Application of the MFC Method in Electrohydraulic Servo Drive with a Valve Controlled by Synchronous Motor

Andrzej Milecki, Dominik Rybarczyk, and Piotr Owczarek

Institute of Mechanical Technology, Poznan University of Technology,
ul. Piotrowo 3, 60-965 Poznań, Poland
{Andrzej.milecki,Dominik.rybarczyk,Piotr.owczarek}@put.poznan.pl

Abstract. The article describes the use of the Model Following Control method to control of electrohydraulic servo drive. In the drive a new, designed by us, proportional valve with a synchronous motor controlled by dedicated power electronics is used. The model of the electrohydraulic servo drive controlled by MFC method prepared in MATLAB-Simulink is described. The laboratory test stand is described and step responses of the drive are shown.

Keywords: electrohydraulic servo drive, proportional valve, model following control, synchronous motor.

1 Introduction

Electrohydraulic servo drives are highly non-linear devices. Nevertheless, as their controller classic one-loop PID controllers are most frequently used. They work well in situations, in which no large changes of the drive parameters occur. Therefore, it is difficult to design a suitable PID control system of electrohydraulic drives when their parameters changes in time. For this reason, it is necessary to look for new control methods and solutions, which are not susceptible to big changes of drive parameters or are able to adapt to such changes. One of the technique recently used in control of non-linear system is the Model Following Control (MFC). This method allows to ensure high quality control and the resistance to external interference in quite easy way [5, 6], therefore it is worth to test the use of this method in electrohydraulics.

In the article the Authors describe the application of the MFC method for control of the electrohydraulic servo drive with proportional valve controlled by modern low power synchronous motor.

2 Model Following Control Method

Over the last 20 years many attempts have been taken to use the Model Following Control in different devices and processes [1, 3–5, 9, 19]. In the paper [13] a research results of the use of MFC technology for testing of the pump control with synchronous motor. The MFC method is a two-loop structure, which is noted for its

R. Szewczyk, C. Zieliński, and M. Kaliczyńska (eds.), *Recent Advances in Automation, Robotics and Measuring Techniques*, Advances in Intelligent Systems and Computing 267,
DOI: 10.1007/978-3-319-05353-0_17,

simplicity and relatively high robustness to disturbances and stable perturbations. In design of MFC system the object is mostly represented by transfer function. In some cases also the state variable approach has also been employed. However the state variable system representation seems to be improper in order to clarify basic universal properties of the MFC structure.

There is difficult to find in the literature papers, which deal with the application of MFC method in control of electrohydraulic servo drives. In the paper [2] a special model-following control scheme is developed in order to force a linear system behavior. The linearization is achieved by feed forward compensation and proportional feedback. The study [11] was focused on the compensation of the impact of the load changes in the electrohydraulic drive. There are no publications which described the use of MFC method in electrohydraulic servo drive with proportional valve controlled by synchronous motor.

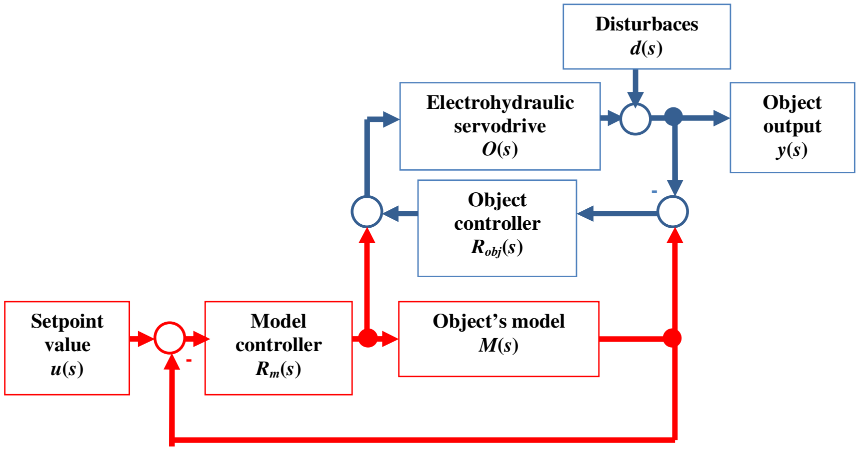

Fig. 1. Model Following Control structure

The principle of MFC method is based on the idea of Model Based Control (MBC). It means, that a part of the control system structure is a mathematical model of the object. Model Following Control structure bases on two regulators: the regulator of the model (main regulator) and the regulator of the object (correcting regulator). So, the whole structure consists of two loops with feedback: main object loop and model loop. The mathematical model of the object is identified by a mathematical analysis or by experimental test. The first loop consists of the model of a controlled object and the PID controller. The difference between output of the model and the output of the real object and output signal from the PID regulator used in model loop is used for the control signal correction. In booth loops the same PID regulator is applied. If the model perfectly fits the real object, the system works like a classical one-loop PID controller (signals from correcting loop is equal to zero). Due to the principle of operation of the described system, on the input of correcting regulator (in contrast to the control model), a step function signal will be never occur.

