Imitation Simulator for PID Controller Adjustment

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Abstract. The article contains the description of the structure and functionality of the developed imitation simulator of PID controllers adjustment, which makes it possible to setup their typical modifications on the example of a hypothetical technological process taking into account the peculiarities of real controllers and restrictions, introduced by actuators and control signals.

1. Introduction
The quality of technological processes of the continuous and hybrid productions is largely determined by the quality indicators of the transition processes of technological parameters. Despite the obvious progress and achievements in the field of automatic control theory, for the implementation of the required technological modes and achievement of quality parameters are still used primarily proportional-integral-differential (PID) controllers as relatively easy to configure and providing the necessary result [1-2].

The principles of construction, modification of PID controllers and methods of their adjustment, including experimental ones, are well enough researched and described in a wide range of sources, for example, in [2-6]. Programs of automated calculation of parameters, such as, for example, P.I.D.-Expert or PIDTune, and also the whole environments of dynamic modelling, such as MatLab Simulink, containing tools of autotuning taking into account restrictions, render invaluable help in adjustment of controllers.

However the first of them implement the "strict" model of adjustment which is limited by the underlying methods of calculation and often does not consider features of real controllers and restrictions [6-8], made by actuators and control signals; the second provide rich functionality, but require the development of specialized models, accounting for the features of the object and the actuator, the complexity and cost of which can exceed the effect obtained.

Therefore, to improve the quality of process control, it is important to develop a compromise application. On the one hand, it is built on the modular principle and allows to account for some or other (by connecting the appropriate modules) typical limitations in the setting and features of real PID controllers, depending on the process. And on the other, it is free from the need to develop full-featured models.

From the point of view of the authors, it is reasonable to combine the calculation module with the interface module, which will not simply provide the results of the setting in the form of numerical
values of parameters and transition diagrams, and additionally visualize the technological component of the process, in order to finally get a simulator for setting up PID controllers.

In the turn, simulators play a major role in the development of professional skills and competencies, as well as allow to fully master the nature of the processes that are necessary to acquire the profession.

2. Structure and functionality of the application
Two basic modules can be distinguished in the application: the calculation and the interface ones. As the calculation module assumes layout of conditions, based on the problem solved, it is a set of simulation subprograms, designed in the form of ready-made functional blocks that form the final program simulator [9-10].

In contrast to the dynamic simulation programs, these blocks are specified for specific application tasks (taking into account actuator limitations and a control signal type) and require a limited set of typical setting design parameters, the source of which are equipment data sheets and process guidelines.

Thus, the calculation module makes it possible to differentiate the PID controller setting process depending on the control signal and actuator type, together with significant actuator limitations. The differentiation involves the appropriate simulation subprogram [11].

For example, for a simple case where the control is carried out by an analogue set-point signal and the speed of the actuator is high enough, i.e. slightly impairs the dynamic performance of the system, it is possible to use the elementary simulation subprogram shown in Figure 1 (hereafter, for clarity, the object model is included in the simulation subprogram).

![Figure 1 - Simulation program with no actuator limitations](image-url)

This program in the simulator is used to calculate the reference setpoint value, expressed as a percentage, used to control the pump motor by a frequency inverter.

The PID controller generates the output value according to the law (1)

\[ Q_i = KP \cdot INP_i + \frac{KD \cdot (INP_i - INP_{i-1})}{\Delta t} + KI \cdot \Delta t \cdot \sum_{k=i}^{\infty} INP_k, \quad (1) \]

where INP - the value received at the input of the controller; i - the current clock; KP, KD and KI - coefficients at proportional, differential and integral components, respectively; \( \Delta t \) - recalculation period of the block in seconds (duration of the clock).

To describe the technological control object the first order inertial transfer function with delay (2) is used
where $K$ is the transfer coefficient, $T$ is the time constant, and $\tau$ is the delay of the control object [12].

In case of use of the PWM (pulse-width modulated) control signal and necessity to account for the resource limitation of the non-inertial actuator operation, it is possible to use a simulation program in Figure 2.

The program in the simulator is used to simulate PID temperature control in a reagent tank by controlling an electric heater with electric pulses of constant frequency and variable duration.

To convert the control signal of the PID regulator "PID" into a sequence of latitudinal-modulated pulses of single amplitude, the "IREG" unit is used. The pulse duration is determined by the formula (3)

$$ T_{imp} = \frac{T_{max} \cdot INP}{100}, \quad (3) $$

where $INP$ is the input value (INP) of the "IREG" block in the range [-100 ... 100]; $T_{max}$ is the maximum pulse duration in seconds. At $T_{imp} < T_{min}$, where $T_{min}$ - minimum pulse duration in seconds, the pulse is not generated [7].

The duration of the pause between pulses is defined as (4)

$$ T_{pause} = T_{max} - T_{imp}, \quad (4) $$

Certainly, the choice of $T_{min}$ and $T_{max}$ values should be made primarily based on the characteristics of the actuator, which is also worked out in this simulation model.

