Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 100 (2015) 370 – 375
Procedia Engineering
www.elsevier.com/locate/procedia

25th DAAAM International Symposium on Intelligent Manufacturing and Automation, DAAAM 2014

Accuracy of Relay Identification Depending on Relay Parameters

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Abstract

Combination of relay feedback experiment and control synthesis is usually a part of autotuning principles. This contribution deals with the relay based identification of continuous time plants because the knowledge of the controlled system parameters is important for the quality of control. The feedback relay schemes can use different types of relays. This paper is focused on biased relay with hysteresis. The controlled system is identified as a first order transfer function because most of industrial plants can be sufficiently approximated by a first order linear stable system with time delay term. The main aim is to analyze the precision of controlled system parameters identification when the feedback relay parameters will vary. Matlab program environment is used for all simulations conducted in this paper.

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Keywords: Autotuning; biased relay; describing functions; hysteresis; relay oscillations

1. Introduction

The feedback relay test [1] introduced by Aström and Hägglung in 1984 is considered as an important tool for automatic tuning of controller parameters. It identifies the parameters needed for Ziegler-Nichols method [3]. This test is based on observation that the closed loop oscillates with constant period when the output is delayed behind the input by $-\pi$ radians. The ultimate gain and frequency can be identified by a simple relay experiment. These critical values can be used in Ziegler-Nichols rule for controller parameters design which is simple but suffers from several drawbacks.

In the following years many authors try to improve the methodology in both ways, the relay experiment as well as control design [2]-[4], [13]-[15]. Some of them need the controlled system parameters while the original approach

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Peer-review under responsibility of DAAAM International Vienna
doi:10.1016/j.proeng.2015.01.380

provides no explicit parameters of the transfer function. Direct estimation of transfer function parameters starts to appear during the period of more than two decades. It was mainly based on introduction of asymmetry and hysteresis to the relay experiment [5], [8], [9]. This contribution brings an analysis how the asymmetry and hysteresis influence the quality and accuracy of controlled system parameters identification.

The scheme of the relay feedback loop can be seen in Fig. 1. The goal of the original test was to indicate the critical point in the Nyquist plot of the open loop. However, the identification experiments can utilize different types of relay, e.g. biased with or without hysteresis. The characteristics of various relays are depicted in Fig. 2.

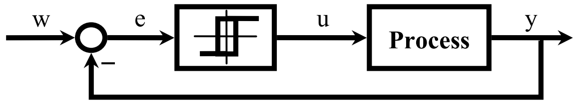

Fig. 1. Relay based identification loop.

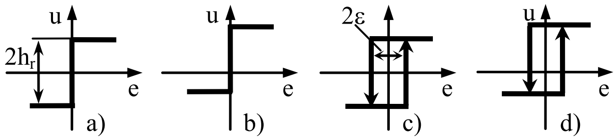

Fig. 2. Various types of relay.

Almost every industrial process can be approximated by first order transfer function with time delay. The model for stable first order system with time delay is:

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

2. Relay experiment

The purpose of the relay experiment is to estimate the parameters of the unknown controlled system. A biased relay brings further development of this process as can be seen in [2], [5], [6], [7], [11], [12]. Typical response from the biased relay experiment performed on first order stable system is depicted in Fig. 3. The relay asymmetry is required for the process gain estimation. A biased relay with hysteresis is used in this contribution.

The proportional gain ca be solved from the equation [10]:

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

When the biased relay is used the output value oscillates in one period. These oscillations can be described by relations [8]:

$$A_u = (\mu_0 + \mu) \cdot K \cdot \left(1 - e^{-\frac{\Theta}{T}}\right) + \varepsilon \cdot e^{-\frac{\Theta}{T}} \tag{3}$$

$$A_d = (\mu_0 - \mu) \cdot K \cdot \left(1 - e^{-\frac{\Theta}{T}}\right) - \varepsilon \cdot e^{-\frac{\Theta}{T}} \tag{4}$$

$$T_{u1} = T \cdot \ln \frac{2 \cdot \mu \cdot K \cdot e^{\frac{\Theta}{T}} + \mu_0 \cdot K - \mu \cdot K + \varepsilon}{\mu \cdot K + \mu_0 \cdot K - \varepsilon} \tag{5}$$

$$T_{u2} = T \cdot \ln \frac{2 \cdot \mu \cdot K \cdot e^{\frac{\Theta}{T}} - \mu_0 \cdot K - \mu \cdot K + \varepsilon}{\mu \cdot K - \mu_0 \cdot K - \varepsilon} \tag{6}$$

