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PRACTICAL ASPECTS REGARDING IMPLEMENTATION OF PID CONTROLLER ON A PROGRAMMABLE LOGIC CONTROLLER

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Abstract: *The accessibility of programmable logic controller, abbreviated as PLC, with real-time signal processing performance for the control of fast systems (such as hydraulic drives), allows the implementation of high-performance control algorithms that are executed in real time. The paper presents the software and hardware considerations for the implementation in a common PLC of a Proportional-Integral-Derivative PID controller.*

Keywords: *PID controller, PLC, servo hydraulics, servo valve driver*

1. Preliminary

PID algorithm, mathematical form

$$u(t) = A(e(t) + \frac{1}{T_i}\int_0^t e(\tau)d\tau + T_d\frac{de(t)}{dt}) \tag{1}$$

where $u(t)$ is the command value of the actuator, $e(t)$ is error value, the difference between desired target value and actual value of the process variable, A is then gain value, T_i is the integration time value and T_d is the derivation time value.

PID algorithm, numerical implementation using the trapezoidal method

$$u_k = A\left[e_k + \frac{T_s}{2T_i}\sum_{n=1}^{k}(e_n + e_{n-1}) + \frac{T_d}{T_s}(e_k - e_{k-1})\right] \tag{2}$$

where u_k is the command value of the actuator, e_k is error value, the difference between desired target value and actual value of the process variable and T_s is the sampling period value.

PID algorithm, form of FIR (*F*inite *I*mpulse *R*esponse) filter

$$u_k = u_{k-1} + A\left[\left(1 + \frac{T_s}{2T_i} + \frac{T_d}{T_s}\right)e_k - \left(1 - \frac{T_s}{2T_i} + 2\frac{T_d}{T_s}\right)e_{k-1} + \frac{T_d}{T_s}e_{k-2}\right] \tag{3}$$

The PID algorithm with the derivative of the process signal, eliminates the derivative kick

$$u_k = A\left[e_k + \frac{T_s}{2T_i}\sum_{n=1}^{k}(e_n + e_{n-1}) - \frac{T_d}{T_s}(y_k - y_{k-1})\right] \tag{4}$$

where y_k is the process variable.

The relation (4) can also be written like this

$$u_k = u_{k-1} + A\left[\left(1 + \frac{T_s}{2T_i}\right) e_k - \left(1 - \frac{T_s}{2T_i}\right) e_{k-1} + \frac{T_d}{T_s}(y_k - 2y_{k-1} + y_{k-2})\right] \quad (5)$$

