Self Tuning Techniques on PLC Background and Control Systems with Self Tuning Methods Design

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Abstract. *Advanced Process Control techniques have become standard functions of distributed control systems. Self tuning methods belong to Advanced Process Control (APC) techniques. APC techniques contain software packages for advanced control based on mathematical methods. APC tools are designed to increase the process capacity, yield and quality of products. Most of nowadays digital industry regulators and PLCs are provided with some kind of the self tuning constant algorithm. Practical part of the paper deals with design of the control systems which contain self tuning regulator. A control system with PID Self Tuner by Siemens and with visualization in WinCC is designed. There is a description of an implementation of the PID regulator as a function block which can be also used for extension control functions. Control systems for relay and moment self tuner with visualizations in WinCC are also designed.*

Keywords

Advanced Process Control, control system, PID controller, self tuning, PLC, visualization.

1. Introduction

It is not possible to increase demand for the performance, quality and efficiency of industrial processes without subvention of the control system. Control systems expansion is influenced by many improvements in the area of the microelectronics and application of the mathematical methods developed in control theory. APC (Advanced Process Control) methods are modern control methods which have been used in control systems.

All the PLC producers offer APC functions in their portfolio. APC contains software packages for advanced control based on mathematical methods. There are not only tools for self tuning, but also tools for manufacturing costs optimization and energy savings. APC tools are designed to increase the process capacity, yield and quality of products and for costs savings. These reasons have become very actual in nowadays, because of the worldwide economic depression. APC tools are implemented to DCS/PCS (Process Control Systems/Distributed Control Systems) based on the PLC (Programmable Logic Controller). Some of the methods are implemented directly to the PLC but the most of them are implemented as supervisory functions on higher level of the control system.

These functions offer diagnostic, monitoring and optimization functions for control implemented directly in the PLC.

2. Self Tuning Methods

The main part of the control systems are still the PID regulators. Control theory deals with definition of their parameters. The starting point of the PID regulator constants calculation is a simple experiment apart from the algebraic approach. A simplified system model is created on the basis of the experiment. The PID regulator constants are calculated from the parameters of the identified system model. The idea of the automation of this process is evident and the most of the PID controllers are equipped by some self tuning algorithm (self tuner).

There are several methods for tuning PID controllers. Generally it can be distinguished between model based self tuner and none model based self tuner. The controlled system is generally identified as three or four parameters model (a first-order system with time delay or a second order system with time delay) and the constants of the controller are calculated according to the identified model in the case of the model based self tuner. The constants of controllers are directly edited according to the parameters of the measured responses in the case of non-model based self tuner [1], [2].

The following text in this chapter describes the most used self tuning methods and their implementation in the commercial PLCs.

Methods based on step response are primarily used for the systems with slow response (e.g. temperature systems) and are based on measurement and evaluation of the step response of the controlled system as the reaction on the set point change. The controlled system is identified as three or four parameters model [3].

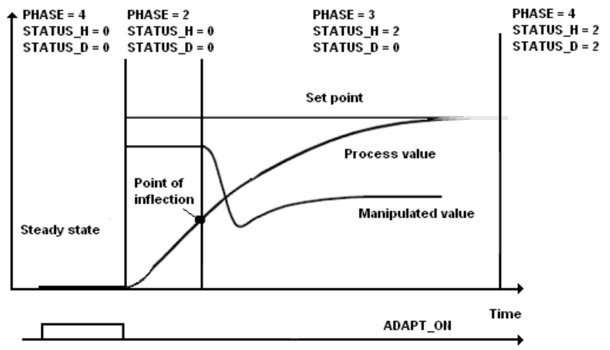

Fig. 1: The step response method by PID Self Tuner [3].

Implementation of this method is very common. PID Self Tuner by Siemens (Fig. 1), PIDE by Rockwell Automation, TUNE by ABB and Profit PID by Honeywell are based on the step response tuning method. Other PLC producers have also their own step response tuning method (B&R, Omron, GE Fanuc, Mitsubishi etc.).

The relay method comes out from the critical gain and the critical period of the controlled system. There are two modes: a setting mode and a control mode. The relay regulator is connected in the closed loop in setting phase. The process value oscillates along set point in closed loop with relay.

Controlled systems behaviour from the frequency point of view is generally a lowpass filter. This fact is used for approximate analysis of the controlled system.

