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Identification of the Unknown Parameters of an Object

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Introduction

The modelling of the control system starts from the definition of the system model structure, which defines the deployment of the system components in the environment as well as the links among these components. One of the main problems of the control is the identification of the parameters of the controlled object. The control designer must have the most exact possible mathematical description of the object. The evaluation of the precision of the control object becomes relevant only when the system is working under unforeseen conditions. This way, the initial conditions may differ from the calculated ones, whereas the control and measurement signals may be distorted by noises that were not evaluated during the design of the control system. The model of the object is necessary while controlling the process with serious delays compared to the main time constant of the process or for regulating a non-linear process. These cases cannot be resolved in a satisfactorily way by a standard PID process control therefore the model corrector is used. However, it may be necessary to create a model of the object for any stable and aperiodic processes in any order whatsoever. That is why it is important to have as much information on the controlled object as possible while designing the control. In addition, during the development of a control system, simulations can verify that the implemented algorithms work as expected.

In this article, the problem of the identification of the parameters of the unknown object in the closed loop system using the black box identification mode is researched. For this, a communication link between Matlab and the programmable logic controller (hereinafter PLC) is used. The control system is created in the PLC. The PLC processes the control and measurement signals and the design of the object model is executed in Matlab and is based on the received parameters. The adequacy of the model of the object for a real object is tested in Matlab in real time.

The training panel (see Fig. 1) simulates the process of a chemical reaction vessel model, including the ability to control the temperature and the feeding level. Together with the control function of the PLC it is possible to solve various exercises of control engineering.
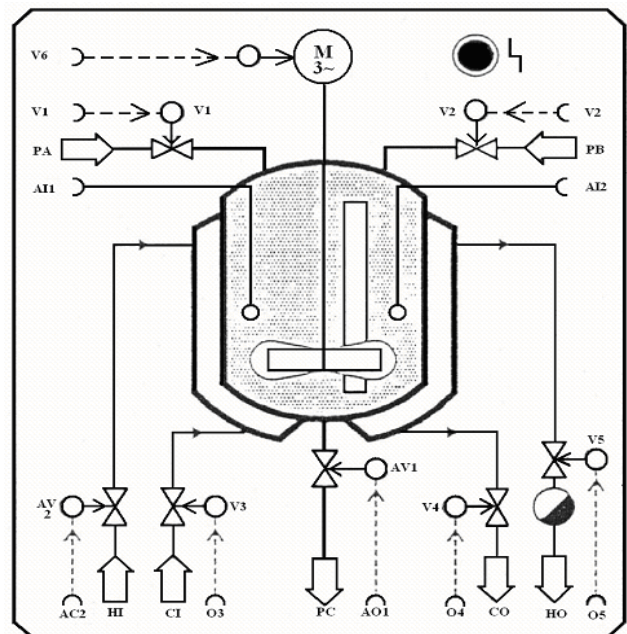

Fig. 1. The process of a chemical reaction vessel

The reaction vessel is equipped with a double-walled jacket. The heating and cooling medium can be pumped through the interstice of the vessel. The drainage quantity of the final product C1 (PC), i.e. the draining of the vessel, is continuously adjustable via an analog control signal AV1 (actuator). The proportional valve AV2 is used as the actuator in order to continuously adjust the inflow quantity of the heating medium. The heating medium circulation is only active when the outflow valve V5 opens towards the direction of the condenser and when the inflow valve AV2 is open. The valve V3 opens the inflow of the cooling medium. The cooling medium circulation is only active, when the inflow valve V3 and the outflow valve V4 are open.

The temperature of products A1 and B1 (via valves V1 and V2) as well as the temperature of the medium in the

cooling circuit (V3 and V4) are simulated with 5 degrees Celsius. The temperature of the medium in the heating circulation is simulated with 100 degrees Celsius (AV2, V5). The limiting temperature values, for the final product C in the vessel, range from a minimum of 5 degrees Celsius to a maximum of 100 degrees Celsius. In case the cooler products A1 or B1 are added to the already warmed up final product C1, then a fall in the temperature occurs accordingly to the mixing ratio of the cold and warm vessel substances.

