RELAY METHOD ON AUTO-TUNING AUTOMATION SOLUTIONS

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Abstract: The PID controller is in the back-bone of the majority of control systems in industrial environment. As for its simplicity or experienced efficiency the PID controller came to stay. Therefore, it is justified to work on improvements to its implementation and efficiency, since any innovation in this widely applied method will have a tremendous impact. By studying modern methods of self-tuning, the Relay method for system identification appears as a way to the improvements. Throughout this work, Relay method and some improvements are presented and implemented in software on a Siemens PLC. As a recent method, Siemens does not have Relay-based algorithms for the calibration of PID controllers in the high range of automation solutions. This technique of automatic calibration of PID controllers can be efficiently applied to most industrial control systems, with low interference in the production process. This is auto-tuning the distance of a button in the SCADA (Supervisory Control and Data Acquisition) system.

Keywords: Auto-tuning, Automation, PID, Relay Method.

1) INTRODUCTION

There is an increasing interest of auto-tuning solutions, since any innovation in the PID controller design will have a tremendous impact.

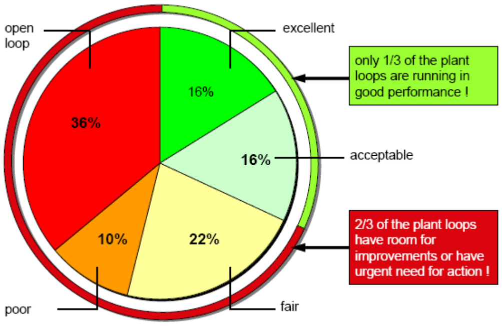
The goal of this work is to study, improve and implement in, a Siemens automation solution, modern auto-tuning methodology that can be applied to most control loops existing in industrial environment.

It is known that great part of PID controllers PID who play its role in the industry, make it below of its excellent regulation. These can be optimized by 2 ways, appealing the time consuming tests of manual regulation or through techniques of auto-tuning. After a brief study of some of the techniques of auto-tuning existing, the one that I considered more adequate to the use in processes of unknown and varied model and whose use does not intervene significantly with the productive process is known as “Relay Method”.

In this work, I study and implement an automatic technique for calibration of PID controllers that can have application to the majority of the systems of industrial control;

Nowadays automation is available with many different tools and equipments that make it possible to attain the high standards of quality and efficiency.

Empirical studies have shown that many of the existing control loops in industrial processes do not fulfil their duties with the desired efficiency, leaving a large potential for improvement.



Source: Control Engineering May 2008

Figure 1 - Potential improvements in control loops

Advantages of betting in optimal control:

- Decrease consumption of electricity;
- Less equipment wear field;
- Increased productive capacity;
- Reduction of processing time;
- Increase the quality of the final product;
- Reduce the workload of operators;
- Increased safety of operation;
- Reduced sensitivity to disturbance;
- Stops or maintenance work, less frequent;
- Increased efficiency of production;
- Minimizing the environmental impact, by saving reagents.

The paper is organized as follows. Section 2 describes the experimental system setup, were the test were made. Section 3 describes the classic Relay method, discussing practical aspects of the implementation, and the improvements that were.

Section 4, the experimental results of different controllers with the experimental setup are evaluated and discussed. The influence of the parameters in the performance of the projected controllers is also evaluated.

Finally, in Section 5, we present conclusions and directions for future work.

2) EXPERIMENTAL SETUP

In order to enable the development and testing of the proposed algorithms was given an experimental platform, enabling the analysis, operation and data recording. To this end, it took 3 key equipment, and software development.

The 3 key equipment used were, a ET200S-CPU SIEMENS PLC, the pilot plant of the PCT-9 Armfield® and a computer monitoring system.

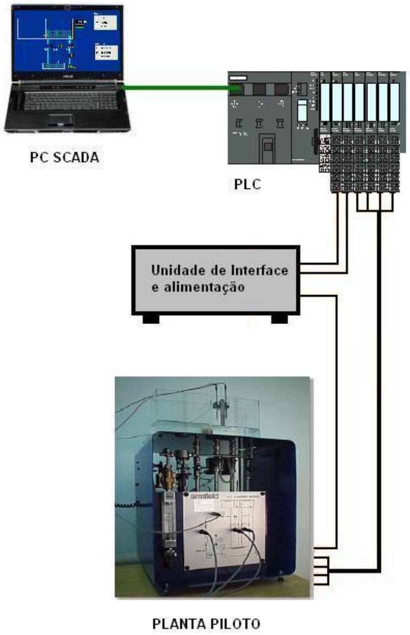


Figure 2 - Experimental setup

The objective is to control the water level in the tank. The water is pumped to the tank with a level sensor, by a water pump and a control valve that will be our control output via an analogue 4-20mA signal.