The PID regulator constants are calculated from identified critical gain and critical period of the system by some control law, e.g. Ziegler-Nichols method.

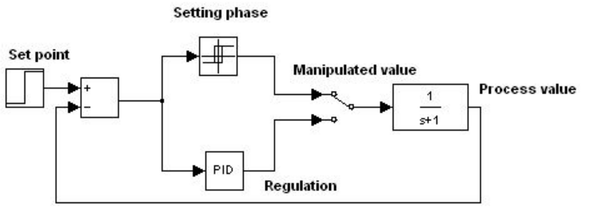

Fig. 2: The principle of the relay method.

Implementation of the relay method: Siemens S7 200, Bernecker&Rainer, Tecomat.

Another self tuning method is so called system moments method. This method was developed by Prof. Schlegel in ZCU Pilsen, Czech Republic. This method extends a control function of the standard PID regulator with self tuning method based on three characteristic process values determined by identification procedure based on suitable rectangle pulse [4].

An operator has to reach steady state of the controlled system, choose the type of the regulator and start identification procedure. Rectangle manipulated signal is then applied to the controlled system.

Three evaluated values have clear physical meaning: static gain, delay and reaction time. They are obtained from the first three moments of the system response. The parameters of the PID regulator are then calculated according to these evaluated values [4], [5].

There are other several self tuning methods implemented in PLCs.

EXACT method (Expert Adaptive Controller Tuning) is an out of date method developed and implemented in older versions of Foxboro PLCs. A principle of this method is the monitoring of changes of the set point, disturbance value and process value. Design or redesign of the regulator parameters is made according to evaluated responses. Latzel method, implemented in older PLC SIPARD DR21 by Siemens, uses evaluation of step response to design regulation parameters by optimum module.

There are many other methods for self tuning function including fuzzy logic, neural networks, genetic algorithms and their combinations.

3. Control System with PID Self Tuner

PID Self Tuner is a function block (FB50) in Step 7 TunPID Library by Siemens which offers self tuning. This block can be used for tuning parameters of PI/PID regulators in function blocks FB41, FB42, software packages Standard PID Control, Modular PID control and function modules FM 355C.

The use of the function block FB58 is another possibility. It can be primarily used for temperature system control and consists of self tuning algorithm and PID regulator. Parameters optimization is done by ADAPT_ON or ADAPT1ST block inputs. The first self tuning procedure is started by ADAPT1ST = TRUE. The self tuning algorithm is divided into several phases (Fig. 1).

Controlled system is simulated in the simulation software WINMOD. With reference to controlled system requirements a second order system with no delay is chosen.

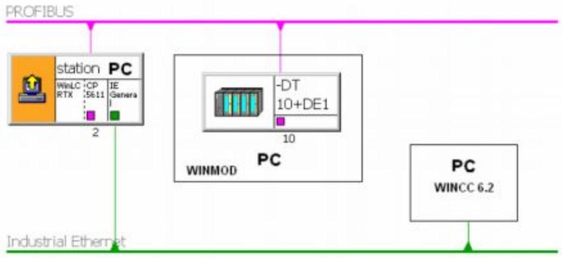

Fig. 3: Block scheme of the control system.

PC with simulation of controlled system is connected to a PC with software PLC by Profibus. Communication between PC with software PLC and PC with visualization in WINCC 6.2 is done through Industrial Ethernet. Software PLC SIMATIC WinAC RTX 2005 is suitable for control applications which require efficient control system, large data transfer, data processing and quick response in real time.

WinAC RTX 2005 works on a standard PC with operating systems Windows XP Professional or Windows XP Embedded. This configuration is named soft real time systems, because of non-deterministic operating systems with special kernel packages installed with WinAC RTX 2005 software.

3.1. PLC Program

Two programs for PLC were created. The first program consists of organization block OB35 where PID Self Tuner (FB50) and PID regulator (FB41) are placed. Author's own regulator was implemented and tested instead of the standard Siemens regulator FB41 for connection to PID Self Tuner. The regulator is connected to the PID Self Tuner in the second program for PLC.

PID algorithm of designed PID regulator operates as a position algorithm. Proportional, integral and derivative actions are connected in parallel form and can be activated or deactivated individually by setting zero to Kp and/or Ti and/or Td constants. This allows P, PI, PD, and PID controllers to be configured. Pure I and D controllers are also possible but not recommended [5], [6].

