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DIGITAL CASCADE PRESSURE AND POSITION REGULATOR FOR ELECTROHYDRAULIC STEERING SYSTEM[140]

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Digital cascade pressure and position regulator for electrohydraulic steering system: *The work is carried out design and synthesis of the structure of a digital cascade controller with feedback on pressure and position of electrohydraulic steering system. Developed software implementation based on which it is built into the controller for mobile applications. Filled empirical tuning of the regulator in terms of physical experiment on steering electrohydraulic drive system with digital control. Were carried out experimental research and analysis of the behavior of the studied system with built-in regulator.*

Key words: *Digital Cascade Regulator, Pressure, Position, Electrohydraulic, Steering System;*

INTRODUCTION

The advent of digital control in hydraulic steering devices (HKU) low speed mobile machines, allows for control in different modes, depending on how you set the control action, namely: mechanical - through the steering wheel, electric - an electronic joystick and / or remote - using GPS. This leads to the need for an effective integrated management system ensures the quality behaviour of the entire electrohydraulic system.

The uncertainty in the system in question is caused by the presence of dead band and other nonlinearities. Deadband due to the positive overlap of electrohydraulic (EH) directional valve, which prevents the use of values close to zero control signal. This limits the minimum value of tracking error. Nonlinearities arise from regularities of hydraulic drive, describing the system as they believe the odds of transmission depend on the closed volume in the left and right chamber of the executive servocylinder.

Mentioned nonlinear effects are not significant, which allows the use of linear regulators for implementation of the tracking system in position. From the point of view of the linear control theory non-linear effects occur as the uncertainty in the transfer function of the object:

$$y(j\omega) = G(j\omega)\big(1 + W_{\Delta}(j\omega)\Delta(j\omega)\big)u(j\omega), |\Delta(j\omega)| \leq 1 \tag{1}$$

In many cases, the implementation of feedback, if only a proportional element, reduces the uncertainty of the closed system compared to the open system. Deviations from the nominal

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dynamics can be presented as starting disturbance. In this case the presence of the input of the feedback output signal suppress such interference in a particular frequency range.

Based on such considerations have information except for the position of the working cylinder, and information and pressure drop between the two chambers can be expected that the introduction of feedback pressure will reduce the uncertainty in channel position caused by the following factors:

- Dead band in EH directional valve;
- Occasional freight disturbances which are a function of the road surface;
- Nonlinearity nature of the processes running on the system.

Cascade systems are widely used in the control system of electrical machines, processes in continuous production, control of level in the related reservoirs, unsustainable control of sites, relay systems and others.

In cascade systems, the inner contour has a superior performance as compared with the outer contour. The regulator it is set mostly on the requirements for maximum performance boost and suppression of interfering signals and external contours are adjusted according to the requirements of accuracy in steady state [2].

The main objective of this work is to present the design and implementation of digital regulator with cascade structure including feedback on pressure and position for incorporation in electrohydraulic steering system with applications in low speed mobile machinery.

1. Design and synthesis of control system

The digital cascade regulator designed for installation in automatic control system (ACS) of electrohydraulic steering implemented on existing test bench for electrohydraulic steering units (EHSU). The hydraulic scheme of the test bench shown in Fig.1.

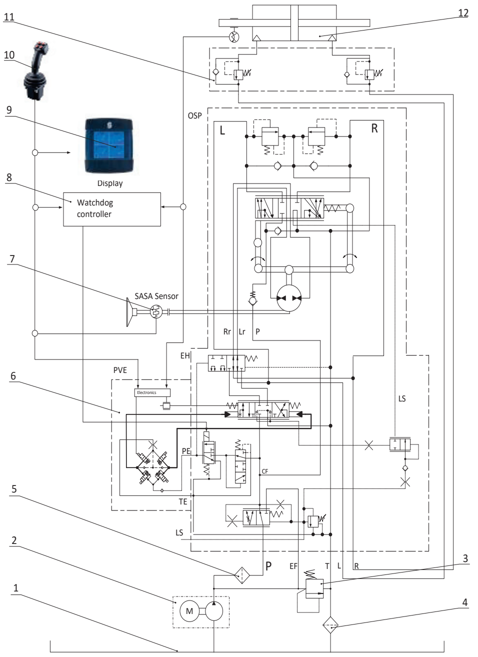

Fig.1 Hydraulic scheme of test bench for EHSU [1].