The normalized dead time [8] of the controlled process ($L = \Theta / T$) is derived from (3) or (4) as:

$$\begin{gathered} L = \ln \frac{(\mu_0 + \mu) \cdot K - \varepsilon}{(\mu_0 + \mu) \cdot K - A_u} \\ or \\ L = \ln \frac{(\mu - \mu_0) \cdot K - \varepsilon}{(\mu - \mu_0) \cdot K + A_d} \end{gathered} \tag{7}$$

The time constant [8] can be obtained from (5) or (6) as:

$$\begin{gathered} T = T_{u1} \cdot \left(\ln \frac{2 \cdot \mu \cdot K \cdot e^{L} + \mu_0 \cdot K - \mu \cdot K + \varepsilon}{\mu \cdot K + \mu_0 \cdot K - \varepsilon} \right)^{-1} \\ or \\ T = T_{u2} \cdot \left(\ln \frac{2 \cdot \mu \cdot K \cdot e^{L} - \mu_0 \cdot K - \mu \cdot K + \varepsilon}{\mu \cdot K - \mu_0 \cdot K - \varepsilon} \right)^{-1} \end{gathered} \tag{8}$$

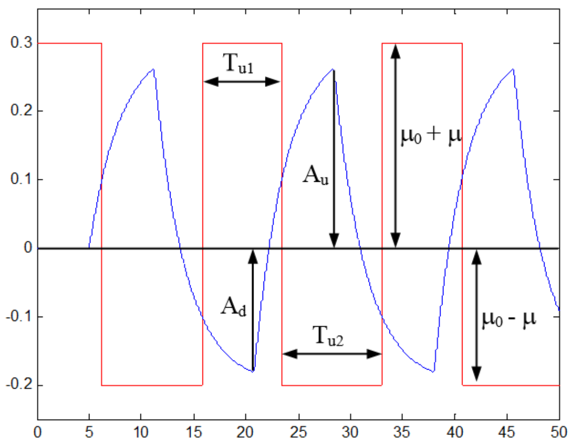

Fig. 3. Oscillations of first order stable system.

3. Examples and results

The main goal of this contribution is focused on the accuracy of identified parameters depending upon the relay parameters. Since the identification must estimate all the parameters of the unknown controlled system a biased relay experiment is used. All simulations are performed in Matlab environment in the developed program system which is depicted in Fig. 4. This program simplifies the identification process when the parameters need to be changed frequently. The detailed description can be found in [16].

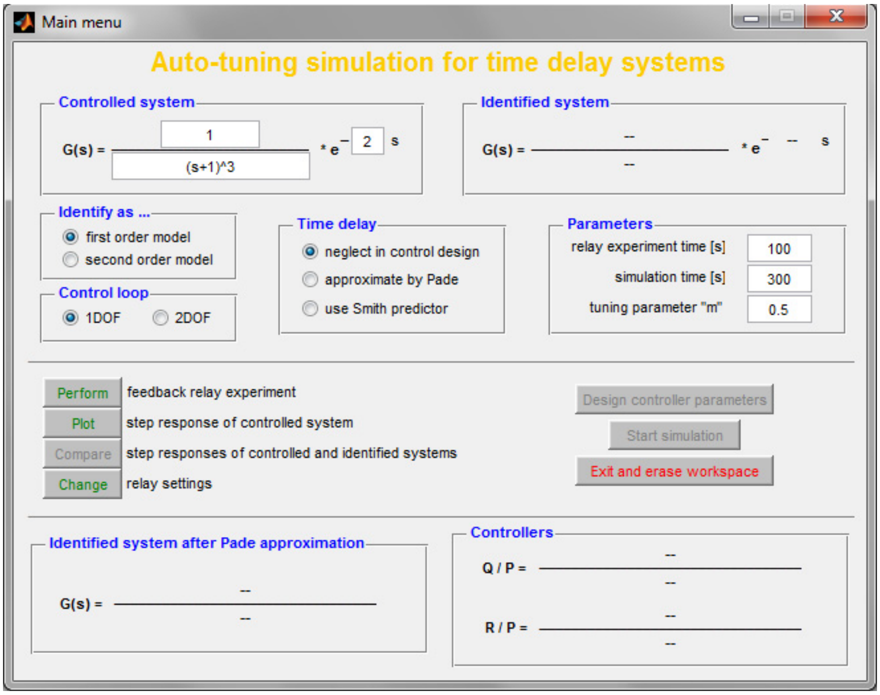

Fig. 4. Program system in Matlab.

