PROCESS SIMULATION AND CONTROLLER TUNING

Section 1 – Tutorial

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History

Revision	Date	Change Sections	Reason
0	May 2021		Initial issue

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1 INTRODUCTION

The use of PID controller to performe basic control tasks on a variety of industrial processes is widely applied. Practically all PLC vendors provide an implementation of PID control algorithm in the PLC basic library, but the controller must be adjusted to specific implementation in the PLC and process specification in order to aim acceptable control limits.

This task is not always easy to do for the control engineer due to the lack of information on current implementations and/or the availability of the plant during the commissioning phase.

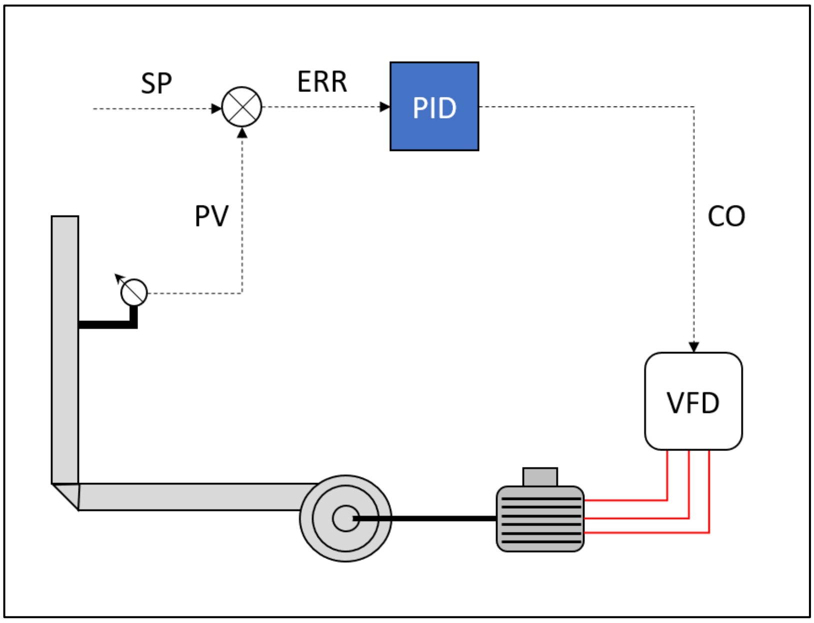
The use of simulation is capable to overcome both problems and provide to the control engineer a better understanding of the process behavior on different parametrizations in the control system that need to be taken into consideration for proper tuning of the controller.

This tutorial explains how to perform a basic simulation of the plant and the application of techniques to obtain the controller gains which can be used as initial values during the commissioning phase.

2 PROCESS SIMULATION

2.1 Use Case – Static Pressure Control

As a use case it is proposed the control of the static pressure in a duct through the speed regulation of a motor which drive a centrifugal fan. The next figure shows the configuration of the plant.



This type of plant is typical for combustion air systems where a pressure must be maintained in order to ensure proper air flow to the burners.

2.2 Affinity Laws

Affinity laws govern the relashionship of fan speed, pressure developed by the fan and input power to the fan.

