PLANT EXPERIMENTAL IDENTIFICATION USING VIRTUAL INSTRUMENTATION

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***Abstract* – In this paper the experimental identification problem of plants is presented, in order to establish their mathematical models which permit the adoption of a suitable control law. 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 plants (physical real processes), Virtual Instruments were designed and realized which provide in the end a mathematical model which is based of choosing the automation equipment of the aim followed. The result of some experimental attempts which was realized on different thermal plants illustrates the utility of the demarches performed in this paper.**

Keywords: *experimental identification, industrial plant, plant identification, virtual instrumentation.*

1. INTRODUCTION

1.1. Identification of the plants

The industrial processes (plants) 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, an equipment is necessary to be attached for the process (called, automation equipment), composed of 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, achieves 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]. These are usually 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 or experimentally.
Sometimes, in order to obtain the appropriate mathematical models, these two methods of identification are combined.

1.2. 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 experimental identification stages 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.
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.

1.3. The self-stabilizing industrial plants experimental identification based on simplified transfer functions

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

$$G(s) = \frac{K}{1 + Ts} e^{-T_m s} \quad \text{or} \quad (1)$$

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

where K is the gain inherently associated with the plant, T_m is the dead time, T, T_1 and T_2 are time constants [6,7].

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

At present, the identification methods [9, 10 and others] are described by means of a complex mathematical methods (mathematical discreet models, statistical advanced calculation, neuronal networks, etc.), which are difficult to use by non-specialists.

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

The reasons stated above have contributed to the choice of using the graphical language developed by National Instruments (Lab VIEW) [12] in order to develop an experimental method for the identification of plants, assisted by computer.

2. THE IMPLEMENTED IDENTIFICATION METHODS

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

Firs of all, all identification methods described in [1-8] 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 of the most known and simple methods for the first order plants and on for the second order plants 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.

2.1. The first order plants identification

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 plant 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}.

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

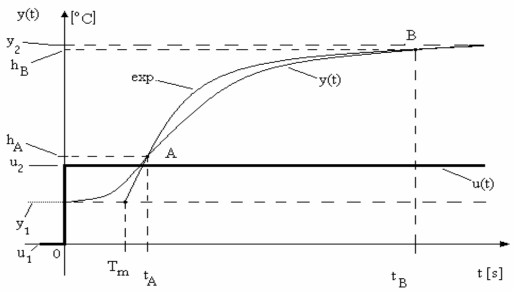

Figure 1: The first order plant identification: u1, y1 – the input and output initial values; u_2, y_2 – the final values of the input and output; $h_B = 0{,}9*(y_2 - y_1)$; A - the inflection point of the obtained experimental curve; t_A and t_B – the proper times of the points A and B.

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

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

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

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

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

2.2. The second order plants identification

The experimental identification of the second order plants [8] is based on the experimental answer of the plants to a testing signal (a step signal), Fig.2.

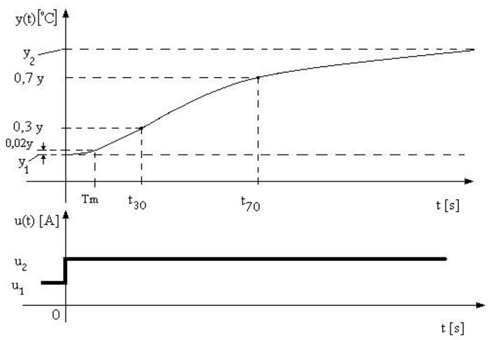

Figure 2: The identification of the second order plants: u_1, y_1 – the input and output initial values; u_2, y_2 – the final values of the input and output; $y = y_2 - y_1$; t_{30} and t_{70} are the proper times of reaching values 0,3*y and 0,7*y respectively.

In the case of implemented method, with the help of the times t_{30} and t_{70} the time constants T_1 and T_2 (from 2) is determined, using the following equations [8]:

$$T_1 + T_2 = \frac{t_{70}}{1.2} \quad (6)$$

$$T_1 - T_2 = \frac{t_{30} + t_{70}}{0.6}\left(0.45 - \frac{t_{30}}{t_{70}}\right) \quad (7)$$

The dead time with help of equation (8) is calculated:

$$T_m = (0.01...0,02)\,y \,. \quad (8)$$

3. THE EXPERIMENTAL INSTALLATION

In order to implement some automated experimental identifications the following laboratory plants (as object to identify) was realized and used, Fig. 3:
- electric oven with resistance, of 2200 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 realized. In order to acquire the temperature data as output signal y(t), sensitive element type RTD (Pt100) and suitable signal adapters were used.
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 was installed Lab VIEW Student Edition 8.0 [12].