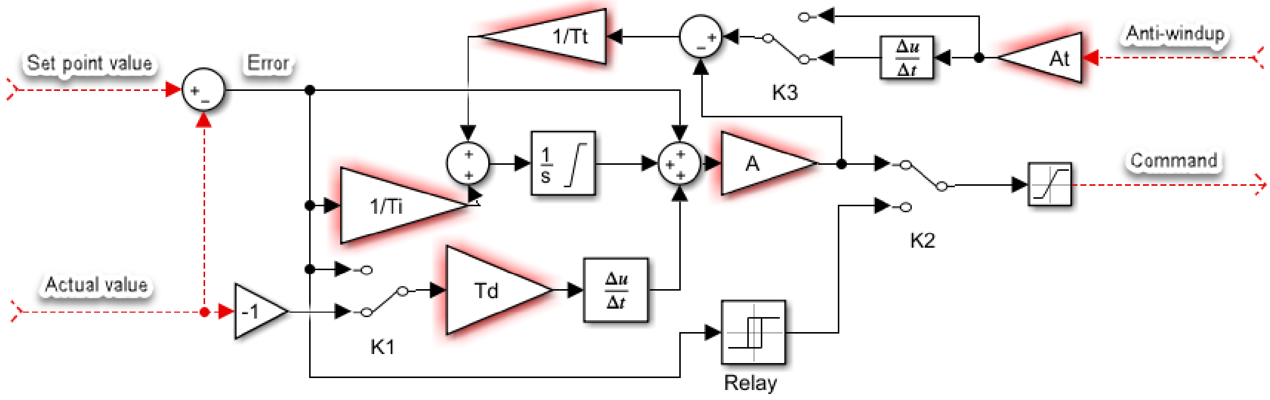

Fig. 1. PID algorithm diagram implemented on PLC

Switch K1 selects the mode of calculus of the derivative component. Thus, its value can be the derivative of the error value e or the derivative of opposite actual value y. The second choice cancels the variation disturbance of the reference point x, the derivative kick, see fig. 1 [1].
Switch K2 is used to adjust the controller parameters, A the gain, T_i the time constant of the integrator, T_d the time constant of the derivative, in the sense of obtaining a stable operation of the controlled process. K2 selects the operating mode of the controller, respectively the normal operation in the closed loop with the PID regulator or the operation in the closed loop through the relay, bringing the regulation process to the stability limit with small amplitude oscillations, known as the Åström-Hägglund tuning method [2]. In the relay closed-loop mode, it is possible, by determining the values of the amplitude and frequency of the process oscillations, to calculate the value of the controller parameters in such a way as to avoid the unstable operation of the automatic regulator [3].
To avoid integral windup, when integral term of a PID controller accumulates a significant error during periods when the process is saturated, is necessary to implement anti-windup scheme based on back-calculation [4]. For this purpose, the *[t]* entry, the command execution input or its derived value, selected from K3, is required.
Parameters of the PID regulator with the phase margin value of 45^0 is

$$A = 0.9K_u \quad (6)$$

$$T_d = 0.1816T_u \quad (7)$$

$$T_i = 6.25T_d \quad (8)$$

where K_u is the inverse of the gain in the closed loop through the relay, and T_u is the oscillation period.

2. Simulation

In fig. 3 shows the simulation model for a hydraulic servo cylinder [5] with the proposed PID controller. A servo valve Rexroth 4WSE2EM10 actuates the hydraulic cylinder. The stroke of the cylinder is *200mm*. The servo valve is driven by with a current of *-30…30mA* and has a flow rate of *-60...60l/min*. The speed of the hydraulic cylinder rod varies in the range *-0.6...0.6m/s* corresponding to a flow rate of *-60...60l/min*.

