

VIRTUAL CONTROL SYSTEM OF EXOTHERMIC REACTOR USING THE CONTROLLER KRGN 90

VIRTUÁLNY RIADIACI SYSTÉM EXOTERMICKÉHO REAKTORA NA BÁZE KRGN 90

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Abstract

This contribution presents both the design and the realization of one unit of a virtual lab. The lab includes two autonomous objects. First object is a virtual model of a technological process, in this paper represented by a nonlinear model of an unstable continuous stirred tank reactor. Second one, as industrial controller has been used the virtual controller KRGN 90. Two illustrative time responses of control processes are included in the paper, related to two control parameter settings.

Príspevok prezentuje riešenie virtuálneho laboratória. Laboratórium obsahuje dve samostatné časti. Prvú tvorí virtuálny model technologického procesu, ktorý je v príspevku reprezentovaný nelineárnym modelom exotermického reaktora. Ako priemyselný regulátor bol použitý virtuálny model regulátora KRGN 90. V príspevku sú uvedené aj ilustračné príklady.

Key words

technological process, industrial programmable controller, simulation of non-linear dynamic systems

proces technologický, regulátor priemyselný programovateľný, simulácia nelineárných dynamických systémov

Introduction

A virtual environment application for education process is an effective tool, providing some advantages in comparison to classical approaches:

- Virtual processes are cheap; they can be used without a technical support and maintenance.
- Virtual reality because of its software nature offers high flexibility and reliability during its use.
- Virtual solution can be effectively used in e-learning application and distance education as well.
- There is a possibility to build virtual technological cells, production units and factories, too.

At Department of Information Technology and Automation, the research in the above mentioned topic has been started on the level of virtual technological processes and virtual industrial controllers two years ago. Nowadays, two types of virtual controllers, KRGN 90 (Trellis Trenčín) and UDC 3000/3300 (Honeywell) are available for a practical education purposes. The following virtual processes have been still realized:

- Hydraulic systems with one, two or three tanks.
- Universal non-linear dynamic model of a 3rd – order system.
- Unstable continuous stirred tank reactor controlled by the feed temperature.
- Exothermic continuous stirred tank reactor controlled by coolant temperature.

This paper presents design, realization and demonstration of an exothermic reactor controlled by the virtual eight-loop industrial controller KRGN 90.

The structure of the paper is as follows:

- The next section presents a non-linear dynamic model of an unstable continuous stirred tank reactor in the form of non-linear system of differential equations.
- The brief description of the program implementation of the virtual exothermic reactor is given in the following section .
- A separate short section is devoted to a virtual controller KRGN 90 description.
- An illustrative example of the virtual reactor controlled by the virtual controller KRGN 90 finishes the paper.

Non-linear dynamic model of a continuous stirred tank reactor

An unstable continuous stirred tank reactor has been chosen for an implementation as a virtual one in this paper. The simple exothermic reaction is of the first order $A \rightarrow B$. The scheme is given in the Fig. 1.

The dynamic non-linear model is represented by two first-order non-linear differential equations. The first one simulates a material balance of the reactant A :

$$\frac{dC_A}{dt} = \frac{q}{V}(C_{Af} - C_A) - k_0 \frac{E}{RT} C_A, \quad (1)$$

where

C_A is concentration of reactor contents

C_{Af} - feed concentration of reactant A

$\frac{E}{R}$ - reduced activation energy

k_0 - preexponential factor

q - feed flow rate

t - time variable

T - reactor temperature

V - reactor volume.

The second equation describes a dynamic of enthalpy balance:

$$\frac{dT}{dt} = \frac{q}{V}(T_f - T) - \frac{\Delta H}{\rho C_p} k_0 \frac{E}{RT} C_A + \frac{UA}{V\rho C_p}(T_c - T), \quad (2)$$

where

C_p is heat capacity of reactor contents

T_c - coolant temperature

T_f - feed temperature

UA - heat transfer coefficient

$-\Delta H$ - heat of reaction

ρ - density of reactor contents.