This allows to tuning the correcting regulator with much larger reserves of stability (for example: with a higher gain coefficient). This allows to make more effective correction of disturbances. In hydraulic drive systems, the disturbances can be: load, mass, stiffness, temperature and supply pressure changes [2]. As usual, also friction may very during movement.

3 Electrohydraulic Servo Drive with Synchronous Motor

3.1 Proportional Valve with Synchronous Motor

Due to the development of modern control methods and production technology both, the properties and the prices of modern synchronous motors significantly dropped. Therefore it has become possible to use them in applications where even15 years ago this would be economically unprofitable. Modern synchronous motors ensure high positioning accuracy with high dynamics. In the proposed here valve (see Fig. 2), the spool is actuated by a low-power Permanent Magnet Synchronous Motor (PMSM). The motor (1) was connected to the spool (3) by flexible coupling bellows (2). Applying the electrical power to the motor causes rotation and simultaneously axial translation of the spool. Control edge openings x are proportional to the angular motor position and to the pitch of used thread (5). Direction of rotation determines direction of spool translation and opening or closing of valve gaps.

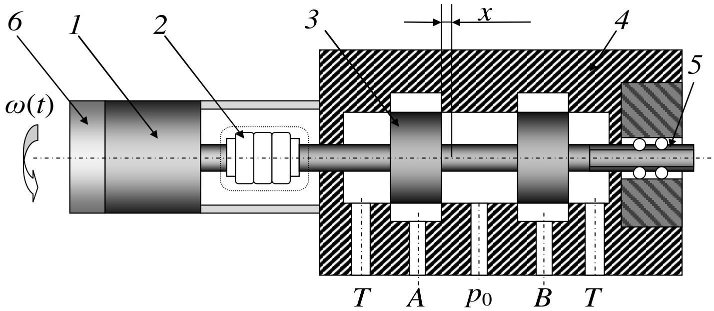

Fig. 2. Proportional valve with synchronous motor

In the valve, the low power PMSM motor type B&R 8LVA23 was applied. Its basic parameters are: rated speed 3000 rev./min, rated current 2.9 A and stall torque 0.680 Nm. The engine was equipped with an absolute encoder type EnDat, providing a continuous information about the current position, even after a power failure, which assures a very high positioning accuracy and resolution of 262144 pulses on one revolution.

3.2 Modelling of the Servo Drive Controlled by MFC Method

In order to test, assure proper design and to implement the MFC method it was necessary to build at first a model of the electrohydraulic servo drive based on the described above valve. Model of servo drive was constructed based on the mathematical description of the hydraulic drive given in:

$$Q_a(t) = Q_{sa}(t) + Q_{ha}(t) + Q_v(t) \tag{1}$$

$$Q_b(t) = Q_{sb}(t) + Q_{hb}(t) - Q_v(t) - Q_{vb}(t) \tag{2}$$

$$Q_b(t) = K_{Qp}\, x(t) - K_l\, p_b(t) \tag{3}$$

$$Q_{ha}(t) = A\frac{dy(t)}{dt} \tag{4}$$

$$Q_{hb}(t) = aA\frac{dy(t)}{dt} \tag{5}$$

$$Q_{sa}(t) = \frac{V_a}{E_o}\frac{dp_a(t)}{dt} \tag{6}$$

$$Q_{sb}(t) = -\frac{V_b}{E_o}\frac{dp_b(t)}{dt} \tag{7}$$

$$Q_v(t) = K_v[p_a(t) - p_b(t)] \tag{8}$$

$$Q_{vb}(t) = K_{vb}\, p_b(t) \tag{9}$$

$$m\frac{d^2y(t)}{dt^2} + D\frac{dy(t)}{dt} = A[p_a(t) - ap_b(t)] \tag{10}$$

where: Q_a, Q_b – flow, Q_{ha}, Q_{hb} – absorption of the actuator chambers, Q_{sa}, Q_{sb} – flow of the covering losses due to compressibility, Q_{vb} – leakage flow on the piston rod, p_a, p_b – the pressure in the chambers of the actuator, A_a, A_b – active surfaces of the piston, V_a, V_b – the volume of liquid in the chambers of the actuator.

