ELECTROTHERMAL ACTUATORS WITH PWM CONTROL

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Keywords*:*

electrothermal actuators, PWM-control

Abstract

In recent years, as an alternative to continuous control with the use of standard analog automation signals (voltage or current), the Pulse Width Modulation (PWM) control was introduced. Although, it is often considered as the equivalent of a continuous control, in practice this continuous control strategy is not feasible with the use of simple electrothermal actuators. The paper presents the investigation results of selected electrothermal actuators operation under ON-OFF and PWM control. It shows clearly that the pulse width modulation for electrothermal actuators results in discontinuous control, which is only a slight modification of the two-point control method.

1. Introduction

The automation structure plays a significant role in improving the performance of a heating, ventilation and air conditioning systems. Very often, even if properly designed, they don't meet the requirements of the design intent. Among others, the reasons can include lack of integrated design between HVAC and control systems, aiming for reduction of investment costs in building automation, application of substitute solutions, however not equivalent. Sometimes problems arise not only at a control level but also at the physical one. The result of separation of system-derived aspects and automation is that industries mutually assume idealized work standards which are not kept in reality. Designers expect ideal control, without regulation control overshoot and time delays. Programmers working also as automation experts rarely use feedback - assuming instead, that the behaviour of actuators is proportional to the control signal.

Figure no. 1 shows a basic configuration of the automatic control system. This is a closed control system loop with a negative feedback automatically ensuring the required change of a controlled variable. For the HVAC industry, a valve and its drive often function as an actuator and a room with HVAC terminal elements (heater, chilled beam, fan coil) usually function as an object - inertial element of various orders.

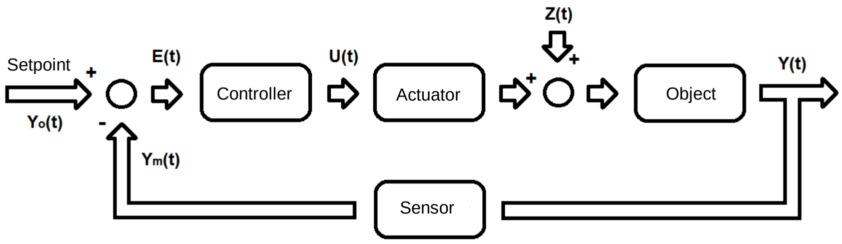

Fig. 1. The basic configuration of the automatic control system

In recent years PWM control is implemented as an alternative for continuous control, with the use of standard analog automation systems: voltage 0÷10V DC or current 4÷20 mA. Then, electrothermal actuators are very often used as driver elements. This method allows for reduction of investment costs of automation systems by reducing the number of wires, replacement of analog modules with digital ones in control cabinets as well as reduction of actuator costs. Although this method is very often treated as an equivalent of continuous control, in practice, due to very strong non-linearity, it is most often a functional equivalent of the two-point control for electrothermal actuators (usually used as part of the driver element in the HVAC industry).

2. PWM control

PWM is a control method of a voltage or current signal with a constant amplitude and frequency consisting in a change of pulse width modulation signal. The most important parameter of PWM signal is a duty cycle described by the formula no. 1:

$$k_w = \frac{T_{ON}}{T} \tag{1}$$

where:
k_w – duty cycle,
T_{ON} – high state period
T – total period of the signal described by the formula no. 2:

$$T = T_{ON} + T_{OFF} \tag{2}$$

where additionally:
T_{OFF} – low state period [2].

Signal interpretation with impulse modulation is presented in Fig. No. 2.