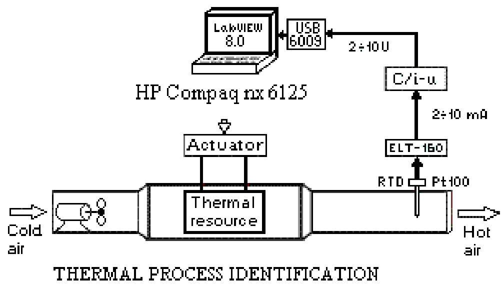

Figure 3: The experimental installations

4. THE ACHIEVEMENT OF VIRTUAL INSTRUMENTS

4.1. The Virtual Instrument for data acquisition

The Virtual Instrument for the data acquisition is due to acquire the values of the physical parameter from the plant output with a certain frequency. In this case the physical output parameter is temperature from heating battery or electric ovens (Fig.3).
The designed and realized Virtual Instrument that solves the above problem has two components: the Front Panel (Fig. 4) and the Bloc Diagram (Fig. 5).

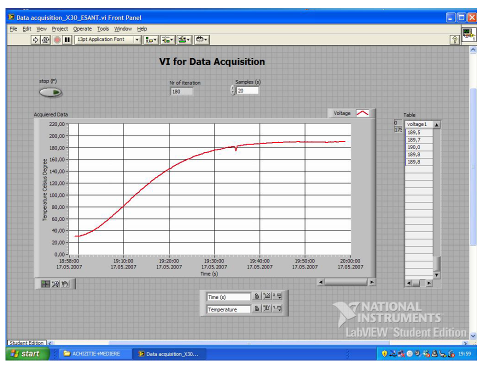

Figure 4: The Front Panel of the VI for Data Acquisition; experimental results for the electric air heating battery

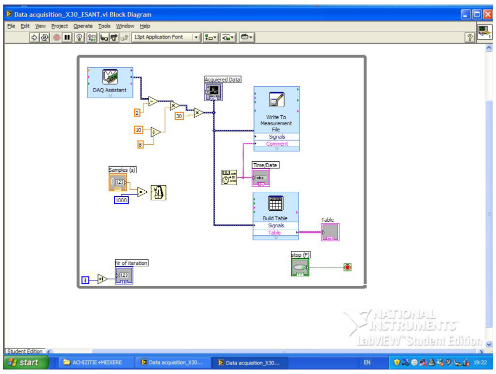

Figure 5: The Block Diagram of the VI for Data Acquisition

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.

4.2. The Virtual Instruments realized for the data processing and calculation of parameters

4.2.1. The first order plant identification

This achieved Virtual Instrument had to extract the archived data from a file and processing data so that, finally, to be obtained the step unit response and then to compute the **K**, $\mathbf{T_m}$ and **T** parameters (1).
In Fig. 6 the Frontal Panel and in Fig. 7 the Block Diagram is presented for this Virtual Instrument.

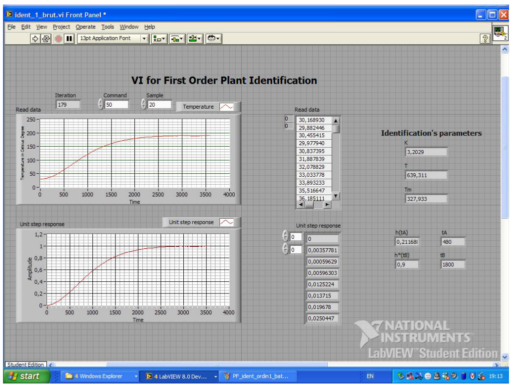

Figure 6: The Front Panel of the VI for the first order plant identification; the experimental results for electric air heating battery, u(t)=50%

In the Front Panel the read data and the step unit response are displayed. The main parameters of this method are displayed by means of the K, T_m and T indicators**.** It also are displayed the coordinates of the A and B.