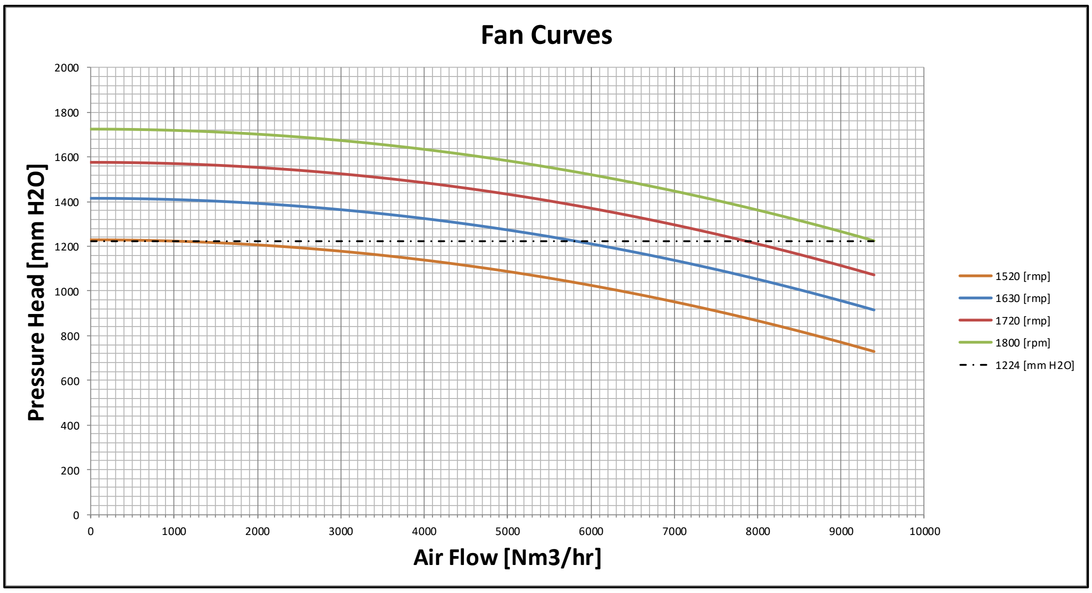
Speed	Pressure	Power
$\frac{Q_1}{Q_2} = \frac{N_1}{N_2}$	$\frac{H_1}{H_2} = \left[\frac{N_1}{N_2}\right]^2$	$\frac{BHP_1}{BHP_2} = \left[\frac{N_1}{N_2}\right]^3$

The Affinity Laws are used to estimate a new static pressure point according to the new speed calculated by the PID controller. Then the fan curve is adjusted to the new operation conditions.

The model is build thru the nominal conditions for the fan which are stablished during the design of the plant. For this example the conditions are:

- Nominal Fan Speed: 1800 [RPM]
- Nominal Pressure Head: 1224 [mm H_2O]
- Nominal Air Flow: 9400 [Nm^3/hr]

Next figure shows different fan curves at different speeds.

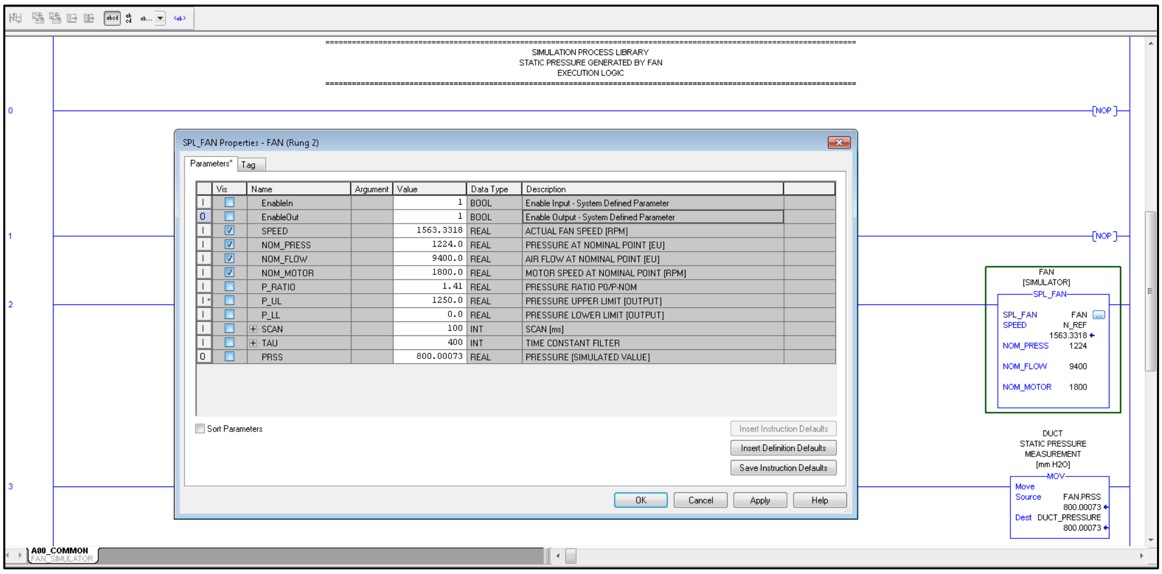


It can be noticed that each curve provides the same air flow at different static pressure heads.

