Design of Control System for an Electrohydraulic Drive Based on the Valve with PMSM Motor

Dominik Rybarczyk, Piotr Owczarek and Arkadiusz Kubacki

Abstract The article describes design of control system and test stand for an electrohydraulic drive based on the new kind proportional valve with synchronous motor type PMSM (Permanent Magnets Synchronous Motor). In the second part, the chosen laboratory investigations of proposed valve with PMSM are presented. The study included the test of the basic characteristics of the drive such as step response and temperature of oil impact.

Keywords Electrohydraulic drive · Proportional valve · Permanent magnets synchronous motor

1 Introduction

Despite intensive development of the drive based on an electric motors, particularly visible in the last 30 years in associated primarily with the development of electronics and computer control systems, electrohydraulic drives are still used as actuators of multiple machines. Main advantage of electrohydraulic drives, with opposite to the electric drives, are easy implementation of linear displacement, ability to obtain very high power and high energy ratio: controlled to control—from 10^4 to 10^6. In commercial practice, electrohydraulic actuators capable of generating forces in order of the MN and obtaining speed of 0.1 m/s. Providing for such type of drives, high bandwidth (above 40 Hz) and positioning accuracy of better than ±0.01 mm, requires the use of the advanced control method and precised and fast valve.

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Many investigations and related publications about electrohydraulic drives focused on improvement them properties, by implementation of modern methods of control [1–3]. Murrenhoff [4] described the cross-cutting trends in the design and development of electrohydraulic valves. His article presented new type solution, by using of the direct drive in a proportional valve in hydraulic system. Research on build and properties of proportional valves were conducted by [5]. Paper [8] presented modelling and simulation of hydraulic spool valves by using simple mathematical expressions to describe the geometry of the sliding spool metering edge. Described here control stand is equipped with a new type of proportional valve with synchronous motor Author detailed described in: [6, 7].

2 Test Stand and Control System

2.1 Assumptions

During the design process, it was assumed that test stand should:

- allow the same valve tests, such as measuring the flow rate and recording the step response of the valve spool,
- allow the measurement of the actuator position and its changes over time,
- be able to performed drive test under load and measuring the force,
- have the possibility of quick and efficient testing of advanced control systems, such Model Following Control methods,
- have the possibility of quick reconfiguration of hardware electrohydraulic drive and its control system.

2.2 Test Stand Structure

Mechanical and measurement part consists of two blocks. The first one is allowed to measure the basis valve characteristics of the valve (Fig. 1) while the second is designed to test the entire electrohydraulic drive (Fig. 2). Control system was common for both parts. It consists of two main elements: the master controller like PLC with touch panel and the slave, which is a synchronous motor PMSM controller.

The flow meter type HySense QG100 is used, which parameters were: max. flow $Q = 30\ \mathrm{dm^3/min}$, max. pressure $p = 30$ MPa, non-linearity ±0.5 %, 1640 pulses per $\mathrm{dm^3}$. It is connected to the counter module in the PLC. Hydraulic power supply characteristics were: motor power = 37 kW, maximum flow rate = 100 $\mathrm{dm^3/min}$, maximum pressure $p_0 = 40$ MPa, filtration at 6 μ.

Test stand was equipped with double acting hydraulic cylinder. The stroke of the hydraulic cylinder was 200 mm. The diameters of piston was $A = 40$ mm and the