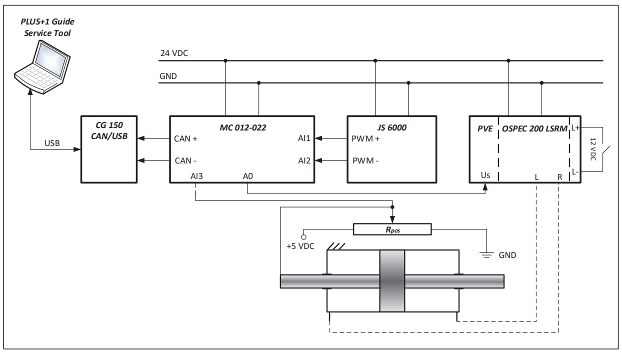

Fig.2 Connection diagram of the components of ACS.

The existing system of digital control (Figure 2) is built on the base controller for mobile applications *MC012-022* type and electronic joystick type *JS6000*, by which operated built-in EHSU, electro PVE module consisting of two-way, two-position valves connected in parallel [1]. Reporting dynamic pressure change in the two working chambers of the executive servo cylinder used for sensors for mobile applications *MBS1250* type of *Danfoss*, with operating range Pressure *0 ÷ 250bar*, an amendment of the output voltage of *0.5 ÷ 4.5V* and error $e \leq 0.5\ \%$.

They were carried out design and synthesis of the structure of a digital cascade regulator with three feedbacks shown in Figure 3.

The global feedback is the position y of the piston of cylinder (Hydr.Cylinder) measured by position sensor. Signal of position compared with that of reference, and the result of the compare $e_y = y_{ref} - y_m$ to an input digital proportional-integral (PI) regulator.

Reference:

$$y_{ref}(kT_s) = y_{ref}\big((k-1)T_s\big) + v(kT_s)T_s,\ v(kT_s) \in \{v_{min}, v_{max}, 0\} \tag{2}$$

The looming signal is a periodic signal that can be divided into 4 sections - linearly increasing, linearly decreasing, stepwise linearly increasing and stepwise linearly decreasing. This signal is typical of electrohydraulic drive systems with applications in mobile hydraulics.

Local feedback is pressure drop Δp measured in the two working chambers of the executive servo cylinder (Hydr.Cylinder) sensors included in the load pressure system (Fig.1 pos.11). This signal is filtered by developed low-pass filter and compared with the signal from PI-regulator, which serves as a reference Δp_{ref}, and the result $e_{pr} = \Delta p_{ref} - \Delta p_m$ is input the digital proportional regulator (P) calculating parameters of control signal u voltage to PVE module.

Digital PI Regulator:

$$\Delta p_{ref}\left(e^{j\omega}\right) = \left(K_p + K_I \frac{T_s}{e^{j\omega}-1}\right)\left(y_{ref}\left(e^{j\omega}\right) - y_m\left(e^{j\omega}\right)\right) \tag{3}$$

The looming signal desired pressure drop on the cylinder is obtained depending on the position error e_y. For its calculation, the standard PI-regulator presented in a discreet appearance. Integral component is approximated to first difference. The presentation of the regulator in a discreet form facilitates its implementation in programmable controller as:

$$\Delta p_{ref}(kT_s) = K_p\left(y_{ref}(kT_s) - y_m(kT_s)\right) + I(kT_s) \tag{4}$$

$$I(kT_s) = I\big((k-1)T_s\big) + \left(y_{ref}(kT_s) - y_m(kT_s)\right)T_s \tag{5}$$