2.3 Fan Simulation Block

The operation of the fan at different speeds is implemented in a library block which simulates the fan at the operation conditions required by the system. This simulation block is used as the process variable feedback for the PID controller, namely is capable to calculate the static pressure at the new operation conditions for the fan.

The next figure show the simulation block parameters for the fan.



Besides the nominal conditions the simulation block needs to be parameterized with:

- Pressure Ratio = Pressure at zero air flow / Pressure at nominal conditions
- Pressure Upper Limit
- Pressure Lower Limit
- Block Scan Rate
- Time Constant for the First-Order-Filter (Typically 4 to 5 times the Scan Rate)

Once all the information needed to setup the simulation block has been established, we can continue with the development of out PID controller logic.

3 PID CONTROLLER TUNING

The PID control algorithm is a general implementation for a control loop mechanism which employs feedback in order to estimate an error signal. It is the de facto control when an automatic adjustment for a process is required.

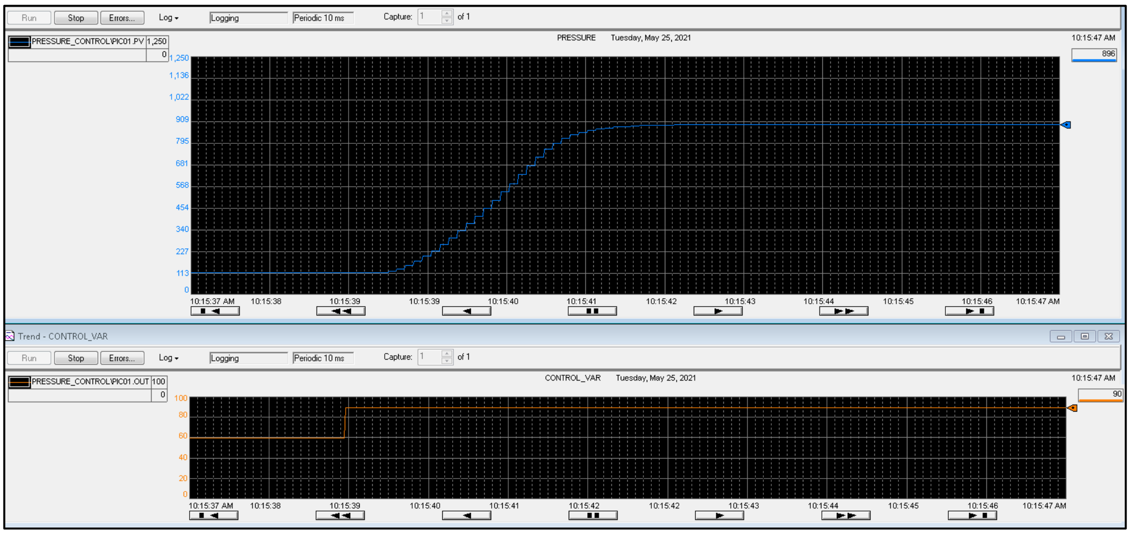
The distinguishing feature of the PID controller is the ability to use the three *control terms* of proportional, integral and derivative influence on the controller output to apply accurate and optimal control [Wikipedia].

To achieve an optimal control function, these three terms must be derived from the process and/or application due to they depend on the response characteristics which are external to the controller, so as first step the plant must be identified.

3.1 Plant Identification

Any identification process technique uses an excitation signal – signal which contents high frequency spectrum. The signal is feed to the plant in order to obtain its natural response.

The most used identification technique for industrial processes is the Step Test. The procedure is performed as an open loop (control output is set manually), feeding a step signal to the plant and recording its response (through the precess variable). The next figure shows the Step Test applied to our system.



