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Experimental Identification of a Hydraulic Process Simulated on ASTANK 2 Integrated Laboratory Platform

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Abstract

Systems identification, that deals with system mathematical model determination based on experimentally acquired data, represents a field of great present interest in research and technology. The aim of this paper is to build a software instrument for implementing and testing identification methods on the ASTANK 2 integrated laboratory platform for identification and control techniques, in order to draw important conclusions regarding the parameters that affect the obtained model and the best identification method to be used .

Key words: *ASTANK 2 integrated platform, experimental identification, least squares method .*

Introduction

Systems identification represents a very important, even indispensable, area in the field of process automatic control, due to the facilities offered to process modelling based on experimentally obtained input-output data, in a normal operation or as a result of test signals application for the analyzed system. Depending on the imposed quality criterion and on the applied methods, one can obtain models that can very well estimate the process behaviour, particularly in the vicinity of significant operation points. In this respect, systems identification is implied in many operational fields, the most relevant being the following:

- modelling industrial processes for purposes of knowledge or control;
- study of phenomena described by time series;
- dynamic systems analysis;
- simulation of systems behaviour;
- automatic control of technological processes.

The obtained model highlights the essential features of a system, being a set of mathematical expressions that reflect the links between its physical variables, represented in a form of algebraical equations, differential equations, or differential equations systems.

In order to obtain the mathematical model of a process, one may use two different approaches:

- pure mathematical modelling, on the basis of physical-chemical laws that rule the behaviour of the analyzed process;

- experimental identification, that consists in determining a mathematical model on the basis of input-output experimental acquired data.

Considering the fact that analytical modelling is very difficult to conduct and, sometimes, almost impossible, applying an identification technique represents, in most of the situations, the only solution in order to obtain the model of the studied process, pursuant to the starting point in developing control structures.

ASTANK 2 Integrated Laboratory Platform

ASTANK 2 integrated laboratory platform for identification and control techniques is particularly designed to simulate a real process having a nonlinear behaviour depicted by fluid dynamics [4]. It describes a hydraulic system based on a process formed of two open tanks, one of constant section, the other of variable section, between them being manoeuvred a fluid by means of a pumping and distribution system, as seen in Figure 1.

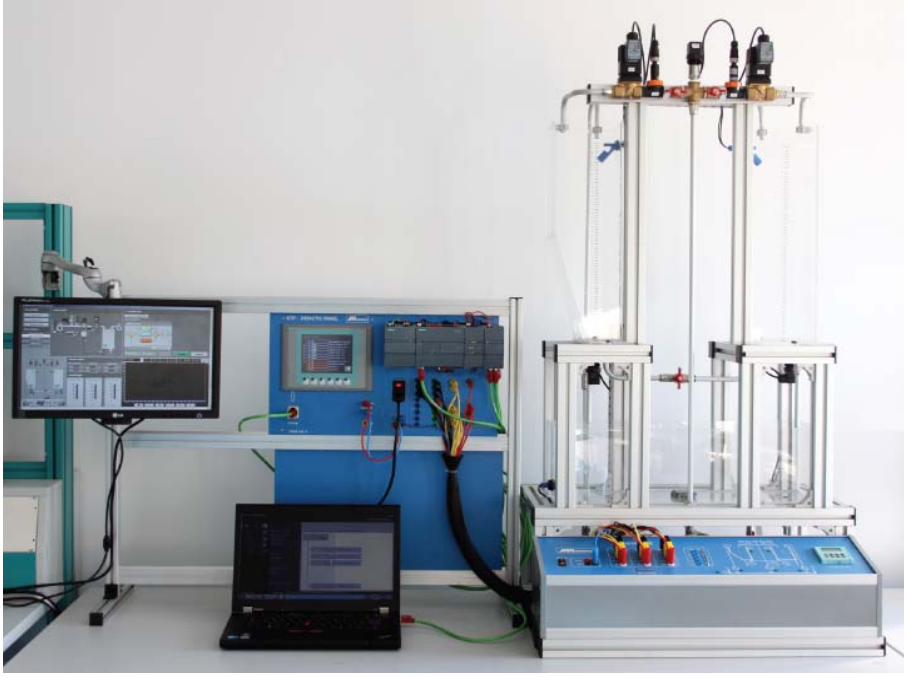

Fig. 1. ASTANK 2 platform [4].