Implemented PID regulators have purely parallel form with filtration of derivation part (1)

$$G_R(s) = K_P + \frac{1}{T_I \cdot s} + \frac{T_D \cdot s}{\frac{T_D \cdot s}{\alpha} + 1}. \qquad (1)$$

Although transfer function (1) is not so often implemented in commercial PLC it brings some advantages [6].

To suppress a small constant oscillation due to the manipulated value quantization (for example due to a limited resolution of the manipulated value by the actuator valve) a dead band is applied to the error signal of the controller. Transfer function of PID regulator is in a component recursion form with filtration of derivate action value by a discrete analogy of continuous low pass filter. The PID regulator implements the control law with two degrees of freedom and anti-wind up.

It is possible to switch over four modes: an automatic, a semiautomatic, a direct and a test mode.

Priorities of modes (1-highest priority, 4-lowest priority):

1. test mode,
2. direct mode,
3. semiautomatic mode,
4. automatic mode.

The set point (chosen by RqAuto from HmiCmd UDT) is taken from the function block input Sp for calculation of the manipulated value in automatic mode. The set point Sp is established for the set point from the table or list of set points from optimization procedures or visualisation of technology in the automatic mode of control.

In the semiautomatic mode the set point (chosen by RqMan from HmiCmd UDT) is taken from HmiSp.ManSp for automatic manipulated value computation. The set point HmiSp.ManSp is established for the set point entered by operator from visualization.

The value ModeTestVal is directly copied from the function block input to manipulated value in the test mode (chosen by ModeTest from the function block input). This value is limited according OutHiLim and OutLolim values. The manual manipulated value ModeTestVal is intended for manual manipulated value setting from visualization. This mode corresponds with manual mode in classical PID functions blocks.

The value ModeDirectVal is directly copied from the function block input to manipulated value in the direct mode (chosen by ModeDirect from the function block input). This value is limited according OutHiLim and OutLolim values. The manual manipulated value ModeDirectVal is intended for the manual manipulated value setting directly from Step 7 software during commissioning. This mode corresponds with manual mode in classical PID functions blocks.

The simplified function block scheme of the implemented PID regulator is on Fig. 4.

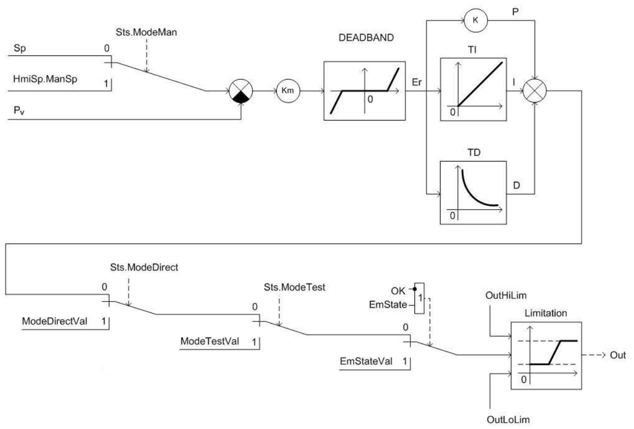

Fig. 4: The simplified function block scheme of the implemented PID regulator.

3.2. Visualization

Visualization of the control system was created in WinCC 6.2. The application consists of four windows. An operator can switch over windows by the help in the menu. The main window (Fig. 5) is divided into four parts, panels. Panel Control is at the top in the middle and allows controlling the tuning procedure. On the right side there is a panel for identification parameters of the controlled system. Visualization of the closed loop values is placed at the bottom panel. There are set point, process value, manipulated value and value in the test and directly mode (manual value). On the left side there is a panel where P, I and D constants and limits for manipulated values for identification are shown.