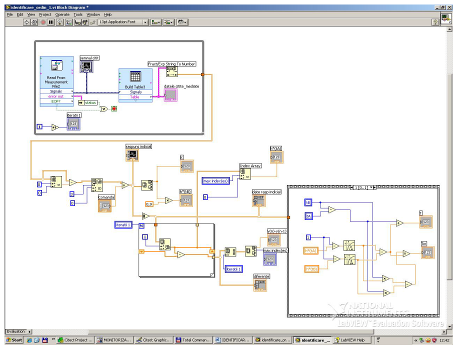

Figure 7: The Block Diagram of the first order plant identification

4.2.2. The second order plant identification

This achieved Virtual Instrument had to extract the archived data from a file and processing data so that, finally, the K, T_1, T_2 and T_m parameters could be obtained.
In Fig. 8 the Front Panel and in Fig. 9 the Block Diagram is presented for this Virtual Instrument.

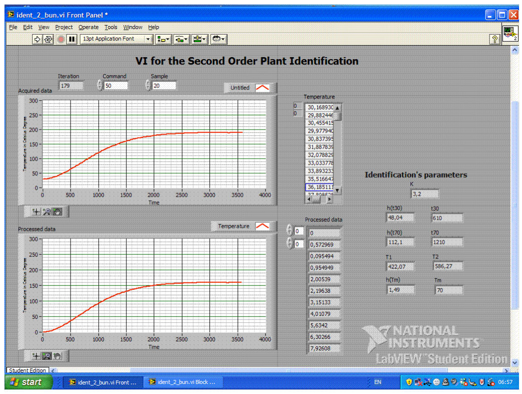

Figure 8: The Front Panel of the VI for the second order plant identification; experimental results for the electric air heating battery, u(t)=50%.

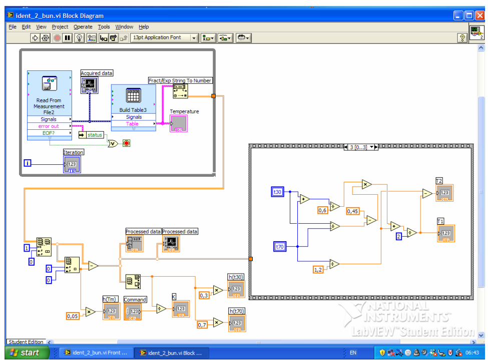

Figure 9: The Bloc Diagram of the VI for the second order plant identification.

To implement the procedure of the second order plant identification (Fig. 9) a *While Loop* for data reading part, some LabVIEW functions to compute the y-coordinates of the characteristic points (see Fig 1) and *a Sequence Loop* for the parameters calculation was used.

5. THE EXPERIMENTAL ACHIEVEMENTS

The experimental attempts were realized 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, was applied the step heating current (X% from nominal current value for identified objects). Simultaneously was set on the data acquisition application.
- After the steady-state value was touched, the data acquisition program and the identification object supply were turn out.
- The acquired data was processed in aim of obtaining the mathematical model.

5.1. The laboratory objects identification as first order plants

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

- for the electric air heating battery (ehb):

K = 3.2; T = 639.31 s; T_m = 327.93 s.

$$G_{ehb}(s) = \frac{3.2}{639.31s+1}e^{-327.93s} \tag{9}$$

- for the electric oven with resistance (eo):

K = 32.45 s; T = 1836.94 s; T_m = 890.29 s.

$$G_{eo}(s) = \frac{32.45}{1836.94s+1}e^{-890.29s} \tag{10}$$

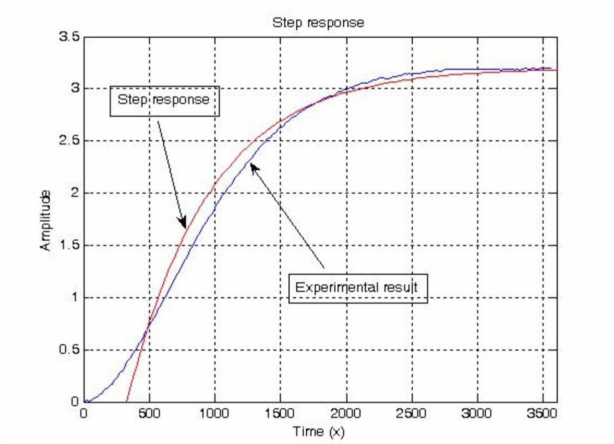

Figure 8: The experimental step response and the simulated step response for the electric air heating battery.

