

DEVELOPMENT OF AN AUTO-TUNING PID AND APPLICATIONS TO THE PULP AND PAPER INDUSTRY

M. Grégoire¹, A. Desbiens², É. Richard³

¹ Algosys Inc., 360, rue Franquet, entrée 10, Sainte-Foy (Québec), Canada, G1P 4N9 (e-mail: mgregoire@algosys.com)

² Université Laval, Department of Electrical and Computer Engineering, Pavillon Adrien-Pouliot, Sainte-Foy (Québec), Canada, G1K 7P4 (e-mail: desbiens@gel.ulaval.ca)

³ Abitibi-Consolidated, Papeterie Beaulieu, 1, rue du Moulin, Beaulieu (Québec) Canada, G0A 1E0, (e-mail: eric_richard@abicon.com)

Abstract

An auto-tuning industrial PID is presented. The auto-tuning is realized in three steps. The process is first adequately excited in order to generate good quality data for the second step, the process identification. The last step is the PID tuning based on the evaluated parametric model. The auto-tuning PID has been implemented on two different control systems and successful applications to processes of the pulp and paper industry are analyzed.

1. Introduction

Many single-input single-output industrial control loops are poorly tuned [1, 2]. In particular, it was estimated that in the pulp and paper industries, the output variance could be reduced by 30-50% by improving loop tuning, controller selection and equipment maintenance [2]. In other continuous production industries, the statistics are probably similar. The lack of resources and time and the use of trials and errors PID tuning often explain these results.

This paper presents a robust auto-tuning PID (DynAxiom® from Algosys). The auto-tuning algorithm is detailed in the following section. The implementation of the auto-tuning PID on two industrial control systems is presented in section 3. Finally, some applications to processes found in the pulp and paper industry are described in section 4.

2. Auto-tuning PID

To be accepted by the industries, an auto-tuning PID must have some essential qualities:

- The auto-tuning PID is easy to use. The parameters that the user must enter are self-explanatory
- The auto-tuning sequence is not too long and does not disturb too much the production. During this time, the process must remain in closed-loop control.
- The auto-tuning PID is able to deal with different types of dynamics: processes with and without a delay,

processes with zeros (minimal and non-minimal phase), integrating processes, etc.

- The performances of the loop are improved by the use of the auto-tuning. The loop must also be robust to process behavior changes.

The algorithm of the auto-tuning PID can be separated in three steps. The process must be first adequately excited in order to generate good quality data for the second step, the process identification. Based on the evaluated parametric model, the PID tunings are calculated. Figure 1 shows the structure of the auto-tuner.

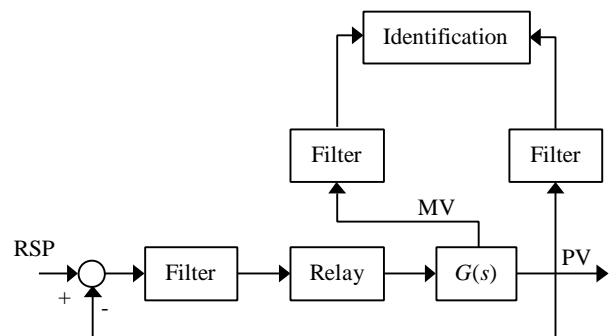


Figure 1: Auto-tuning PID

As many other auto-tuning PID controllers, the excitation is based on a relay feedback experiment [3]. The system excited by the relay, $G(s)$, can be either the process itself or the process in closed-loop with an existing regulator. In the first case, the relay output is the manipulated variable (MV). When $G(s)$ is a closed-loop, the relay output is its set point. The relay insures that the process output remains under control while providing a good excitation and limiting the amplitude of the oscillation. To make it more robust to the industrial environment, hysteresis is added to the relay.

If the excited system $G(s)$ is the open-loop process, the value of the relay loop set point (RSP) is set equal to the initial value of the measured process variable (PV). When $G(s)$ is a closed-loop, the value of RSP is the initial value of the loop set point.