As long as the value at the input (INP) is non-negative, pulses are generated at the output (Up) and at negative values - at the output (Dn) [7]. Since the heater has no reverse mode (i.e. cooling mode), all control signals are removed from the output (Up).

Figure 2 – Simulation program for accounting of the actuator triggering resource and PWM control
To register the influence of the actuator frequency and reduce the depreciation of the switching equipment (actuator) of the heater let us use the block "Insensitivity Zone" DZONE. This block can be installed both in front of the "PID" block (in this case the insensitivity zone by reagent temperature would be entered) and in front of the "IREG" pulse controller (ignoring control pulses of short duration). We use the second solution (Fig. 2) due to the presence of thermal asymmetry of the object. This implementation provides a reduction in the number of starts in the area of the established value due to the fact that the small values of the control signal of the PID controller (block "PID"), arising from an insignificant mismatch and which requires a brief switching on of the heater, are ignored, and thus are considered equal to zero. A side effect of this solution is a decrease in control accuracy. The "Insensitivity Zone" unit works in the following way - as long as the value at its input (INP) is greater than the value of the insensitivity zone submitted to the input (DLT), the value itself from the input (INP) is transmitted to the output (Q). Otherwise, the output (Q) is zero [7].

As one more example let's review the simulation program of adjustment of the PID controller, taking into account as restrictions the speed and stroke (the "saturation" restriction type) of the integrating...
actuator type, and also influence of aperture smoothing and a zone of insensitivity on regulated technological parameter and a zone of insensitivity of the actuator. In addition, this program allows to work out the setting of the PID controller in a cascade control, in which the PID controller performs regulation of the technological parameter of the external circuit, and the three-position controller provides regulation of the technological parameter of the internal circuit on a signal of the PID controller task. In this case it is possible to directly control the three-step regulator in manual mode with ignoring the task signal from the external loop controller, which allows to work out such a feature of "behavior" of real PID controllers as integral saturation. The program simulates PID temperature control at the heat exchanger output by controlling the "More" and "Less" pulse width modulation of the reversing valve actuator that changes the fluid flow. The SHTOK block is responsible for the simulation of the actuator operation. This block allows you to set the full stroke time of the control valve stem, the amount of stroke, to monitor the limit switches on the position of the stem, and calculates the "real" position of the stem. The DZONE "Insensitive Zone" block allows for the implementation of a temperature insensitive zone. Thus, the mismatch values, smaller insensitivity zone values, will not arrive at the "PID" link input - the mismatch calculated by block "X-Y" ≠0 is zero and, accordingly, the controller will not generate an output signal. This will reduce the switching frequency of the executive device and thus increase its resource.

Figure 4 – The user interface of the application

The "Mode" parameter determines the choice of control mode: direct control mode of the actuator stem position (Mode=0) and automatic cascade control of the solvent temperature (Mode=1). The
value of the parameter is also used to stop the accumulation of integral component error and to prevent integral saturation in stem position control mode (automatic temperature control mode is disabled), in which Mode\(=0\).

To filter small changes in the control signal of the "PID" unit, an APERT aperture block is used to reduce the switching frequency of the valve actuator and to prevent frequent changes in the direction of the stem movement (reversal). The block implements the IF algorithm \[|\text{INP}-\text{IQ}|<\text{LIM} \text{ THEN Q:=IQ ELSE Q:=INP}\] [7].

Direct operator control of the stem position is implemented by the "Three-position Controller" PREG block based on threshold values compared to the current stem position (INP), calculated from the insensitivity zone on the valve stem position and the stem position setpoint (Handle position). Thus, control commands of the actuator are issued: at INP>MAX, the outputs QL=1, QH=0 (closing); at INP<MIN, the outputs QL=0, QH=1 (opening); at MIN<INP<MAX, the outputs QL=0, QH=0 (actuator stopped - value within the insensitive zone).

Since the program provides two control modes, the mode selection is organized by means of the "Choice of two" SEL blocks. This unit sends an output (SEL) value from the input ((IN0) or (IN1)) whose number is set at the input (IG) [7].

The interface part of the application makes it possible to evaluate the quality of setting of PID controllers for the considered typical applications (types of actuators, configurable limitations, applied control signals) and the overall process flow based on the analysis of numerical values of process parameters as well as tracking the dynamics of their change according to real-time graphs (trends).

In addition, the interface part increases the visibility of the process, thus simplifying the perception of information and increasing involvement in the training process, which has a positive impact on the results (quality) of training the trainee.

3. Conclusions

Therefore, the article considers the use of a simulator to improve the quality of process control, enabling to consider the necessary (by connecting the appropriate modules) typical limitations of actuators and features of real PID controllers and does not require the development of full-featured process models. The simulation program is formed, proceeding from a solved problem and conditions, in the form of the typical simulation subprograms designed as functional blocks.

The results of setting are visualized in the form of numerical values of parameters on the technological mnemonic scheme and graphs of their transition processes, which allows you to comprehensively assess the quality of PID controllers.

4. References

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