Industrial Processes' Identification Using Virtual Instrumentation

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***Abstract*—In this paper the experimental identification problem of industrial processes is presented, in order to establish their mathematical models which permit the adoption of an automation solutions and the specification of a suitable control law respectively. With this aim in view, the authors were resorted to using Virtual Instrumentation with the aid of the Lab VIEW development medium. In order to solve the problem of acquisition and processing data from physical real processes, Virtual Instruments was designed and realized which provide in the end a mathematical model which is based on choosing the automation equipment of the aim followed. The realized Virtual Instruments gave the opportunity to be used either in student instruction field with the virtual processes identification techniques or to put the identification of some real processes to good use of diverse beneficiaries. The results of some experimental attempts which was realized on different thermal processes illustrates the utility of the demarches performed in this paper.**

***Index Terms*—experimental identification, industrial process, process identification, virtual instrumenta-tion.**

I. INTRODUCTION

A. *Identification of the processes*

The industrial processes (IP) are purpose oriented technical systems having the task of changing the inputs (raw matters, energies, information) in wanted outputs (in general, material goods) in conditions of efficiency and in ecologic conditions of development.

In order to obtain the required performances (quality, quantity) it is necessary to manage the transformation process by automatic control or monitoring. In this purpose, it is necessary some an equipment for the process should be attached (called, automation equipment), composed of a number of structural elements, which solves the following problems: acquires the working data from the process, takes proper decision directing to the aim and the acquired data, realizes interventions which influence the process until the desirable results are obtained.

Choosing/adoption the automation equipment enforces only that know the features/properties of respective process.

At present, the properties of the industrial process for choosing the type of controller can be emphasized through the utilization of their appropriate mathematical models [1-5]. Usually, these are linear differential equations (with constant or variable coefficients), transfer functions, etc., which binds the input and the output parameters of the considered process, reflecting its stationary and dynamic properties.

The operation through which the mathematical model of a process is established gets the name of *identification*.

The identification can be [6-8]:

- *theoretically*, when through the application of laws which govern the phenomena from the analyzed process it is necessary for the appropriate mathematical model to be obtained; model which binds the input and the output parameters of the process;

- *experimentally*, when on the basis of some experimental attempts achieved during the process and acquired data processing the appropriate mathematical model is obtained.

Sometimes, in order to obtain the appropriate mathematical models, these two methods of identification are combined.

B. *The experimental identification with testing signals*

As part of experimental identification the conception of the mathematical model is followed through processing, with the help of simple and efficient algorithms, of some experimental obtained results, in certain experimentation conditions.

The stages of experimental identification refer to [7]: the organization and the realization of data acquisition; the interpretation and the processing acquired data; the deduction of the mathematic model through mathematical approximation of the results.

The first stage requires the adoption of some proper methods and proceedings which have in view the following appearances: the initial information about the process (its main structure, the parameters which intervene and the connection between these); the possibility to accomplish the experiment (in natural conditions of its operation or through break natural operation); the form and the limits of variation of the physical parameters which intervene; the influence of dynamic features of the transducers and the used devices in order to achieve data acquisition.

The second stage enforces in the first place the selection and systematization of the results obtained with the aim of the detachment of useful information from acquired data, then the errors correction of the method, the device and of the transmitted information. After this stage, the experimental results are obtained in the shape of table or charts, fitted with what methods of approximation will be used in the third stage.

As part of *the third stage* differently mathematical methods of estimate the obtained results is applied; methods which leads to a mathematical model in the shape of a differential equation or as a transfer function [1, 6-8].

Practically it is usually followed, by the obtaining of the transfer function of the process because this is in tight touch with the output experimental determinations.