The tank has 2 electro-valves through which the flow out of the tank is handled. Operation of the system will be made through the said motorized valve.

The SCADA system offers an easy control of the system, integrating the possibility of graphical analyses. The auto-tuning methodology is parameterized and activated directly in the SCADA system.

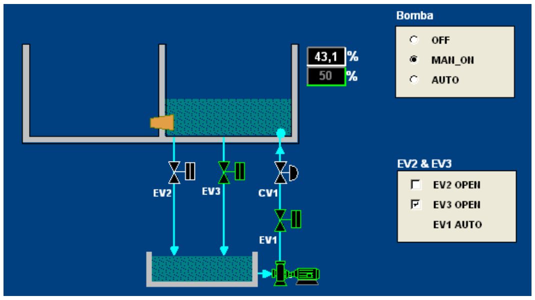


Figure 3 - SCADA system image

3) PID CONTROLLER

As was already told this paper is dedicated to modern auto-tuning solutions that can be used in the design of a PID controller. Because this is a well studied subject I will just represent the discrete PID formula used in the PLC.

$$u(n) = k_P e(n) + \frac{k_P T}{T_i}\sum_{k=0}^{n} e(k) + \frac{k_P T_d}{T}(y(n) - y(n-1))$$

4) TUNING METHODOLOGIES

a) Conventional Tuning Methods

Ziegler and Nichols proposed in 1942 two different tuning strategies for PID controllers. These have been successful contributions that proportionate acceptable control performance in many systems. However these methods have week points that led them not to be widely used. Because its implementation is quite unpredictable many times causing unintended disturbance in the production process.

b) Tuning with Relay Method

The relay method presented as an alternative to the conventional method of Ziegler-Nichols for closed loop, in the identification of model systems by Astrom and Hagglund [8] in 1994, seems to be the solutions. It has the advantage to generate and maintain a controlled oscillation (the magnitude of the oscillation can be defined). The success of this method is due to the simplicity of the mechanisms of identification and calibration, and also its applicability in slow or highly nonlinear systems. Relay method is very efficient in determining the critical gain K_u and critical frequency ω_u.

Advantages of the Relay method:
- Requires little mathematical processing;
- Identify the characteristics of the model around its, critical frequency (where phase margin is $-\pi$);
- Fits various industrial processes;
- Application does not require knowledge of the mathematical model of the system;
- Calibration possible in production, because the disturbance is limited by its parameters;
- Low sensitivity to disturbances;
- For processes with a very high time constant, it is more efficient in terms of time than conventional methods of step or pulse;
- Avoids the tedious, procedure of trial and error in determining the critical gain.

The relay proposed by Astrom and Hagglund was an Ideal Relay.

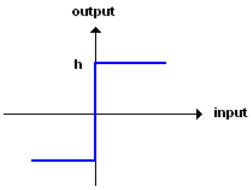


Figure 4 - Ideal Relay

Their procedure determines the gain introduces capable of introducing a delay of half cycle when operating in feedback. This is the critical gain, which is related to the point where the *Nyquist* curve first crosses the real axis. Part of the success of this method of identification comes from the fact that this can be taken directly from the experimental results, since very rarely the model of the system is know.

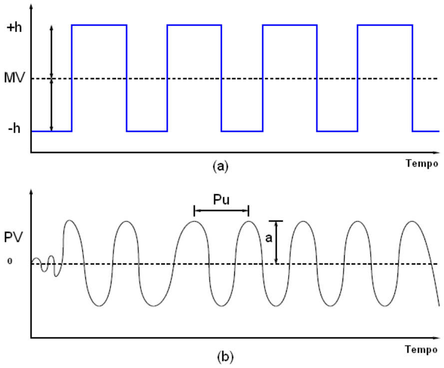


Figure 5 - Example of relay implementation

The procedure is relatively simple and efficient. Involves, physically moving the manipulated variable from the process. Considering a system of positive static gain. When increasing the input (action), the output of the system tends to increase. When the PV (process value) passages of the SP (setpoint), the input is moved in the opposite direction. As a result we have an oscillation of the system, were the amplitude can be adjusted.

The relay was integrated in a PID controller, resulting in a similar model to the one in figure 6. When the operator activates the auto-tuning, the PID is deactivated and the control passes on to the relay, after determining the parameters, the PID controller is activated with the calculated gains.