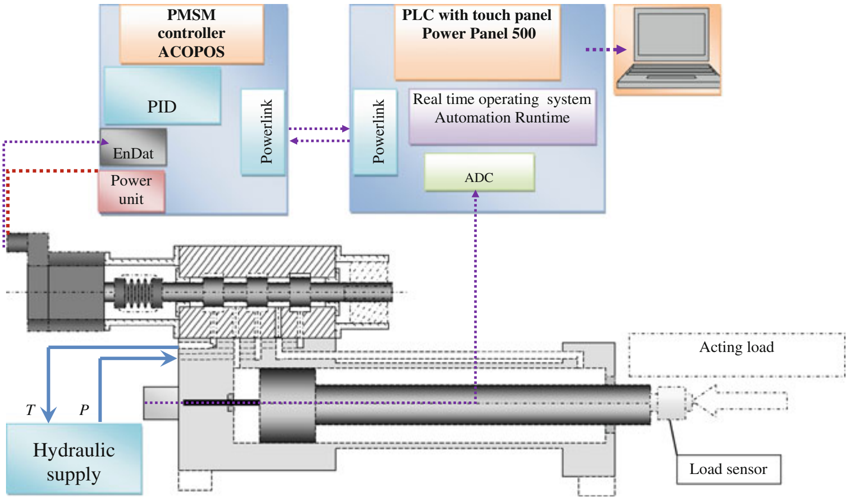

Fig. 1 Control stand for perform servo drive test

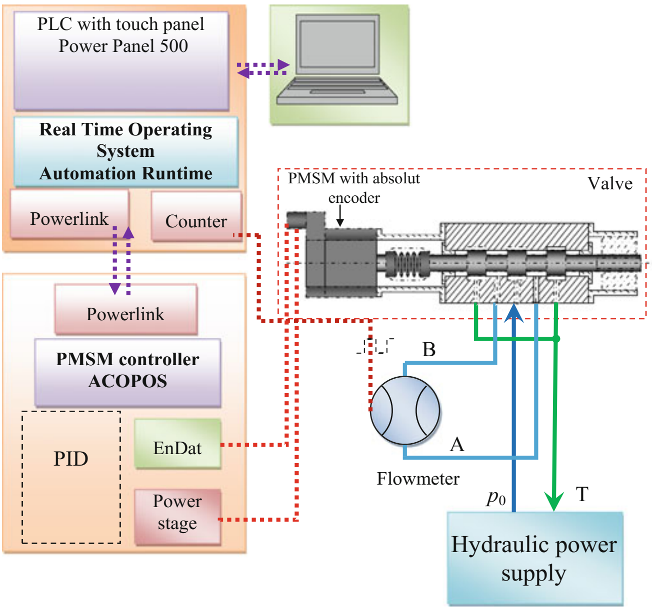

Fig. 2 Control stand for measure of the valve flow

piston rod $Aa = 63$ mm. The cylinder was equipped with internal magnetostrictive position sensor, providing the actual position of cylinder piston.

In the valve, Authors used PMSM motors type B&R 8LVA23. The motor is connected to the spool by flexible coupling bellow. Moving of the motor shaft caused rotation and simultaneously axial translation of the spool in the valve body. This movement was proportional to the angular motor displacement. Therefore, the described valve is defined as the "proportional". Direction of rotation determines the direction of spool translation and opening or closing of valve gaps. It results in the flow of oil to and from the actuator chambers and displacement of piston. The spool diameter was 10 mm. In the valve there were three rectangular gaps in the body. Dimension each of them were: 2.5 mm × 2 mm. Therefore valve size can be defined as 10 (below 64 dm^3/min) [6].

Basis parameters of the PMSM motor with is used in the valve were: the rated speed 3000 rev/min, rated current 2.9 A and stall torque 0.68 Nm. The motor is equipped with an absolute encoder type EnDat, providing a continuous information about the current position, even after a power failure. Also it assures high positioning accuracy (262144 pulses on revolution). Thanks to this the drive is able to assure the linear resolution of 0.5 μm [6, 9].

The test drive equipped with an auxiliary hydraulic system based on an outer cylinder for loading drive (Figs. 1 and 3). Additionally, there is mounted force sensor type HBMC9B, which allows measurement of the force up to 50 kN.

The PLC is equipped with the processor core type Intel Atom 1.6 GHz (Fig. 4). System was running under real-time operating system type Automation Runtime. The main control program is written in Structured Text and ANSI C. It has been divided into several tasks made of a certain determinism of time. The task responsible for the work of PID and MFC electrohydraulic servo drive controllers, synchronous motor control (homing, start, stop, setting the parameters of motion,