With the aim of experimental identification of the processes the following categories of methods are used [6-7]: identification *with testing signal*; identification *without testing signal*, using the parameters from *the natural operation of the process*; the methods using *the adjustable models.*

The identification methods with testing signals are active methods because in order to achieve identification of the processes they acted externally by applying testing signals (input signals). The identification is based on the fact that the testing signals applied to the entrance of the process causes variations of the outputs, which reflected these features. With the aim of identification the testing signal type is used: *step*, *ramp, impulse* and *sine-wave.*

C. *The self-stabilizing industrial processes experimental identification based on simplified transfer functions*

Big majority of the industrial processes (the one with transfer of mass, of energy, of warmth etc.) owns the behavior with self-stabilizing, with or without dead time, characterized by simplified transfer functions as type:

$$G(s) = \frac{K}{1+Ts} e^{-\tau s} \qquad (1)$$

or

$$G(s) = \frac{K}{(1+T_1 s)(1+T_2 s)} e^{-\tau s} \qquad (2)$$

where K is the gain inherently associated with the plant, τ is the dead time, T, T_1 and T_2 are time constants.

The models characterized by transfer function (1) are typical for the objects which realized a pressure, level or flow rate control; sometimes it can characterize the heating processes too. The models type (2) is specific to heating process with more elements for storing the energy.

When, on the basis of initial information the process estimation with the above models is adopted, the problem of identification is reduced to the evaluation of parameters K, τ, T, T_1 and T_2 on the basis of the process response to the applied testing signal.

At present, there are few mentions in specialty literature about the experimental identification of some simple processes, such as processes characterized by transfer functions type (1) and (2). In general, the identification methods [9, 10 and others] are described by means of a complex mathematical methods (discreet mathematical models, advanced statistical calculation, neuronal networks, etc.), which are difficult to use by non-specialists.

There is a powerful programming language, Matlab, which can be used in processes' identification [11]. Matlab is a high-performance language for technical computing but in order to use it with success the user needs proper qualification.

In [12] an easy method of experimental identification is presented, assisted by computer, by using the Lookout development medium. Lookout software is less complex than the Lab VIEW development environment.

The reasons stated above have contributed to the choice of using the graphical language developed by National Instruments (Lab VIEW) [14] in order to *develop an experimental method for the identification of processes, assisted by computer.* The language is easy to understand and use, even by those who have little experience in the programming field.

II. THE IMPLEMENTED IDENTIFICATION METHOD

For the experimental identification of the process basis on simplified transfer function some graphic and graphic-analytical methods were suggested and utilized.

Firs of all, all identification methods described in [1, 5-8] require the transformation of obtained experimental graphics in unit step response, and then require the effectuation of graphic buildings on the obtained curves. These because the unit step response only is in direct connection with transfer functions and differential equations. There were elaborated function atlases and some nomograms which can be used in order to compare the experimental curves with these offline computed curves. These obtained models are used in order to choose a proper control law [2-5].

The described methods have the major disadvantage that require some graphic buildings on experimental obtained curves; that offers low precisions.

In this paper one from the most known and simple methods for the first order processes identification are implemented on computer by means of Virtual Instrumentation. Practically, in this way, an *automatic* (computer aided) *identification* is achieved when the operator works with friendly Front Panels and he does not have to realize any graphic buildings or calculations.

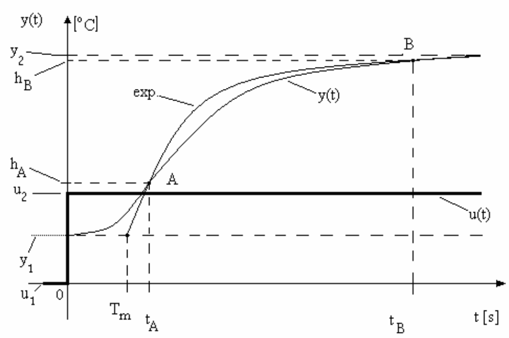


Figure 1 - The first order process identification:
u_1, y_1 – the input and output initial values;
u_2, y_2 – the final values of the input and output;
$h_B = 0,9*(y_2 - y_1)$;
A - the inflection point of the obtained experimental curve;
t_A and t_B – the proper times of the points A and B.

