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AUTO-TUNING CONTROL OF REAL TIME MODEL

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Abstract: *This contribution deals with an application of relay based auto-tuning combined with algebraic controller design to a laboratory heat exchange model. First phase is an identification of the controlled system parameters. It is performed by the relay experiment with biased relay in the feedback loop. Second phase is a computation of the controller parameters through parameterized solution of Diophantine equations in the ring of proper and stable rational functions. Controller parameters are tuned through a pole-placement problem as a desired multiple root of the characteristic closed loop equation.*

Key words: *diophantine equations, feedback control, auto-tuning, relay*

1. INTRODUCTION

The most used controllers in the industry are still of PID type. They have a simple and understandable structure and they are quite resistant to the control loop changes. However, knowledge of the controlled system parameters is required for the proper controller synthesis. One of the possible solutions is usage of the auto-tuning procedure. The principle was introduced by Åström in1984 when a symmetrical relay was used to obtain critical parameters of the controlled system. After it, many studies about the automatic tuning of the controllers are reported (Majhi *et al.,* 1998), (Morilla *et al.,* 2000), (Vyhlídal, 2000), (Vítečková *et al.,* 2004).

2. RELAY IDENTIFICATION

The identification procedure consists of an experiment with biased relay in the feedback loop as can be seen in Fig.1. Typical output from this experiment is shown in Fig.2. The controlled system is then approximated by the first order transfer function with time delay:

$$G(s) = \frac{K}{Ts+1} \cdot e^{-\Theta s} \tag{1}$$

Estimation of the process gain can be computed from (Vyhlídal, 2000):

$$K = \frac{\int_0^{iT_y} y(t)dt}{\int_0^{iT_y} u(t)dt} \qquad i = 1,2,3,... \tag{2}$$

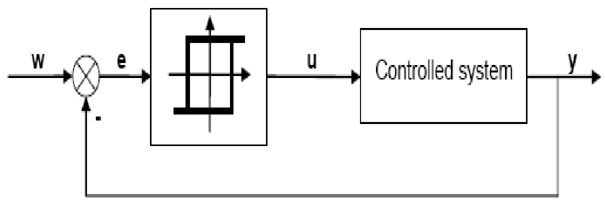

Fig. 1. Relay in the feedback loop

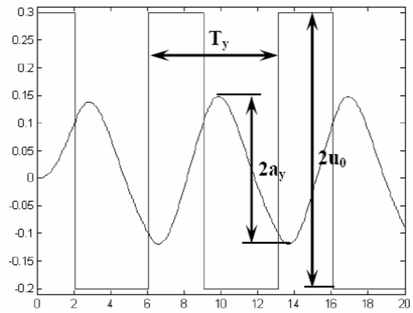

Fig. 2. Relay oscillations

The time constant and time delay term are given by (Vítečková *et al.* 2004):

$$T = \frac{T_y}{2\pi} \cdot \sqrt{\frac{16 \cdot K^2 \cdot u_0^2}{\pi^2 \cdot a_y^2} - 1} \tag{3}$$

$$\Theta = \frac{T_y}{2\pi} \cdot \left[\pi - arctg\frac{2\pi \cdot T}{T_y} - arctg\frac{\varepsilon}{\sqrt{a_y^2 - \varepsilon^2}} \right] \tag{4}$$

where ε is relay hysteresis.

3. CONTROLLER

The control design is based on the fractional approach (Vidyasagar, 1987), (Kučera, 1993), (Prokop *et al.,* 1997), (Prokop *et al.,* 2002). The conversion between polynomial and R_{PS} form can be expressed as:

$$G(s) = \frac{b(s)}{a(s)} = \frac{\frac{b(s)}{(s+m)^n}}{\frac{a(s)}{(s+m)^n}} = \frac{B(s)}{A(s)}$$

$$n = \max(\deg(a), \deg(b)), \quad m > 0 \tag{5}$$

The time delay term is approximated by the Taylor approximation of the denominator (6) before the controller synthesis.

$$e^{-\Theta s} = \frac{1}{e^{\Theta s}} = \frac{1}{1+\Theta s} \tag{6}$$

All stabilizing controllers are given by the general solution of the Diophantine equation:

$$AP + BQ = 1 \tag{7}$$

which can be expressed by:

$$P = P_0 + BZ \qquad Q = Q_0 - AZ \tag{8}$$

where P_0 and Q_0 are particular solutions of (7) and Z is an arbitrary element of R_{PS}.