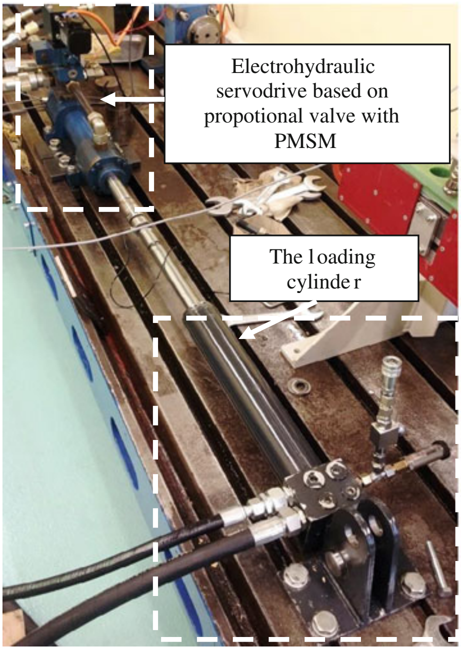

Fig. 3 View on the mechanical part of the control stand

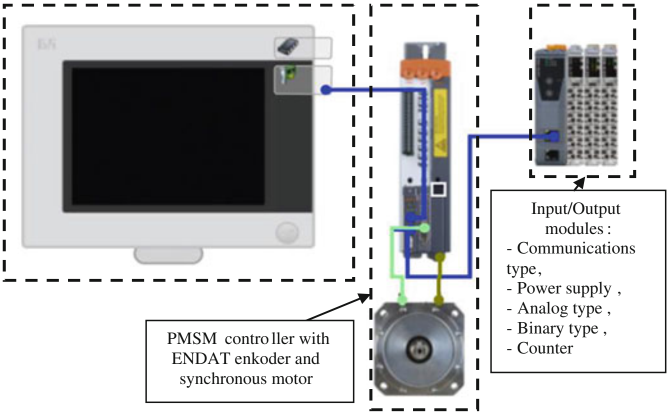

Fig. 4 Control systems schematic taken from Automation Studio software

acceleration, speed) was performed with a time base of 0.8 ms. With the same timebase, task responsible for communication between the inverter and the PLC are worked. Communication was carried out using the Powerlink interface [9]. The charge visualization was performed in steps of 12 ms, in order to not loading the CPU of PLC. There are also implements a thread and library which allowing user to generate code directly from Matlab Simulink software.

In order to performed easier communication between operator and service facilities Author designed the dedicated visualization on the touch panel, which significantly easier to perform and supervise tests (Fig. 5). On visualization,

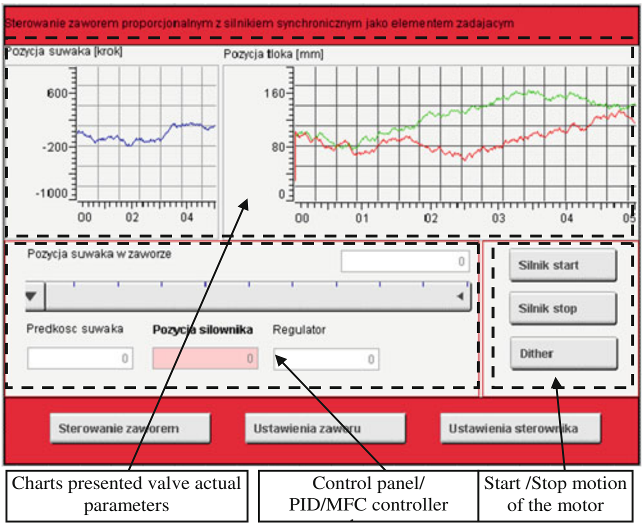

Fig. 5 Visualisation

immediately after the measurement, there are presented charts of the recorded signals on the screen. The application allowed the change the basic drive parameters such as: setting valve slider position, setting speed limits, setting the maximum range of drive motion. The graphs presented current parameters of the individual measured values such as fluid flow rate or motion velocity.

2.3 Testing

The electrohydraulic drive was tested by used of the step response signals, for values equal to: 20, 40, 60, 80 and 100 % of valve spool maximum displacement (in

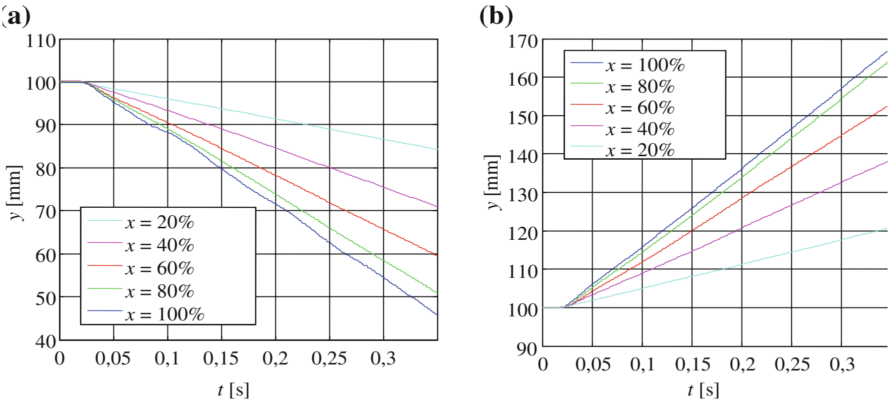

Fig. 6 Movement of electrohydraulic drive piston in open loop 15 MPa of hydraulic supply pressure: **a** valve open in “+” direction, **b** valve open in “–” direction