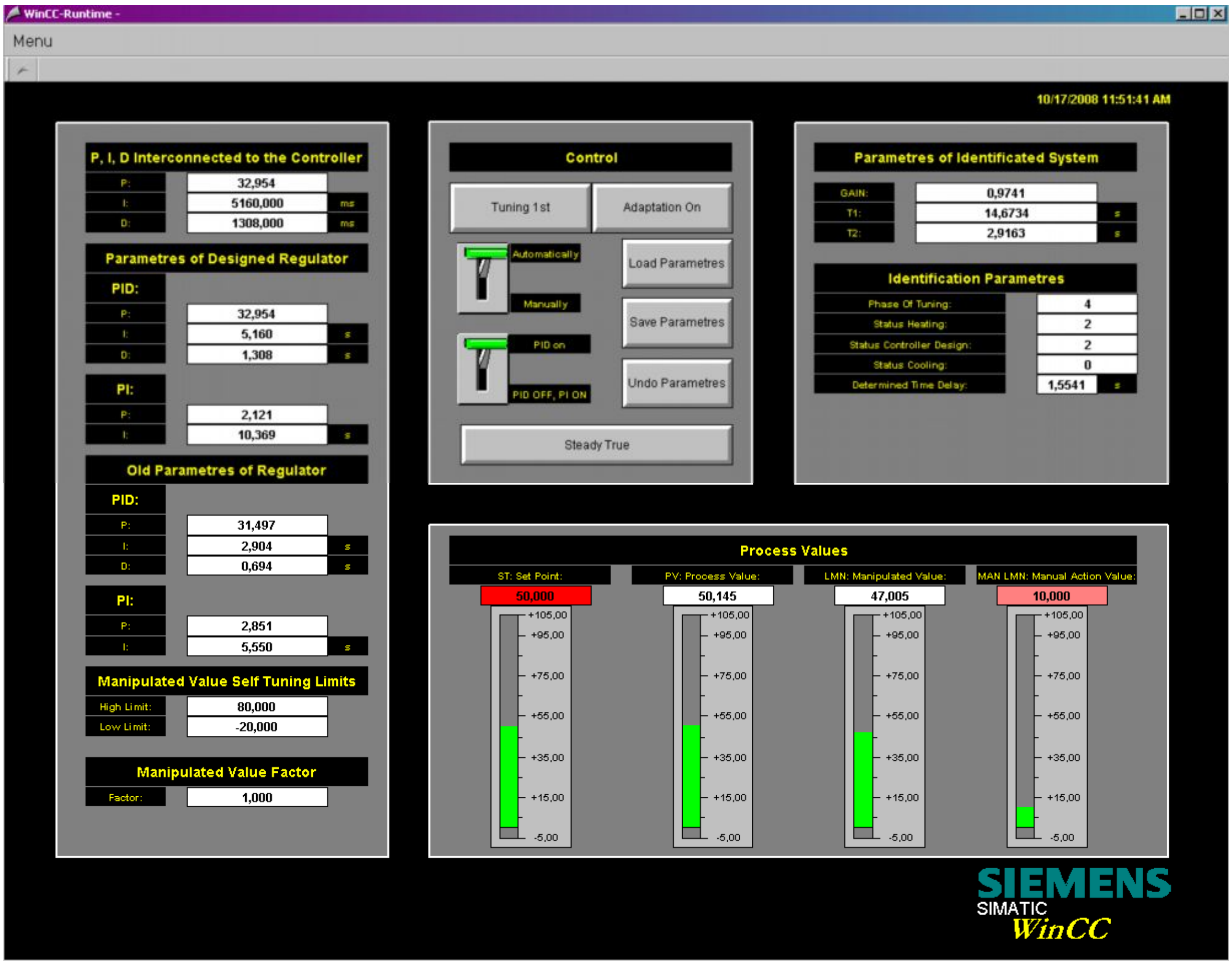

Fig. 5: The visualization main window.

4. Control System with Relay and Moment Self Tuner

The main advantage of Rex control system by *Rexcontrols* company (Pilsen, Czech Republic) is compatibility with Matlab/Simulink. User gets all its advantages for advanced regulation techniques design. Rex control system is used in PLC WinPAC or WinCON by ICPDAS. The RexCore (the kernel of Rex) is one of the tasks of Windows CE .NET deterministic operating system running in the PLC.

Function block PIDAT of Rex Library is equipped with self tuning relay method function. Function block PIDMA extends the function of the classical PID regulator by self tuning moment method [4].