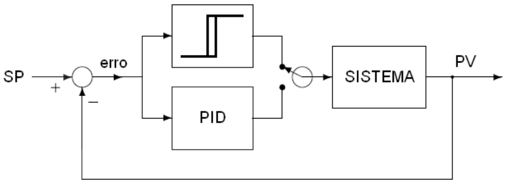


Figure 6 - Controller with integrated relay

The classic Ideal Relay proposed by Astrom and Hagglund, was improved mainly in two aspects:

- Less sensitivity to the presence of noise, with the introduction of hysteresis.
- Automatic adjust of the Out_Bias (mid value used as output of the Relay) necessary to easily obtain a symmetric oscillation of PV around SP.

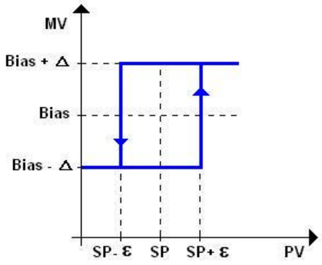


Figure 7 - Relay with hysteresis

Without the addiction of hysteresis, the calibration of the controller is easily affected by the presence of noise or disturbances in PV.

In an experiment using relay with hysteresis the critical gain can be easily obtained from the equation:

$$K_u = \frac{4\Delta}{\pi\sqrt{a^2-\varepsilon^2}}$$

Where Δ represents the amplitude of actuation used in the relay, ε represents the hysteresis and a is the amplitude of the resulting oscillation.

As for the critical period, P_u, it can be obtained directly from the oscillation, like demonstrated in figure 5.

Having K_u and P_u we can calculate de PID gains using the table for the closed-loop method of Ziegler-Nichols:

	Kp	Ti	Td
P	$0,5K_u$		
PI	$0,4K_u$	$0,8P_u$	
PID	$0,6K_u$	$0,5P_u$	$0,125P_u$

Table 1 - Ziegler-Nichols table for the closed-loop method

The automatic adjust of Out_Bias brings us to the situation were the upper and lower actuation values of the relay produce similar effect on the process, resulting in a better approximation of the mathematical model used.

Within each complete period of PV, Out_Bias is corrected if the difference between the positive and negative periods is more than 10% of the oscillation period:

$$Out\_Bias = Out\_Bias_{-1}\left(1+\frac{T_{UP}-T_{DOWN}}{2(T_{UP}+T_{DOWN})}\right)$$

It is now possible to calibrate a PID controller, by pressing a button in the SCADA system, after defining hysteresis and the magnitude of actuation of the relay.

5) EXPERIMENTAL RESULTS

In this section are presented and discusses the results obtained in experiments performed with different tuning methodologies. It is also studied the effect of parameter variation in the relay.

a) Ziegler-Nichols open-loop tuning method

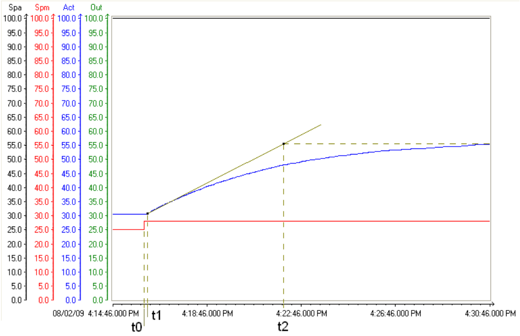


Figure 8 - Reaction curve of open-loop Ziegler-Nichols tuning[1]

This method presents some difficulties in implementation. The experience takes a long time (20 minutes) in this system, and must be initiated at a stable PV. Another difficulty of this method is the amplitude of the step that has to be different depending on the systems characteristics.

The estimation by this method caused a change in PV, about 30%, which makes the use of this method, during the production process impractical for many systems.

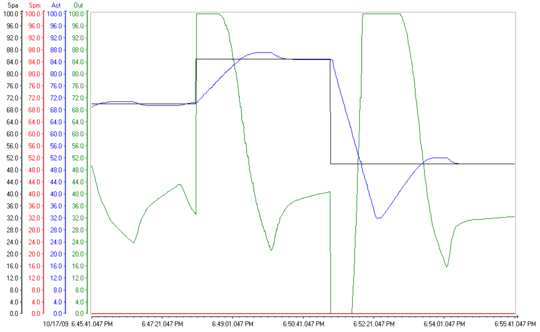


Figure 9 - Performance test to ZN open-loop tuned PID

The controller reveals some overshoot and good steady-state follow-up. The controller responds quickly and smoothly.

On the way down to the setpoint of 50% the driver revealed a large deviation due to a blockage of the valve and not the control methodology.

b) Ziegler-Nichols closed-loop tuning method

This experiment also took 20m. It's an iterative method that can become dangerous because of the uncontrolled oscillation that it generates.

