$m^3/s, $p_{\max} = 21$ MPa); (pressure scope is from 13 to 23 MPa, value of each mark for pressure is 1 MPa)

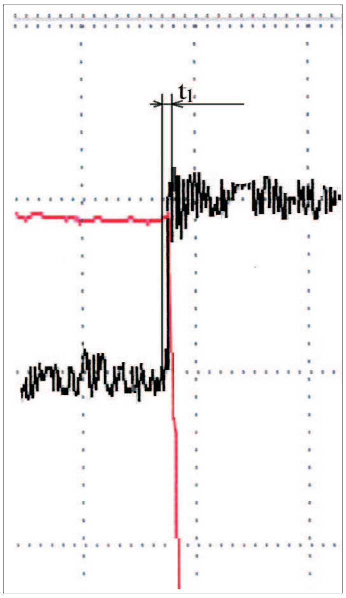


Fig. 7. Pressure increase in the phase of flow decrease

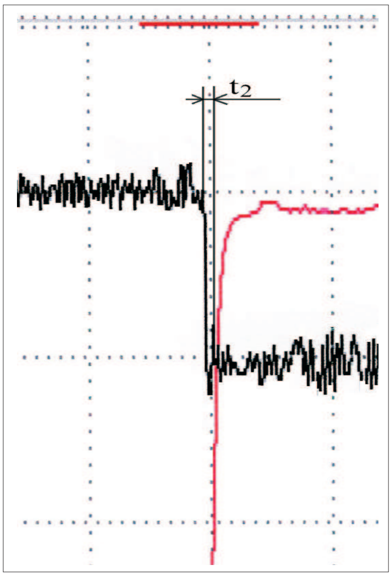


Fig. 8. Pressure decrease in the phase of flow increase

3.4 Recording variation of pressure jump upon transition from denominated to maximal pressure

Upon flow regulation, which is conditioned by pressure change, there occurred a short growth in pressure over the maximal value. This means that a jump occurs which impacts the system badly, and is thus limited by standards to the value $p_{prs} < 135\% p_n$. The pressure jump upon transition from the pump's denominated to maximal pressure may be adjusted, but must always remain within limits stipulated by "MIL" standard. Simulation will be carried out through increasing the jump by a certain value. Value of flow Q_c will be reduced to half value, $Q'_c = 1.5 \cdot 10^{-5} \mathrm{m}^3/\mathrm{s}$, so that the pump decreases the flow considerably slower, which is why in the regulation process a greater jump occurs.

The mentioned reduction of flow has been carried out by closing one of the two flow-through apertures on the regulation valve distribution cartridge, as shown in Figure 9. Diagram showing the change of flow with pressure change is portrayed in Figure 10. [6] and [7].

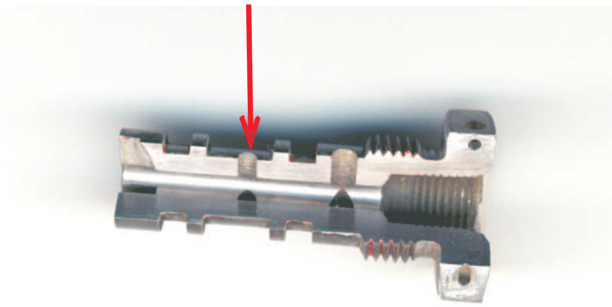


Fig. 9. Partial cross-section of regulation valve body

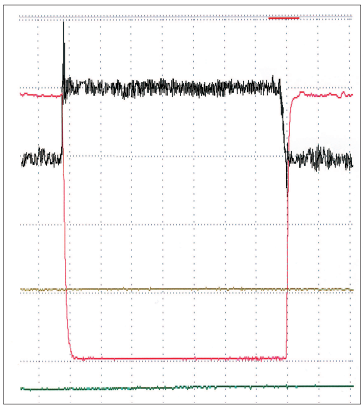


Fig. 10. Diagram of flow regulation process with changed values of pressure jump and temporal constant t_2 (pressure scope and mark value as in Figure 6.)

Figure 11 shows the diagram of the entire process of flow regulation with changed values of pressure jump. From that diagram, a section has been singled out and considerably zoomed-in as it defines more precisely the jump value amounting to p = 2 MPa above denominated pressure, Figure 12.

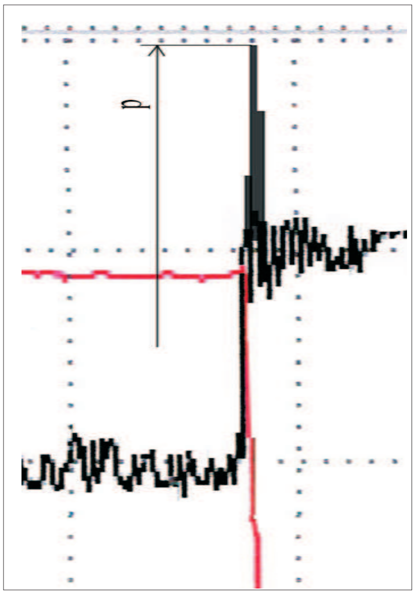


Fig. 11. Increasing pressure in the phase of flow reduction (jump)

