Objects Identification in a Loop with PID controller

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Abstract – **This paper presents an experimental method for collecting data on processes identification. The data is acquired by an experiment, conducted in a closed loop with a PID controller. For the purposes of the experiment, a critical operating mode is achieved. The analytical expressions of the amplitude frequency characteristic and the phase-frequency characteristic are used for the definition of two parameters.**

Keywords – **Object control by a PID controller, Critical operation mode in a closed loop, High order models**

I. Introduction

During the identification of the controllable objects (CO), there is a search for an analytical model, based on experimental readings. The analytical models are suitable for repeatedly reproduction of experiments with the real physical objects with reasonable accuracy - independently of or jointly with measuring and/or controllable devices (CD). Analytical models are most frequently used for laboratory setting of the elements of the controllable device, by the CD system simulation with CO or for producing scaled (reduced or enlarged) physical models [1].

Collecting informative data is a very important stage of the identification, by which an adequate analytical model of the physical processes can be evaluated [2]. The proposed identification method has the following characteristics (advantages):

Informative identification data is collect by experiment, for which a conventional PID controller [3, 4] is sufficient in a circuit for constant operating with CO

The method is applicable to high order models [5] with transportation lag (Straits models).

II. Theoretical Setup of the Identification Method

The proposed identification method calculates the parameters in the model of CO, using the experimental results from the critical process in the loop and the analytical expressions for: amplitude frequency characteristics (AFC) and phase-frequency characteristics (PFC).

The analitical expressions of the frequency characteristics (FC) for the proposed model are found according to the rules of the control theory (CT) and they contain manifestly and most frequently non-linear the unknown parameters.

The experimental results for the amplitude and the phase are measured from a critical operation mode of the object in the closed loop. Eventually, the task becomes solving a system of non-linear equations, according to the unknown parameters. Fig. 1 shows the indications of the signals in the loop CD and CO. These indications are used in the paper.

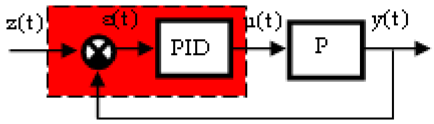

Fig. 1. Indications of the signals in a loop with a PID controller

It is indicated in the figure:
P – Controllable object;
PID – Control device (PID controller);
z(t).- Reference value (set point);
u(t).- Control signal sent to the system(control signal) ;
y(t) – The measured output of the system(process variable);
y(t)-z(t)= ε(t) – error value (system error).

The identification method of CO uses experimental data collected from the critical operating mode of the loop. The critical operating mode is well presented in CT but the well-known Nyquist stability criterion for stability of linear systems presents best the critical mode. Fig. 2 shows the amplitude-phase-frequency characteristics of the open structure:

$W_{OC}(j\omega) = W_{PID}(s)*W_P(s),$

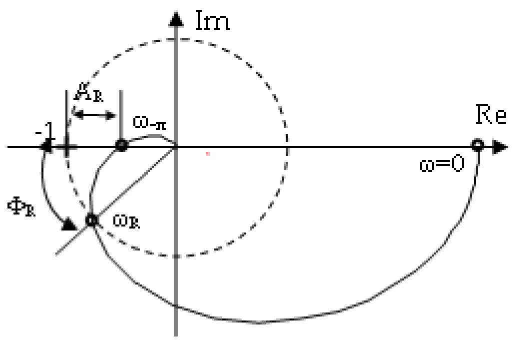

Fig. 2. APFC characteristics of the open structure

In Fig. 2 by A_R and Φ_R are marked the corresponding stability margins.

According to the Fig. 2.the critical operating mode represents the case when amplitude-phase-frequency

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characteristics (APFC) crosses the real axes, in the point *(-1,j0)* (theNyquist point). It is known from the CT, that the crossing is impossible in case of first and second order transfer functions (TF) $W_{OC}(j\omega)$ without transportation lag. Therefore it is considered the case of third and higher order TF.

