EXPERIMENTAL ANALYSIS OF TRANSIENT REGIME OF AN ELECTROMECHANICAL ACTUATOR WITH VOLATILE LIQUID USING THE UNIT STEP RESPONSE

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REZUMAT. Obiectivul acestei lucrări este analiza regimului tranzitoriu al unui actuator electromecanic cu lichid volatil, pe baza funcției indiciale, determinată experimental. Determinările experimentale au fost efectuate pentru două lichide volatile cu volatilitate diferită şi pentru diferite poziții de lucru ale actuatorului. Pe baza determinărilor experimentale privind alungirea actuatorului, a fost determinată funcția indicială a acestuia, fiind analizat regimul lui tranzitoriu.

Cuvinte cheie: studiu; actuator electromecanic; lichid volatil; regim tranzitoriu; funcție indicială

ABSTRACT. The objective of this paper is analysis of transient regime of an electromechanical actuator with volatile liquid, based on the unit step response determined experimentally. Measurements have done for two volatile liquids with different volatility and for different operating positions of the actuator. Based on the measurements done concerning actuator elongation, the actuator unit step responses were determined, its transient behavior being analyzed.

Keywords: study; electromechanical actuator; volatile liquid; transient regime; unit step response

1. INTRODUCTION

An actuator typically is a mechanical device for moving or controlling a mechanism or system. It is operated by a source of energy, usually in the form of an electric current or hydraulic fluid pressure (it takes energy created by electricity, liquid or air), and converts that into some kind of motion. The most common type of actuator is powered by air.

In engineering, actuators are frequently used as mechanisms to introduce motion, or to clamp an object so as to prevent motion. In electronic engineering, actuators are a subdivision of transducers.

Actuators are typically used in manufacturing or industrial applications and may be used in motors, pumps, switches, and valves.

An example of actuator is the electromechanical actuator with sylphon and volatile liquid.

The present paper analyzes the behavior of an electromechanical actuator with sylphon and volatile liquid, using the unit step response, and it is a part of a broader study that aims to find ways to improve the performance of such an actuator, to determine the optimum operating conditions thereof, as well as to find command and control possibilities.

At the beggining, in the paper is presented an electromechanical actuator with sylphon and volatile liquid, whose experimental model was developed and has been the object of the study presented in this paper. [1]

The electromechanical actuator with volatile liquid is based on a flexible corrugated metal tube (sylphon). Inside, the sylphon is partially filled with a volatile liquid. Heating the sylphon (with a heating resistance, using a Peltier element or by entering into an environment, such as a liquid, at a certain temperature), a part of the volatile liquid evaporates, the vapor pressure causing the sylphon elongation. [2]

In terms of systems theory, the electromechanical actuator with volatile liquid, described above, is a dynamic system. [2]

Elastic chamber of electromechanical actuator with volatile liquid is the place of performing the processes such as vaporization in gaseous atmosphere, boiling, evaporation and condensation.

The behaviour of the electromechanical actuator with volatile liquid is dependent on physicochemical processes occurring inside the sylphon: evaporation and condensation.

The way how these processes occur in the actuator operation is influenced by:

- the nature of the volatile liquid used
- the ambient temperature
- the geometric configuration of the elastic chamber

- the nature of the material used to make the elastic chamber
- the operating position of the actuator
- the variation law of the step signal applied to the actuator input.

Carrying out the above enumerated processes depends on the influence of these factors and manifests in the form of the unit step response and in the transient regime duration.

In the following it is presented the experimental study performed in the aim to analyze the transient regime of an electromechanical actuator with volatile liquid, using the unit step response.

In the experimental measurements done were used, for partial filling of sylphon, two different volatile liquids: petroleum ether and ethyl ether. The physico-chemical properties of these liquids [3] are presented in Table 1.

Table 1

The physic-chemical properties of volatile liquids used

	Petroleum ether	Ethyl ether
boiling temperature	20-75 °C	34,2-34,6 °C
auto-ignition temperature	288 °C	160 °C

2. EXPERIMENTAL STAND

Fig.1 shows a schematic diagram of a test stand for study the dynamic characteristics of electromechanical actuator with volatile liquid. [4]