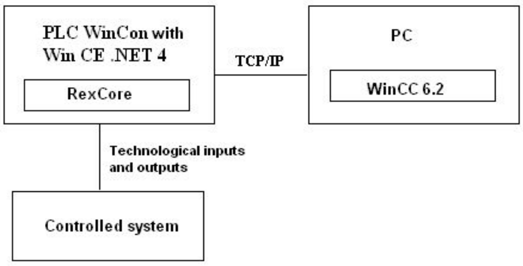

Fig. 6: Control system block scheme.

Block scheme of the control system design is shown on Fig. 6. Controlled system is connected to the PLC by technological inputs and outputs. Visualization is made in WinCC 6.2.

Control system simulation scheme with PIDMA function block in PLC WinCON with Windows CE .NET 4 is shown on Fig. 7.

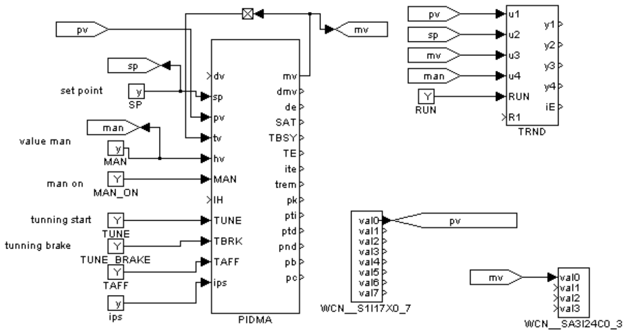

Fig. 7: Simulation scheme with PIDMA function block.

Figure 8 contains an example of identification procedure of moment method.

The visualisation of controls systems with both relay and moment self tuners (Fig. 9) are similar to the main visualisation window of control system with PID Self Tuner shown on Fig. 5.

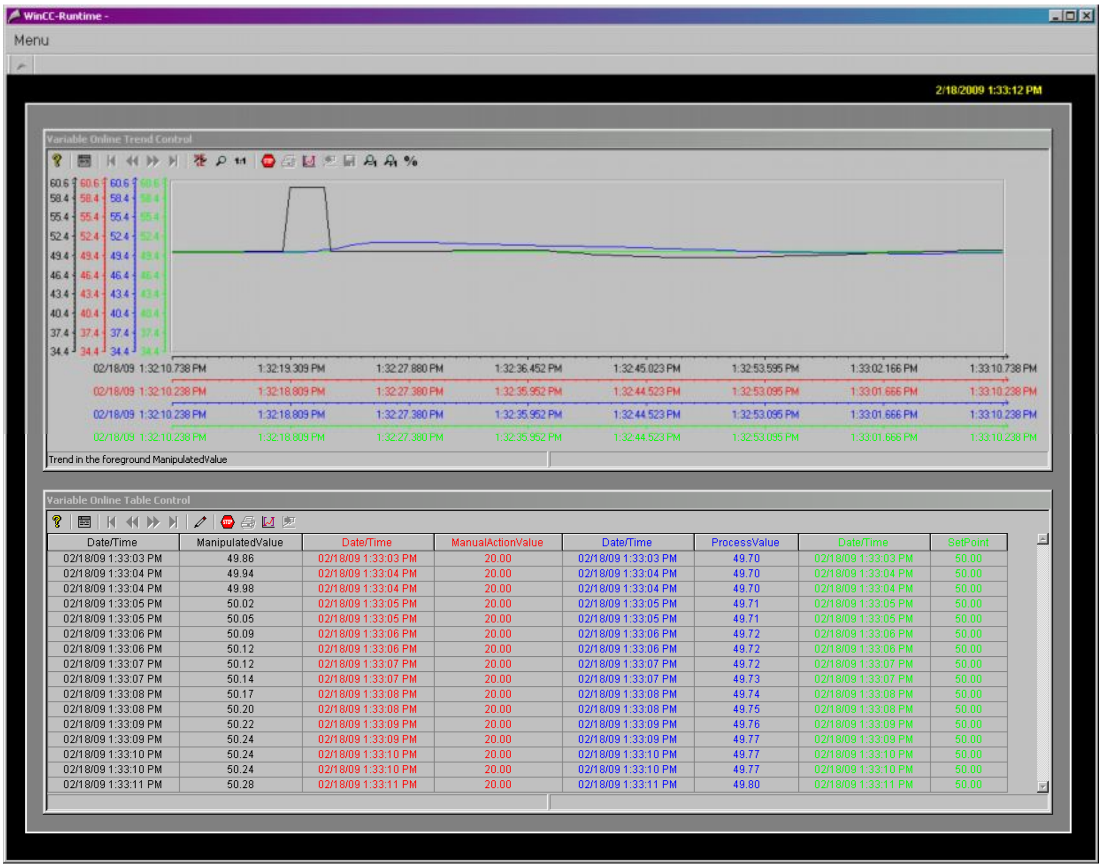

Fig. 8: Identification procedure of the moment method.