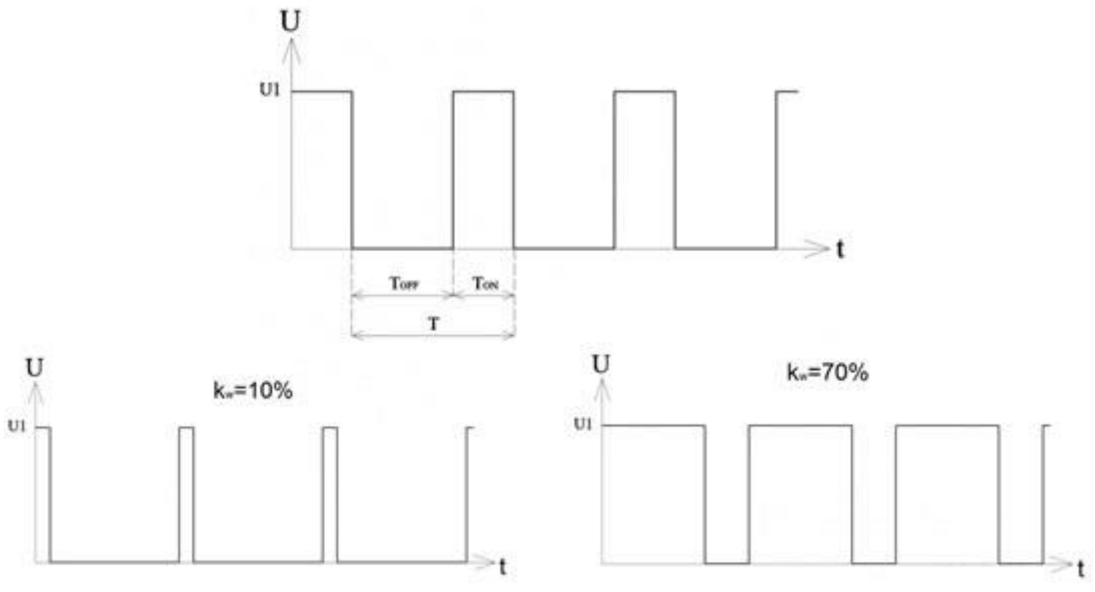

Fig. 2. Graphical interpretation of the pulse modulated signal

In non-continuous PWM control time T_{ON} is proportional to control signal value. Theoretically, it is then assumed that with the use of electrothermal actuators the valve can also reach intermediate opening stages. Opening/closing time of electrothermal actuators (usually several minutes) is long relatively to *T* period (the period of the signal is much shorter than the time constant of the actuator). One can theoretically assume that the average voltage of the signal causes intermediate valve opening states [1]. Unfortunately, practical solutions of electrothermal actuators and using them together with PWM control does not make it possible to reach the assumed goals.

3. Tests accomplished

3.1. Electrothermal actuators

In order to carry out tests, several representative electrothermal actuators from several manufacturers have been chosen (Danfoss, Oventrop, Salus, Siemens, TA Hydronics), which differ in supply voltage (24V AC, 230V AC) and in the location when inactive (NC – normally closed, NO – normally open).

3.2. Test and laboratory set-up

For the purpose of planned testing, a special dedicated test and laboratory set-up has been prepared. Figure No. 3 shows part of the set-up.

Fig. 3. Experimental set-up for testing electrothermal actuators

The laboratory set-up has been made to consist of the following elements: the element of the electrothermal actuator under test connected to a precise potentiometer (LCP–50FC–1k), with a software installed including a dedicated PWM algorithm of a PLC actuator (Siemens S7-1200), a data acquisition device (Ahlborn 2590) and regulated power supply.

3.3. Tests results

Measurements have been carried out in several series for two types of control modes: two-point and PWM. All measurements have been conducted at ambient temperature of 22°C.
Two-point control – by providing power supply to the actuator or by disconnecting it from the power supply in a predefined time, descriptions of opening/closing degree have been read as a function of time with concurrent setting of opening time and closing time counted until reaching 95 percent of the set value. Figure No. 4 shows the test results for ON/OFF control (opening degree of the actuator – SO as a function of time – t).Table no. 1 includes main parameters for tested actuators. Labels A-E are assigned randomly to the tested actuators.
PWM control – using properly programmed PLC emitting a pulse modulated signal at regular time intervals, opening/closing degree of the actuator have been read as a function of a duty cycle k_w (different level of a duty cycle). Figure No. 5 shows the test results for PWM control (opening degree of the actuator – SO as a function of a duty cycle k_w). Table No. 2 includes the opening degrees of a given actuator depending on a duty cycle k_w during opening stroke (O) and closing stroke (Z) of actuators.

