COMPARISON OF EXPERIMENTAL RESULTS WITH SIMULATION STUDIES OF "DIGITAL" HYDROSTATIC TRANSMISSION

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Abstract: *The publication presents the results of experimental research on a "digital" hydrostatic transmission conducted at INOE 2000 IHP within the framework of the grant "Method of effective use of the digital hydraulics concept in multi-source hydrostatic drive systems". The primary goal of the research is to compare the effectiveness (efficiency) of using different methods of controlling the pump capacity and the hydraulic motor capacity in multi-source, hydrostatic drive systems and to compare the experimental results with simulation studies obtained in the MATLAB Simulink program.*

Keywords: *"Digital" hydrostatic transmission, modelling and simulation, experimental tests*

1. Introduction

Hydrostatic drives, also referred to as hydrostatic transmissions, are typically created by hydraulically connecting pumps and motors. A motor with constant displacement and a pump with variable displacement make up a standard hydrostatic gearbox. The system typically operates at maximum efficiency when the motor is operating at its highest volumetric displacement. When power is needed, hydraulic systems use fluids under pressure to convey power or perform tasks at a desired area. The history of technology has shown that fluid power is a valuable medium. It has been utilised in construction, agricultural, and aerospace equipment as well as more complicated designs like the water wheel. The following are some benefits of fluid flow over other power transmission technologies, such as electrical, pneumatically, and mechanical systems:

- Compared to its equivalents, hydraulic pumps and motors are substantially lighter and smaller than electric or petrol motors with the same horsepower.

- Due to their extreme flexibility, hydraulic hoses can send power to nearly any spot and route fluid lines around other pieces of equipment.

- Compared to a mechanical system that can generate the same amount of force, a hydraulic system is far smaller.

- A fixed gear ratio is not necessary because speeds may be readily adjusted for every operating circumstance.

The efficiency of a hydraulic system can be somewhat poor, which is a drawback. "Most mechanical systems are more efficient than hydraulic systems, even if hydraulic systems are far more efficient than electrical systems. The pump is the main part of the hydraulic system that supplies power. Axial-piston pumps, gear pumps, and vane pumps are only a few examples of the numerous varieties of pump arrangements. The most often used pumps are axial-piston pumps because they have great operating efficiency (up to 85%), can withstand high pressures, and can be controlled via variable displacement. We can further divide these pumps into two types: variable displacement and fixed displacement. For each cycle, fixed displacement pumps transport the same volume of fluid. Only when the pump's speed has been changed can the volume be altered. Pumps with variable displacement have the ability to regulate the flow without regard to the speed of the pump.

1.1. A "Digital" Hydrostatic Drive System Model

The "digital" pump is made up of a number of parallel arrays of constant displacement pumps (e.g. gear pumps) of various sizes. A grid of on-off valves allows the individual pumps to be switched between the load and idle states as the flow requirement varies (fig.1).
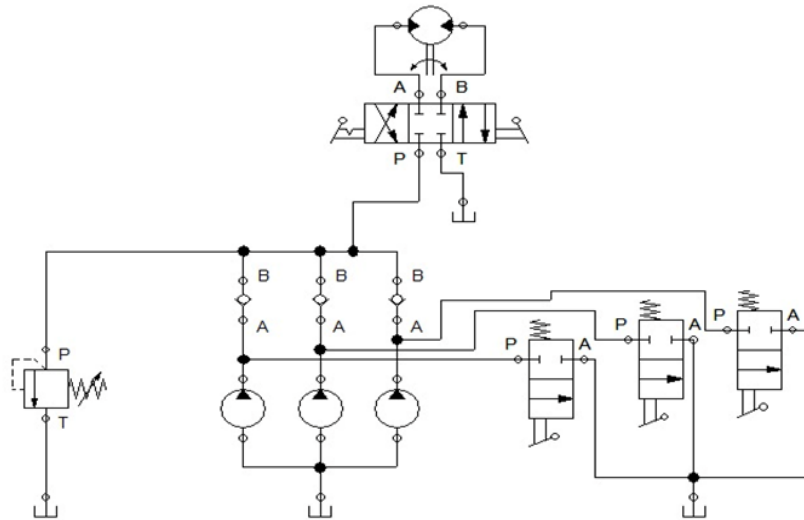