P Regulator:

$$u(kT_s) = K_{pr}\left(\Delta p_{ref}(kT_s) - \Delta p_m(kT_s)\right) \tag{6}$$

The aim of this regulator is to reduce the error between the set and the measured pressure drop over the cylinder piston, by applying a control signal $u(kT_s)$. Increasing this ratio improves the response of the system but at the same time increases the noise level in the control signal, which is undesirable because of the time constant of the solenoid not compensated control unit (converter) - PVE. In it the electrical signal voltage is converted into a hydraulic signal of flow rate q_s controlling integrated EH directional valve in (EHSU), which in turn determines the direction of the executive cylinder at the time of flow rate q. External drag forces in the system formed disturbances (DM) of flow rate q_l. Is taken into account a hydraulic capacity in the system (K_{hc}).

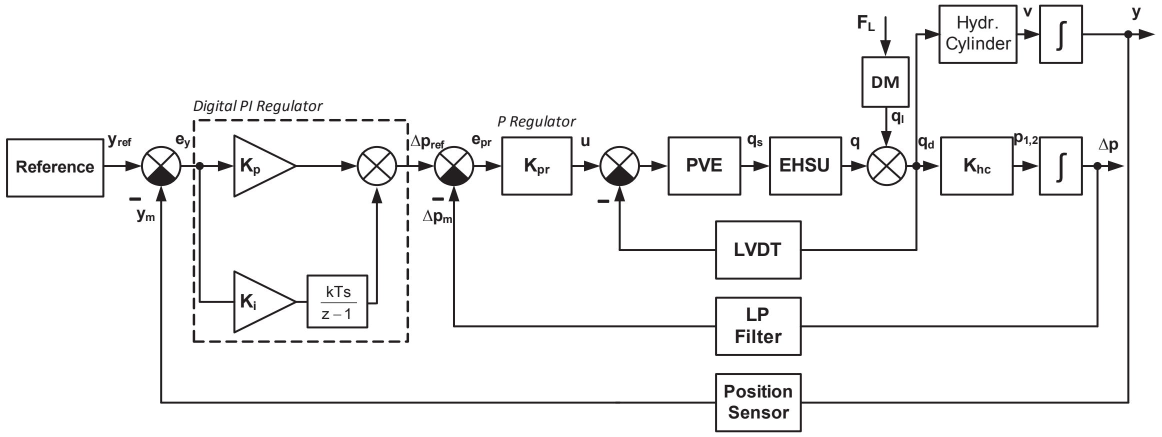

Fig.3 Structural diagram of a digital cascade regulator

The third negative feedback is entailed in decision and constructive implementation of EHSU type OSPE 200 LSRM. She realized internal device tracking function of integrated spool of EH directional valve (EHSU) by LVDT position sensor and closed by PVE modules (Fig. 4).

PVE:

Flow rate through two-way two-position valves (NO-NC) valves [4]:

$$q_{s,(NO,NC)} = \mu S_v \sqrt{\frac{2}{\rho}(p_1 - p_2)} \tag{7}$$

Flow rate caused by the compressibility of the working fluid:

$$q_d = \frac{dp}{dt}\frac{V}{K} + \frac{dV}{dt} = q_{in} - q_{out} \tag{8}$$

Pressure drop in two-way two-position valves (NO-NC) valves:

$$\Delta p_s = \frac{K}{V}\int\left(q_{in} - q_{out} - \dot{V}\right)dt + p_i \tag{9}$$

EHSU:

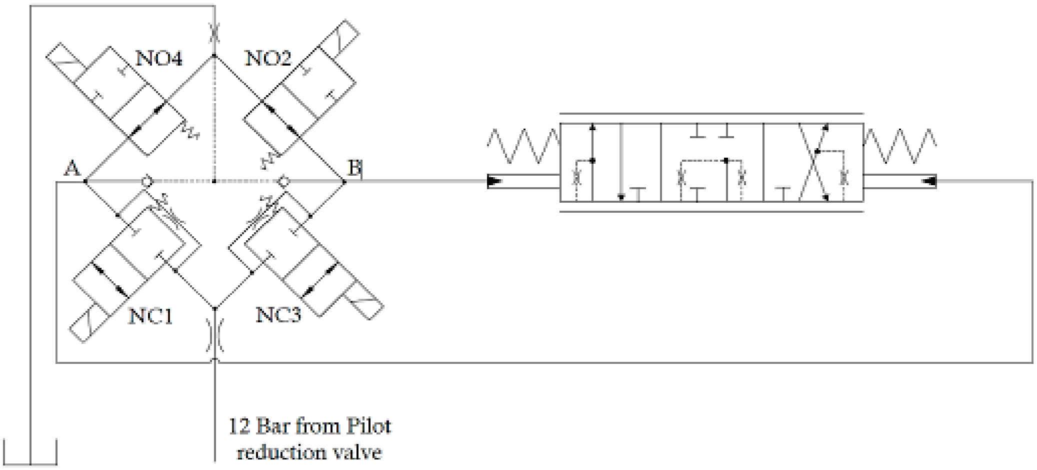

Fig.4 Hydraulic control scheme of EH directional valve in EHSU

Equation of motion of the spool in EH directional valve:

$$F_{res}(t) = m_{sp}.\ddot{x}\,(t), \qquad \dot{x}(t) = \int \frac{F_{res}(t)}{m_{sp}} + \dot{x}\,dt \tag{10}$$

Flow rate supplied to the working chambers of the executive servocylinder:

$$q = A.v + \frac{AH}{4K}\frac{d(p_1-p_2)}{dt}\ , \qquad \Delta q = A.\Delta v + \frac{AH}{4K}\frac{d(\Delta p_{1,2})}{dt} \tag{11}$$

Equation of motion of the executive servo cylinder:

$$m\frac{dv}{dt} = A.p_{1,2} - D.v - F_L, \qquad m\frac{d\Delta v}{dt} = A.\Delta p_{1,2} - D.\Delta v - \Delta F_L \tag{12}$$

Equation of EH valve $\Delta q = k_{xq}.\Delta x - k_{pq}.\Delta p_{1,2}$. Hydraulic capacity is $C_h = \frac{AH}{4K}$. Assuming that $\Delta q \equiv q,\ \Delta v \equiv v$ и $\Delta p_{1,2} \equiv p_{1,2}$ follows:

$$p_{1,2} = \frac{1}{C_h S},\ v = \frac{1}{mS+D}.\left(A.p_{1,2} - F_L\right) \text{ и } q = k_{xq}.x - k_{pq}.\Delta p_{1,2} \tag{13}$$

LP Filter:

$$\Delta p_m(kT_s) = a_1\Delta p_m((k-1)T_s) + a_2\Delta p(kT_s) \tag{14}$$

2. Programming and implementation of the control system

Figure 4 shows the Data Flow model of the designed cascade system which is used for code generation and embedding in the *C28xx* microcontroller of *Texas Instruments*. Generation of C code from the Data Flow model is with the help of *Plus+1 Guide ISE* of *Danfoss* being in a line with model based design methodology [1]. Developed model is composed of several subsystem:

- generation of reference signal (timer for generation of a clock signal, counter for trajectory stages, logical combinatorial net for calculation of the current speed and integrator which calculates the position reference from speed);
- control signal calculation (scaling and offsetting of the control signal in the range 2.5÷7.5V);