When using the auto-tuner for the first time on a process, the following information is required:

- Sampling period.
- Process type: Is the process stable, unstable or with integration?
- Action type: Is the sign of the gain of the process positive (inverse) or negative (direct)?
- Initial relay output: This is the value of the first amplitude of the signal generated by the relay.
- Excitation structure: Is $G(s)$ the process itself or the process in closed-loop with an existing regulator?
- Controller type: What is the type of regulator that must be used during the tuning phase: PI, PID, or selection by the algorithm itself? If the third choice is selected, the auto-tuner will use the best controller structure which is suitable for the identified process model.
- Maximal relay change: This is the maximal incremental value of the signal generated by the relay. If the algorithm calculates a change at the output of the relay which is larger than the maximal value, the signal is clamped.
- PV amplitude: This is the approximate value of the desired amplitude of the measured process variable during the excitation sequence. This parameter is useful to avoid large disturbances on the production and for safety reasons.
- PV maximal value: This is the maximal value of the difference between the amplitude of PV during the excitation sequence and its initial value (value of PV at the beginning of the auto-tuning). If PV comes too close to this value, the relay switches. The switch is made before the limit is reached to take into account the process dynamics. If PV becomes larger than this value, the excitation is stopped.
- MV maximal value: This parameter applies only if $G(s)$ is the open-loop process. This is the maximal value of the difference between the amplitude of the relay output (MV in this case) during the excitation sequence and its initial value (value of the relay output at the beginning of the auto-tuning). If the algorithm calculates an output of the relay which is outside the limits, the signal is clamped.
- Minimal number of periods of oscillations during the excitation: This parameter ensures a minimal number of points for the identification. The default value is 4.
- Maximal number of periods of oscillations during the excitation: This parameter ensures that the excitation does not last forever. The excitation may also be automatically stopped before the maximal number of periods is reached if the frequency of the oscillations seems constant. The default value is 8.

First-order filters can also be added to the set point and to the measured variable. The time constants must then be specified.

For subsequent auto-tunings on the same process, all parameters of the above list will be automatically suggested by the algorithm since results from past auto-tunings are kept into a database.

During the excitation by the relay, the amplitude of the relay output is automatically modified in order to respect as much as possible the above specifications on PV.

The first step of the process identification based on the recorded MV and PV data during the excitation sequence is the design of adequate filters. From data analysis, the cut-off frequencies of the band-pass filters are selected to put more weight on the frequencies located around the estimated closed-loop bandwidth, to eliminate operating points and low frequency drifts and to remove high frequency noise [4]. Both the process input and output are filtered. Based on the filtered data, a parametric model is calculated using the least-squares identification algorithm [5]. To realize a compromise between parsimony and model flexibility, up to four parameters (besides the delay) can be estimated. Indeed, for most industrial processes, a second-order model is realistic. As stated by Box and Jenkins [6], for many practical situations, when the effect of noise is appreciable, a delayed first-order or second-order model would often provide as elaborate a model as could be justified for the data. The model identification is repeated with different delays to select the best model.

The tuning of the PID is not based on the critical gain and critical period of the oscillations of the system during the excitation sequence. The PID tunings are calculated using a unified robust PI design method based on the parametric model of the process [7]. The controller parameters are selected in order to approximately minimize the distance between the open-loop transfer function (controller and process in series) and a specified contour on the Nichols chart. The contour then corresponds to the desired maximum peak closed-loop resonance, which is closely related to the peak overshoot to a set point step change if a second order system is assumed. Since the design ensures that the open-loop frequency response does not cross the specified contour, minimal gain and phase margins are warranted. This method leads to good results for any type of process dynamics. It allows a fast response to a set point change while limiting the overshoot [7].

Comparisons of a similar, but simpler, auto-tuner with three commercial auto-tuner (Fisher DPR 910, Foxboro Exact 760C and Leeds & Northrup Electromax V) have already been performed [8]. It has been shown that it is able to cope with more different process dynamics and it leads to better performances.

3. Implementation

The auto-tuning PID has been implemented on two different industrial control systems. The first control system is a Provox DCS (Fisher Rosemount). The auto-tuner algorithm is programmed in C in order to be compatible with the VMS operating system. The communication between the auto-tuner and the DCS is made using a Computer Highway Interface Package (CHIP), a software package that lets a host computer access data of a Provox instrumentation system via the system's data highway. The interface with the operator is still very simple and the commands from/to the menu are performed through the use of files.

The auto-tuner algorithm has also been programmed to be compatible with the FIX32 (Intellution) SCADA software. The algorithm is in C++. The operating system is Window NT and the communications between the auto-tuner and the FIX32 database are realized with the EDA (Easy Data Access) tool. The interface with the operator is a typical Window interface. For every tuning session, all the parameters (excitation and tuning) are saved into a database. Therefore, the operator can easily repeat tunings on the same process and see the time evolution of the tuning parameters.

4. Results

The results presented is an application of the auto-tuner to a plant of the Papeterie Beupré (Abitibi-Consolidated), where a Provox system is used. The auto-tuner has been successfully tested on different types of loops: level, flow rate and pressure. Typical results for a level loop are discussed in the following paragraph.