Unknown parameters such as capacity of the wires and the flow rate has been identified with used of the Kalman filter. The model was implemented in the model loop of the MFC controller. Control system implemented on PLC controller enable to switch between PID and MFC controller.

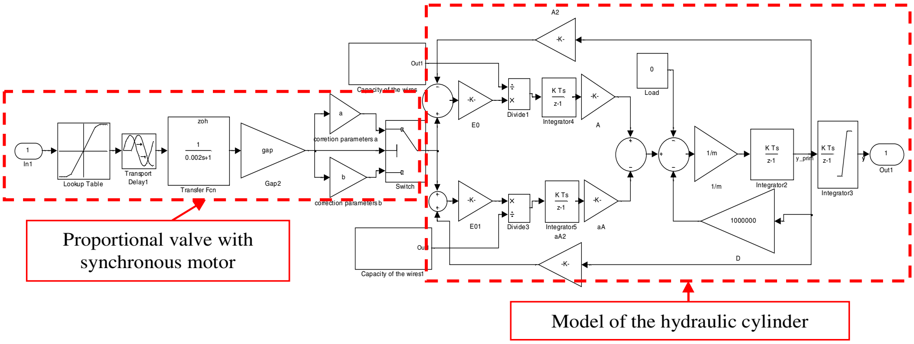

Fig. 3. Model of the electrohydraulic servo drive used in MFC controller (the model was built based on the mathematical description in section 3.2 of the article)

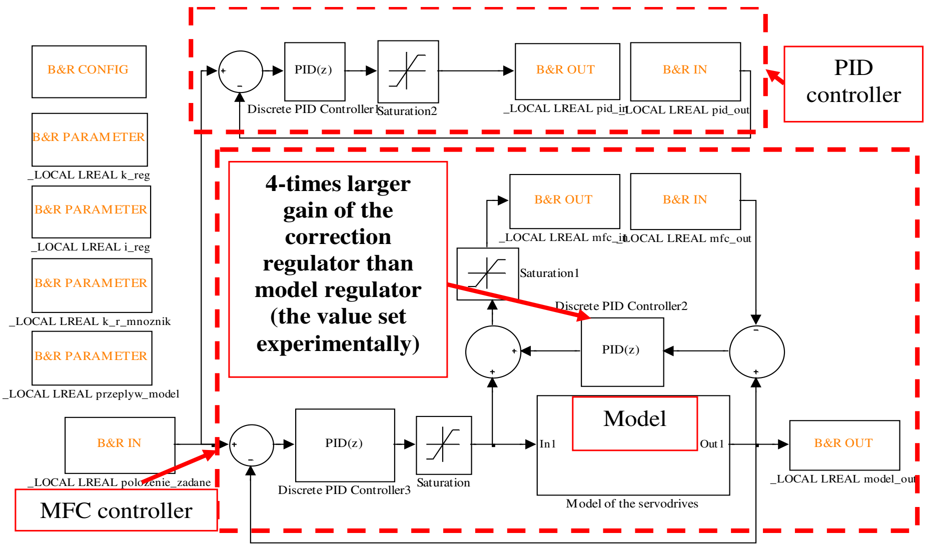

Fig. 4. Control system implemented on PLC

4 Experimental Test Stand and Investigations

In Fig. 5 the scheme of the experimental stand for testing of the electrohydraulic servo drive based on proportional valve driven by synchronous motor, is shown. The stand enables to check up the effectiveness of the control system based on the MFC method. The test stand consists of a single-acting cylinder with a proportional valve controlled by synchronous motor and control system based on PLC technology. The piston of the cylinder was coupled to the position sensor. A control system was based on master controller which was PLC with touch panel and servo-inverter which acts as a slave controller. As a communication interface between the PLC and the servo-inverter, a Powerlink network was used. The PLC was running under the control of real-time operating system. The complete application enabled real-time control and the system was working with sampling frequency of 1250 Hz.

In the described system, Authors used the rapid prototyping technique for control system design and implementation. This means that the model of the control system has been built previously in software environment and recompiled for the C code and then implemented it as one of the task class in the CPU unit. Due to the discrete work of the industrial controller, it was required to discretize the continuous model of control system. The discrete time base was $T = 0.0008$ s.