The vessel has the ability to enable natural heat exchange with the environment, which is always active, even when no heating or cooling functions are carried out.

The method for evaluating the parameters of an object

The overall system structure of the estimation of the parameters of an object is shown in Fig. 2.
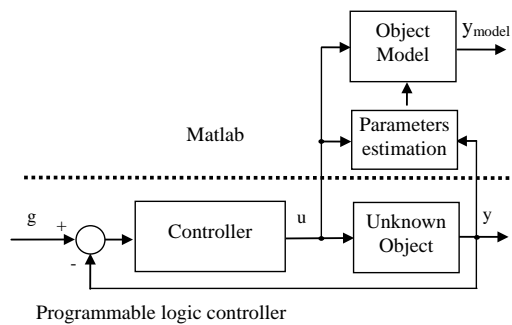

Fig. 2. System structure of the estimation of the unknown object parameters

The object is connected to the PLC Modicon 140 CPU 650 50, which has a realized control system and measures the input u and output y signals of the object. A single pole low pass input filter processes the output signal y of the object; the resolution of the A/D converter is 15 Bit; the signal is measured with an absolute accuracy error at 25 °C that equals $\pm$ 0.03%. 12 Bit D/A converter processes the input signal u of the object; accuracy error at 25 °C equals $\pm$ 0.15% of the full scale.

One way to access the data in the PLC is through the Wonderware Modicon Modbus Ethernet I/O Server. To enable real time communication between the I/O server and Matlab a gateway is implemented in C++. The Modicon Modbus Ethernet I/O Server is configured as written in [1].

The estimation of the parameters of an unknown object is conducted in such order:

1. The control system is designed in the PLC by implementing a standard PID control of an unknown object to meet the minimum performance specifications.

2. The interval for reading data from the PLC is indicated – 100 ms.

3. A step input signal g of the control system is applied. Based on the values of the object's input and output signals in the closed loop system the parameters of the object transfer function are obtained [2].

4. The adequacy of the system model response to the real object response to the same input signal g is

verified by calculating the arithmetical mean of the response error.

$$AME = \frac{1}{n}\sum_{i=1}^{n}|e(i)|, \qquad (1)$$

here AME is the arithmetical mean of the response error; n is the number of points of the calculated response error. The response error e (hereinafter response error) between the responses of the real (unknown) object and the model of the object into the input is calculated

$$e = y - y_{model}. \qquad (2)$$

The identification of the parameters of the heat exchange transfer function

Below there is presented an approach for identifying the parameters of the object for the heat exchange in the reactor vessel model. In fact, the object model obtained through the described procedure is generally good.

Firstly, a temperature control PI controller is designed in the PLC for the product of the chemical reaction vessel model. The controller output – the manipulated variable u (inflow valve AV2) is determined through the discrete PID closed-loop control algorithm, based on the controlled variable y (product C1 temperature) and reference variable g (desired product C1 temperature) (see Fig. 3).
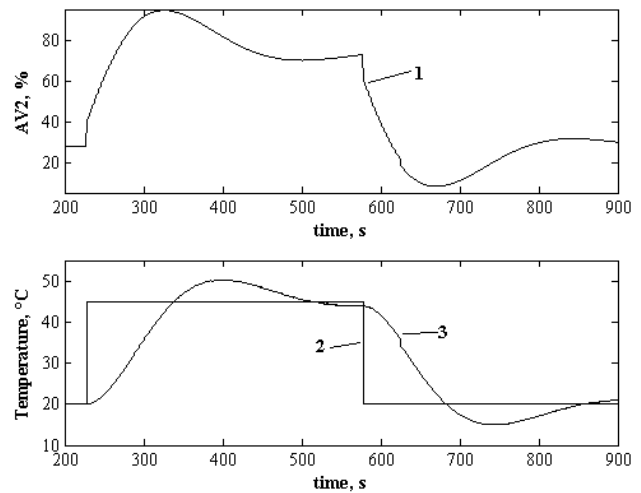