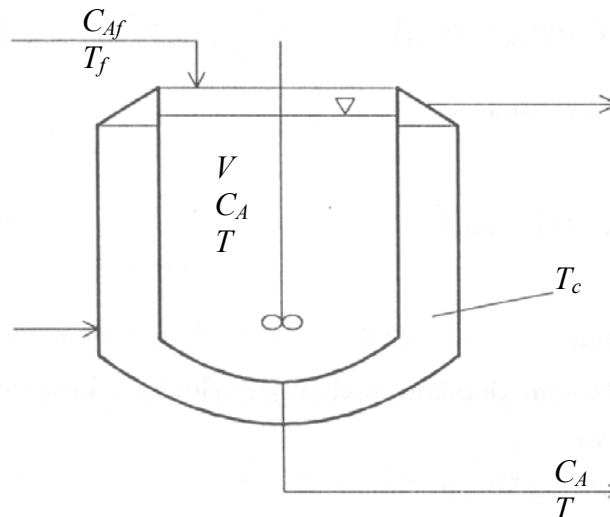


Fig. 1: Unstable continuous stirred tank reactor [6]

The manipulated variable is the coolant temperature T_c and the controlled variable is the reactor temperature T . C_A is the effluent concentration. C_{Af} , T_f and q are respectively the feed concentration, temperature and flow rate.

Program implementation of the virtual reactor

The dynamic model of the reactor is non-linear, thus a suitable method of a numeric integration has to be chosen. From the accuracy, rate and convergence points of view, the Runge-Kutta method of 4th order has been chosen [6]. The core of this method is given by expressions (3) and (4):

$$x_{k+1} = x_k + \frac{1}{6}k_1 + \frac{1}{3}k_2 + \frac{1}{3}k_3 + \frac{1}{6}k_4, \quad (3)$$

where

$$\begin{aligned} k_1 &= hf(t_k, x_k) \\ k_2 &= hf\left(t_k + \frac{1}{2}h, x_k + \frac{1}{2}k_1\right) \\ k_3 &= hf\left(t_k + \frac{1}{2}h, x_k + \frac{1}{2}k_2\right) \\ k_4 &= hf(t_k + h, x_k + k_3) \end{aligned} \quad (4)$$

The error of this method is approximately $O(h^4)$ [2] only.

Before the implementation, the equation (1) and (2) has been rewritten because of faster computation into more suitable form of the following differential equations:

$$\begin{aligned} \frac{dx_1}{dt} &= k_1(c_{Av} - x_1) - y \\ \frac{dx_2}{dt} &= k_1T_v + k_4T_c - (k_1 + k_4)x_2 - k_3y \end{aligned}, \quad (5)$$

where

$$\begin{aligned} y &= x_1 k_0 e^{-\frac{k_2}{x_2}}; \quad x_1 = C_A; \quad x_2 = T \\ k_1 &= \frac{q}{V}; \quad k_2 = \frac{E}{R}; \quad k_3 = \frac{\Delta H}{\rho C_p}; \quad k_4 = \frac{UA}{V\rho C_p} \\ k_0 &= 7,2 \cdot 10^{10} \text{ min}^{-1} \\ C_A &= 9,3413 \cdot 10^{-2} \text{ mol.l}^{-1} \\ C_{Af} &= 1 \text{ mol.l}^{-1} \\ \frac{E}{R} &= 8750 \text{ K} \\ q &= 100 \text{ l.min}^{-1} \\ T &= 385 \text{ K} \\ V &= 100 \text{ l} \\ C_p &= 0,239 \text{ J.g}^{-1} \cdot \text{K}^{-1} \\ T_c &= 311,1 \text{ K} \\ T_f &= 350 \text{ K} \\ UA &= 5 \cdot 10^4 \text{ J.min}^{-1} \cdot \text{K}^{-1} \\ -\Delta H &= 5 \cdot 10^4 \text{ J.mol}^{-1} \\ \rho &= 1000 \text{ g.l}^{-1} \end{aligned}$$

The controlled variable is the reactor temperature T , the steady state value of this temperature is approximately 385 K; this value represents Set Point for the controller.

A disturbance process variable is the feed reactant concentration C_{Af} . For the simulation, the interval 0.9 to 1.1 mol.l⁻¹ of the values has been chosen. The lower limit of this interval leads to unstable processes of non-controlled reactor. In the opposite, the upper value of this variable results in slow aperiodic dynamic of the system.

The control action is performed by temperature control of the coolant T_c , which is supposed in the operating interval 273 to 373K.

Virtual Controller KRGN 90

The virtual controller KRGN 90 is an simulation model of the industrial programmable controller with eight independent control loops designed for small and middle control applications to monitor and control tens to hundreds information points. Its application topic is mainly in building management systems, glass, chemical, food and other industrial control systems.

For the virtual representation, there an analysis of the control functions has been performed. Thus, the virtual controller has implemented subset program modules of the original controller firmware. For the illustration, the view on the operator interface is given in the Fig. 2. There are keys for the SET POINT changing, AUTO or MANUAL mode of the specified loop setting, manual OUTPUT operating. The monitoring of the control process is available by following displays SET POINT, PROCESS and OUTPUT respectively. The alarms of different signalization and deviation bargraphs monitoring are available too. The development of the virtual controllers KRGN 90 has been accomplished by [8] and [7].