The response get from the Step Test belongs to a First-Order system plus dead time. This type of system has 3 main parameters which are:

K_p: System's Gain

τ_0: System's Time Constant

θ_0: System's Dead Time

3.1.2 Parameters Estimation

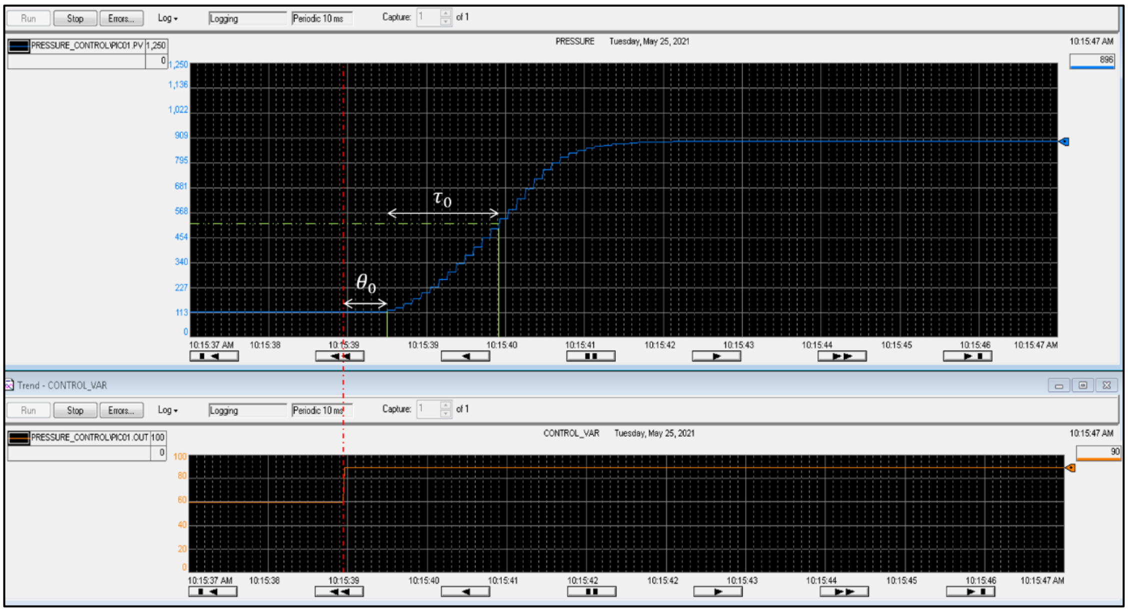
From the Step Test graphic these parameters can be estimated trhu the next procedure:

1. Establish the Zero Time axel: *This is the time when the Step is applied.*
2. Calculate the change for the Control Output (ΔCO)
3. Calculate the change for the Process Variable (ΔPV)
4. Calculate the System's Gain ($\frac{\Delta PV}{\Delta CO}$)
5. Estimate the Dead Time (θ_0): *This is the time elapsed from the time zero until a response of PV starts.*
6. Estimate the Time Constant (τ_0): *This is the time elapsed from the dead time thru $0.63 * \Delta PV$.*

For the proposed system the parameters estimation was as follow:

- Control Output Change = 30%
- Process Variable Change = 63%
- Systems Gain = 2.1
- Dead Time = 0.6 sec
- Time Constant = 1.3 sec

The next figure show the parameters measurement.



3.2 PID Tuning

Note: Due to the diversity of processes, elements characteristics, control algorithms, and objectives it is impractical to use a sigle tuning method always. Also, it must be clear that controller gains cannot be computed precisely, so the intention of the technique presented is to get an initial gains set which can be used as a base for further fine tuning.

Once the plant parameters have been identified, those are used to calculate the controller gains. The Ziegler-Nichols technique is used to estimate the gains for a PI controller which was used for the static pressure control.

The equations used to calculate the controller gains are:

$$K_c = 0.5 * \frac{\tau_0}{(K_p * \theta_0)}$$

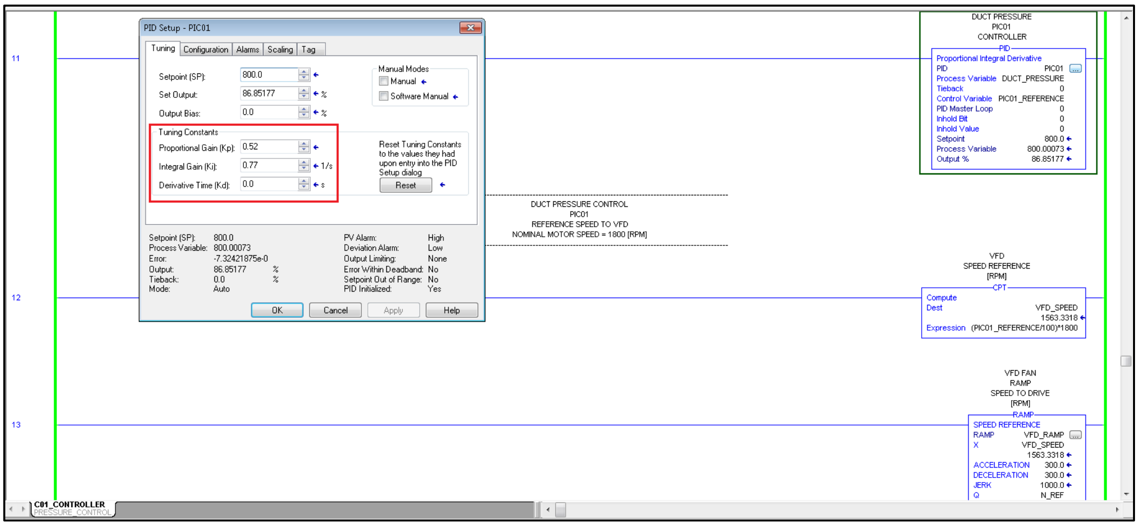
$$T_i = \tau_0$$

For the PI controller the gains estimation was as follow:

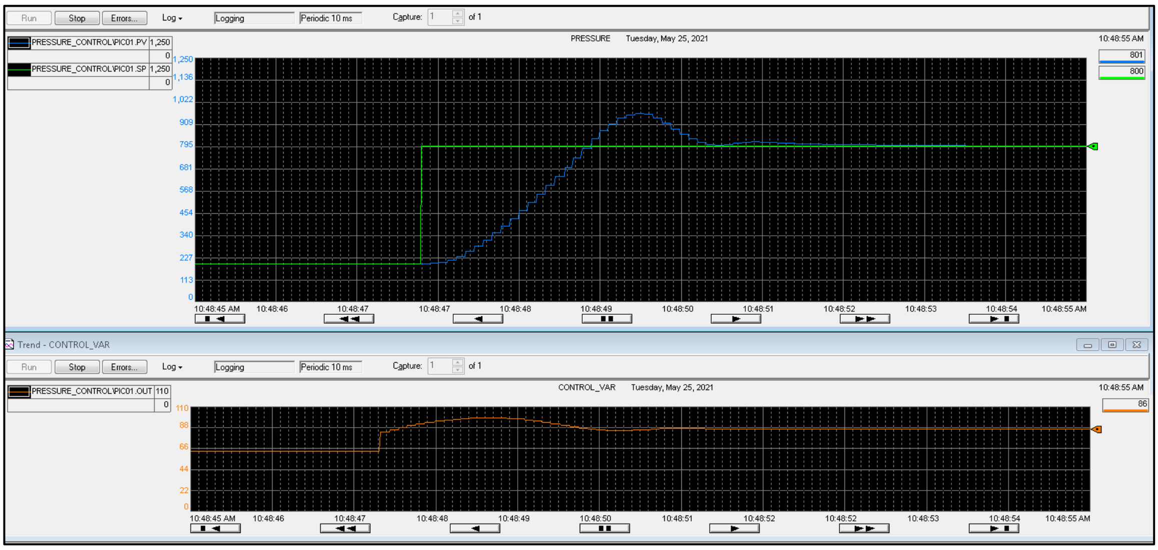
- Proportional Gain = 0.52
- Integral Gain[1] ($1/T_i$) = 0.77

[1] **According with PID Implementation for Logix 5000 Controllers General Instructions (1756-RM003S)**

The next figure shows the gains calculated set into the PID controller block.



After the PID tuning a test in automatic was performed to check the controller performance.



4 REFERENCE

The PLC program used for the tutorial can be downloaded from:

https://github.com/acadena-repo/PROCESS-SIMULATION-PID-TUNING