Capítulo 1

Introduction to Process Control

1. Systems Control

The goal is to keep one or more variables of interest in the original system close to reference values. To this end, an additional subsystem, will be connected to the original system.

An automated process is a dynamical system with an industrial purpose. The goal may be:

- To obtain a product with a given temperature
- To obtain a certain flow of a product
- To store a product with a given height
- To generate electrical energy, etc.

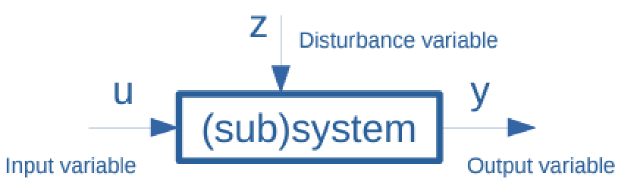
2. Process Control

Question: What is the adequate input value to control the output? I.e. What is the control law?

Answer: It depend on the system behavior

Conclusion: We need a system model to control and analyze the system behavior.

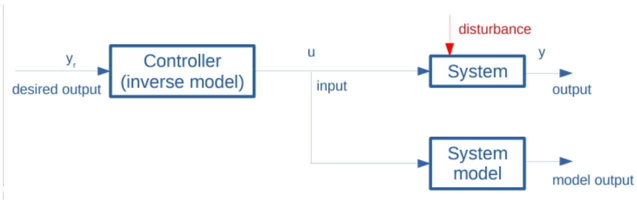
Automated control of systems and processes is usually represented by means of Block Diagrams. Each block represents a process component or subsystem: valves, tanks, reactors, etc. Transfer Functions are used as mathematical models. Each block has its own input and output variables, depicted as arrows.



2.1. Closed Loop Control

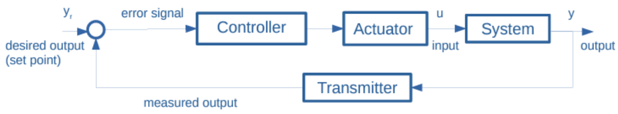
Open Loop Control

- Simple and cheap
- Not useful in the presence of important model errors or distrubances



Closed Loop Control

- Robust in the presence of model errors
- Robust in the presence of distrubances



Main features of Process Control:

- System models are usually non-linear
- Processes are often stable and over-damped
- Delays play a vital role
- Improving the behavior in the presence of distrubances is more important than dealing with set point changes

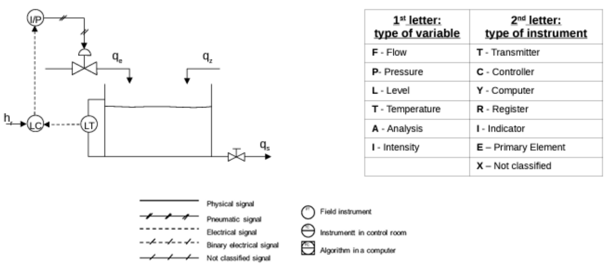
2.2. Process Control Methods

Control systems may present one single loop (Basic Regulatory control or BRC Control) or several closed loops (Cascade-based Advanced Control). Other advanced control schemes that we will see are: Feed Forward Control and the Smith Predictor.

3. P&ID

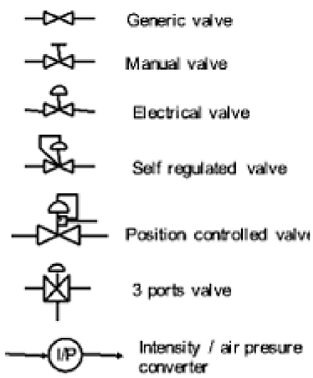
P&ID Representation of Processes:

- P&ID: Piping and Instrimentation Diagram
- International notation, essential to specify and deploy the industrial control systems layout



1st letter: type of variable	2nd letter: type of instrument
F - Flow	T - Transmitter
P- Pressure	C - Controller
L - Level	Y - Computer
T - Temperature	R - Register
A - Analysis	I - Indicator
I - Intensity	E – Primary Element
	X – Not classified

Different types of valves have different P&ID representations


Generic valve
Manual valve
Electrical valve
Self regulated valve
Position controlled valv
3 ports valve
I/P
Intensity / air presure converter

Capítulo 2

System Models and Control Requirements

1. Models

A model of a system is a mathematical approximation of its behavior.