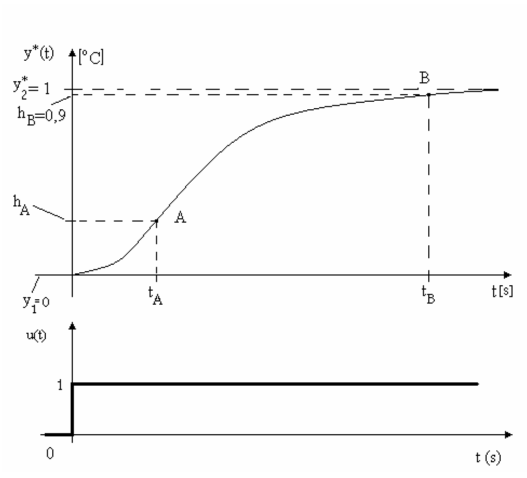


Figure 2- The unit step response of the process

The identification method described in [6-7], and implemented with the help of Virtual Instrumentation, is based on the experimental curve y(t) of the process response to a testing signal (a step-signal) u(t), Fig.1. To obtain some high performances usually the testing signal u(t) is chosen so that to bring the process' response y(t) to the nominal values of operating zone. This input signal is expressed in percents from its maximum value U_{max}.

Accomplishing displacement of the obtained experimental curve y(t) with y_1 value and accomplishing the rate-setting to the steady-state value and the command value (which is not 1 %), the unit step response of the process (Fig.2) is obtained.

It is supposed that the behavior of the process can be estimated with an exponential curve (exp, Fig 1), which passed through the points A and B, and it is displaced with τ given the situation t=0. $\tau = T_m$ is a calculated dead time (Fig. 1).

Based on coordinate of A and B points the time constant T and dead time τ from (1) is calculated [6-7].

$$T = \frac{t_B - t_A}{ln[1-y^*(t_A)] - ln[1-y^*(t_B)]} \quad (3)$$

$$\tau = \frac{t_B\, ln[1-y^*(t_A)] - t_A\, ln[1-y^*(t_B)]}{ln[1-y^*(t_A)] - ln[1-y^*(t_B)]} \quad (4)$$

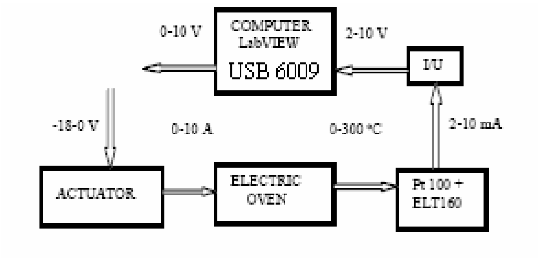
The gain is calculated with the help of (5):

$$K = \left.\frac{dy}{du}\right|_{u=u_n} \cong \frac{\Delta y}{\Delta u} = \frac{y_2 - y_1}{u_2 - u_1} \quad (5)$$

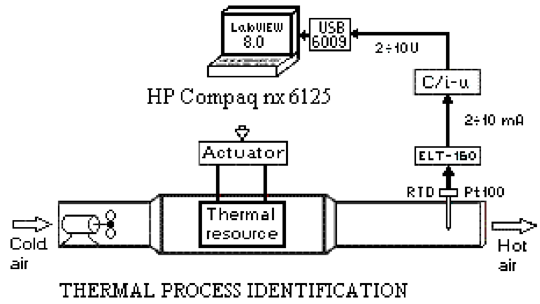
Obviously, by substitution of graphic processing [6-7] with a numeric automatic processing, the precision of identification methods sensible increase.

III. THE EXPERIMENTAL INSTALLATION

In order to implement some automated experimental identifications the following laboratory processes (as object to identify) was achieved and used, Fig. 3:



a. electric ovens



b. electric air heating battery

Figure 3 - The experimental installations

- electric oven with resistance, of 2200 W and 400 W;
- electric oven with infrared bulbs, of 440 W;
- electric air heating battery, of 1800 W.

The actuators of used equipments are realized based on SCR (Silicon Controlled Rectifier) which permit to fix the desire values of heating current that represent the input value u(t). Through a suddenly change of the phase angle fired SCR power control, based on a proper power control, the step variation of testing signal u(t) % is achieved.