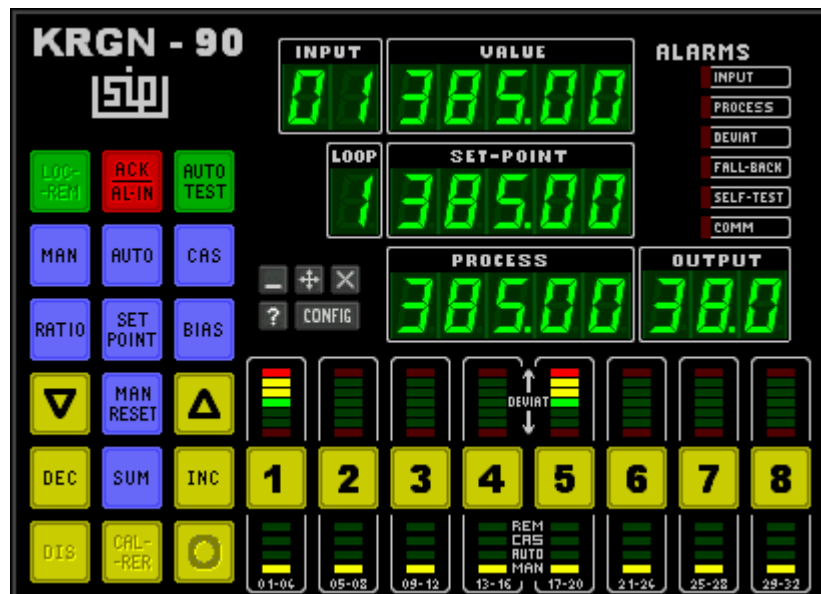


Fig. 2. View on the operator interface

Illustrative example

For the demonstration purpose, two cases have been simulated by two sets of the control parameters GAIN, RESET and RATE of the virtual controller KRGN 90. On the presented

Figures, the time responses of the reactor temperature T [K] and the reactor concentration C_A [mol.l⁻¹] are depicted. The time axis is in units of seconds.

Both the controller parameters settings have been simulated for the step changing of the feed concentration C_{Af} (disturbance) from 1.0 to 0.9 mol.l⁻¹ in time $t = 18$ s.

The responses in the Fig. 3 and 4 correspond to the controller setting GAIN = 0.4, RESET = 0.015 s⁻¹ and RATE = 0.0 s.

The same initial conditions have been used for the second simulation experiment, but with GAIN = 0.4, RESET = 0.015 s⁻¹ and RATE = 15 s (See Fig. 5 and Fig. 6).

The rapid improving of control process dynamic is evident after setting the D-part of control action (RATE = 15 s), see Fig. 4 and 6 respectively.

Conclusions

Virtual technological processes and virtual controllers have become cost-effective tools for virtual laboratories building [9]. Their advantages are relevant in the area of e-learning, distance education and web application [3] and [4], as well. The above presented virtual model connected to the virtual controllers KRGN 90 and UDC 3300 has been successfully used for the operator training during training courses, which has been organized by the Department of Information Technology and Automation in year 2005 in Pro CS Šaľa, Rautenbach Žiar nad Hronom and Continental Púchov.