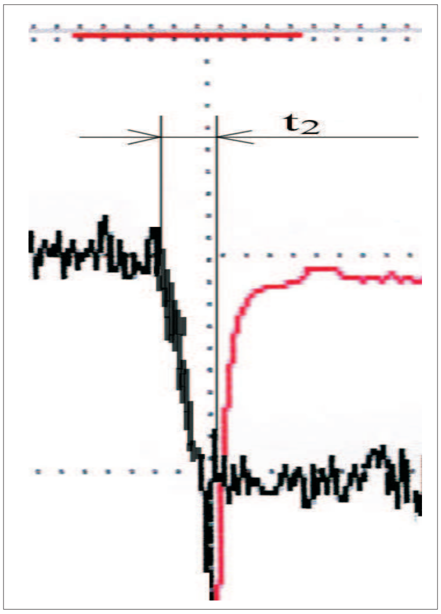


Fig. 12. Reducing pressure in the phase of flow increase

3.5. Recording temporal constant t_2

Another change has been effected on the pump, with the task of correcting temporal constant t_2. It is very important that the pump should have as small a temporal constant t_2 as possible, enabling that the pump return to full flow in the shortest period of time. That characteristic is very important for the possibility of efficient supply of fluid to the system. The coil stiffness of reactive piston considerably affects the transitional process of the pump's switch from the mode of minimal flow and maximal pressure, to the mode of denominated flow and denominated pressure. In the experiment, the coil stiffness $C_2 = 2 \cdot 10^4$ N/m has been reduced to $C_2^* = 1.27 \cdot 10^4$ N/m. Coil stiffness C_2 results in longer transitional process, which means that the temporal constant, t_2, will be increased by a certain value.

Recording of the regulation process has been carried out as per item 2.3, whereas the changes diagram is shown in Figure 11, Figure 12 shows the right side of the diagram considerably zoomed-in so as to make the temporal constant t_2 easily readable; it amounts to $t_2 = 0.2$ s.

Experimental research has been carried out on a physical model designed according to the hydraulic system in which the hydropump works in the system under actual conditions. Experiments have mainly encompassed research of dynamic characteristic such as dynamic processes whereby transitional phenomena and changes occur upon flow regulation. The mentioned characteristics are exceptionally important for the application on aircraft hydrosystems, taking into account the fact that in those systems exceptionally fast processes take place.

4. Conclusions

On the grounds of research carried out in the work, the following salient conclusions may be drawn:

The given ascertainment is confirmed that the axial piston hydropump belongs to the group of complex components of aircraft hydrosystem in whose inner structure numerous and complex interactions occur which have not been studied in sufficient detail yet. The mentioned circumstances impose the need and justify the obligation for constant improvement of characteristics, so as to enhance performances of the complete hydraulic system on the aircraft. It has been ascertained that the hydrosystems on aircraft are very complex and have to meet numerous rather strict requirements that are set before the hydropumps which are the generators of hydrostatic energy in the systems. Analyses have shown that the most suitable pumps for application in these fields are the axial piston pumps operating in two modes. Thus, depending on pressure feedback, the pump works in the constant flow mode or in constant pressure mode. Furthermore, it has been concluded that hydropumps with tilt plate have an advantage in application, since they have a small inertial mass of parts that participate in the process of transferring the pump from one mode to the other and vice versa. Because of the mentioned facts, the pumps with tilt plate have lower temporal constant, which is a very important characteristic for aircraft hydrosystems.

Taking into account the numerous strict requirements concerning the hydropump construction, in that process, theoretical (mathematical, structural and program) models are used which describe very complex dynamic processes of multivariable control system. The correctness and validity of the theoretical model and results obtained in such a manner are easiest to check on an actual physical model. A physical model was made in the laboratory where we could test all the characteristics which had been simulated on the theoretical model. All the relevant parameters have been registered by means of the data acquisition system constituting an integral part of the entire system. Dynamic processes have been registered in certain diagrams from which it is easy to read temporal constants and some other salient data.

By comparing diagrams of dynamic processes obtained by the help of theoretical and physical, laboratory model, it has been determined that the theoretical model is very correct since the dynamic feedback in both cases is very similar. If temporal constants t_1 and t_2 obtained in one and the other manner are compared, one can observe that the values are approximately the same. Possibilities have also been explored as to how temporal constant amount can be changed by the change of certain construction parameters on the hydropump itself. In this case as well, the results from the theoretical and physical model match exceptionally well [8].

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Badania eksperymentalne charakterystycznych parametrów procesów hydrodynamicznych w tłokowo-osiowych pompach o zmiennej wydajności i stałym ciśnieniu

Streszczenie

Hydrauliczne pompy tłokowe o zmiennej wydajności i stałym ciśnieniu posiadają możliwości sterowania wydajnością na drodze zmiany wartości ciśnienia sterującego. Ww rozwiązanie z ciśnieniowym sprzężeniem zwrotnym w celu sterowania wydajnością pompy spowodowało szerokie wykorzystanie tych pomp w złożonych systemach, w szczególnie w aeronautyce i inżynierii kosmicznej. Modelowanie matematyczne jest pierwszą fazą przy definiowaniu koncepcji projektu i jest przeprowadzane na początku prac projektowych. Następną bardzo ważną fazą jest sprawdzenie charakterystyk w modelu fizycznym pompy. Optymalne rozwiązanie projektu pompy hydraulicznej jest osiągane na drodze gruntownej analizy parametrów technicznych otrzymanych z modelu fizycznego na bazie rezultatów symulacji modelu matematycznego. W artykule zaprezentowano możliwości selekcji najważniejszych parametrów, ich korekcji wartości i ewentualnej symulacji w modelu matematycznym , pokazującej zmiany charakterystyk roboczych analizowanych pomp. Na podstawie powyższych analiz można dokonać odpowiednich zmian w dokumentacji roboczej służącej do produkcji prototypowej. Końcowym rezultatem powyższych prac, po wykonaniu wszystkich rodzajów testów, na prototypach z ostateczna wersją rozwiązania projektu, jest uruchomiona produkcji seryjnej projektowanych pomp hydraulicznych.