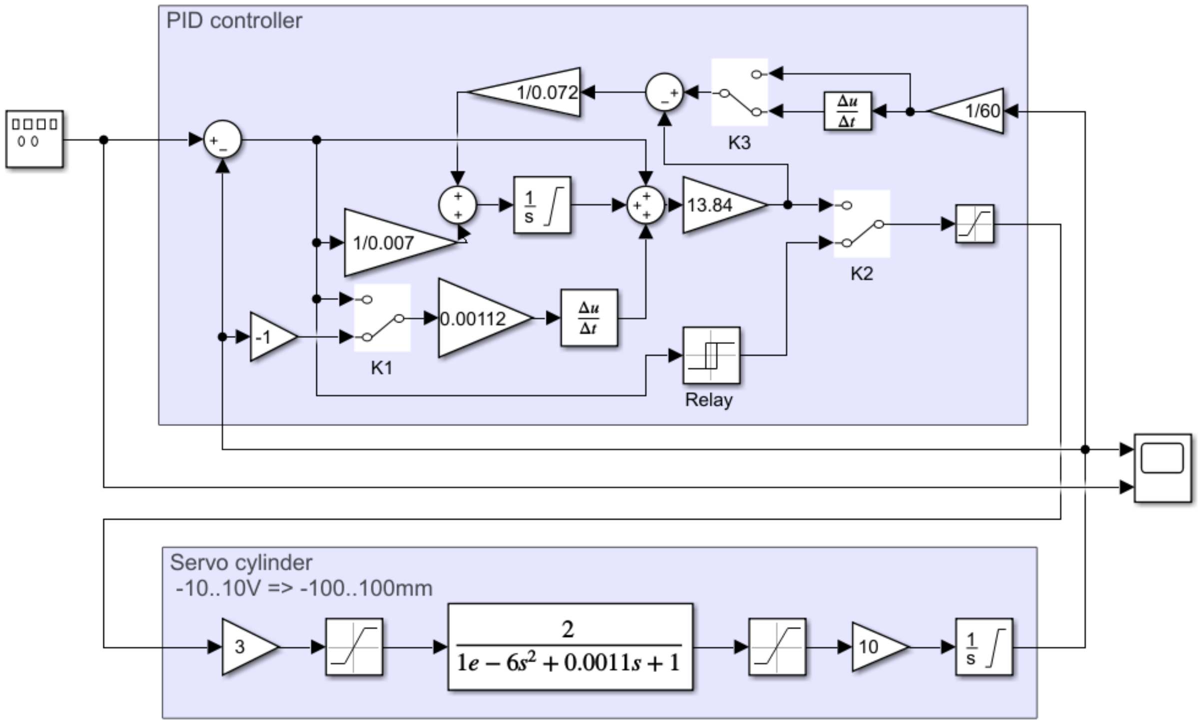

Fig. 2. Matlab model of the automation system

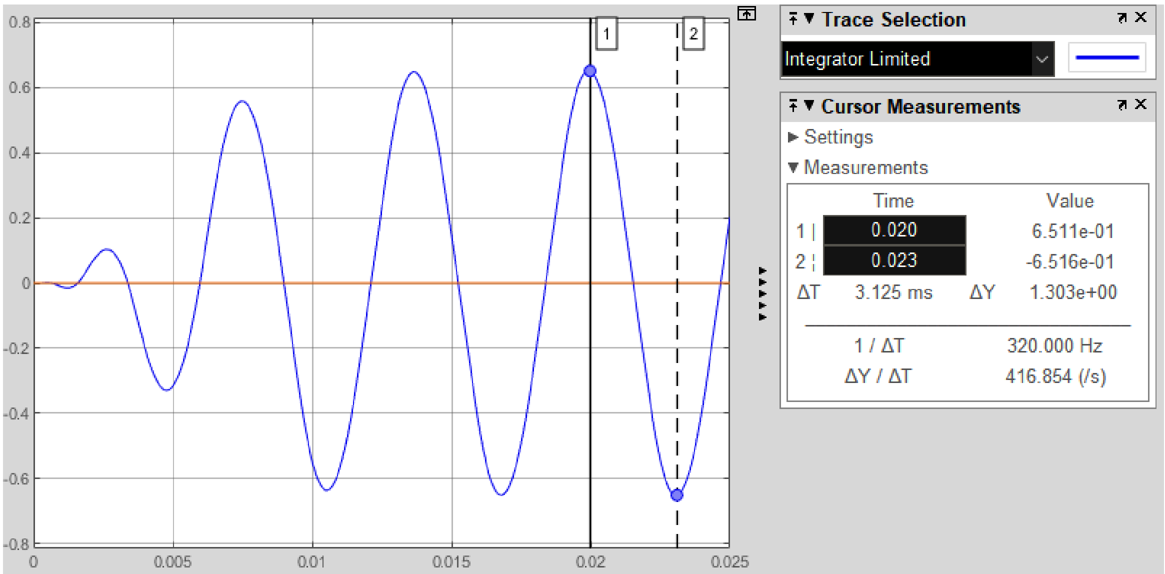

Fig. 3. Closed loop response with relay for *-10mm* and *10mm* saturation limits

For $K_u = \frac{20}{1.3} = 15.38$ and $T_u = 2 * 3.125 = 6.25ms$ the result is

$$A = 13.84\,;\ T_d = 1.12ms\,;\ T_i = 7ms \tag{9}$$

see fig. 2 and (6), (7) and (8).