Fig. 3. System response to 45°C step input, when the agitator V6 is switched „On" and the vessel level is 40%; 1 – control signal u, 2 – reference input g, 3 – process variable y

The simplest model structure that is often a first choice is ARX [2]. The ARX model is a linear difference equation that relates the object input u (inflow valve AV2) to the output y (product C1 temperature)

$$y(t) + a_1 y(t-1) + ... + a_{n_a} y(t-n_a) =$$
$$= b_1 u(t-n_k) + ... + b_{n_b} u(t-n_k-n_b+1) + e(t). \qquad (3)$$

The structure is thus entirely defined by the number of poles n_a, the number of zeros n_b+1, and the actual time delay in the system n_k. The percentage of the output

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variations that were reproduced by the ARX models varied from 62 to 95.

Another choice is to use the Output-error (OE) model [2], which estimates the parameters of the output-error model and their co-variances from input u and output y data

$$y(t) = \frac{B(q)}{A(q)} u(t - n_k) + e(t), \quad (4)$$

here n_k is the input delay. The orders of the numerator and denominator polynomials are n_b and n_a. The percentage of the output variations that were reproduced by the OE models varied from 96 to 99.

The transfer function of the heat exchange of the reaction vessel model was defined as

$$W(s) = \frac{0.01488s^4 - 0.0033s^3 - 5.953s^2 + 1.32s + 0.0002603}{s^4 + 397s^3 + 157.1s^2 + 2.498s + 0.0006291}. \quad (5)$$

It can be seen that order of the transfer function is higher than order of the object transfer function given in [3]. The responses of the system and the model of the object to the system's step reference signal has been researched (see Fig. 4.).
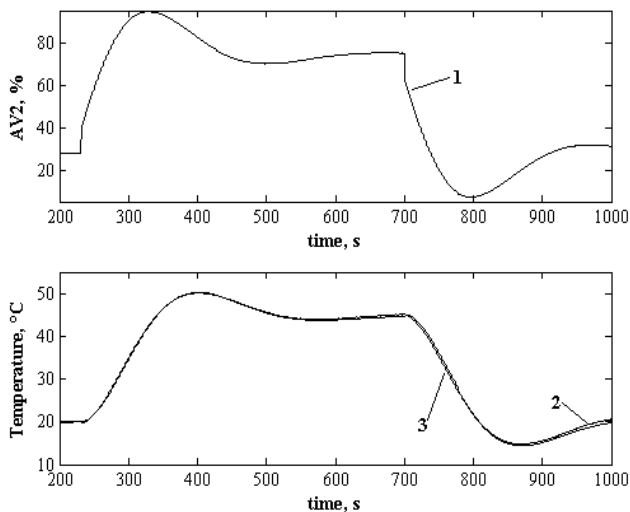

Fig. 4. System response to 45°C step input, when the agitator V6 is switched „On" and the vessel level is 40%; 1 – control signal u, 2 – process variable y, 3 – object model variable y_{model}

The variation of the response error e is presented in Fig. 5. The arithmetical mean of the response error value is 0.3273.

Judging by the responses from the system and the model of the object (see Fig. 4-5) to the system step input it can be concluded that the order of the model, which was higher than the actual plant order allowed to minimize the response error.