Table 1 shows the initial value of the parameters required by the auto-tuner.

Name	Value	Name	Value
Sampling period	3 seconds	Maximal relay change	100 %
Process type	Integrator	PV amplitude	10 %
Action type	Direct	PV maximal value	± 5 %
Initial relay output	10 %	MV maximal value	± 30 %
Excitation structure	Open-loop	Min. number of oscillations	4
Controller type	PI	Max. number of oscillations	8

Table 1: Initial parameters for the level loop.

The excitation of the process by the relay is depicted in Figure 2. The specifications on MV and PV are respected.

It can also be seen that the amplitude and the length of each step vary throughout the excitation sequence.

Based on the data plotted in Figure 2, a parametric model can be obtained by off-line identification. Its conversion to the Laplace domain leads to the following transfer function:

$$G_m(s) = \frac{-0.005e^{-6s}}{s(1+13.08s)} \quad (1)$$

For the model of equation 1, the regulator calculated with the unified PI tuning method is:

$$G_c(s) = \frac{K_c(1+T_i s)}{T_i s} \quad (2)$$

where $K_c = 5.28$ and $T_i = 104.4$ seconds. Prior to the auto-tuning, the PI parameters were $K_c = 1.0$ and $T_i = 240$ seconds.

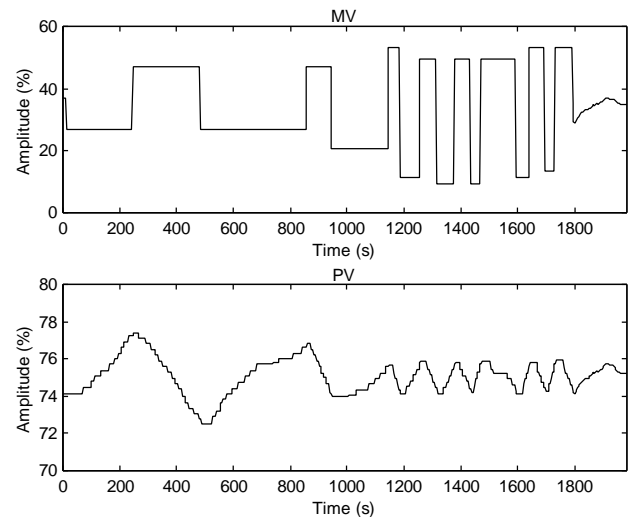


Figure 2: Excitation of the process output.

Figure 3 compares these two sets of tuning. A set point step change, from 75% to 70%, is applied at time $t = 100$ seconds. The set point is brought back to 75% at time $t = 1600$ seconds. With the new tuning, the PV reaches its set point within 600 seconds. The response time with the previous tuning is over 2000 seconds. The overshoot is similar for both tunings. Unless a filter is added to the set point, the PV necessarily exhibits an overshoot to a set point step because of the presence of an integrator in both the process and the controller. It can also be noticed that the improvement in the PV performance requires a more active MV.

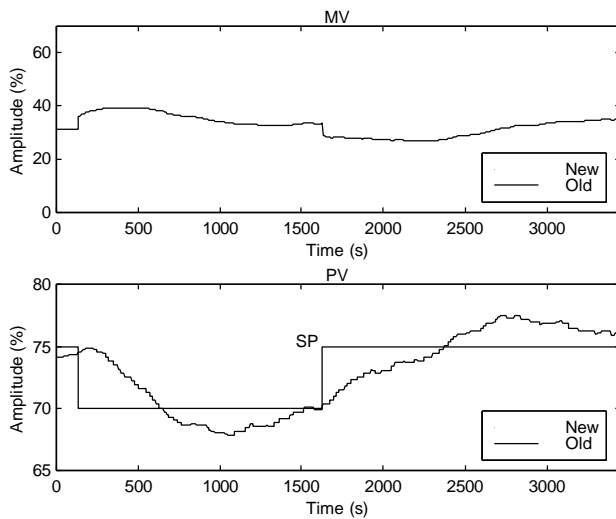


Figure 3: Comparison of the old and the new tuning.

5. Conclusion

A robust auto-tuning PID was presented. The process excitation is realized using a supervised relay. A model is then calculated with an off-line parametric identification algorithm. Finally, the PID tuning is obtained by a model-based frequency design method. The auto-tuner has been implemented on two industrial control systems. The experimental results shows the good performances of the algorithm. Current works aim at improving the excitation sequence and at reducing the number of parameters the user must select.

6. References

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