The control aim is not only to stabilize the control loop but also to track the reference value asymptotically and/or reject the disturbances. These requirements are expressed through the divisibility conditions in R_{PS}. Asymptotic reference tracking is achieved when the denominator F_w divides P in R_{PS}. For the step function it is given by:

$$F_w = \frac{s}{s+m} \quad m > 0 \tag{9}$$

4. LABORATORY MODEL

The laboratory model used in this contribution is the representation of time delay systems. It is based on the principle of transferring heated liquid through the pipeline to the heat exchanger. Scheme of the model is shown in Fig.3.

The liquid is transferred by continuously controllable pump "6" to the flow heater "1". Temperature of the liquid is measured by platinum thermometers "T1", "T2" and "T3". Heated liquid flows through 15 meters long heat-insulated pipeline "2". Next, the liquid flows to the heat exchanger "3". Heat consumption can be adjusted by two fans "4" and "5". Fan "5" can be controlled only in two states (on/off) while fan "4" can be controlled continuously and it is used especially for disturbances generation. Finally, the liquid is returned to the pump "6" which creates the media circulation. The tank "7" compensates the water thermal expansion effect.

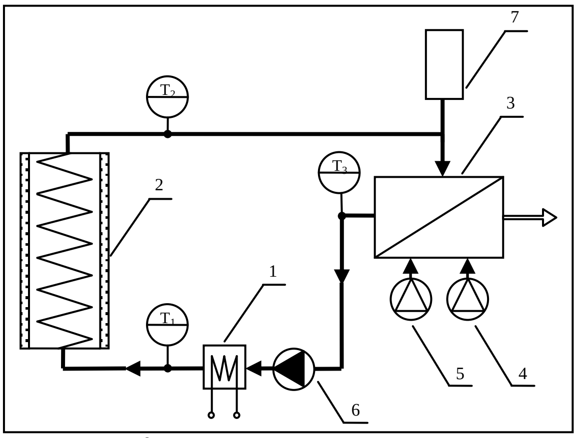

Fig. 3. Scheme of the laboratory model

5. EXPERIMENT

The output from the experiment is shown in Fig.4. Controlled value in the experiment is temperature of the liquid measured by thermometer "T2". Sampling period is 10 seconds throughout the whole measurement. The experiment begins with the electric input of the heater set to 30%. Next, the biased relay oscillations are performed. The margins are 20% and 50% of electric input to the heater. Hysteresis of the relay is set to 2°C. After three cycles of the relay, the stored values are used for the transfer function approximation and controller design is performed. The control is started immediately after relay oscillations are stopped. Reference value in the part of control response is set to 60°C.

Approximated transfer function from the relay experiment in Fig.4 is given by:

$$G(s) = \frac{0.88}{343s+1} \cdot e^{-204s} \tag{10}$$

Transfer function after the time delay approximation is in the form:

$$G(s) = \frac{0.88}{343s+1} \cdot \frac{1}{1+204s} \tag{11}$$

Discrete controller parameters for 10 second sampling period and m = 0.0035 are:

$$\frac{Q(z)}{P(z)} = \frac{0.86z^2 - 1.66z^1 + 0.80}{z^2 - 1.94z^1 + 0.94} \tag{12}$$

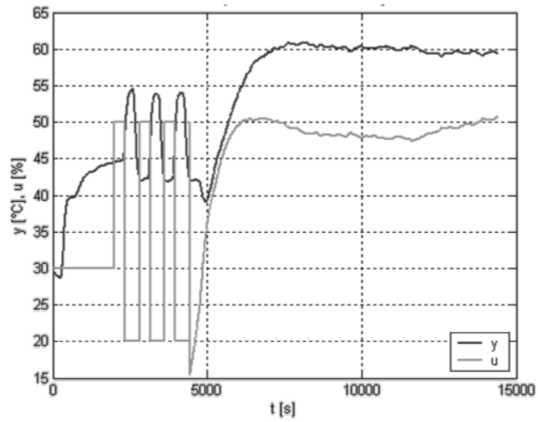

Fig. 4. Relay experiment and control response

6. CONCLUSION

This contribution showed the real application of the relay based auto-tuning which was previously studied and simulated in Matlab. It proved that the controlled system parameters can be obtained from the relay experiment as the first order transfer function approximation. The consecutive controller design was performed through the solution of Diophantine equation. The experiment proved the controller ability to stabilize and control the heat exchange laboratory model.

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