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Industrial test setup for autotuning of PID controllers in large-scale processes: Applied to Tennessee Eastman process ⋆

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Abstract:
Although many PID tuning approaches are available, it is not easy to find a method that does not require any engineer/operator interference. In this work, we present a fully automated approach for PID tuning based on relay feedback. This method involves sending the relay feedback test data from PLCs (Programmable Logic Controller) into a historian, analyzing the test data using a tuning application to generate a tuning report that contains PID parameters and sending the report back to the operator station to retune the controllers in PLCs.
This paper is focused on the following three keys steps: 1) A method to identify persistent steady-state conditions in a control loop using routine operating data because any tuning test is performed when the process is operating at steady state, 2) A novel procedure to implement relay based tuning test, 3) A new model identification method which is a combination of frequency-domain and time-domain analysis. Subsequently, the identified plant model is used to obtain PID tuning parameters based on IMC design.
The approach has been tested on an industrial test setup in which all the control loops of the Tennessee Eastman process are controlled by a Siemens PLC. The necessary relay parameters, the hysteresis and relay amplitude, for the test are estimated automatically where interference by an engineer or an operator is not required. The new method for model identification is robust against measurement noises. The proposed method is able to tune the important control loops in the Tennessee Eastman process successfully.

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1. INTRODUCTION

A typical industrial plant has hundreds of control loops where 90% of the loops are controlled by PID controllers (Desborough and Miller, 2002). These controllers have to be tuned individually to match process dynamics in order to provide good control performance. Although the heuristic approaches by control engineers have been proven adequate for a large number of control loops, the manual tuning methods are very cumbersome and time consuming in particular, for those plants with slow responses. Also, the improvement in control loop performance mainly depends on the experience and the process knowledge of personnel. It is a well-known fact that many industrial control loops are poorly tuned by trial and error where performance of the control loops is not taken into consideration. Hence, the tuning methods without human interference draw more and more attention of the researchers and practising engineers.

Industrial experience has clearly indicated that it is highly desirable to have an push-button option on the Human Machine Interface (HMI) to put a control loop in tune mode to obtain PID tuning values. Earlier authors proposed different autotuning methods which have great practical values. However, they all suffer from some major limitations that are explained well by Hang et al. (2002). For example, the Cohen-Coon method (Cohen and Coon, 1953) requires an open-loop test on the process and is thus inconvenient to apply. The disadvantage of the closed-loop step method by Yuwana and Seborg (1982) and the Bristol method is the need of large setpoint change to trigger the tuning which may drive the process away from the operating point. To overcome these disadvantages, Åström and Hägglund (1984) proposed an automatic tuning controller that was based on the relay feedback technique. This method soon became a superior alternative to the conventional tuning.

A huge progress has been made in the last three decades in the area of auto tuning of PID controllers. Majority of the progress is in line with or variations of the method suggested by Åström and Hägglund (1984). Luyben (2002) summarized the applications and extensions of auto-tuning method and proposed the Auto-Tuning Variation (ATV) method. In the ATV method, the ultimate frequency and the ultimate gain which represent the most important process information can be directly extracted

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using a describing function. The recent studies on auto-tuning of PID controllers are reported by Leva (2007).

The auto-tuning method based on relay feedback is used widely in process industries due to its ease of implementation (Blevins and Nixon, 2011). This technique has several advantages over other methods, for instance it is time-saving and easy to use. The method is carried out under closed-loop control and, with an appropriate choice of the relay parameters, the process output can be kept close to the set point. This maintains the operating point in the linear region where the frequency response is useful, hence the method works well on highly nonlinear processes (Åström and Hägglund (1988)). The method is also extended to be applicable in presence of disturbances in the process (Hang et al. (1993)).

The relay-based tuning method provides two pieces of information, namely ultimate gain and ultimate period which are used by for Ziegler-Nichols PI and PID tuning rules . However, these tuning rules do not provide a good trade-off between robustness and performance of control loops. On the other hand, PI and PID tuning rules based on IMC (Internal Model Control) design are preferred because of their Pareto-optimality between performance and robustness. The tuning test based on relay feedback can easily be automated which we use for the model identification.