An input-output model of a systme is a set of equations that provide a nice estimation of the actual output values of the system within a certain range of input values.

1.1. Operation point

A continuous automated process operates at a specific woring point in order to comply wiht the production goal.

The working point is usually an equilibrium point of the system, which meand that all involved variables are constant over time (i.e. their derivatives are zero).

1.2. Equilibrium point

The variable values at the Equilibrium Point (equilibrium values) are usually denoted with a 0 subscript. SInce they are the final values when all the variables are kept constant, they are also referred to as the values when $t = \infty$.

Some equilibrium values must be known to determine the rest.

Broadly speaking, industrial processes are systems that present a non linear behavior. Even though there are serveral techniques to implement their control systems, this course will ofcus on the methods for linear incremental modeling around the so-called Equilibrium Point (E.P.)

In order to design and implement the control system of an industrial process we will need, first of all, a linear model around a certain equilibrium point.

The model may be obtained by meand of:

- Linearizarion of differential equations
- Identification of actual systme behavior

Linearization of a multi-input dynamical system

Original system equations:

$$f(y, y', y'', ..., u, u', u'', ...) = 0$$

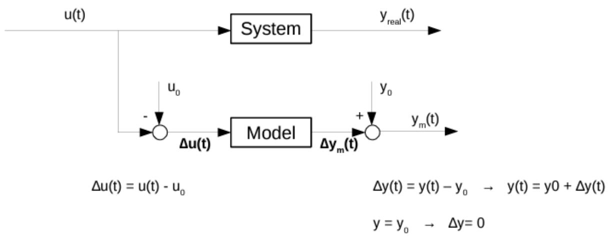
Nominal values:

$$y_0, y_0', y_0'', ..., u_0, u_0', u_0'', ...$$

Linearized model

$$\left.\frac{\partial f}{\partial y}\right|_0 \Delta y + \left.\frac{\partial f}{\partial y'}\right|_0 \Delta y' + \left.\frac{\partial f}{\partial y''}\right|_0 \Delta y'' + ... + \left.\frac{\partial f}{\partial u}\right|_0 \Delta u + \left.\frac{\partial f}{\partial u'}\right|_0 \Delta u' + \left.\frac{\partial f}{\partial u''}\right|_0 \Delta u'' + ... = 0$$

The linear model is an incremental model



The controller, the actuator, the transmitter, etc. are dynamical systems that we well model by means of differential equations.

In order to tune the controllers properly, transfer functions defined in the Laplace domain will be used instead of differential equations.

A transfer function is a linear model around a specific equilibrium point.

The linear approximation quality degrades as the variables get away from the selected equilibrium point.

1.3. Linearization of a tank system

In the following system:

a) Calculate the value for h_0 at the equilibrium point defined by $F_{10} = 1m^3/s$. Using Simulink, verify that this is an equilibrium point $(dh/dt = 0)$

$$dh/dt = 0 \rightarrow F_{i0} - 0{,}3\sqrt{2gh_0} = 0$$

$$h_0 = \frac{F_{i0}^2}{2ga^2}$$

$$F_{i0} = 1 \rightarrow h_0 = 0{,}5669$$

b) Obtain the liner model around this equilibrium point and calculate $H(s)/F_i(s)$

$$A\Delta\dot{h} = \Delta F_i(t) - \left.\frac{a\sqrt{2g}}{2\sqrt{h}}\right|_0 \Delta h(t)$$

$$\Delta\dot{h}(t) + 0{,}882\Delta h(t) = \Delta F_i(t)$$

$$\frac{H(s)}{F_1(s)} = \frac{1}{s + 0{,}882} = \frac{1{,}134}{1 + 1{,}134s}$$

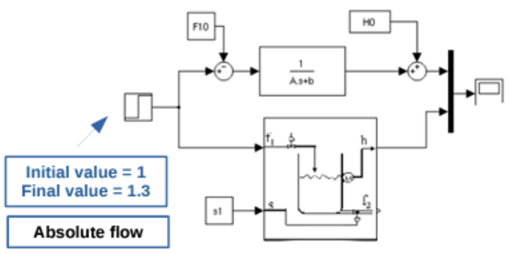
c) Obtain the new steady value h_{0_2}, both using the linear model and the non-linear model, when the flow grows 30 % form the previous equilibrium value ($F_{i0_2} = 1{,}3m^3/s$)