In order to acquire the temperature data as output signal y(t), the sensitive element type RTD (Pt100) and suitable signal adapters were used.

So, for the electric oven of low power (440 W) an AT-2F16 signal adapter (with range of the temperature of 0^oC – 200^oC and output 4 – 20 mA) was used and for the other objects an ELT160 signal adapter (with range of the temperature of 0^oC – 300^oC and output 2 – 10 mA) was used. This unified current from the adaptors' output was converted to a voltage 2-10 V, with the help of some calibrate resistance.

The electric signal delivered from transducer, proportional with temperature, is applied to a HP Compaq 6125 laptop by means of NI USB 6009 acquisition board [13]. As development software Lab VIEW Student Edition 8.0 was installed [14].

IV. THE ACHIEVEMENT OF VIRTUAL INSTRUMENTS

A. *The Virtual Instruments for data acquisition*

The Virtual Instrument for the data acquisition is due to acquire the values of the physical parameter from the process output with a certain frequency. In this case the physical output parameter is temperature from the air heating battery or the electric ovens.

As it was mentioned above, the variation of physical parameter in variation of voltage was transformed, in range 2-10 V. So the NI USB 6009 acquisition board for referenced single-ended input mode was configured.

The output signal y(t) (2-10 V) is applied to the analogical input AI0 of the acquisition board.

The achievement of data acquisition VI was realized based on the following steps:

- data acquisition with a desired sample of user;
- conversion of acquired voltage in real technological parameter, as Celsius degrees for temperature;
- graphical displaying of acquired parameter so that the operator can view the evolution of parameter in real time;
- saving the acquired data and also the time, for further processing;
- display data in table in real time;
- stop the data acquisition sequence when the steady-state value is settled.

The designed and realized Virtual Instrument that solves the above problem has two components: the Front Panel (FP) and the Bloc Diagram (DB).

The Front Panel of the achieved data acquisition VI is presented in Fig. 4. A Waveform Chart for acquired signal from the acquisition board, one stop button, one control for sampling time, one indicator of iteration number and one table with acquired data can be noticed. These were selected from Lab VIEW control palette [13].

The Block Diagram corresponding to the above Front Panel is presented in Fig. 5.

Because the acquisition board was configured to acquire voltage in range of 0-10 V, and the input signal was in range of 2-10 V, a signal processing to result directly the value of proper temperature of the acquisition moment was necessary. This processing with the help of *DAQ Assistant Express VI* and some functions available in Lab VIEW function palette was achieved. Using *Write To Measurement File VI* the archiving of data and display data in table was realized. To acquire data with a desired sample a proper configuration of a *DAQ Assistant Express VI* was realized. All this VI and functions are placed in a *While loop* which has its stop button on the Front Panel. By pushing this button the acquisition in stopped.

B. The Virtual Instrument achieved for the data processing and calculation of parameters

This achieved Virtual Instrument had to extract the archived data from a file and processing data so that, finally, the step unit response and then the K, τ and T parameters could be obtained.

In Fig. 6 the Frontal Panel for this Virtual Instrument is presented and it can be observed that there are displayed the read data and the step unit response, too. The main parameters of this method by means of the K, τ and T indicators are displayed. Also the coordinates of the A and B are displayed.

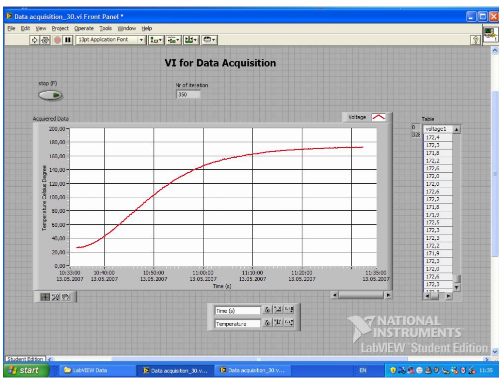


Figure 4 The Front Panel of the Data Acquisition VI; the acquired experimental data for the electric air heating battery, u(t)=50%;