Fig. 1. Schema of "digital" hydraulic circuit

2. Scientific Goal of The Project

The scientific goal of this project is to compare the effectiveness (efficiency) of using different methods of controlling the pump flow rate and hydraulic motor capacity in multi-source, hydrostatic drive systems. Currently, the point is to compare a traditional hydrostatic system composed of multi-piston, axial hydrostatic unit with a "digital" hydrostatic transmission that allows for changing the liquid flow rate in the system with an appropriate displacement pumps (4 gear pumps on one shaft of an electric motor).

After comparing the results, it will be possible to answer the questions:

1. Will replacing a pump with the ability to change the flow rate (e.g. multi-piston axial pump with a tilting disc) and proportional control (implemented using a proportional valve) with a system consisting of a "digital" hydraulic transmission meet the requirements for the power supply units and control used for the construction of multi-source hydrostatic drive systems?

2. What will be the energy efficiency above the change described?

3. Will the dynamic parameters of the hydraulic system subjected to such modifications meet the requirements for multi-source systems?

4. What types of savings will result from this modified arrangement?

5. What will be the impact of replacing a typical hydraulic system with a system built according to the concept of "digital hydraulics" in the area of efficiency, reliability, safety and ecology (carbon footprint, emissions of harmful substances, e.g. in the case of using an internal combustion engine: carbon dioxide, nitrogen oxides, particulate matter)?

2.1 Technical Data of the Experimental Testing Pumping System

• Three – phase induction motor power …… 11 kW;

• 3-phase supply voltage ……………………. 380 V 50 Hz;

- Motor speed ……………………………… 1475 rev/min;
- Variable speed drive ……………………… Altivar 71; 15 kW;
- Motor speed adjustment range …………… 10÷50 Hz ;
- Max. flow ………………………..………... Q = 45 l/min ;
- Max. pressure ………………….………… f(Q): 100÷200 bar;
- Pumps displacement ……………….……… 2, 4, 8, 16 cm3 /rev.

2.2 Technical Means Used During Experimental Test

Fluid working environment:
- Working fluid: HP 46 hydraulic oil;
- Filter fineness: 10m;
- Maximum temperature of the working fluid: 40 ± 5ºC.

Equipment used:
- Flow transducer   accuracy class 2.0;
- Speed transducer   accuracy class 1.0;
- Torque meter   accuracy class 1.0;
- Thermometer 0 to 100ºC,   accuracy class 2.0;
- Pressure transducer 0 to 160 bar;
- Power supply 24 V / 10A.

a)   **General view of valves connection**   b)   **The view of electric motor with pumps**
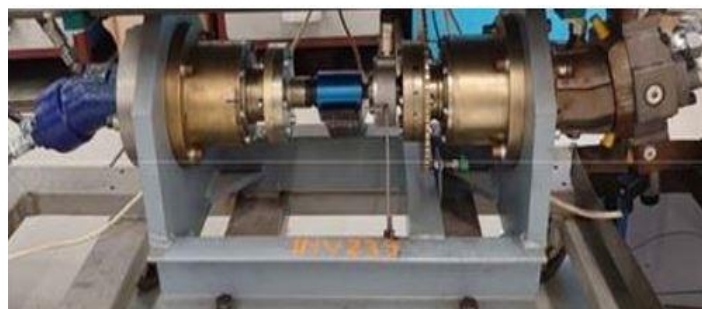
c)   **The view of hydraulic motor with load**