As an example a first order transfer function is given in the form:

$$G(s) = \frac{K}{Ts+1} \cdot e^{-\Theta s} = \frac{4}{3s+1} \cdot e^{-5s} \qquad (9)$$

The aim of the experiment is to analyse the accuracy of relay identification with different relay parameters, namely asymmetry and hysteresis. The simulation is performed sequentially in the developed program system for various relay settings. The results of the experiments are summarized in tables 1-5.

Table 1. Identified parameters when relay hysteresis is not present.

Asymmetry	10 %	20 %	30 %	40 %	50 %	60 %
Gain K	3.86	3.93	3.96	3.97	3.96	3.97
Time constant T	2.78	2.90	2.94	2.96	2.95	2.96
Time delay Θ	5.09	5.05	5.03	5.02	5.03	5.03

Table 2. Identified parameters when ε = 0.1.

Asymmetry	10 %	20 %	30 %	40 %	50 %	60 %
Gain K	3.85	3.94	3.95	3.95	3.97	3.98
Time constant T	2.75	2.90	2.93	2.92	2.95	2.97
Time delay Θ	5.13	5.05	5.04	5.05	5.04	5.03

Table 3. Identified parameters when ε = 0.2.

Asymmetry	10 %	20 %	30 %	40 %	50 %	60 %
Gain K	3.87	3.91	3.95	3.96	3.96	3.96
Time constant T	2.76	2.85	2.91	2.94	2.94	2.94
Time delay Θ	5.14	5.10	5.06	5.05	5.05	5.06

Table 4. Identified parameters when ε = 0.3.

Asymmetry	10 %	20 %	30 %	40 %	50 %	60 %
Gain K	3.88	3.95	3.93	3.96	3.96	3.96
Time constant T	2.78	2.90	2.88	2.93	2.93	2.93
Time delay Θ	5.15	5.07	5.10	5.06	5.07	5.07

Table 5. Identified parameters when ε = 0.4.

Asymmetry	10 %	20 %	30 %	40 %	50 %	60 %
Gain K	3.88	3.94	3.94	3.94	3.96	3.95
Time constant T	2.74	2.87	2.88	2.88	2.92	2.91
Time delay Θ	5.20	5.11	5.11	5.12	5.08	5.08

Following recommendations can be concluded from the obtained results. Bigger values of relay asymmetry (around 40 %) cause better accuracy of all identified parameters. Better accuracy is also gained for smaller values of relay hysteresis (around 0.1).

The recommended values for the relay experiment are used for approximation of high order system:

$$G(s) = \frac{5}{(s+1)^6} \cdot e^{-5s} \tag{10}$$

The relay hysteresis is 0.1 and margins are 0.30 and -0.18 so the asymmetry is 40 %. The approximated first order transfer function is in the form:

$$\tilde{G}(s) = \frac{4.97}{2.79s+1} \cdot e^{-8.75s} \tag{11}$$

Step responses and frequency responses of the controlled system (10) and approximated system (11) are shown in Fig. 5.

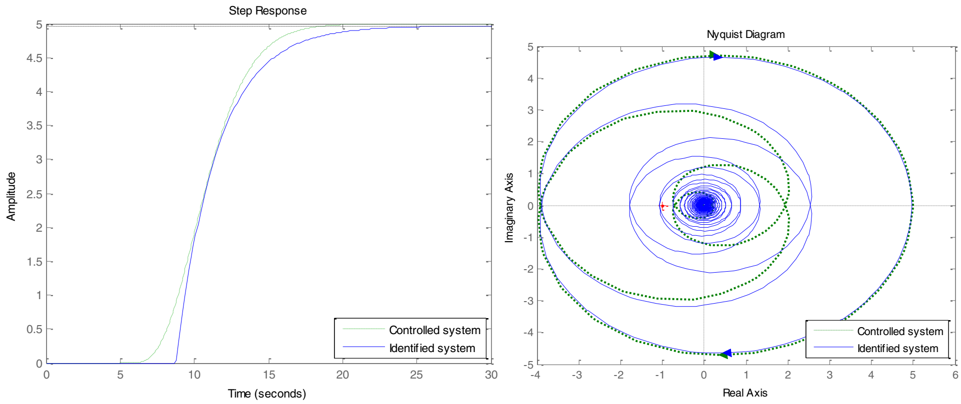

Fig. 5. Comparison of step and frequency responses.

Conclusion

The contribution described the feedback relay method for identification of controlled system parameters. The knowledge of accurate parameters plays a key role for a control design. The goal of the paper was to investigate how the different relay settings influence the accuracy of the identification method. As a result a set of relay parameters were recommended according to the observed data. The future research will be focused on second order approximation and 2DOF control loop.

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