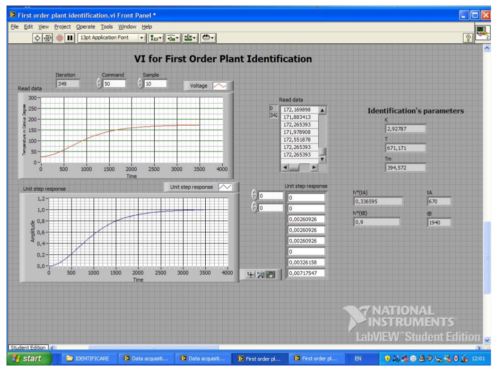


Figure 6 – The Front Panel of the Data Processing VI; experimental results for electric air heating battery, u(t)=50%

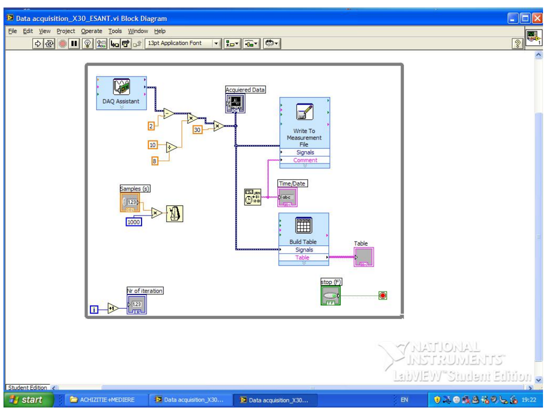


Figure 5 The Block Diagram of Data Acquisition VI

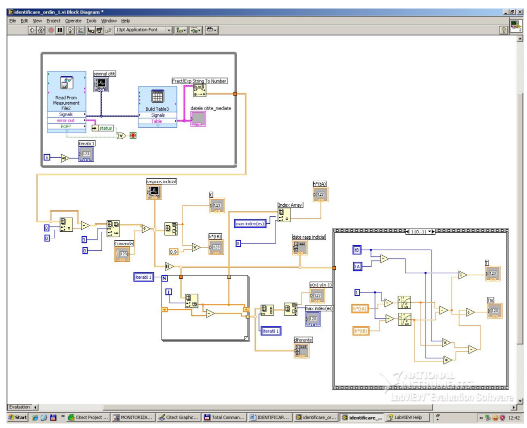


Figure 7 – The Block Diagram of Data Processing VI

To implement the procedure of the first order process identification, based on [6-7] (Fig. 1 and Fig. 2), a *While Loop* for data reading part was used and in order to obtain the unit step response a translation and a rate-setting of the experimental curve with the help of available functions from Lab VIEW functions palette was achieved. To determine the coordinate of A and B points the inflection point and then the corresponding times t_A and t_B was calculated. Using this time values, based on (3) and (4), placed in a For Loop, the time constant T and τ were computed.

The gain K was calculated by implementing (5).

V. THE EXPERIMENTAL ACHIEVEMENTS

The experimental attempts were achieved in the following order:

- All devices presented in Fig. 3 were in normal state of function, fixing zero as the value of the heating current.
- At the considered moment t=0, the step heating current (X% from nominal current value for identified objects) was applied. It was simultaneously set on the data acquisition application.
- After the steady-state value was touched, the data acquisition program and the identification object supply were turned out.
- The acquired data were processed with the aim of obtaining the mathematical model.

In Fig. 4 and 6 the obtained experimental results for the electric air heating battery, with u(t)=50% (i=4 A) from nominal value, are presented.

In Fig. 8 and 9 the obtained results in experimental identification of the oven with infrared bulbs are presented. In this case u(t)=50% and the corresponding heating current is i=1,5 A.

Analyzing the acquired data it can be observe that the implemented method of identification can be used in both cases. Obviously, due to inflection point that has smaller coordinate values, the oven with infrared bulb has a mathematical model more appropriate to reality.