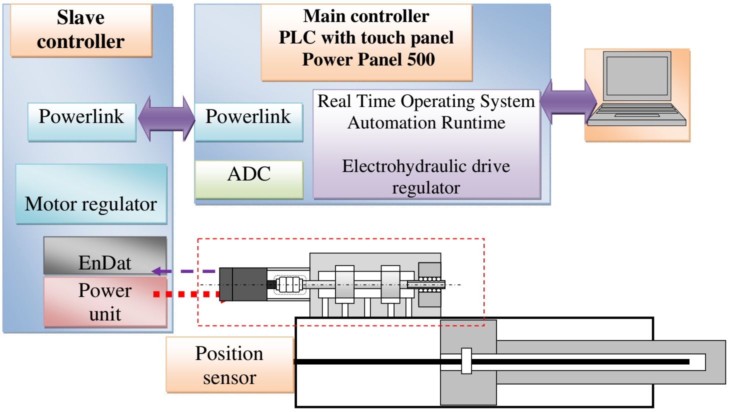

Fig. 5. Control system scheme

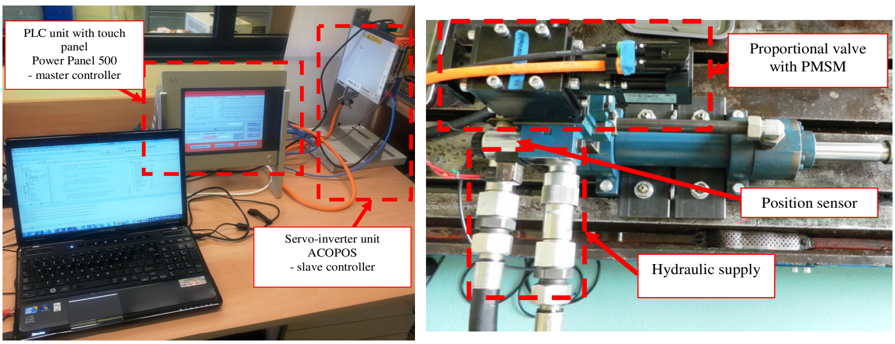

Fig. 6. Electrohydraulic servo drive and control stand view

5 Experimental Investigation

During the investigations on the system input a step signal was given. The experiment results are shown in the charts below (Fig. 8). The study was performed for two types of regulator: PID controller and MFC controller. The both regulator's gain coefficients, derivative and integrative time constants were established experimentally and were as matched to achieve the step response as fast as possible, but without oscillation. In the next step the hydraulic supply pressure was changed from 8 MPa to 2 MPa. The PID and MFC coefficients remain unchanged. The investigation results shown that recorded step response of the servo drive controlled by MFC was significantly better in comparison to the step response obtained when the drive was controlled by PID controller.

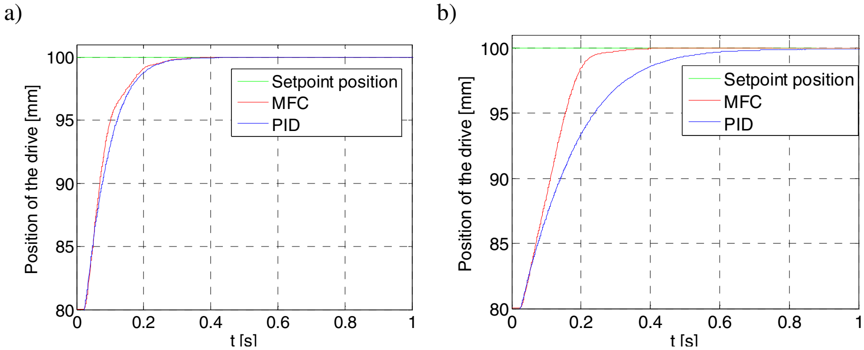

Fig. 7. Position of drive with use of PID controller and MFC controller for pressure supply: a) 8 MPa, b) 2 MPa

6 Conclusion

MFC method is commonly used in process control that require automatic adjustment. The presented here research results were executed to verify the use of MFC method capabilities in control of electrohydraulic servo drive.

The main advantage of the described here MFC method is a significant simplification of the controller structure, in comparison with other types of advance method of control, like for example adaptive control. Taking into account the collected results, MFC method seems to be more robust and more resistant on external disturbances in comparison with classical PID control method.

The research of the usage of the MFC method in control of electrohydraulic servo drives will be continued in near future. The currently ongoing studies are aimed at checking the effectiveness of the MFC method with load impact changes.

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