Fig. 2. Experimental Equipment

2.3 Hydraulic Schematic Diagram of Experimental Testing Stand

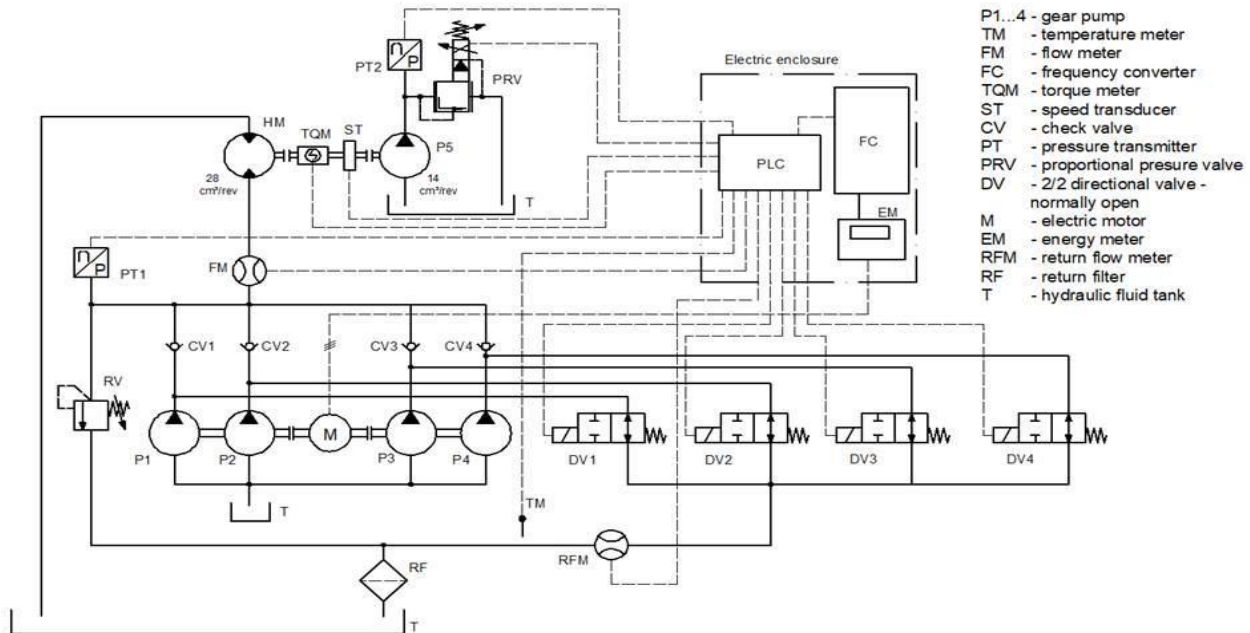Figure 3 displays the "digital" hydraulic schema used in the experiment.

Fig. 3. Schema of "digital" hydrostatic transmission testing stand

2.4 Equipment Characteristics

No.	Equipment	Product type	Manufacturer	Charateristics
1	Pressure transducer	S-10	Wika	- Supply 10…30 VDC - Range 0…400 bar - Output sig. 4…20 mA
2	Flow transducer 1 (output flow)	EVS3100	Hydac	- Supply 10…30 VDC - Pmax. 400 bar - Range 6…60 l/min - Output sig. 4…20 mA
3	Flow transducer 2 (return flow)	VT1541VADNSOA4	Sika	- Supply 4.5…24 VDC - Range 2…40 l/min - pulses/liter 915 - Pmax. 300 bar - Meas. instrument TD 32500 - Output sig. 4…20 mA
4	Temperature trans.	TSOCB1	Comeco	- Range 0…100 °C - Output sig. 4…20 mA
5	Torque transducer	DR-2493	Lorenz messtechnik	- Supply 12…28 VDC - Range 500 Nm - Output sig. ± 10 V
6	Speed transducer	8.A020.3132.0360	Kubler	- Supply 10…30VDC, 150 mA - 360 pulses/rev
7	Solenoid controlled valve	HK EMDV 10 NO1 24DC	Hansa Flex	- MN10 - Rated flow 30 l/min - Pmax. 350 bar

3. Traditional Hydrostatic Transmission Simulation Model

The simulation model's creation aims to analyze the hydrostatic transmission (fig. 4), specifically the flow through the overflow valve during start up (Q_z) in relation to valve opening pressure (p_o), hydraulic motor angular velocity (ω_s), hydraulic pump side pressure (p_p), and hydraulic motor side pressure (p_s). The aim of simulation research is an answer whether the "digital" hydraulics can be used in a multi-source hydrostatic drive system? Are their parameters similar to the clasic hydrostatic transmission?