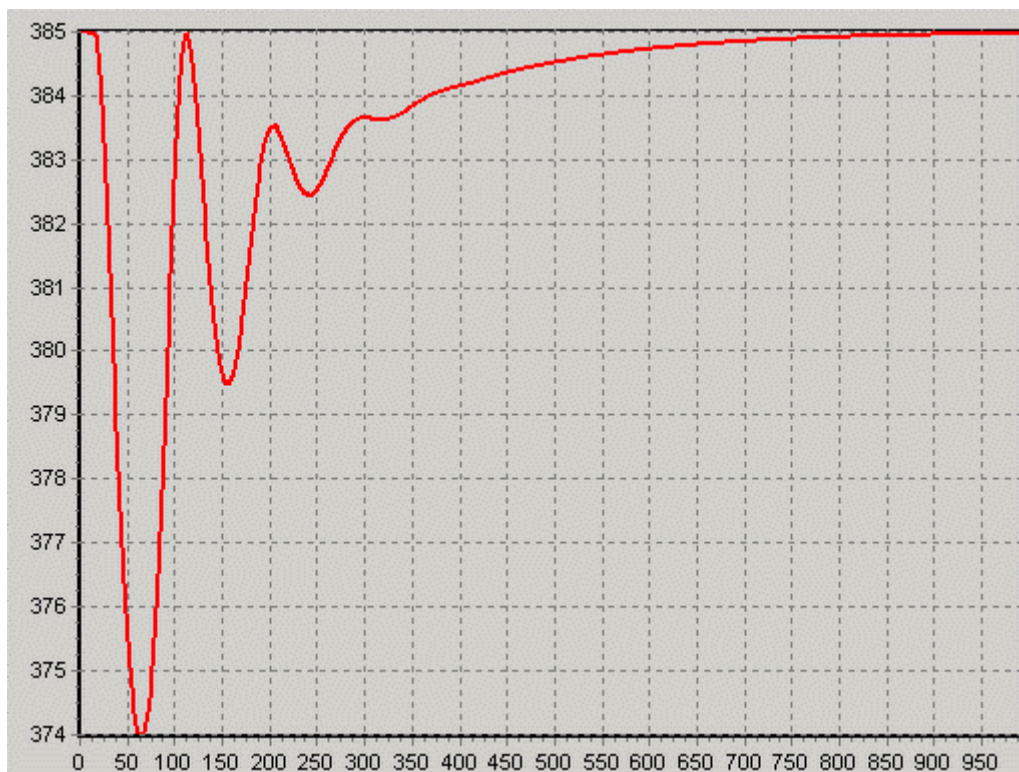


Fig. 3. Temperature time response

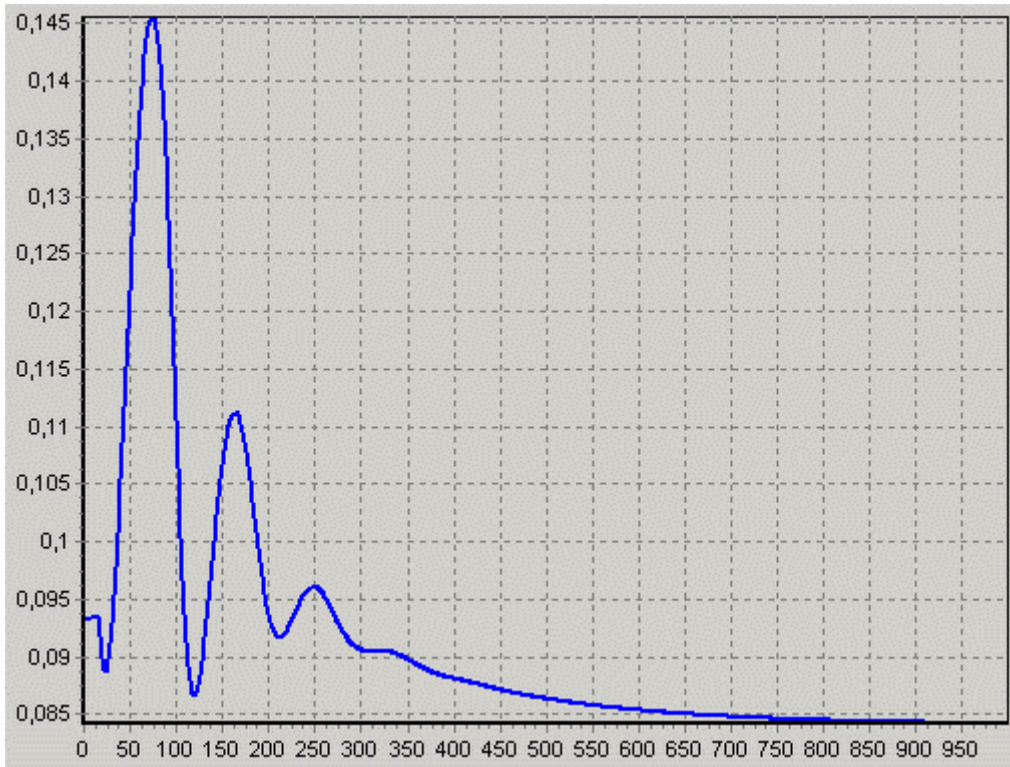


Fig. 4. Concentration time response

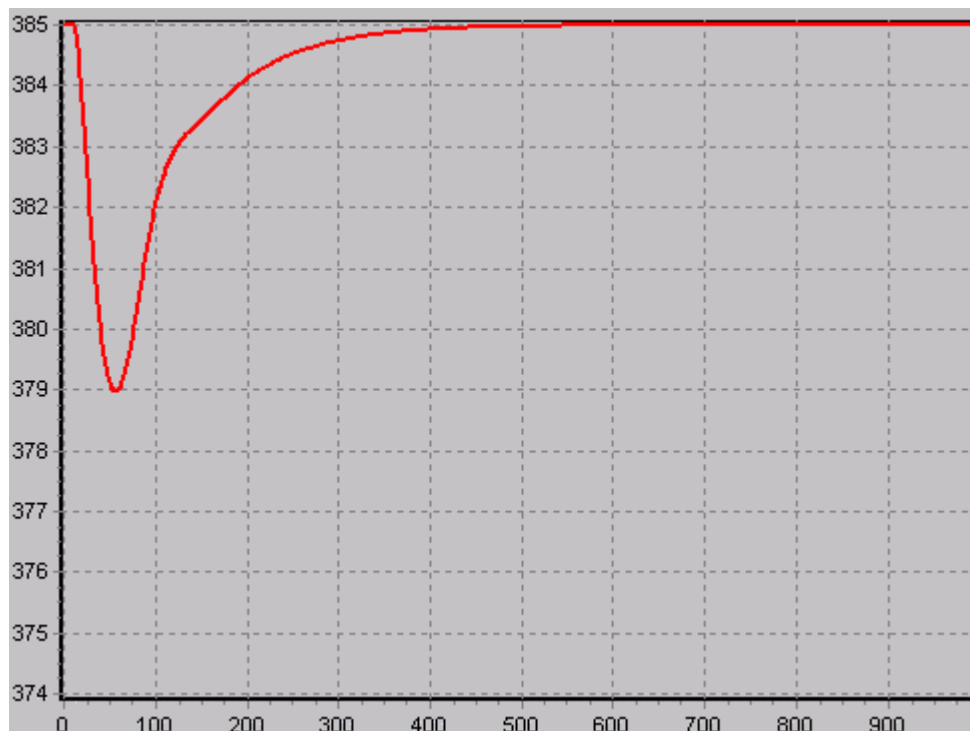