On the other hand, it could be written for the common TF (controller + object) P mode,

$$W_{OC}(j\omega) = W_{PID}(s)*W_P(s)=K_{PID}*K_P*\frac{B(s)}{A(s)} \qquad (1)$$

where: K_{PID}– static coefficient of the controller in P mode.
K_P– static coefficient of the controllable object.
$\frac{B(s)}{A(s)}$ – fractional-rational part of the common TF.
It follows from the last expression:

1. We could change the APFC by increasing (decreasing) K_{PID}, so it could cross the real axes in the Nyquist point, or we could set the loop by the contoller to operate in the critical mode.
2. If the controller is only proportional (only *P*), the rest of the TF is exactly the TF of the object, or $K_P*\frac{B(s)}{A(s)}=W_P(s)$, which gives us a reason to think that the parameters of the critical operating mode are only parameters of the object, on which the proposed method is based.

The basic parameter which characterizes the critical operating mode is the critical frequency - $\omega_{кр}$, that is the frequency at which:

The module| $W_{oc}(j\ \omega_{кр})| = A(\omega_{кр}) =1$
and the phase $arg(W_{oc}(j\ \omega_{кр})) = \Phi(\omega_{кр}) = -\pi$.

The last considerations lead to the conclusion that:

The loop could be set to a critical operating mode by increasing K_{PID}, so APFC could cross the real axes in the point *(-1, j0)*. In this operating mode, the output process *y(t)* oscillates with a constant amplitude and is in antiphase with the input control signal *u(t)*.

The last fact is used for simple experimental realisation of the critical operating mode and experimental data collection for identification.

In case of operation with classical PID controller, the critical operating mode shall be set up as follows:

1. The PID controller is set for operation in P mode, and the integral and the derivative terms are excluded, by setting the appropriate values of the parameters for setting ($T_и\to\infty$, $T_д\to 0$).
2. An average value is set with regard to the maximum control range.
3. A small value is defined of the coefficient of proportionality K_{PID}, for which the process of the output y(t) decreases. The coefficient K_{PID} is increased smoothly, and y(t) is monitored (the characteristic is built). The process is supposed to change to a slower attenuation and to an increase of the oscillation. The increasing continues until fluctuations with constant amplitude Δy_{kp}, constant cycle, $T_{кр}$ and in antiphase with the input *u(t)* are established.
4. The oscillations of the *y(t)*are being written over several cycles. The amplitude Δy_{kp} and the established oscillations $T_{кр}$. are defined from the diagram.

The analytical expressions of TF, AFC and PFC of the model by which the controllable object of the proposed method could be defined are shown in Table. 1.

TABLE I
MODELS OF APFC AND PFC

№	TF of the model	System of PFC and AFC
1.	$\frac{K_p}{Ts+1}*e^{-\tau s}$	$\pi = \omega_{кр}\tau + arctg(\omega_{кр}T)$ $A_{cr} = \frac{K_p}{\sqrt{1+(\omega_{кр}T)^2}} = \frac{\Delta y_{кр}}{\Delta u}$
2.	$\frac{K_p}{(Ts+1)^2}*e^{-\tau s}$	$\pi = \omega_{кр}\tau + 2*arctg(\omega_{кр}T)$ $A_{cr} = \frac{K_p}{1+(\omega_{кр}T)^2} = \frac{\Delta y_{кр}}{\Delta u}$
3.	$\frac{K_p}{(Ts+1)^n}$	$\pi = n*arctg(\omega_{кр}T)$ $A_{cr} = \frac{Kp}{(\sqrt{1+(\omega_{кр}T)^2})^n} = \frac{\Delta y_{cr}}{\Delta u}$

It is typical for all the presented formulas, that they contain three unknown parameters: (K_P, T, τиK_P, T, n).