In order to validate the correctness of the obtained results the step responses of both identified processes characterized by transfer function (1) were simulated in Matlab development medium [11]. The simulated curves were put over the obtained experimental curves of the two identified processes (Fig. 8 and Fig. 9).

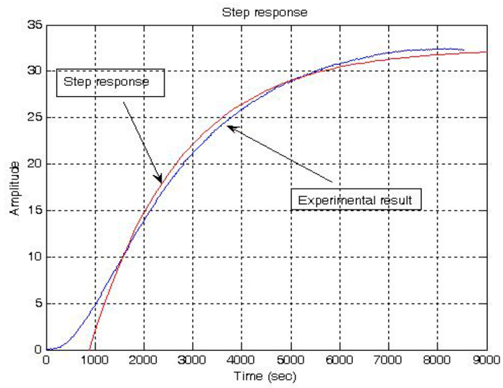

Figure 9: The experimental step response and the simulated step response for the electric oven with resistance.

5.2. The laboratory objects identification as second order plants

The experimental identification's results of the two identified objects lead to the following transfer functions: G_{ehb} (s) for the electric air heating battery and G_{eo} (s) for the electric oven with resistance.

- for the electric air heating battery (ehb):

K = 3.2; T_1 = 422.06 s; T_2 = 586.27 s; T_m = 70 s.

$$G_{ehb}(s) = \frac{3.2}{(422.06s+1)(586.27s+1)}e^{-70s} \tag{11}$$

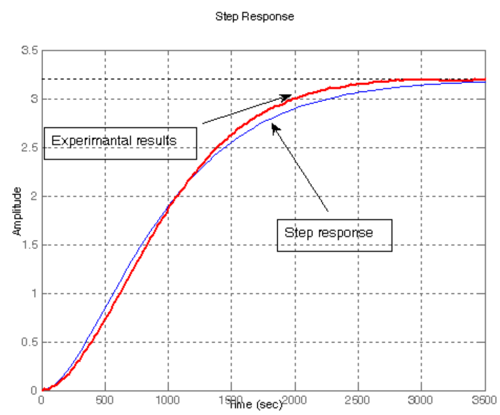

Figure 10: The experimental step response and the simulated step response for the electric air heating battery.

- for the electric oven with resistance (eo):
K = 32.45 s; T_1 = 1310.4 s; T_2 = 1431.27 s;
T_m = 310 s.

$$G_{eo}(s) = \frac{32.45}{(1310.4s+1)(1431.27s+1)} e^{-310s} \quad (12)$$

In Fig. 10 and Fig. 11 the simulated curves were put over the obtained experimental curves of the two identified processes.

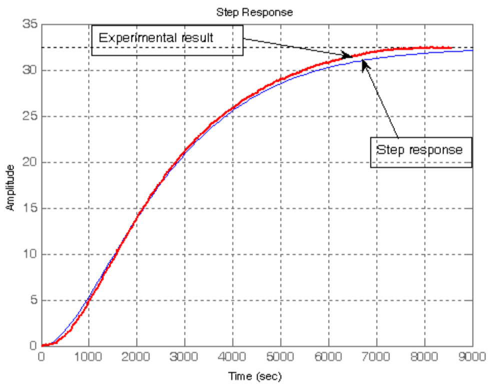

Figure 11: The experimental step response and the simulated step response for the electric oven with resistance.

6. 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 with the curves displayed on the conventional recorder devices of the process;
It was eliminated the manual graphical data processing in order to obtaining the mathematical model; the identification's precision was sensitive increase;
A reduce identification's time and a grown precision were resulted;
The identification results from figures 8, 9, 10 and 11, show that considering the objects as second order plans are more suitable than as first order plants;
In order to realize the process's (plants) identification it can be used the conventional equipments existing on the identified process: transducers, command devices, recorders;
The user's mobility was increased by using a Laptop and USB acquisition boards; this simplify the identification procedure of industrial processes.

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