Fig. 5. Temperature time response for RATE = 15s

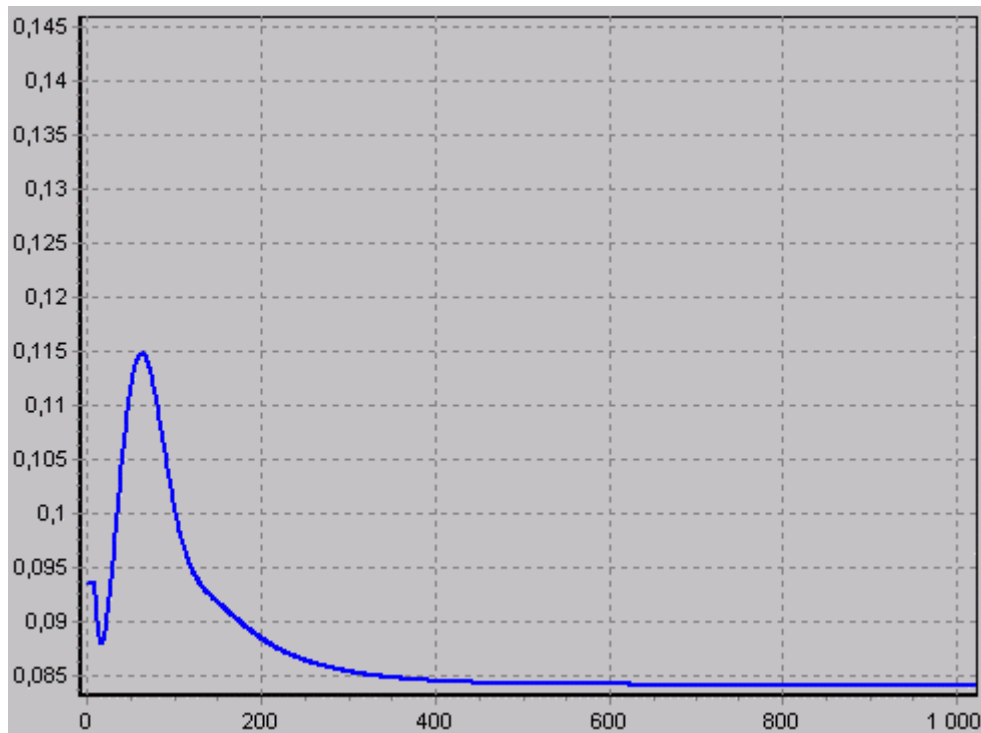


Fig. 6. Concentration time response for $RATE = 15s$

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