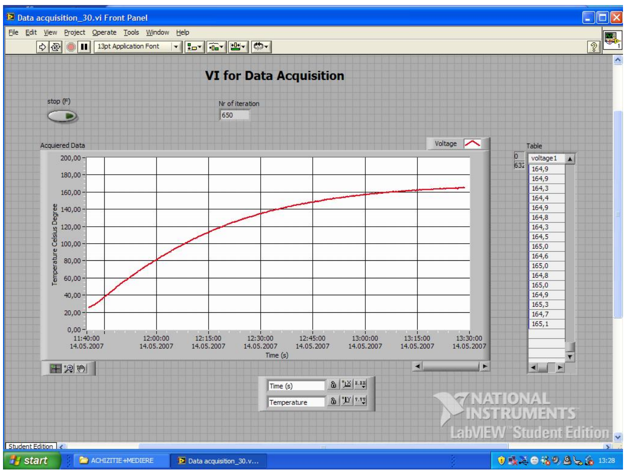


Figure 8. The Front Panel of the Data Acquisition VI for oven with infrared bulbs; u(t)=50%

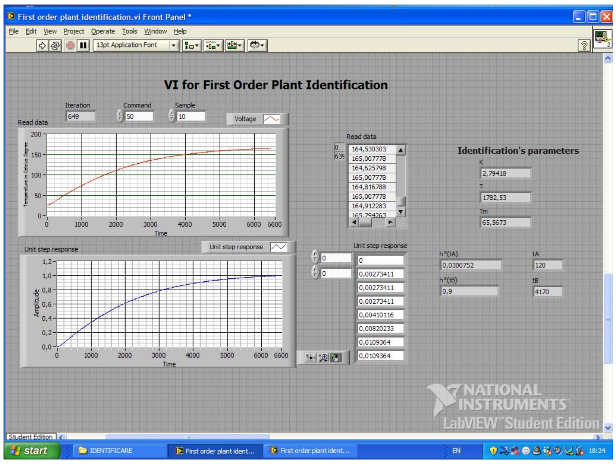


Figure 9. The Front Panel of Data Processing VI; experimental results for oven with infrared bulb; u(t)=50%

The mathematical model of electric air heating battery is affected by bigger method errors.

The following obtained results can be read on the front panels of realized virtual instruments:

- for oven with infrared bulbs (ib):
$h_B = 0.9$; $t_B = 4170$ s; $h_A = 0.0300752$; $t_A = 120$ s;
K = 2.79418 s; T = 1782.53 s; $\tau = 65.5673$ s.

- for electric air heating battery (ehb):
$h_B = 0.9$; $t_B = 1740$ s ; $h_A = 0.145941$; $t_A = 360$ s;
K = 2.9278; T = 671.171 s; $\tau = 394.5$ s.

So, based on implemented identification procedure the following transfer functions were obtained:

$$G_{ib}(s) = \frac{2.794}{1282.53\,s + 1} e^{-65.56\,s} \quad (6)$$

$$G_{ehb}(s) = \frac{2.9278}{671.171\,s + 1} e^{-394.5\,s} \quad (7)$$

Analyzing the obtained data it can be see that the transition time of both identified processes are sensitive different. So, for the oven with infrared bulbs the time of transition was approximately two hours and for the electric air heating battery it was approximately one hour.

VI. CONCLUSIONS

After these achieved researches the following conclusions were obtained:

The achieved Virtual Instruments are friendly and easy to handle even by non specialists (experts);

The Virtual Instrument for data acquisition worked properly; this was resulted after the obtained curves were compare whit the curves displayed on the conventional recorder devices of the process;

In order to obtaining the mathematical model the manual graphical data processing was eliminated; the identification precision significantly increased;

All calculations for obtaining the identification parameters were realized automatically;

A reduced identification time and a grown precision resulted;

In order to realize the identification of the process (plants) the conventional equipments existing on the identified process can be used: transducers, command devices, recorders;

The user's mobility was increased by using a Laptop and USB acquisition boards; this simplifies the identification procedure of the industrial processes (plants).

The obtained experimental results encourage the authors to continue the research in order to extend the studying area in processes' experimental identification field: identification same processes of superior order, increasing the precision of identification, choosing the controller type based on identification's results, validation of obtained results by implementing these results in control loop of identified processes.

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