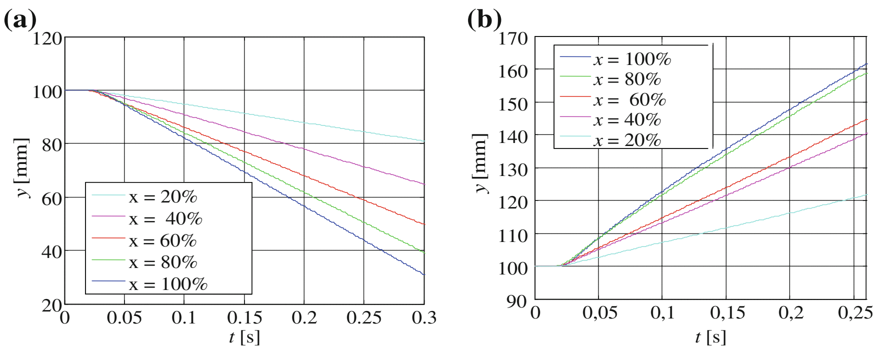

Fig. 7 Movement of electrohydraulic drive piston in open loop 10 MPa of hydraulic supply pressure: **a** valve open in “+” direction, **b** valve open in “–” direction

both directions). The experiment is performed for the supply pressure p_0 amounting to 5, 10 and 15 MPa. The results are shown in Figs. 6, 7 and 8. The recorded data indicate that the valve was characterized by a significant time delay, which is caused by PLC controller and communication interface, which is used to control the PMSM.

Collected charts show that the speed of movement of the piston is dependent on the supply pressure. Sample speed values for the pressure of 5 MPa are: the valve opening of 100 %–70 mm/s, the valve opening of 60 %–60 mm/s, the valve opening of 20 %–21 mm/s.

In test stand Authors used non-zinc hydraulic oil with high viscosity index type Draco HV 46 Premium Oil. During tests oil temperature is recorded. Collected values are compare in Table 1 and Fig. 9. Reflected differences in the speed of piston movements are caused of changes of oil viscosity [1, 2].

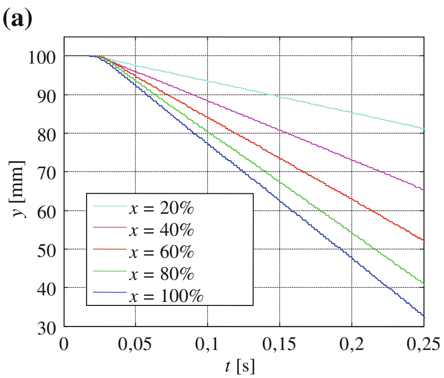

Fig. 8 Movement of electrohydraulic drive piston in open loop for 5 MPa of hydraulic supply pressure: **a** valve open in "+" direction, **b** valve open in "–" direction

Table 1 Oil temperature during drive tests

Oil temperature during drive tests (°C)			
x	5 (MPa)	10 (MPa)	15 (MPa)
100 % +	26.5	34.2	50.0
80 % +	25.3	32.7	48.0
60 % +	24.5	29.7	47.9
40 % +	24.5	27.7	47.5
20 % +	23.5	23.4	46.5
20 % –	27.3	37.3	42.6
40 % –	27.5	38.0	43.3
60 % –	27.8	38.9	47.9
80 % –	28.3	39.0	48.0
100 % –	28.3	39.6	45.7

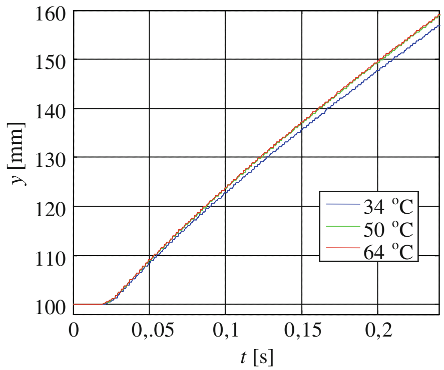

Fig. 9 Oil temperature impact on the electrohydraulic drive

3 Conclusion

In this paper the control stand of an electrohydraulic drive with proportional valve controlled by PM synchronous motor is presented. Mechanical and measurement part are consisted of the two blocks: to measure the basis valve characteristics and to test the entire electrohydraulic drive. Control system was common for both parts. It consists of the PLC with touch panel and a synchronous motor PMSM controller.

The article includes initial research—step response and the impact of oil temperature.

Performed test stand made allowed to conduct further comprehensive investigations of the described here valve and advanced control methods with used of whole drive.

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