3.1 The Mathematical and Numerical Data of the Model:

a) Torque equation for hydraulic motors (1):

$$q_s p_s = M_0 + R_0 \omega_s + I \frac{d\omega_s}{dt}$$

(1)

The initial state: $\omega_s(0)=0$, circumstances of the boundaries: for $q_s p_s \leq M0$ and $\omega_s=0$, $\frac{d\omega_s}{dt}=0$
b) Equation for pump flow (2):

$$q_p \omega_p = G_p p_p + G_r(t)\sqrt{p_p - p_s} + Q_z + \frac{V_p}{E_c} \cdot \frac{dp_p}{dt}$$

(2)

Conditions at the beginning: $p_p(0) = \left[\frac{q_p \omega_p}{G_r}\right]^2$

c) Equation of flow for distribution valves (3):

$$G_r(t)\sqrt{p_p - p_s} = q_s \omega_s + G_s p_s + \frac{V_s}{E_c} \cdot \frac{dp_s}{dt}$$

(3)

Conditions at the beginning: $p_s(0) = 0$
d) Flow from an overflow valve Qz formula (4), (5):
A non-inertial valve:

$$\text{For } p_p < p_o: \quad Q_z = 0$$
$$\text{For } p_p > p_o, \ Q_z = K(p_p - p_o)$$

(4)

The inertial valve:

$$T_z \frac{dQ_z}{dt} = K_z(p_p - p_0) - Q_z$$

(5)

Data:
$q_p \omega_p = 723*10^{-6}[m^3/s]$, $E_c = 1.5*10^9[N/m^2]$, $p_o = 19*10^6[N/m^2]$, $q_s = 4.76*10^{-6}[m^3/rad]$, $R_o = 0.03[Nm/s]$, $G_p = G_s = 5.4*10^{-12} [m^4 s/kg]$, $T_z = 0.2 [s]$, $V_p = 150*10^{-6} [m^3]$, $V_s = 230*10^{-6} [m^3]$, $K_z = 0.52*10-9 [m5/Ns]$, $I_0 = 54*10^{-4}[Nm/s^2]$, $M_0 = 60[Nm]$, $G_r = 7.23*10^{-7} [m^4/N^{0.5}]$.
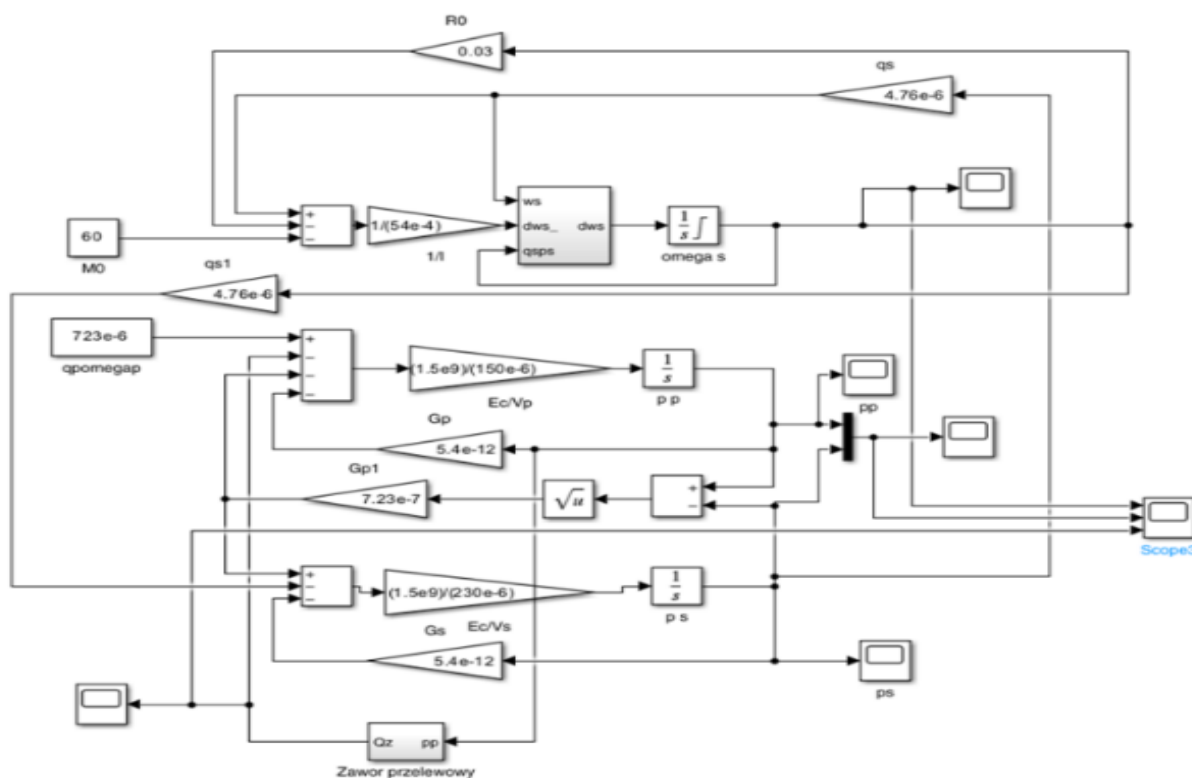
Fig. 4. Schema of simulation model