Although relay based auto-tuning has so many advantages, estimating the relay parameters to initiate the tuning procedure in plants is not straightforward. Moreover, tuning procedure based on relay method needs to be initiated in a control loop at steady state conditions to obtain ultimate frequency and ultimate gain accurately. Generally, in plants, visual inspection of trend plots of controller output and process output is a way of judging whether the control loop is in steady state or not. This is not easy when the process variables are affected by too much measurement noise or other sources. These two issues are addressed in this article. We have developed a method to find the presence of consistent steady state conditions in control loops. In addition, we have fully automated relay based tuning procedure by developing methods to estimate the necessary parameters.

We have implemented our Relay Tuning Function Block (RTFB) in the Simatic PCS7 environment. RTFB detects consistent steady-state, estimates the required relay amplitude and hysteresis and performs the relay-feedback test by a command from HMI. Simba Profibus is used for communication between the PLC and the Tennessee Eastman process model (Ricker (2002)) running in MATLAB. Aspen InfoPlus21 is used as the historian in the PIMAQ® (Plant Information Management and Data Acquistion) framework, and the PIMAQ tuning application analyses the test data to obtain the tuning values. The PIMAQ framework is one of the in-house products of Siemens Oil and Gas Solutions.

This paper is organized as the following. The technical description of RTFB and PIMAQ framework are described in Section 2. The identification method and the tuning rules are introduced in Section 3. The Tennessee Eastman process is briefly described in Section 4. Results are presented and discussed in Section 5, and concluding remarks are given in Section 6.

2. INDUSTRIAL AUTO-TUNING SETUP

In order to develop a fully automatic tuning procedure based on relay method, we need the following as has been explained earlier.

(1) a method to detect an existence of a consistent steady state behaviour in a loop
(2) a procedure to estimate necessary relay parameters
(3) an automatic way of selecting the controller (PID or PI) and the tuning method (*e.g.* Ziegler-Nichols, IMC based or SIMC method)

All the three issues are addressed below.

2.1 Implementation of RTFB

RTFB (Relay Tuning Function Block) is implemented in the PCS7 Simatic environment (using SCL programming language). RTFB is connected in series with the existing PID controller (CA Function Block). All function blocks are compiled, then binaries are executed in PLCs. The main algorithms implemented in the RTFB are as follows.

Detection of a consistent steady state behavior: In general, the visual inspection of process variables in trend plots is a way to identify the presence of steady state conditions. However, the steady state detection in control loops of process plants can be automated by comparing process output with set-point based on the student's t-test (Narasimhan and Jordache (1999)).

A simple algorithm is proposed in this paper to detect the presence of a consistent steady state without using the set-point information. The proposed algorithm is based on the basic definition of the steady state: Steady state is defined as the state of a system when it becomes settled (*If derivative of a quantity with respect to time is zero, the quantity is said to be at steady state*). However, in the reality it is not possible to have a constant process variable in a control loop due to noise.

The steady state detection algorithm in this paper is based on three indices, I_1, I_2, and I_3 which are estimated using process output when the control loop is in the routine operation. These indices must satisfy specific conditions in order to conclude that the control loop is in consistent steady state. The consistent steady state behaviour here refers to the situation in which the process remains in the steady state for a considerable time duration (*e.g* at least 30 sec in chemical process plants).

The process output is denoted by Y here. The main steps involved in the method are as follows.

(1) Estimate recursive mean of Y (low pass filer), Y_μ
(2) Estimate windowed mean of Y, Y_{win}
(3) Calculate VY $= (Y - Y_{win})^2$
(4) Estimate recursive mean of VY, σ_Y^2
(5) Calculate standard deviation of Y, σ_Y
(6) Calculate upper and lower limits of Y using
$Y_{UL} = Y_\mu + 0.5\sigma_Y$
$Y_{LL} = Y_\mu - 0.5\sigma_Y$

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