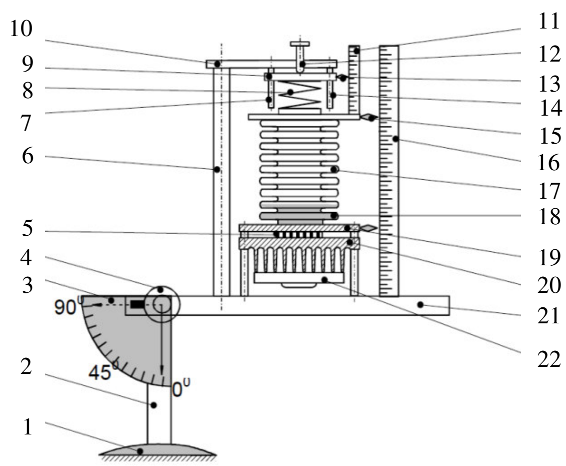

Fig.1. Test stand for studying the dynamic characteristics of electromechanical actuator with volatile liquid [2, 4]
1 – support plate; 2 – vertical lever; 3 – marked scale; 4 – knob; 5 – Peltier element; 6 – vertical support; 7, 14 – guides; 8 – spiral spring; 9 – intermediary plate; 10 – horizontal lever; 11, 16 – marked scale; 12 – threaded ax; 13,15 – pointer; 17 – sylphon; 18 – volatile liquid; 19 – metal cover; 20 – heat sink; 21 – support plate; 22 – fan

Experimental stand (fig.2) consists mainly of a support unit able to assure an adjustable position (vertical, horizontal or inclined) for the electromechanical actuator with volatile liquid, a variable amount of volatile liquid and a load conveniently adjustable. Sylphon heating is effected by means of Peltier elements.

Fig.2. Experimental stand for study of transient regime of the electromechanical actuator with volatile liquid heated with Peltier elements [2]

It was used a performant video camera, able to provide advanced capture and analysis tools. Experimental determinations based on using of video camera offered the advantages of recording, viewing, saving and loading complex image sequences, with the possibility to determine the distances and speeds directly on the images.

3. SYLPHON ELONGATION

Determination of sylphon elongation was carried out, on the one hand, from video recordings, on the other hand using a potentiometric transducer.

Using a digital oscilloscope, there were recorded images of signals proportional to the excitation signal (intensity of electric current through the battery of Peltier elements) and the response signal (sylphon elongation).

Corresponding image of the sylphon partially filled with petrolum ether (1ml) is shown in Fig.3.

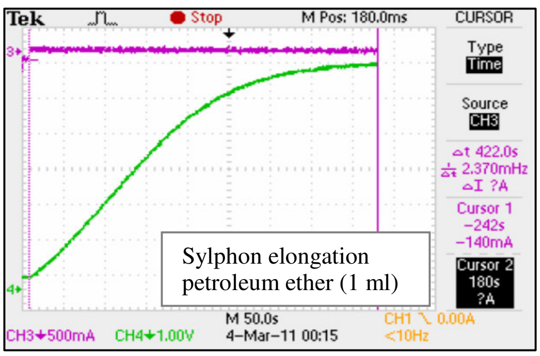

Fig.3. Sylphon elongation for different quantities of petroleum ether [2]

4. UNIT STEP RESPONSES

Experimental unit step responses of the electromechanical actuator with volatile liquid in different conditions

Because experimental data are influenced by errors which are the so-called experimental noise, mathematical processing [5] and analysis of experimental data were required.

To get accurate results and conclusions was necessary to eliminate this noise. To this end, empirical data adjustment was applied, namely was replaced the table of experimental date with a table of data close to the experimental data in order to obtain a sufficiently smooth graph.

Adjustment was performed using the optimal order polynom that approximates, through the least-squares method, the selected groups of experimental data.

Because the best adjustment is obtained for the average points, while taking into account the information on the behavior of function on the both parts of the adjusted points, the number of points for adjusting is chosen odd, and the groups of points are moved along the entire table: are taken, for example, the first five points y_1, y_2, y_3, y_4, y_5 and is adjusted, using them, the average point y_3; then is taken the next group y_2, y_3, y_4, y_5, y_6 and is adjusted the point y_4, etc.., until table is ended. In this way, of course, remain some points at the end of the table, which are adjusted with a lower precision lower. [5]

After mathematical processing of experimental data were drawn the graphs of the unit step responses (sylphon elongation for input signal of 1A current step type).

In fig.4 is shown the graph obtained for 4 ml petroleum ether in different operating conditions (sylphon: vertical, horizontal and vertical with load).