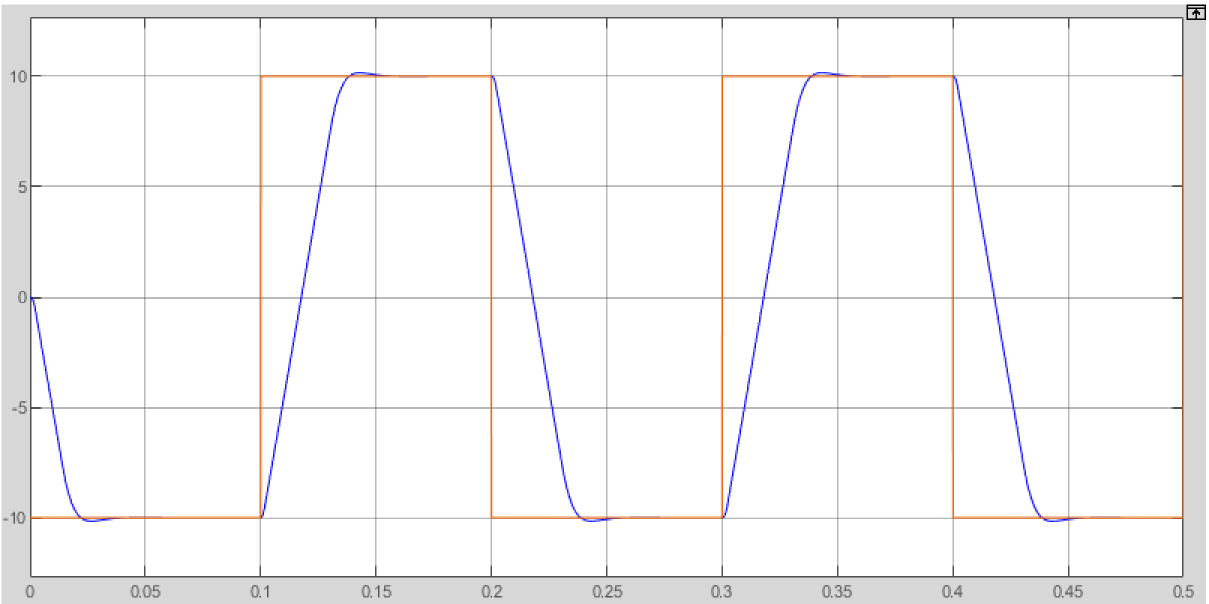

Fig. 4. Response for ±*10mm, 5Hz* input signal - red trace and hydraulic actuator position - blue trace