The next step will be examining the responses of the model of the object and a system, with a capacity level increased up to 60%, to the step reference signal of the system. The arithmetical mean of the response error value is 1.6627.
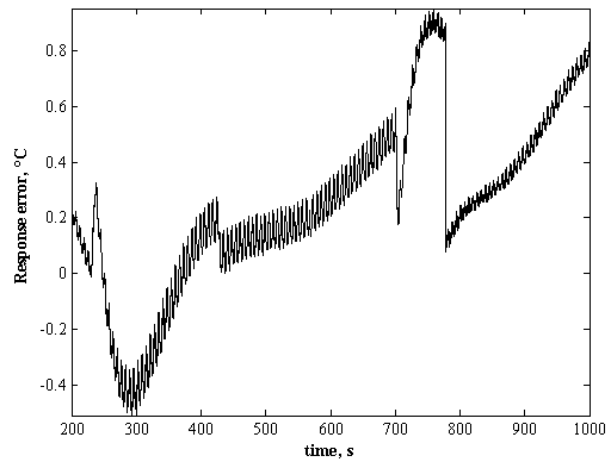

Fig. 5. Response error to the input signal of the system

The defined transfer function (5) shows that the heat exchange is a stable process. The responses of the system and the model of the object to the step control signal u have been researched (Fig. 6.).
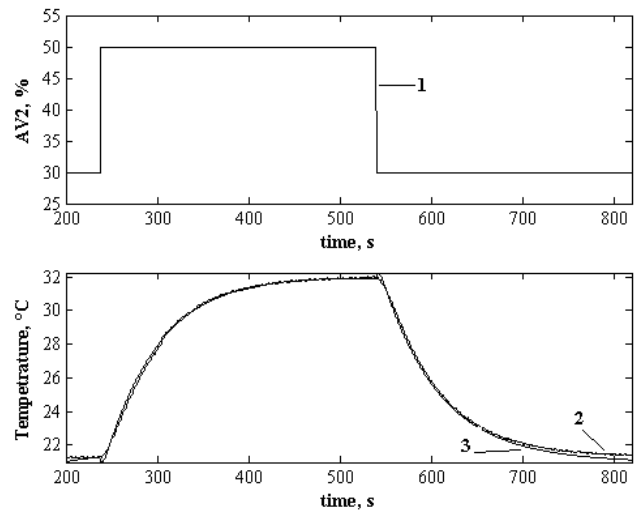

Fig. 6. System response to 50% step control signal u (1), when the agitator V6 is switched „On" and the vessel level is 40%; 2 – process variable y, 3 – object model variable y_{model}
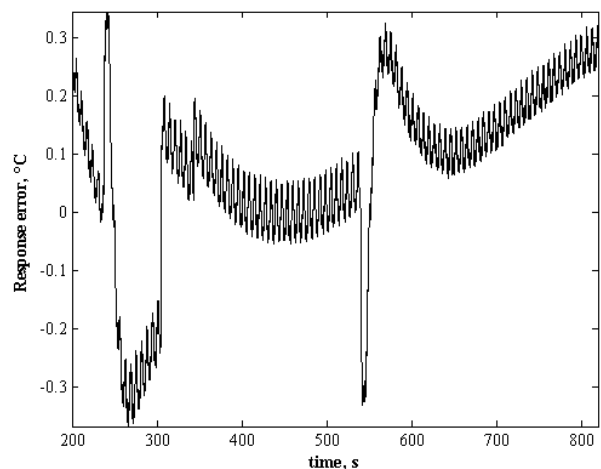

Fig. 7. Response error to the step control signal

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It can be concluded that the response of the model of the object follows the system's response to the step control input with a small error. The arithmetical mean of the response error value is 0.1351.

Based on the responses (see Fig. 4 and Fig. 5) of the system and the model of the object to the step control signal it can be concluded that after the settling time, the error between the output values of the process and the model fluctuates in a fixed interval, because the control signal is constantly changing.

In addition, it can be stated that the vessel level influenced the response accuracy of the model of the object. The accuracy of the model of the object and the response error also are affected by the temperature measurement accuracy (it depends on the update time of the PLC analog modules), PLC program cycle and data interchange speed.

Conclusions

The identification problem has been a long-lasting problem in the PLC applications. The ultimate goal of this research is to provide a method for identifying possible industry models.