3. Comparison of simulation and experimental data

Figures 5 and 6 present the results of experimental studies carried out at the HYDRAULICS AND PNEUMATICS RESEARCH INSTITUTE in Bucharest, within the project "Method of effective use of the "digital" hydraulics concept in multi-source hydrostatic drive systems" (50SD/0065/24).
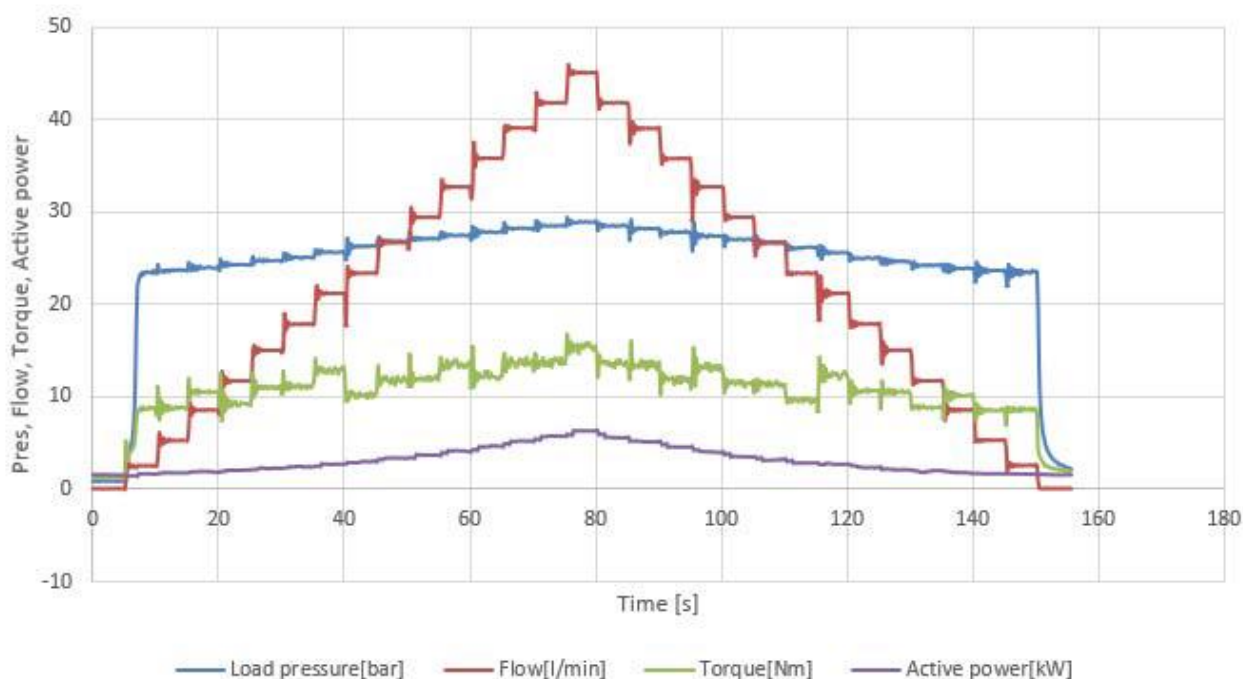