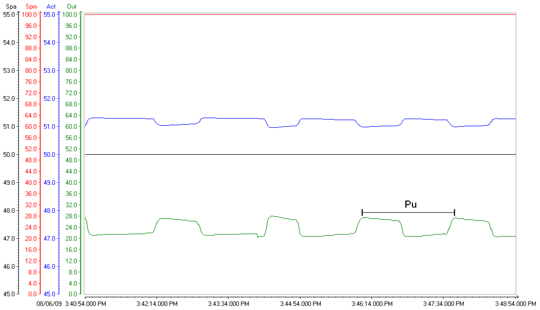


Figure 10 - Closed-loop Ziegler-Nichols tuning

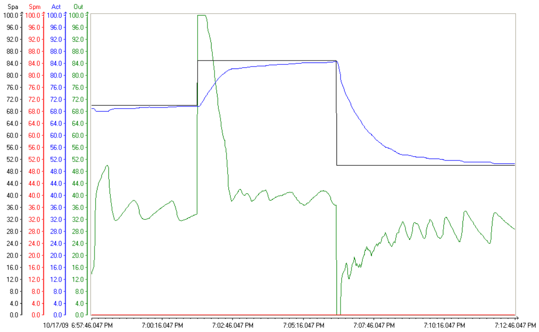


Figure 11 - Performance test to ZN closed-loop tuned PID

The closed-loop method of Ziegler-Nichols gives us a very slow response and an oscillatory behavior. This behavior can succeed of the test characteristics itself and leads to higher wear of the actuator.

c) Ideal Relay

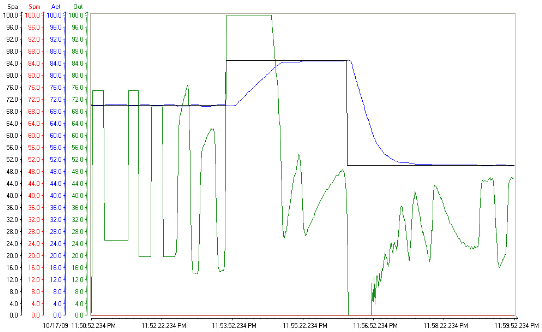


Figure 12 - Test to the PID tuned using Ideal Relay

As can be seen from the above figure, it is not advisable to estimate the PID using an ideal *Relay* because it is very sensitive to disturbances or noise in the process variable. Any passage of PV from SP will cause an unwanted change in the manipulated variable.

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[1] Legend: Spa – Setpoint auto; Spm – Setpoint manual; Act – Actual value (PV); Out – Control output (MV).

d) Relay with 2% hysteresis

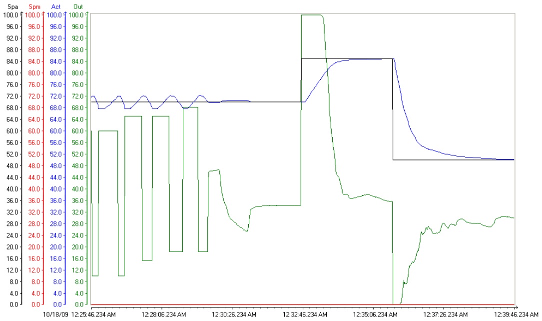

Figure 13 - Test to the PID tuned using Relay (2% hysteresis)

The estimation of parameters with 2% hysteresis represents a significant improvement over the ideal relay. The identification takes about 4 minutes but in turn the response is much smoother.

At this stage, without introducing external disturbances in the system, the PID controller reveals good performance despite being slightly slower than the ideal relay is quite smooth.

e) Automatic adjust of Out_Bias in Relay

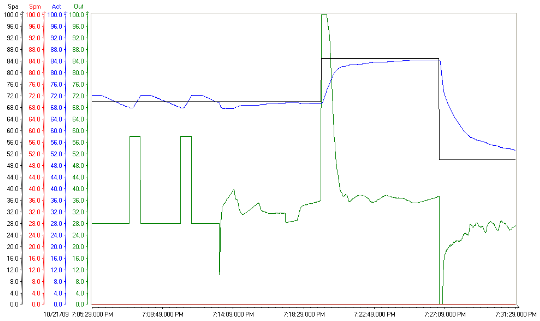

Figure 14 - Test to PID tuned using Relay without Bias auto-adjust

As shown by the figure, higher level is reached much faster than the lower one, suggesting a system unbalanced between the two levels of MV (manipulated variable).

This leads to a less accurate estimation of the values determined during the identification system.

As a result the controller without the automatic adjust, seems to be very slow. A very high value of time integral is the source of great difficulty on eliminating the stationary error.