The stall also contains:

- 4 pressure transducers, 2 level transducers and 2 flow transducers, with 4-20 mA standard output signals, used for monitoring the respective imposed values;
- 2 actuators flow control;
- PLC Siemens S7 – 1200 control equipment;
- Siemens HMI KTP600 control panel with tactile display;
- stall connecting panel (fig. 2) used for transducers data acquisition and control signals transmission to actuators.

There are two types of industrial processes simulated on this stall, respectively:

- a filling-exhaustion process, that may be performed in a tank with constant section, in a tank with variable section or in two interconnected tanks system;

- a flowing process, that refers to pressure control in the pumping system and flow control in the system.

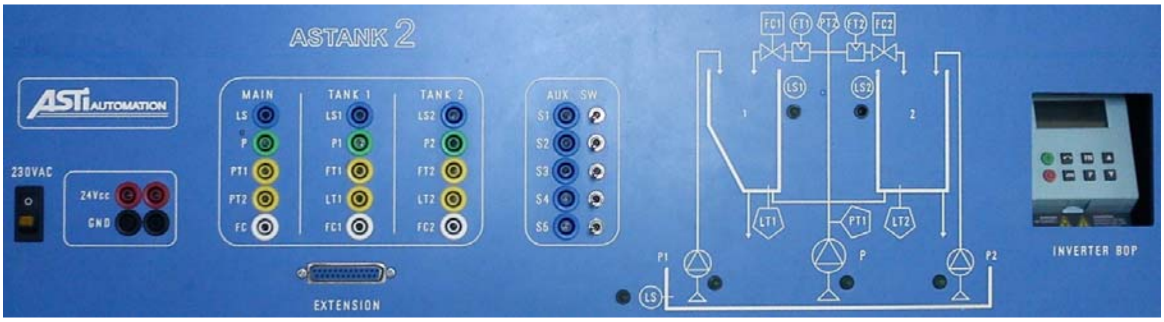

Fig. 2. Stall connecting panel [4].

The filling-exhaustion process specific to a tank is a liquid accumulation process; its diagram for a tank having a constant section is presented in Figure 3 [2].

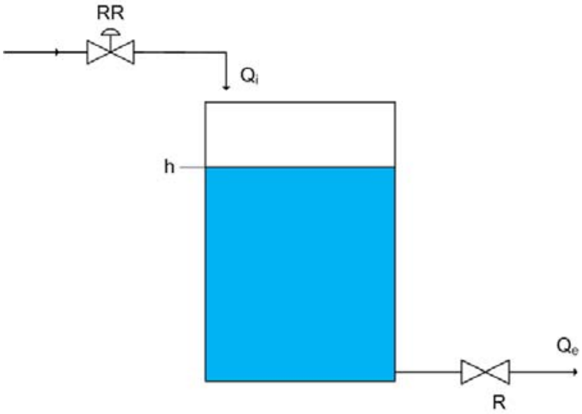

Fig. 3. Tank liquid accumulation process scheme [2]
Q_i – tank input flow; *RR* – actuator; *h*- tank liquid level;
R – hydraulic resistance at the tank output; Q_e – tank output flow.

For this process, one may compute the tank level using the formula [2]

$$h = \frac{Q_i - Q_e}{A} \tag{1}$$

and, consequently

$$\frac{dH}{dt} = \frac{1}{A}(Q_i - Q_e) \tag{2}$$

with

$$\Delta\dot{H} = \frac{1}{A}(\Delta Q_i - \Delta Q_e) \tag{3}$$

$$\Delta H = \frac{1}{A}\int_0^t (\Delta Q_i - \Delta Q_e)\,dt \tag{4}$$

Considering the representation in Figure 3, the output flow can be computed as [2]

$$Q_e = \alpha\, A\, \sqrt{2gh} \tag{5}$$

having α – flow coefficient, A_r – transverse section of the exhaustion actuator, $\sqrt{2gh}$ - velocity formula, derived from Bernoulli law

$$P_H = \rho g h = \rho v^2/2 \tag{6}$$

Using (5), the model of liquid accumulation in the free flowing tank is

$$A\frac{dh}{dt} + \alpha A_r \sqrt{2gh} = Q_i \tag{7}$$

and after performing a linearity around (Q_{i0}, h_0) point, it results

$$A\frac{d\Delta h}{dt} + \frac{\alpha A_r \sqrt{2gh}}{2\sqrt{h_0}}\Delta h = \Delta Q_i \tag{8}$$