The following parameters are needed for the identification, which are defined by the experimental diagram of the critical process, shown in the Fig. 3:

- Critical frequency

$$\omega_{кр} = \frac{2\pi}{T_{кр}} \qquad (2)$$

- Fluctuation range of the controllable (output) variable

$$\Delta y_{кр} = y_{\max} - y_{\min} \qquad (3)$$

- Average value of the controllable variable

$$y_{cp} = \frac{y_{\max} + y_{\min}}{2} \qquad (4)$$

- Average value of the control impact

$$u_{cp} = \frac{\Delta u}{2} \qquad (5)$$

- Variation range of the control impact

$$\Delta u = u_{\max} - u_{\min} \qquad (6)$$

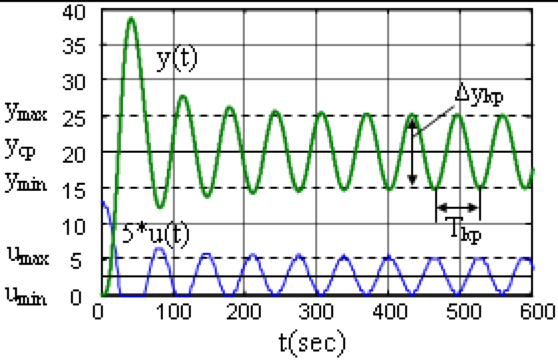


Fig. 3. PID controller operation with object with TF $\frac{50}{(10s+1)^4}$

III. AN ALGORITHM FOR THE CALCULATION METHOD OF THE PARAMETERS OF MODELS

1. Preparation and realization of the experiment and construction of the process in Fig.3
2. Calculation of the static coefficient of the object by the formula:

$$K_p = \frac{y_{cp}}{u_{cp}} \tag{7}$$

3. Calculation of the critical frequency by the formula:

$$\omega_{\kappa p} = \frac{2\pi}{T_{\kappa p}} \tag{8}$$

4. Calculation of the critical module by the formula

$$A_{\kappa p} = \frac{y_{\kappa p}}{\Delta u} \tag{9}$$

5. For the models 1 and 2 in Table 1., it is easy T and τ to be defined – first T from AFC and after that τ from PFC.
6. For the models 3, the system according to T and n is:

$$n = \frac{\pi}{arctg(\omega_{\kappa p}T)} = f_1(T) \tag{10}$$

$$n = \frac{\lg(\frac{K_{o\delta}}{A_{\kappa p}})}{\lg(\sqrt{1+(\omega_{\kappa p}T)^2})} = f_2(T) \tag{11}$$

It is obvious, that the system is non-linear. Methods for solving different non-linear equations systems are known from mathematics.

We propose a decision, which can be easily achieved in computing environment of MATLAB, but it must be taken into account that:

- the unknown n is number of first order lags in the model and can accept equivalent and positive units only, which are greater than or equal to 3, i. e. (n ≥ 3)

- the unknown T is meant as a time constant and thus it can accept positive values only, i. e. T ≥ 0.

IV. VALIDATION OF THE METHOD AND RESULTS

The presented method is validated in the computing environment of MATLAB. Numbers of loops with objects are simulated. In all cases, the aforementioned algorithm is used. For high order models and PID controller a non-linear equations system (9) and (10) is solved. The non-linear equations system is solved building the graphics of the two equations *(T, n)*, and the coordinates of the intersection of the two graphics are the system solution. So, the definitive value of the parameter *n* is supposed to be the nearest equivalent unit.

To illustrate the method, two exampels are shown – with simulated loops with PID controller and fourth and sixth order objects (by the circuit in Fig. 1.), respectively by transfer functions of CO:

$$W_{P1(s)} = \frac{50}{(10s+1)^4} \tag{12}$$

the desired set point is:

$$z_1(t) = 25 * 1(t) \tag{13}$$

and

$$W_{P2(s)} = \frac{5}{(s+1)^6} \tag{14}$$

the desired set point is:

$$z_2(t) = 0.5 * 1(t) \tag{15}$$

The critical operating modes are achieved, respectively when $K_{PID1} = 0.08$ *and* $K_{PID2} = 0.474$.