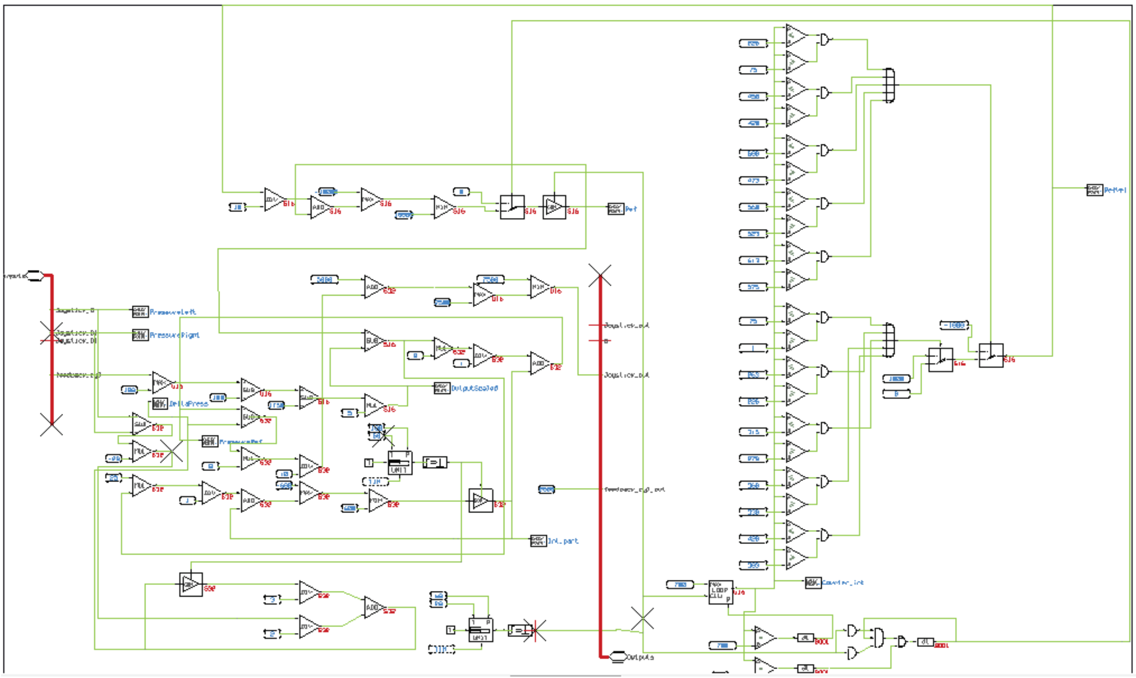

Fig.4 Data Flow model in PLUS+1 Guide (Danfoss).

- signal processing of the sensor signals for spool position and pressure (scaling and offsetting of the values to fixed point precision);
- filter for the measured pressure drop implemented as recursive equation;
- PI-regulator for position and P-regulator for pressure drop.

Implementation of the subsystem should be in line with microcontroller arithmetic capabilities. In our case CPU has only fixed point arithmetic core [3]. For such a reason all real parameters of the regulators and filters must be represented as fractions in appropriate ranges [5].

3. Experimental results and discussion

Designed regulator is programmed in to the microcontroller attached at the test bed for EHSU examination. Its parameters are tuned with the optimization procedure minimizing reference signal tracking errors and supressing load disturbances in pressure. We have recorded response of the servo cylinder. The reference signal varies from minimal to maximal displacement of the cylinder (cylinder position, $0 \div 300mm$). Its character is typical for mobile applications [1]. Figure 5 shows a result from experiment with the designed digital cascade regulator.

On top subfigure there is comparison between reference y_{ref} and measured y_m cylinder position. Next subfigure shows tracking of the reference pressure drop Δp_{ref} and measured Δp_m. At the bottom subfigure there is recorded control signal during the experiment.