The process corresponding to the free flowing exhaustion acts like a 1st order lag element, and the one corresponding to a constrained flowing exhaustion acts like an integral element [2], [3].

Least Squares Identification Method

Least square identification method is used for process parameters estimation on the basis of minimization the sum of the error squares computed as difference between the real output signal and the estimated output signal of the analyzed system [1].

Let us consider the input-output model that describes a mono variable system

$$A(q^{-1})y(t) = B(q^{-1})u(t) + v(t) \tag{9}$$

having $A(q^{-1}) = 1+a_1q^{-1}+a_2q^{-2}+\ldots+a_{na}q^{-na}$, $B(q^{-1}) = b_1q^{-1}+b_2q^{-2}+\ldots b_{nb}q^{-nb}$, with $y(t)$ – system output, $u(t)$ – system input, $v(t)$ – system disturbances and $A(q^{-1}) = 1+a_1q^{-1}+a_2q^{-2}+\ldots+a_{na}q^{-na}$, $B(q^{-1}) = b_1q^{-1}+b_2q^{-2}+\ldots b_{nb}q^{-nb},$ q^{-1} – lag operator, and the notation $\theta=[a_1\ldots a_{na}\ b_1\ldots b_{nb}]$ and $\varphi=[-y(t-1)\ \ldots -y(t-na)\ \ u(t-1)\ldots u(t-nb)]^T$.

In order to identify the system model, one considers a mathematical model described as

$$\bar{A}(q^{-1})y(t) = \bar{B}(q^{-1})u(t) + \varepsilon(t) \tag{10}$$

with $y(t$, $u(t)$ and q^{-1} are as above, ε(t) – the error, A and B – vectors of estimated parameters, $\bar{A}(q^{-1})=1+\bar{a}_1q^{-1}+\ \ldots+\bar{a}_{na}q^{-na}$, $\bar{B}(q^{-1})=1+\bar{b}_1q^{-1}+\ \ldots+\bar{b}_{nb}q^{-nb}$.

Using the notations $\bar{\theta} = [\bar{a}_1 \ldots \bar{a}_{na}\ \ \bar{b}_1 \ldots \bar{b}_{nb}]^T$

$$\varphi(t) = [\ \ y(t-1)\ldots -y(t-na)\ \ u(t-1)\ldots u(t-nb)]^T \tag{11}$$

the output signal is given by

$$y_m(t) = \varphi^{-T}(t)\,\bar{\theta} + \varepsilon(t) \tag{12}$$

and $\bar{\theta}$ estimates vector of the system parameters is computed as

$$\bar{\theta} = \arg\min_{\bar{\theta}} V(\bar{\theta}) \tag{13}$$

with

$$V(\bar{\theta}) = \sum_{i=1}^{n}\left[y(t) - \varphi^{-T}(t)\bar{\theta}\right]^2 \tag{14}$$

With the condition that $\bar{\theta}$ is the minimum argument of $V(\bar{\theta})$, it results that

$$\bar{\theta} = \left(\sum_{i=1}^{N} \bar{\varphi}(t)\bar{\varphi}^{T}(t) \right)^{-1} \sum_{i=1}^{N} \bar{\varphi}(t)y(t) \tag{15}$$

represents the analitical form of the model parameters estimate.

Model parameters estimate $\bar{\theta}$ assumes fixing the model order and then determining the $\bar{\theta}$ vector on the basis of input-output data. This estimate is very important, as it can ofer a starting point for more accurate identification methods, such as the instrumental variable (IV) method or the prediction error method (PEM).