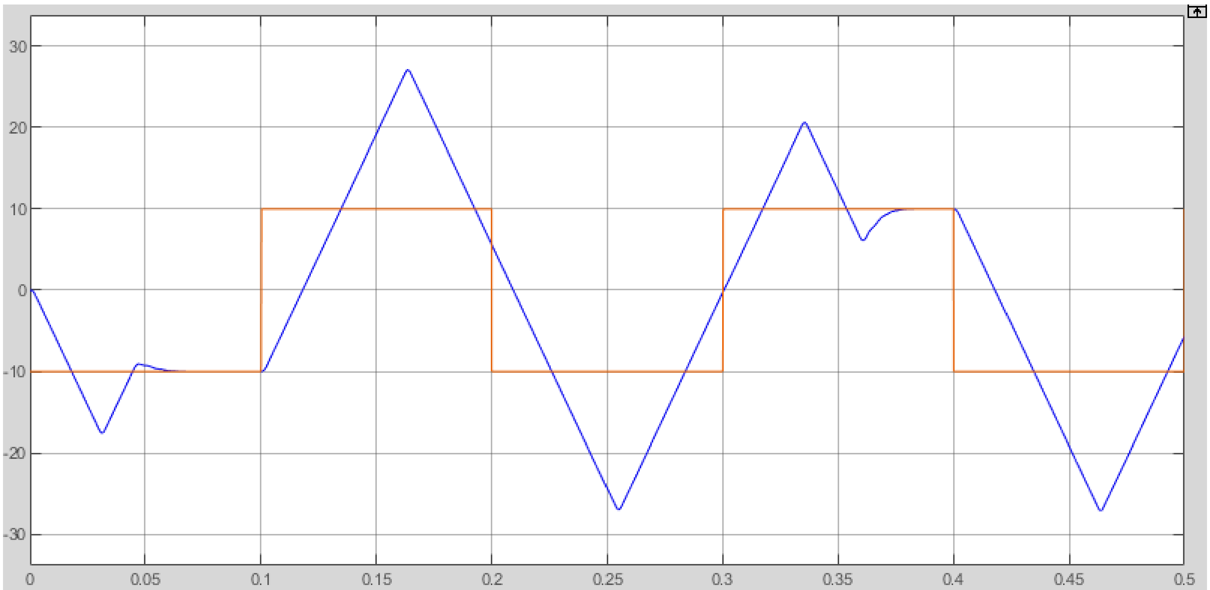

Fig. 5. Response for ±*10mm, 5Hz* input signal, with integral windup

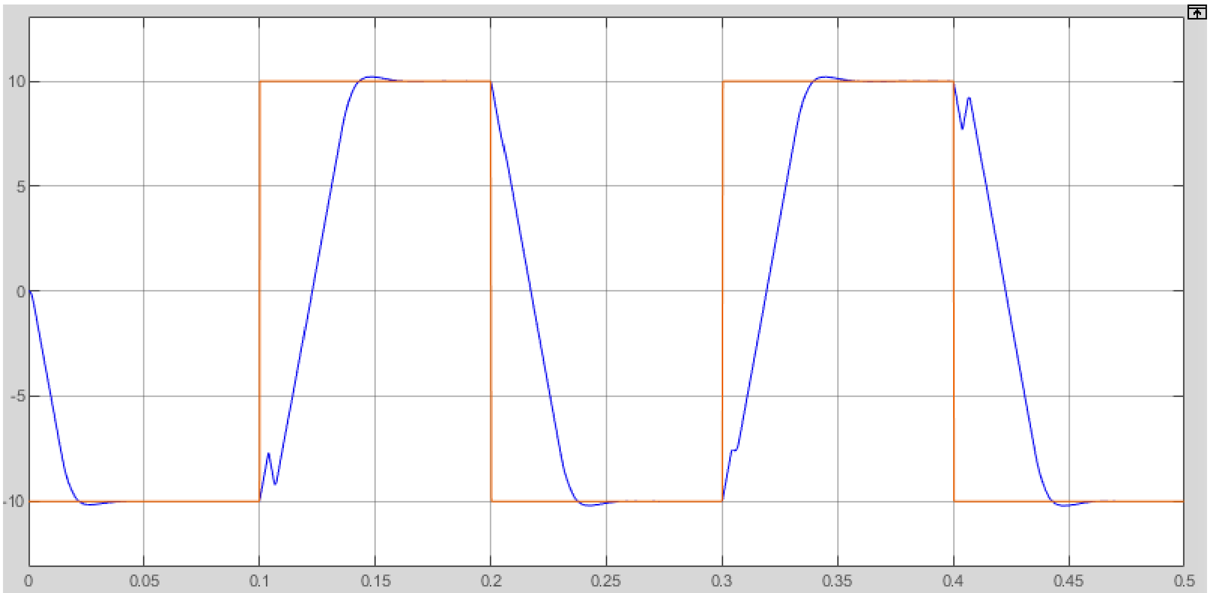

Fig. 6. Response for ±*10mm, 5Hz* input signal, with derivative kick

3. Servo valve driver

Usually PLC has analog input/output modules with unified current *4..20mA* or voltage ±*10V* signals. On the other hand, automation systems with PLC are powered by 24V DC power supplies. To control the servo valve, a voltage to current converter is required. This servo valve driver, see fig. 7, has the role of interfacing the analog voltage signal generated by the PLC with the analog current signal required by the hydraulic device. The driver is powered by the same power supply as the PLC, 24 VDC.