We have evaluated experimental result with the help of numerical estimate of the level of fit between measured dynamical response from cylinder position sensor and reference signal.

$$FIT = 100\left(1 - \frac{\left\| y_{ref} - y_m \right\|_2}{\left\| y_{ref} - E(y_{ref}) \right\|_2}\right), \% \qquad (15)$$

Table 1: Optimal parameters

Regulator	Parameters					FIT
	K_p	K_i	K_{pr}	a_1	a_2	%
Cascade PI&P Regulator	8	25	0.8	0.33	10	96.50

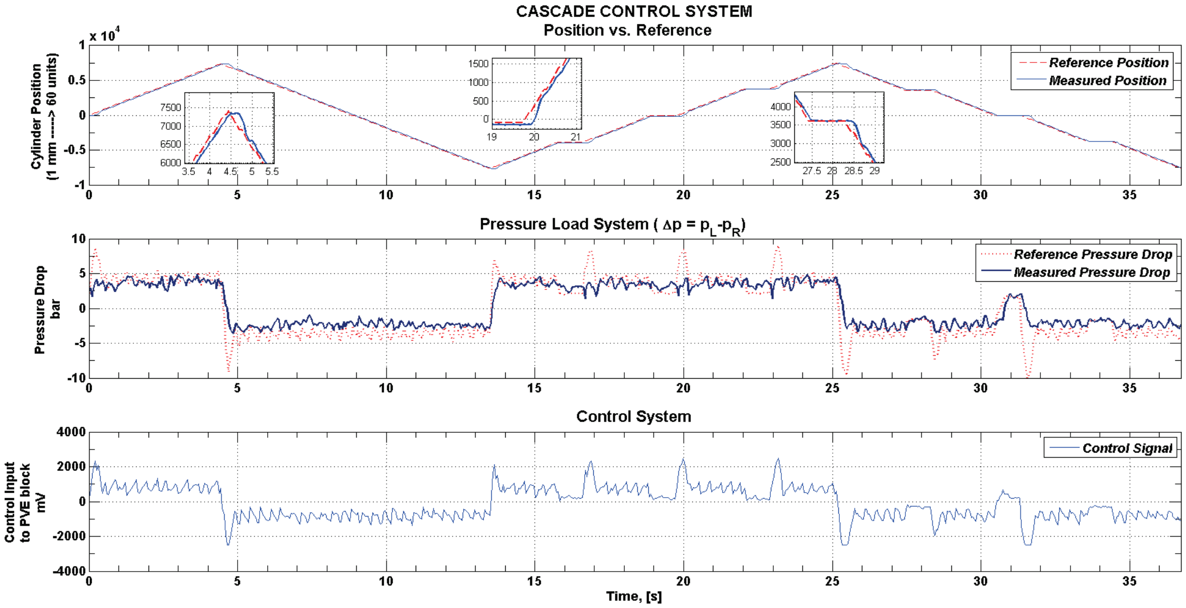

Fig.5 Experimental results with digital cascade regulator

CONCLUSION

There is designed digital cascade regulator for pressure and position to control the electrohydraulic steering system. The regulator is embedded in microcontroller for automotive applications on the base of developed software. We have executed experimental evaluation and optimal tuning of the regulator parameters on the steering system. Experimental results shows that cascade systems satisfies performance requirements for mobile machines ($FIT \geq 90\%$). The system achieves good tracking by position and by pressure which makes proposed control structure applicable to the large field of mobile hydraulics in presence of heavy load conditions and represented as unexpected disturbances in pressure subsystem.

REFERENCE

[1] Mitov, Al., Research of Steering Electrohydraulic Drive System With Digital Control, Dissertation, Technical University of Sofia, 2016.

[2] Corriou, J.-P. Process Control: Theory and Applications, ISBN1447138481, Springer, 2013.

[3] Isermann, R. Digital Control Systems, ISBN 3662023199, Springer, 2013.

[4] Mitov, Al., J. Kralev, Il. Angelov. Investigation of Static Characteristics of Digitally-Controlled Electrohydraulic Steering System, Journal of Food Packaging Science, Technique and Technologies, ISSN 1314-7773, Year 5, Burgas, 2016.

[5] Wang L., S. Chai, D. Yoo, et al. PID and Predictive Control of Electrical Drives and Power Converters Using MATLAB / Simulink, IEEE Press Series on Power Engineering Series, ISBN 1118339444, Wiley 2015.