The following observations were made based on such results: the reaction of the most carefully examined controlled process to a changing reference signal is approximated by Output-error (OE) model, when the order of the model is at least two times bigger, than the order of the process.

The accuracy of the model of the object is mostly influenced by the accuracy of the measurement of the signals.

There was no significant increase in the AME value after changing the feeding level of a real process. Such observed behaviour is valid in the analyzed case, and the AME could be higher in the case of high-order object if its parameters were different from those chosen in the present work.

References

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2. **Ljung L.** System Identification Theory for the User. – Prentice Hall PTR, Upper Saddle River, NJ, 2nd edition, 1999. – 609 p.
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L. Balasevicius, G. Dervinis, V. Baranauskas, A. Derviniene. Identification of the Unknown Parameters of an Object // Electronics and Electrical Engineering. – Kaunas: Technologija, 2010. – No. 4(100). – P. 33–36.

There is presented the method for finding the unknown parameters of an object in Matlab environment. The method is based on the use of input and output data of the process, controlled by a programmable logic controller (PLC). The method for determining the parameters is based on an autoregressive model that has an outer input and output error model. The method was used to find the heat exchange transfer function in the reactor vessel model. Verification has been made of the adequacy of the response of the obtained heat exchange model to the reaction of a system, controlled by PLC. By using the responses of the system and the model of the object, it was found that obtained model does a good approximation of a product's heat exchange process. Based on the obtained results it can be concluded that the results confirm the idea for finding the parameters of an unknown object, when the object is in a closed loop system, which tries to stabilize the system. Ill. 7, bibl. 3 (in English; abstracts in English, Russian and Lithuanian).

Л. Балашявичюс, Г. Дервинис, В. Баранаускас, А. Дервинене. Идентификация неизвестных параметров объекта // Электроника и электротехика. – Каунас: Технология, 2010. – № 4(100). – С. 33–36.

Представлен метод идентификации в программном пакете Матлаб неизвестных параметров объекта. Метод основан на использовании входных и выходных данных процесса, управляемого программируемым логическим контролером (ПЛК). Метод определения параметров использует модель авторегрессии с внешним входом и модель ошибки выхода. Метод использован для определения передаточной функции теплообмена продукта в модели реактора. В Матлаб среде в реальном времени проверена адекватность реакции полученной модели теплоотдачи, реакции ПЛК управляемой системы. С реакций системы и модели теплоотдачи установлено, что полученная модель хорошо аппроксимирует процесс теплообмена продукта. Основываясь на полученных результатах можно утверждать, что результаты подтверждают идею определения параметров неизвестного объекта, когда объект находится в замкнутой системе управления, которая пытается его стабилизировать. Ил. 7, библ. 3 (на английском языке; рефераты на английском, русском и литовском яз.).

L. Balaševičius, G. Dervinis, V. Baranauskas, A. Dervinienė. Nežinomų objekto parametrų identifikavimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2010. – Nr. 4(100). – P. 33–36.

Pateiktas objekto nežinomų parametrų nustatymo „Matlab" aplinkoje metodas, pagrįstas programuojamojo loginio valdiklio (PLV) valdomo proceso įvesties ir išvesties duomenimis. Parametrų nustatymo metodas remiasi autoregresiniu modeliu su išoriniu įvesties ir išvesties paklaidos modeliu. Metodas panaudotas produkto šilumos perdavimo funkcijai nustatyti reaktoriaus talpyklos modelyje. „Matlab" aplinkoje realiu laiku patikrintas gauto šilumos perdavimo modelio reakcijos adekvatumas PLV valdomos sistemos reakcijai. Iš sistemos ir objekto modelio reakcijų nustatyta, kad gautas modelis gerai aproksimuoja produkto šilumos perdavimo procesą. Remiantis gautais rezultatais galima teigti, jog rezultatai patvirtina nežinomo objekto parametrų nustatymo idėją, kai objektas valdomas uždaroje valdymo sistemoje, kuri stengiasi jį stabilizuoti. Il. 7, bibl. 3 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).