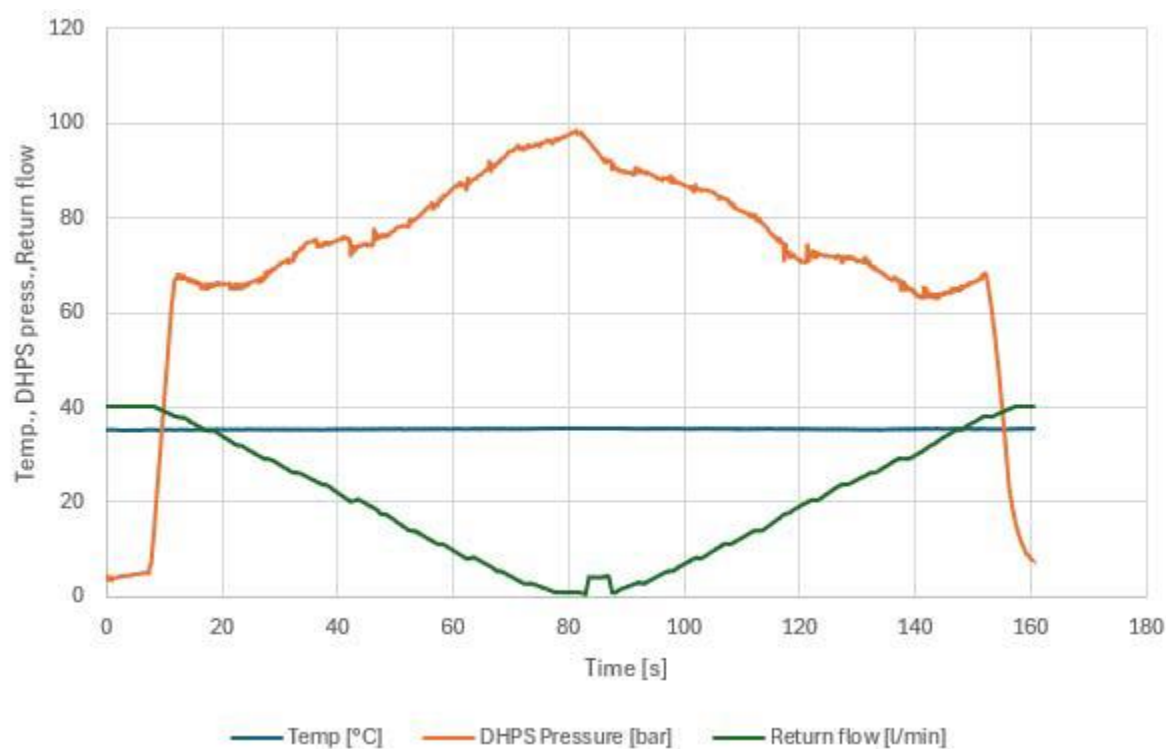**Fig. 5.** Experimental research results