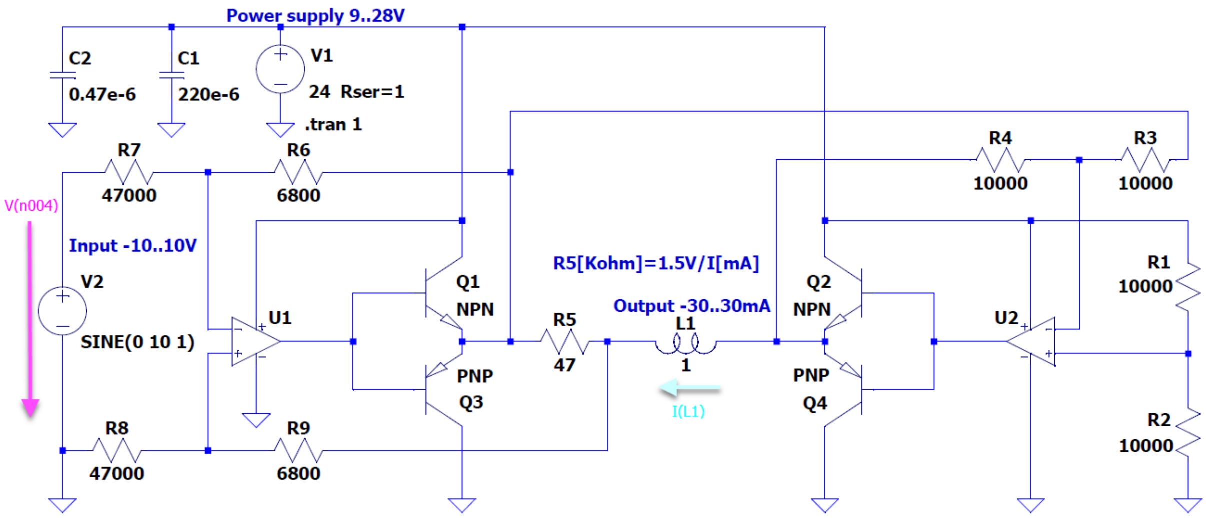

Fig. 7. Electronic schematic of servo valve driver

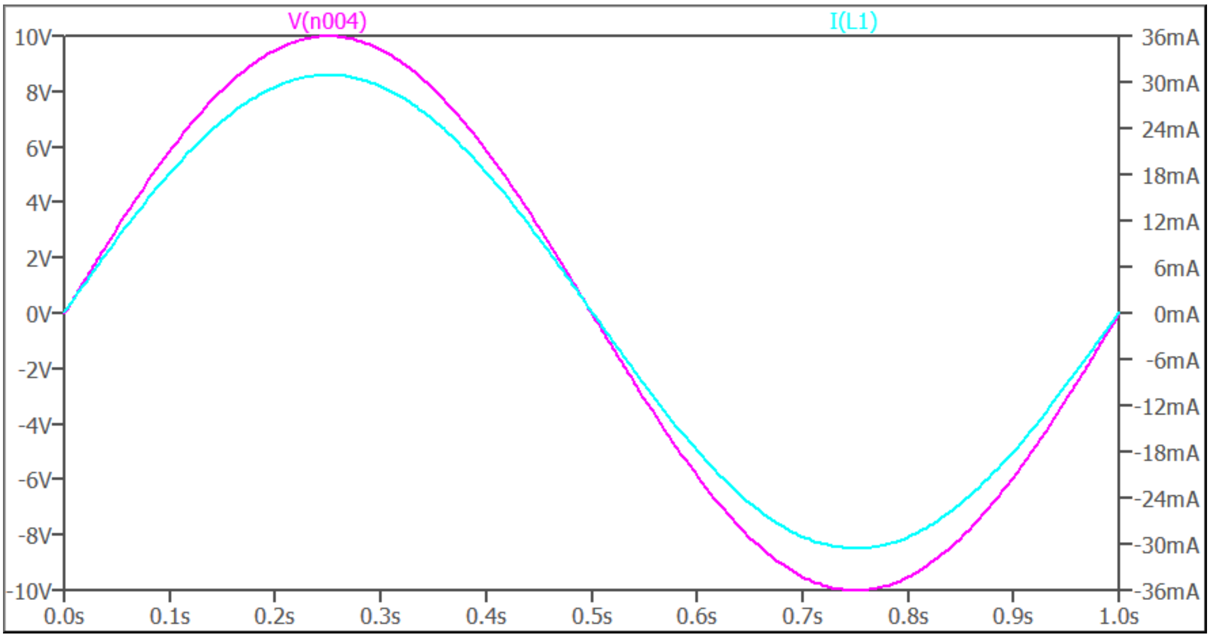

Fig. 8. Transfer function of servo valve driver, input *V(n004)* – fuchsia and output *I(L1)* – aqua

4. Conclusion

This paper presents formulas for implementing software for a PID controller, (2), (3), (4), (5) and fig. 1. The controller has advanced features such as anti-windup, derivative kick cancellation and closed loop regulation with relay. The control algorithm is tested by simulating a hydraulic servo cylinder consisting of a servo valve and a bilateral rod cylinder.
The paper also presents the original electronic diagram of the servo valve driver. The driver is built from a Howland voltage controlled current source adapted for H-bridge output. The circuit is simulated in the LTspice® simulator software.

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