Real-time Identification Application

The identification system of the plant was implemented in the graphical LabView environment developed by National Instruments. The connection to the plant is ensured by Siemens S7 - 1200 automaton [5] that has implemented a Modbus TCP server [6] and a data base that stores the transducers acquired data values.

The application interface was designed with two graphical windows, namely the identification window and the control window. The identification window is divided in two parts : the identification for the constant section tank and the identification for the variable section tank, considering a filling-exhaustion process. Each part contains:

- a graphical representation describing the time evolution of the parameters during the identification process;
- the area for identification data editing, containing the number of samples, the value, the amplitude and the period of the command;
- the area for displaying the identified model, that presents the evolution of the parameters during the identification process and the obtained model, at the end of this process;
- a progress bar that displays the fulfilled percentage of the identification procedure.

The least squares identification method is implemented for the two types of tanks, with constant section and with variable section. The considered model

$$y(t)+a_1*y(t-1)+a_2*y(t-2)=b_1*u(t-1)+b_2*u(t-2) \tag{16}$$

has the discrete transfer function

$$G(z)=\frac{b_0+b_1*z^{-1}}{1+a_1*z^{-1}+a_2*z^{-2}} \tag{17}$$

that allows a LabView implementation, having $\theta=[a_1\ a_2\ b_0\ b_1]$ the vector of unknown parameters and $\varphi=[-y(t-1)\ -y(t-2)\ u(t-1)\ u(t-2)]$, the vector of the input/output values. The unknown parameters vector, computed by means of minimizing the sum of square errors is given by formula (15).

The experiments conducted in this application have shown that the best values for obtaining an accurate mathematical model are:

- number of samples: 100;
- value for the command signal: 50%;
- value of the command phase: 5 sec;
- value for the command amplitude: 30%.

For these values, the computed sum of the square errors is minimum.

All the above presented areas are visible in Figure 4 that presents the graphical interface corresponding to the identification window.

Vas cu sectiune variabila: C:\vasvariabil.txt; numar esantioane 100; comanda medie [%] 50; amplitudine [%] 30; perioada comenzii [s] 5

y(t)+ -0.839423 *y(t-1)+ -0.148885 *y(t-2)= 0.00129835 *u(t-1)+ 0.00411278 * u(t-2)

Vas cu sectiune constanta: C:\vasconstant.txt; perioada comenzii [s] 5; amplitudine [%] 30; comanda medie [%] 50; numar esantioane 100

y(t)+ -1.3065 *y(t-1)+ 0.329426 *y(t-2)= 8.93068E-5 *u(t-1)+ 0.00193957 *u(t-2)

Fig. 4. Graphical interface of the identification window

The LabView implementation of the least square identification method for the two tanks is presented in Figure 5.

Fig. 5. Identification routine for the two tanks of the stall

Conclusions

Consequent to the experiments performed with the designed identification application, the most important conclusions are:

- the initial conditions, the sampling phase and the type of input signals chosen (amplitude, phase, form) have a major impact on the final result of the identification procedure;
- using the least square method for systems identification ofers useful information regarding the dynamics of the system, that can be used for system simulation in the vicinity of an operation point and even for designing an automatic control system for the respective process;
- in order to obtain more accurate models, one can implement instrumental variable method or prediction error method, starting from the results oferred by the least square identification method.

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Identificarea experimentală a unui proces hidraulic simulat pe platforma integrată de laborator ASTANK 2

Rezumat

Identificarea sistemelor reprezintă un domeniu de mare interes şi actualitate în cercetare şi tehnică, tratând problema determinării modelului matematic al unui sistem pe baza datelor obţinute experimental din funcţionarea normală sau la aplicarea unor semnale de test sistemului analizat. Lucrarea are drept scop elaborarea unui pachet software pentru implementarea şi testarea tehnicilor de identificare pe platforma integrată de laborator ASTANK 2 pentru tehnici de identificare şi conducere în ingineria sistemelor. Ca urmare a experimentelor efectuate, au putut fi formulate concluzii importante referitoare la parametrii care afectează acurateţea modelului obţinut, precum şi la alegerea celei mai bune metode de identificare.