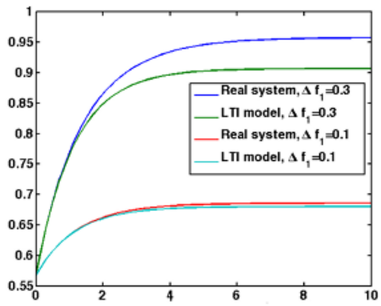
$$\Delta h(\infty) = \frac{\Delta F_i(\infty)}{0{,}0882} = \frac{F_{i02} - F_{i0}}{0{,}0882} = \frac{0{,}3}{0{,}882} = 0{,}34$$

$$h_{linear}(\infty) = h_0 + \Delta h(\infty) = 0{,}5669 + \Delta h(\infty) = 0{,}907$$

$$h_{real}(\infty) = \frac{F_i^2(\infty)}{2ga^2} = \frac{1{,}3^2}{2 \cdot 9{,}8 \cdot 0{,}3^2} = 0{,}958$$

d) Using simulinkg, compare the evolution of $h(t)$ based on the linear model and the non-linear model, when the systems goes drom the equilibrium defined by $F_{i0} = 1$ to the new equilibrium point defined by $F_{i02} = 1{,}3$ (30 % variation) What about 10 % variation?

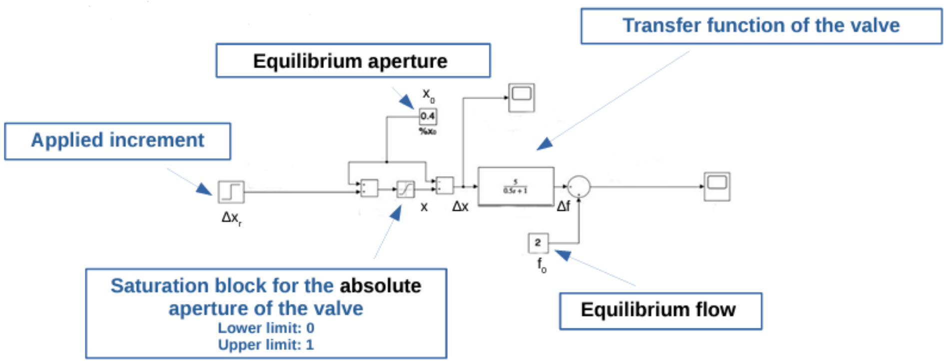




The transfer funciton model is an incremental model. Hence the equilibrium values must always be added, as shown in the previous figures.

The linear model is an approximation of the real system. This is the reason why there is a difference between the exact new equilibrium value and the value porvided by the linear model.

1.4. Modeling a valve



How does a valve work?

- The valve has an aperture range of $[0, 1]$
- The valve is initially opened a given % of the maximum degree of aperture. This is the valve operation point (equilibrium point). E.g. the valve is initially 40 % opened.
- The valve aperture is modified a given % from the operation point (opened or closed). If the valve is opened an additional 10 % then the valve is now 44 % opened $(0{,}4 + 0{,}04 = 0{,}44)$
- The new flow value from the valve is: the flow due to the increment (or reduction) of aperture from the operation point + the equilibrium flow.
- This is only true as long as the valve is not in a saturation state.
- The dynamical model of the valve, the transfer funciton Gv(s), is only used for the incremental opening or closing. The operation point flow f_0 (E.P) is always considered as a constant that must be added to the incremental flow obtained from the model of the valve. This is vary important.

Capítulo 3

Basic Control

1. Introduction

Basic control is a tupe of closed-loop control, with a single control loop. In this section, the transfer functions of the systems to be controlled are of first order or first order + deadtime. We will learn how to design PID controllers for this kind of systems.

The transfer functions that constitute the dynamics of the system to be controlled typically include two types:

Actuator transfer function. This usually corresponds to a flow control valve, steam valve, gas valve, etc.

Transfer functions of the plant (process). This is usually a first order transfer function of a tank, a boiler with heat exchanger, a reactor with heat exchanger, etc.

