Second-order aperiodic link modelling with the use of Siemens programmable logical controller SCL hardware

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Abstract. The paper focuses on the features of modelling the elements of control systems using non-standard tools, in particular, based on the resources provided by industrial logic controllers. The authors point out the features of implementing such models, the control program for an industrial logical controller, as well as the forwarding algorithm for control data to regular simulation modelling tools. A comparative study of the obtained properties with models built in the environment of engineering computing proved to be appropriate to use such hardware and software to solve problems of that kind.

1. Introduction

Modelling of various facilities and control systems using standard hardware and software is supposed to be a relatively trivial task nowadays. Solving this kind of management problems can be difficult mostly when choosing and implementing a management procedure for sophisticated technological facilities, the input information is inaccurate and incomplete. Regarding the peculiarities of applying intelligent approaches to describe regulatory items and implement control laws [1], the applicable nature of their implementation through real industrial equipment which is often already used seems be the most relevant. The use of such equipment places many additional limitations on the modelling process, which be determined by small computing resources, and, consequently, the high-speed response problem [2-4]. An essential part of industrial equipment and computing instruments used in automatic process control systems at machine builders are arranged using integrated solutions of some very small number of developers, including programmable logical controllers, different types of sensors, actuating devices, sectionalized and proportional valves and so on [5-9]. What is more, most processes controlled by programmable logic controllers are typical. They are aimed at solving problems of maintaining pressure or amount used in various environments, stabilizing any sort of process variables at a given level. When solving such control problems, control facilities are approximated productively by second-order aperiodic links [10, 11].

The paper deals with the task of modelling a second-order aperiodic link by a numerical technique in SCL language of Siemens programmable logic controllers and comparing the results with a model implemented by customary engineering computing tools.
2. The application of the model of the second-order aperiodic link by the numerical technique

The mathematical description that is behind the implemented model of the second-order aperiodic link is used for constructing an intelligent control system for the complex processing of oxygen consumption in a gas-oxygen lance of an electric-steelmaking furnace and is its primary part, which determines the possibility of synthesizing control procedures for this item.

The second-order aperiodic link can be represented using elementary units, and its detailed structural chart is shown in Figure 1.

![Figure 1. The structural chart of the second-order aperiodic link.](image)

The differential equation implements the mathematical model of the link shown in Figure 2:

\[
\frac{d^2 y}{dt^2} + \frac{dy}{dt} \cdot k_2 + y(t) \cdot k_3 = x(t) \cdot k_1
\]  

(1)

where

\[
k_1 = k_3 = \frac{1}{T^2}, \quad k_2 = \frac{2d}{T}
\]  

(2)

here \(T\) is the link-time constant, \(d\) is the damping coefficient.

As can be seen from the expression (1) for the successful solution of the equation, it is necessary to determine the derivatives of the first and second order. Considering that control systems with industrial controllers grade the discrete systems and they are considered to be digital and manipulate numerical sequences obtained during digitization, solving differential equations is possible only by numerical techniques if the resources are limited. Real items, as a rule, have large time constants; therefore, numerical techniques of calculation can be used for such facilities, which allow obtaining good results with a small quantization interval.

Let us write the finite-difference equation 1:

\[
y(t') = \sum_{i=0}^{n} \frac{y_{i-1}(2+k_2 \Delta t)-y_{i-2}+x_{i-1} \Delta t^2}{1+k_2 \Delta t+k_3 \Delta t^2}
\]  

(3)

here \(t'\) is a conditional, discrete/sampled time.

Then the value of the function at the current quantization interval:

\[
y_i = \frac{y_{i-1}(2+k_2 \Delta t)-y_{i-2}+x_{i-1} \Delta t^2}{1+k_2 \Delta t+k_3 \Delta t^2}
\]  

(4)

We carry out the rearrangement of the equation (4) and substitute the coefficients (2)

\[
y_i = \frac{\frac{y_{i-1}(2\tau^2+2\tau d \Delta t)-y_{i-2}\tau^2+x \Delta t^2}{\tau^2+2\tau d \Delta t+\Delta t^2}}{T^2+2Td \Delta t+ \Delta t^2}
\]  

(5)
There is a result of the regular algebraic equation. In the following, the type of constant coefficients needs to be defined that be calculated when the controller is restarted or when the parameters of the calculation unit are changed. This procedure speeds up the calculation process much more and decrease the computation load on the programmable logic controller.