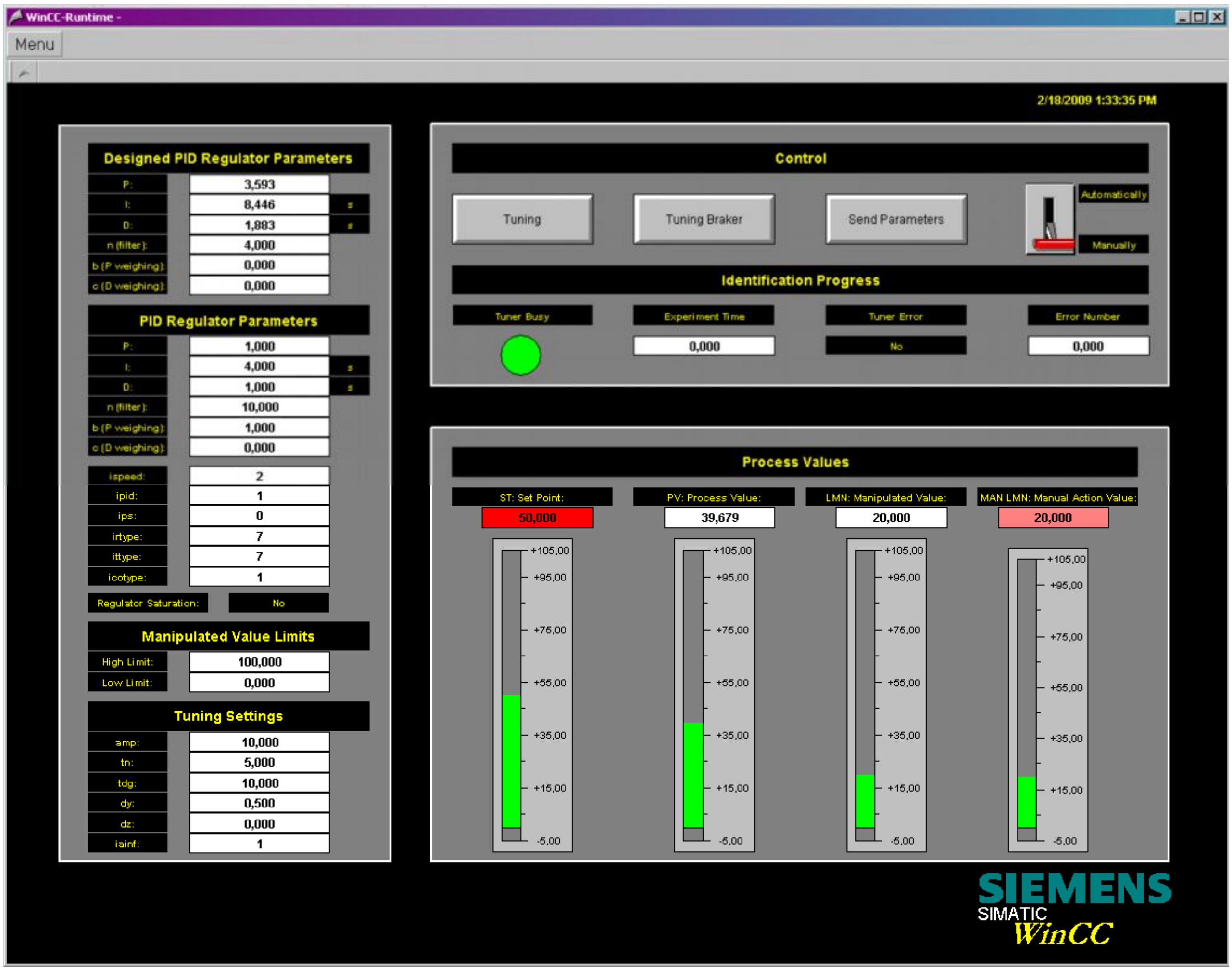

Fig. 9: The visualization of the moment self tuner.