Fig. 6. Experimental research results

The simulation model built and the research results obtained from it initially confirm its correctness (figure 7 and 8). No statistical analysis has been carried out so far to compare the simulation and experimental results. This will be the subject of subsequent publications.
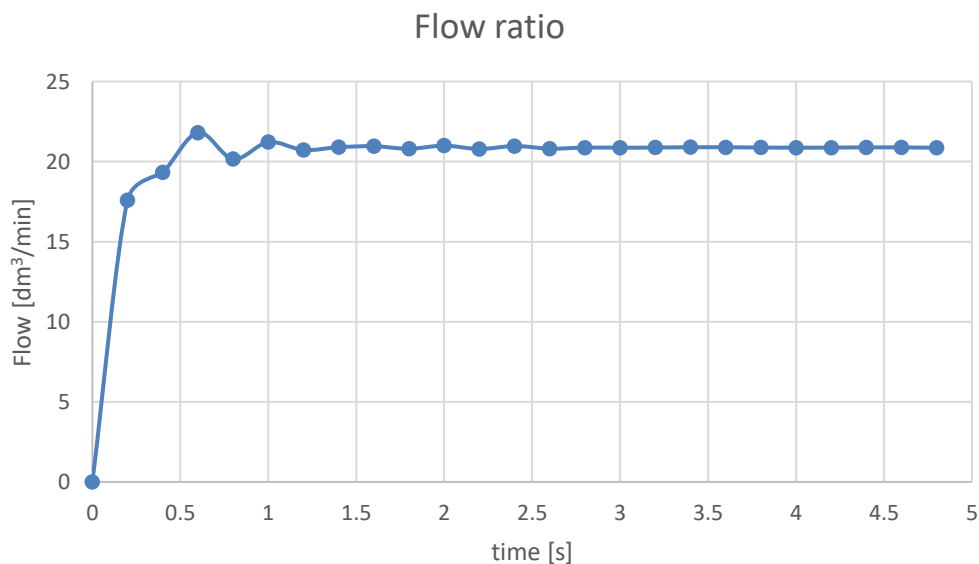

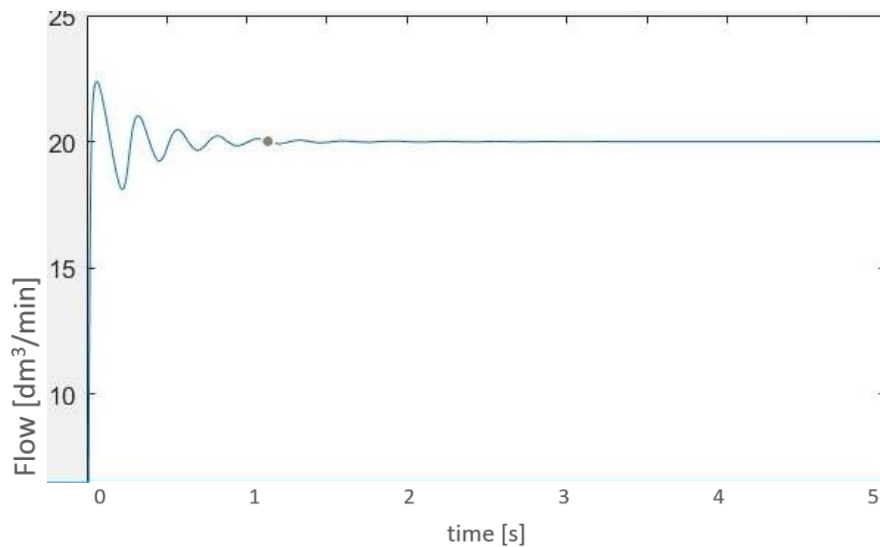**Fig. 7.** Experimental research results for 20 dm³/min flow

Fig. 8. Simulation research results for 20 dm³/min flow

4. Conclusions

The publication presents the preliminary results of the comparison of experimental studies of the "digital" hydrostatic transmission, conducted at INOE 2000 IHP as part of the grant "Method of effective use of the concept of digital hydraulics in multi-source hydrostatic drive systems" with its simulation model. Due to the too short time between obtaining the results of the experimental studies and the deadline for sending the full text of the paper, only symbolic comparison of the simulation model with the experimental studies is included. An extended comparison of the effectiveness (efficiency) of using different methods of controlling the pump capacity and the hydraulic motor capacity in multi-source, hydrostatic drive systems and a comparison of the experimental results with simulation studies obtained in the Matlab Simulink program will be the subject of future publications.

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