\[
y_i = \frac{y_{i-1}(2T^2+2Td\Delta t)}{T^2+2Td\Delta t+\Delta t^2} - \frac{y_{i-2}T^2}{T^2+2Td\Delta t+\Delta t^2} + \frac{x\Delta t^2}{T^2+2Td\Delta t+\Delta t^2}
\]

\[
k_1 = \frac{2T^2+2Td\Delta t}{T^2+2Td\Delta t+\Delta t^2}
\]

\[
k_2 = \frac{T^2}{T^2+2Td\Delta t+\Delta t^2}
\]

\[
k_3 = \frac{\Delta t^2}{T^2+2Td\Delta t+\Delta t^2}
\]

The final form of the equation:

\[
y_i = y_{i-1} \cdot k1 - y_{i-2} \cdot k2 + x \cdot k3
\]  

(6)

3. The synthesis of the control program

The program for calculating the main features of the objective function is performed using SCL language. The main purpose of it is to implement complex algorithms or solve problems related to the field of data management and mathematical calculations [12, 13]. This is what determines the choice of this programming language for developing a program unit for calculating the values and coefficients of the objective function. The Siemens programmable logical controller family supports programming in IEC 61131-3 languages, including SCL. A fragment of the program for calculating the values of the polynomial (6) in SCL for the Siemens industrial controller has the following notation presented below.

```scl
FUNCTION_BLOCK FB1
VAR_INPUT
  x : REAL;
  T : REAL: = 1.0;
  D : REAL: = 0.9;
  Ts : REAL: = 0.01;
END_VAR
VAR
  y_n_1 : REAL;
  y_n_2 : REAL;
END_VAR
VAR_TEMP
  k1, k2, k3 : REAL;
END_VAR
VAR_OUTPUT
  y : REAL;
END_VAR
BEGIN
  k1 := (2*T*T+2*T*D*Ts)/(T*T+2*T*D*Ts+Ts*Ts);
  k2 := (T*T)/(T*T+2*T*D*Ts+Ts*Ts);
  k3 := (Ts*Ts)/(T*T+2*T*D*Ts+Ts*Ts);
  y := y_n_1*k1-y_n_2+x*k3;
  y_n_2 := y_n_1;
  y_n_1 := y;
END_FUNCTION_BLOCK
```
The structure of the program unit corresponds to the language standard and is described in detail in [12, 13]. The block number may be random, not involved in the user program. The input and output signals, link parameters and quantization intervals are described in the interface part. The coefficients and values of the function in the previous calculation intervals are stored in the static area. In addition, the block call should be organized from a watchdog interrupts with a constant call interval equal to the quantization interval.

Figure 2 shows the transient implemented by the computing instruments of the Siemens programmable logical controller when a single step signal with the following parameters is supplied to the model input $T = 1.0$ sec., $d = 0.9$, $\Delta t = 0.02$ sec.

![Diagram of the transient in the system during modelling Siemens programmable logical controller.](image)

**Figure 2.** Diagram of the transient in the system during modelling Siemens programmable logical controller.

4. Analysis of models implemented using various approaches

For verifying the model validity implemented by the Siemens programmable logical controller, we simulate the link shown in Figure 1 using the Simulink environment. OPC (Open Platform Communications) connection is organized to transmit the data obtained during simulation of the second-order aperiodic link using the Siemens programmable logic controller to Matlab engineering computing language. Transmitting data through this type of connection is a simple and effective way of connecting two heterogeneous systems which include Simulink environment and the Siemens programmable logical controller. The structural diagram of the model used in comparative modelling is shown in Figure 3.

![Block diagram of the model in Simulink.](image)

**Figure 3.** Block diagram of the model in Simulink.
Comparative modelling in Simulink software showed suitable convergence property of the numerical calculation method used. The transient process when a unit step signal simulated in a programmable logic controller is fed to the input using Simulink is shown in Figure 4.

![Figure 4](attachment:image.png)

**Figure 4.** Transient graphs for the second-order aperiodic link:
1 - model implemented based on a programmable logic controller;
2 - model implemented in Simulink environment.

The analysis of transients presented in Figure 4 shows a reasonable degree of accuracy when implementing the mathematical formulation of the second-order aperiodic link by non-standard modelling instruments. The inappreciable variances that take place in the transient performance are caused by the discreteness of the model signal processed by the numerical method and are attributed to the processing power limit when transmitting data from a programmable logic controller via an OPC server.

5. Conclusion
To sum up, the models of elementary links implementation through the example of a second-order aperiodic link using the computing capabilities of industrial machinery, allows the authors obtaining a mathematical formulation of the controlled system of satisfactory accuracy, taking into account the limited resources of the facilities used. Besides, it should be noted that modelling and data transmission was carried out exclusively using programming tools of logical process controllers.

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