Controller. The objective of the basic control is to design a PID controller by cancellation of poles and zeros (analythical method) or by empirical methods (tables).

Process: a dynamic system with a particular purpose.

The goal of the control system is to correct deviations from the desired operation point.

2. Controllers Design Methodology

Controllers design is the central aspect of these sections and perhaps the most relevant aspect of the course. For this goal, two methodologies will be studied:

1. Analytical design based on pole-zero cancellation
2. Empirical design based on tables

Depending on the system model we will select the corresponding option.

2.1. Processes without delay

In this case, analytical methods are applied. The main options are root locus analysis, the pole-zero cancellation method or the Ziegler Nichols (Z-N) tables for closed loop processes.

It is not possible to use other tables such as Open-loop Z-N or the AMIGO method.

Transfer function for the design of process controllers without delay:

$$\frac{K_p}{1 + t_p s}$$

Desging methods:

- Closed-loop Z-N methods (applicable with or without delay)
- Analytical pole-zero cancellation design method (also known as direct synthesis).

2.2. Processes with a delay

These are controllers based on Ziegler Nichols (Z-N) tables and the AMIGO mehtod.

The design using Z-N tables or the AMIGO method, is fundamentally based on obtaining a first order function with a delay (First Order Plus Dead Time) of the process.

FOPDT model of the process:

$$\frac{K_p}{1+t_p s}e^{-t_m s}$$

Where:

- K_p: static gain
- t_p: time constant (or period)
- t_m: delay

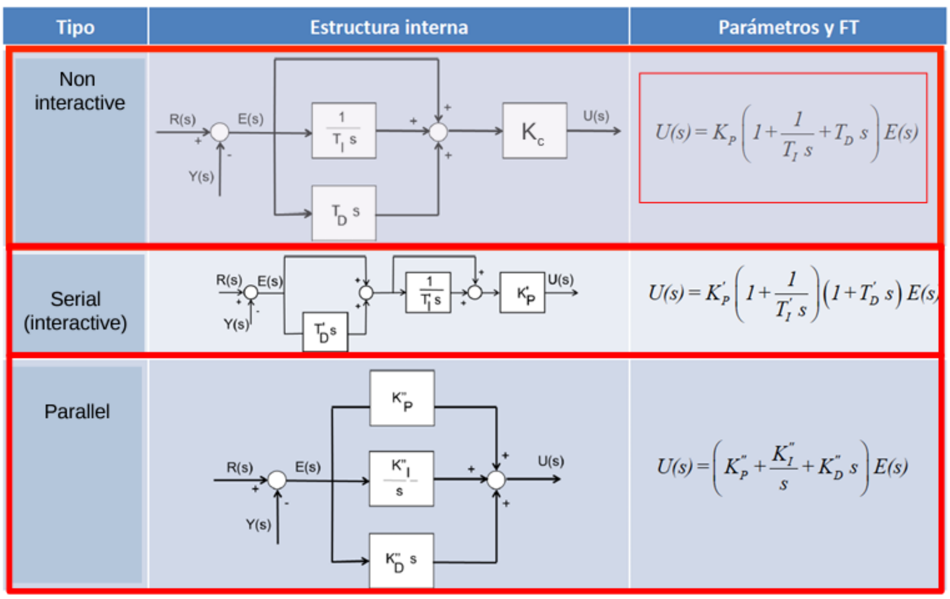
A FOPDT model is representative of many types of processes.

Design methods:

- Closed-loop Z-N method (applicable with or without process delay)
- Open-loop Z-N method (applicable with process delay)
- AMIGO method (applicable with process delay)

3. Basic concepts of PID controller design

PID (Proportional Integral Derivative) controllers are undoubtedly the most widely used in the industry. A PID controller is the result of combining three control actions: proportional action + derivative action + integral action.



3.1. Proportional control: P

Proportional control K_p makes the response speed faster, which is desirable, but it increases the setling time.

A strong proportional control action increases the oscilation and inestability of the system. For safety reasons, overshooting should not exceed 30 %.

The proportional part does not consider time, therefore, the best way to solve the permanent error and consider the variation with respect to time, is to include and set the integral and derivative actions.