The following quantities are reported from the last graphics of the Fig. 3 and Fig.4: Δy_{kp}, T_{kp}, y_{cp}, Δu, u_{cp}.

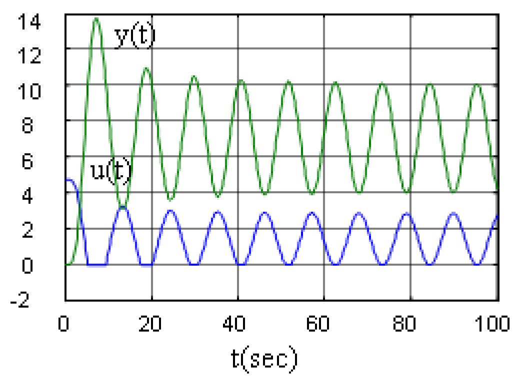


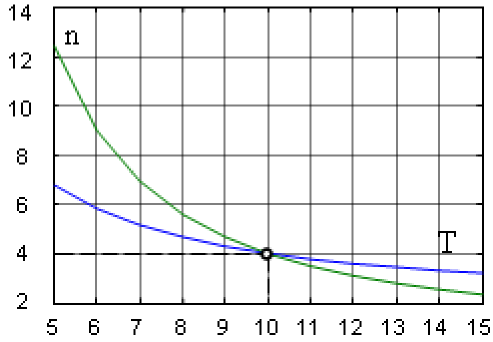
Fig. 4. PID controller operation with object with TF $\frac{5}{(s+1)^6}$

It is calculated from the reported values in Table 2: $K_P = \frac{y_{cp}}{u_{cp}}$; $\omega_{kp} = \frac{2\pi}{T_{kp}}$; $A_{kp} = \frac{\Delta y_{kp}}{\Delta u}$.

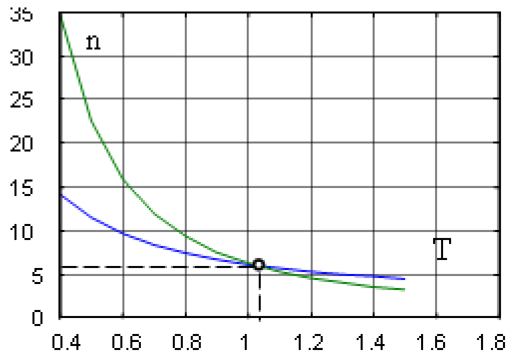
TABLE II

	K_P	Ω_{kp} (r/sec)	A_{kp}
a)	49.38	0.0977	12.469
b)	4.9754	0.562	2.109

The system of equations (9) and (10) is solved graphically (for the cases (a) and (b)) by the obtained values in Table. 2.



a)



b)

V. CONCLUSION

On the basis of the results which are obtained (the coordinates of the intersections in a) and b)), the following conclusions can be drawn:

1. The case a) – it is obvious from the graphic that: T ≈ 10s and n ≈ 4, which is an accurate result for the fourth order model
2. The case b) – it is obvious from the graphic that: $T = 1.02\ (\approx 1)s$ and $n = 5.91\ (\approx 6)$, which is an acceptable accuracy for the sixth order model.
3. In its examination of the identification method, visual reportings and calculations with reasonable accuracy are made for all the models in Tabl. 1 and with different values of the parameters.When MATLAB possibilities for precisely reporting and more accurate calculations are used, the more accurate result would be achieved. It is not a problem for the reader to check that.
4. An advantage of the identification method is that, there is no need of additional operational units for its realisation, except these, used in the loop for practical realisation. It is obvious that the presence of a systemic error in established mode does not influence the results (K_P).

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