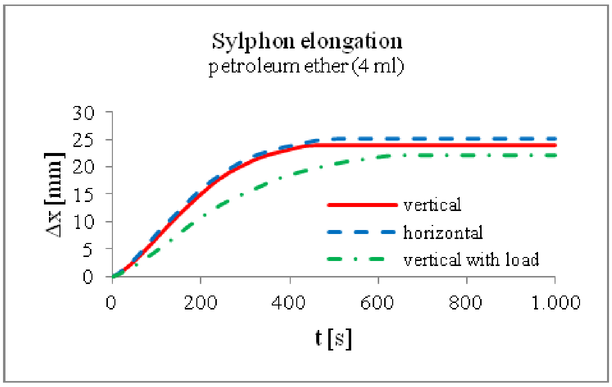

Fig.4. Experimental unit step response of the electromechanical actuator with volatile liquid (4 ml petroleum ether, sylphon positions: vertical, horizontal, vertical with load)

Mathematical expresions of unit step responses

Using the graphs of the experimental unit step responses (as that one shown in fig.4) the mathematical expressions of these functions were deduced (for example, Table 2 presents these functions obtained for petroleum ether and sylphon in vertical position).

Table 2

Unit step response (current step signal – petroleum ether – actuator in vertical position)

V [1]	Proc. type [2]	Process equation [3]	Unit step response [3]	t_m τ $t_s = t_m+3\tau$ [4]
1	PT_1		$x_e(t) = 26\left(1 - e^{-\frac{t}{199,44}}\right)$	$\tau = 199,44$ $t_s = 598,32$
2	PT_1		$x_e(t) = 25,5\left(1 - e^{-\frac{t}{205,02}}\right)$	$\tau = 205,02$ $t_s = 615,06$
3	PT_1		$x_e(t) = 25,2\left(1 - e^{-\frac{t}{198,5}}\right)$	$\tau = 198,5$ $t_s = 595,5$
4	PT_1		$x_e(t) = 24\left(1 - e^{-\frac{t}{200,94}}\right)$	$\tau = 200,94$ $t_s = 602,82$
5	PT_1		$x_e(t) = 28,2\left(1 - e^{-\frac{t}{211,44}}\right)$	$\tau = 211,44$ $t_s = 634,32$
10	PT_1		$x_e(t) = 23\left(1 - e^{-\frac{t}{245}}\right)$	$\tau = 245$ $t_s = 735$
20	PT_1T_m		$x_e(t) = 20\left(1 - e^{-\frac{t-42}{388,18}}\right)$	$t_m = 42$ $\tau = 388,18$ $t_s = 1206,54$

[1] V – volatile liquid volume [ml]
[2] PT_1 – 1st order delay element; PT_1T_m – 1st order delay element with dead time
[3] $x_i(t)$ – input signal (current strength for Peltier elements battery); $x_e(t)$ – output signal (actuator elongation)
[4] t_m – delay time [s]; τ – time constant [s]; t_s – response time [s]

5. CONCLUSIONS

Conclusions regarding the study performed using the stand described above are:

✓ According to the general theory of systems, the electromechanical actuator with volatile liquid is, in terms of dynamic, a dynamic technical system that can be studied using the mathematical model, through the unit step respons.

✓ From the unit step response we can determine the parameters characterizing the behaviour of the electromechanical actuator with volatile liquid in transient regime: delay time, time constant, response time, etc.

✓ The mathematical model of electromechanical actuator with volatile liquid is represented, generally, by a first order differential equation, which means that the actuator is a first order delay element (PT_1 element). When using large quantities of volatile liquid or applying high loads, the equation that represents the mathematical model corresponds to a first order delay element with dead time (PT_1T_m element).

✓ The behavior in transient regime of the electromechanical actuator with volatile liquid depends on its position (vertical or horizontal). Influence of position is reflected in the speed of transient regime, observing, generally, an increasing of speed for the horizontal position. Speed differences between the two positions depend on the nature of volatile liquid used. These differences are higher for petroleum ether and lower for ethyl ether.

✓ The dynamic behaviour of the electromechanical actuator with volatile liquid is influenced by the physico-chemical processes that occur inside the heated sylphon. Sylphon is a closed recipient in which, initially, there is a vaporization in gaseous atmosphere that, depending on the situation (volatile liquid type, temperature, pressure), can be followed by a boiling (vaporization in the entire mass of the liquid).

✓ The form of element equation, the unit step response and transient regime duration, expressed in time constant, is dependent on the nature of volatile liquid used to fill the sylphon. Using a volatile liquid with high volatility, has as consequence the increasing of transient regime speed (by lowering the time constant).

✓ The transient regime of the electromechanical actuator with volatile liquid is influenced by heating temperature. This influence is greater when fluid volatility is higher (the higher boiling temperature is lower). The mentioned disadvantage can be reduced by thermal insulating the sylphon, which is confirmed by experimental measurement performed.

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