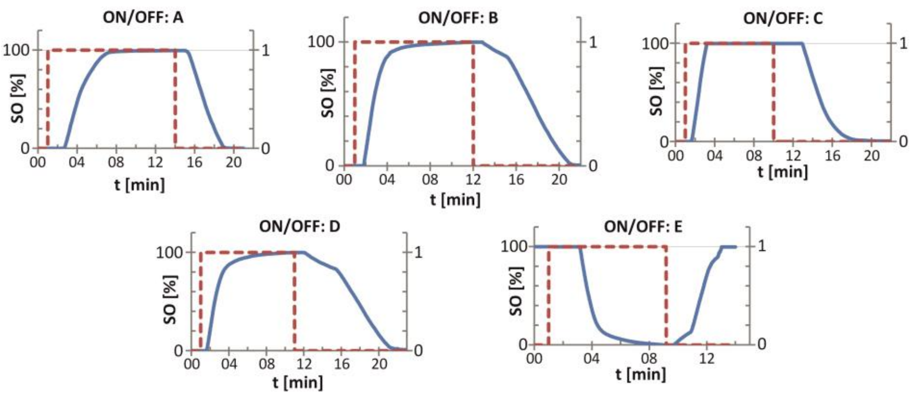

Fig. 4. The opening degree of the actuators as a function of time in the ON-OFF control

Table 1. The opening degree of the actuators as a function of time in the ON/OFF control

No.	**Actuators**	**Opening time**	**Closing time**	**Piston stroke**
		[min]	*[min]*	*[mm]*
1	A	5,41	3,39	3,65
2	B	4,05	8,36	5,37
3	C	2,05	7,19	4,79
4	D	4,41	9,59	5,27
5	E	3,45	5,09	4,06

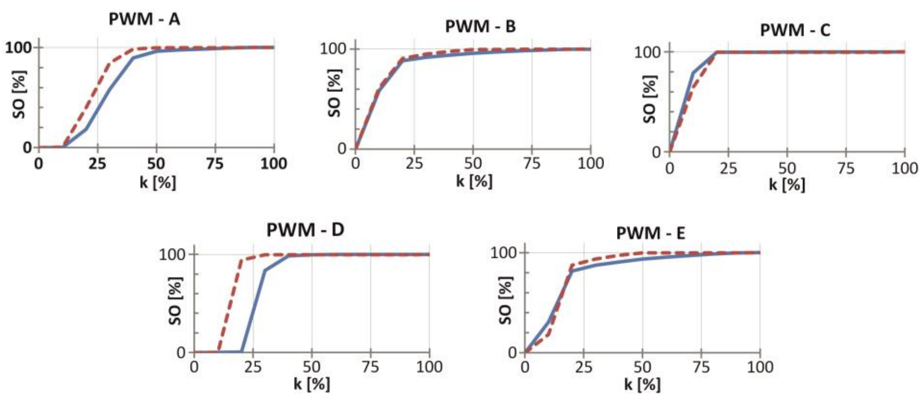

Fig. 5. The opening degree of the actuators as a function of duty cycle in the PWM control

Table 2. Table 1. The opening degree of the actuators as a function of duty cycle in the PWM control

k_w Ratio	**Opening degree of the actuators**									
	A		**B**		**C**		**D**		**E**	
[%]	*[%]*		*[%]*		*[%]*		*[%]*		*[%]*	
	O	Z	O	Z	O	Z	O	Z	O	Z
0	0	0	0	0	0	0	0	0	0	0
10	0	0	59	61	79	65	0	0	31	18
20	18	40	88	91	100	100	0	94	82	88
30	58	85	92	95	100	100	84	100	87	94
40	90	99	94	98	100	100	99	100	91	98
50	96	100	96	100	100	100	100	100	94	100
60	98	100	97	100	100	100	100	100	96	100
70	99	100	98	100	100	100	100	100	97	100
80	99	100	99	100	100	100	100	100	99	100
90	100	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100	100	100

4. Conclusions

Based on the analyses that have been carried out, the conclusion can be drawn that the application of PWM type of control system in case of electrothermal actuators is a functional equivalent of the two-point control method. While PWM control enables determination of a average voltage ($U_{śr}$), when controlling LED brightness and DC motor speed, and at the same time gives the possibility to reach intermediate stages which imitate continuous control, then for elements functioning as electrothermal actuators, it must be treated as two-point or possibly as its slight modification.

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