5. Example of PID Regulator Design

Parameters of the PID regulator design are shown for the controlled system with the transfer function (2)

$$G(s)=\frac{1}{(10\cdot s+1)\cdot(s+1)}. \tag{2}$$

The PID Self Tuner, the relay self tuner and the moment self tuner is used for design parameters of the PID regulator for the controlled system with (2) transfer function. Table 1 contains identified parameters of the controlled system by the PID Self Tuner and Tab. 2 PID regulator parameters calculated by the PID Self Tuner.

Table 3 contains regulator parameters by the relay self tuner and Tab. 4 regulator parameters by the moment self tuner.

In the automatic mode, function blocks PIDAT (relay self tuner) and PIDMA (moment self tuner) implements the PID controls law with two degrees of freedom in the form with weighing factors “b” (for proportional part weighing) and “c” (for derivation part weighing).

Tab.1: Identified parameters by PID Self Tuner.

Gain	1,023
T_1 [s]	9,415
T_2 [s]	0,657

Tab.2: Regulator parameters by PID Self Tuner.

P	16,047
I [s]	2,302
D [s]	0,426

Tab.3: Regulator parameters by the relay self tuner.

P	6,658
I [s]	3,473
D [s]	0,743
N	10
b	0,436
c	0

Tab.4: Regulator parameters by the moment self tuner.

P	6,841
I [s]	3,234
D [s]	0,834
N	4
b	0
c	0

The comparison of the step responses for the PID Self Tuner, the relay and the moment self tuner is shown on Fig. 10.

Similar parameters of the PID regulator design are typical for the relay and the moment tuner. The PID Self Tuner by Siemens has different proportional part of the regulator due to the fact that the PID Self Tuner is primarily used for temperature controlled systems so that a bigger proportional part of the regulator is needed.

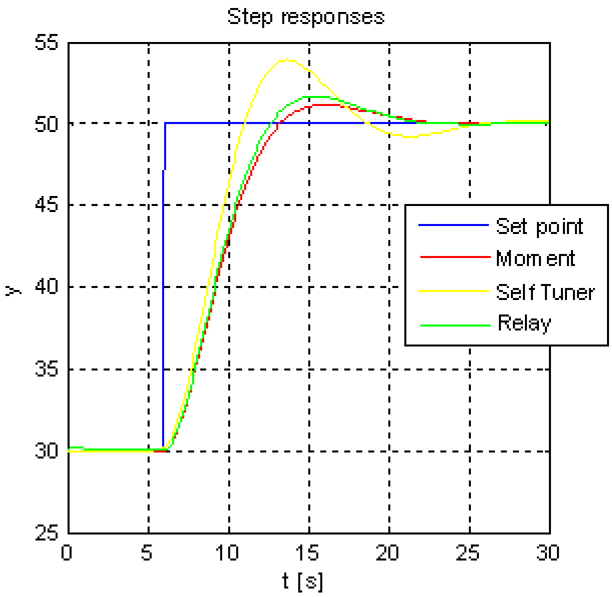

Fig. 10: Control system block scheme.

It is possible to set up slow, normal or fast closed loop speed for the moment self tuner as a parameter of the function blocks of these self tuners.

Moment methods have small overshoots of process value in normal closed loop speed and no overshoots in slow closed loop speed.

6. Conclusion

A description of advanced process control and self tuning techniques on PLC background including self tuners for PID regulator is described in the theoretical part of this paper.

Practical part of this work contains control systems design with self tuning controllers. Step response method is most widely used by PLC producers for self tuning functions.

Control system with PID Self Tuner for PLC Simatic S7 300/400 with visualization in WinCC is introduced. Author’s own PID regulator, designed to control the processes with the PID Self Tuner, implements the PID controls law with two degrees of freedom.

The second practical output of this work includes control systems design for relay and moment self tuners with visualization in WinCC. The relay and the moment self tuner function were also tested on real controlled system.

Example of the PID regulator design and evaluation of suggested controller parameters is the last part of this work.

Acknowledgements

This work is supported by company Ingeteam a.s. based in Ostrava and also by grant of the Grant Agency of the Czech Republic GA102/08/1429 - Safety and security of networked embedded system applications.

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