It thus appears that the automatic adjustment is an important factor in the estimation of the controller, greatly benefit from the automatic adjustment of Out_Bias.

f) Influence of the amplitude of the Relay

In this experiment we test the influence of the amplitude of the manipulated variable (MV) between it's high and low level of the Relay. In previous experiments, the value was fixed at 25%.

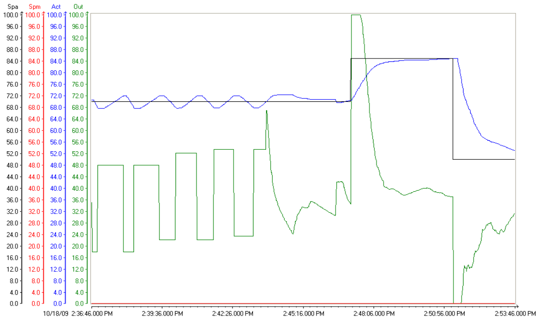

Figure 15 - Test to the PID tuned using (15% amplitude)

The decrease to 15% makes the estimation slower. The decrease resulting in the proportional gain should make it smoother before disturbance.

The controller has been improved by the decrease in the amplitude of the Relay.

g) Influence of disturbance in Relay method

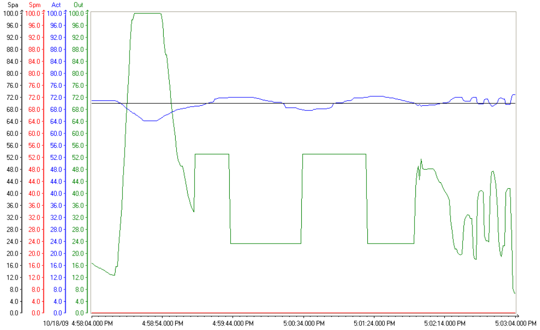

Figure 16 - Calibration and test of PID with disturbance

In order to predict the behavior estimated controllers, in less favorable conditions, it is manually introduced in the experiment a disturbance of about 2% in level of water in the tank.

The disturbances are present since the beginning of the experiment. As shown by the previous figure, the controller reacts to disturbances without much variation in the range of action.

It has been obtained by the method Relay, a controller very efficient and with good behavior in the presence of disturbances.

Parâmetro	**Valor (%)**
ΔPV	2
ΔOut	15
Out_Bias	38,1

Table 2 - Relay parameters in the presence of disturbance

	Kp	**Ti**	**Td**
PID	10,1	48	12

Table 3 - Estimated PID controller gains

6) CONCLUSIONS AND FUTURE WORK

This work's main goal was to improve the

In future work, it would be important to

observer and consequently to a better overall performance.

In order to estimate gain and critical period more precise, the variation can be simultaneously implemented in the iterative process of variation. Thus, in addition to vary the focal point of action that balances the excitement, the amplitude of action would also be adjusted to adapt to the needs of the system.

In order to complement the method of self-tuning presented, it is expected that it can stretch to the development of a monitoring system of higher education that is continuously monitoring and recording the efficiency with which the PID controllers are performing their duties .

In this work, we developed a methodology for auto-tuning which shows that the method Relay is able to be successfully applied to the majority of PID control systems.

In search of a more efficient control several factors that may contribute to their performance. You can not just concentrate on getting the best parameters for the PID and ignore the existence of imperfect actuators or sensors as well as frequent disturbances.

The method Relay easier to tackle the calibration of PID controllers, it allows a rapid avoiding the need for a thorough knowledge of control.

Despite the good performance of the PID controller estimated by the response curve of Ziegler-Nichols, it is considered that the method overcomes the relay because of its simplicity, fewer restrictions and less interference in the production process.

Analysis of the introduction of hysteresis in the relay method, it is concluded that this clearly improves the estimation, reducing their sensitivity to noise and disturbance. Drivers estimated to have an ideal Relay oscillatory behavior even in a stable condition.

It was also concluded that the value should be the least able to easily generate a sustained oscillation, for a value too high increases the proportional gain of PID and respectively, their sensitivity to disturbance.

The automatic convergence enabled improvements to the method of classical Relay, greatly facilitating its implementation and improving the estimation of parameters.

Method Relay appears to be capable of scaling PID controllers with good rejection of disturbances. Once the disturbance decreases, the PID back to respond gently normal. The controllers obtained were able to provide rapid and smooth as needed. This is a method that easily estimated controllers largely identical to the same parameters.

Method Relay proved a successful option to achieve the targets proposed, including to implement a modern method of self-tuning a system of Siemens automation.

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