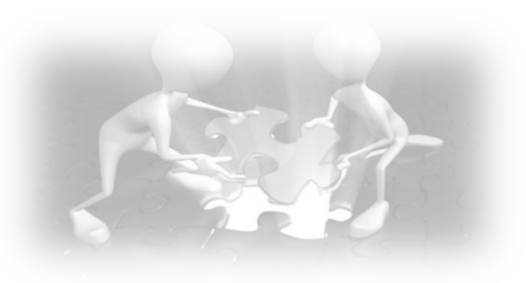


PID auto-tuning

UNICOS

MOC3O02, Feedback systems & Tuning

Enrique Blanco *(CERN, EN/ICE)*
on behalf of the UNICOS team

Outline

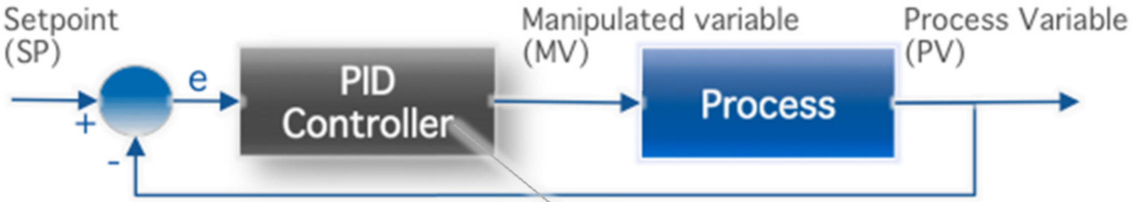
1. Introduction
2. CERN installations (UNICOS)
3. PID auto-tuning: Solution and methods
4. Experimental results
5. Conclusions

Introduction

- The **PID** feedback control algorithm dates back to early nineteens'
- The right tuning of those controllers is essential to increase plant availability and maximize profits in many processes
- Operators and control engineers spend a considerable time in tuning those controllers
- GOAL: (1) Provide automatic methods to tune the PID controllers and (2) make them usable by plant operators

PID control basics

- Basics



SISO control loop schema

$$K_c \cdot \left(e(t) + \frac{1}{T_i} \cdot \int e(t)\,dt + T_d \cdot \frac{d}{dt} e(t) \right)$$

Parameters: K_c, T_i, T_d

- PID are usually tuned by operators (or control engineers).
- The majority of the controllers in industry are **PI**s

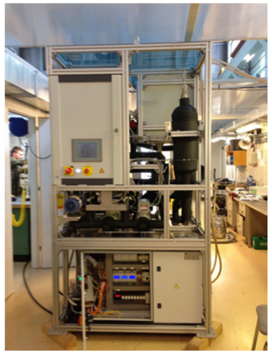
CERN installations

- Industrial facilities for the accelerator complex and the associated experiments
- Continuous process control: temperature, pressure, levels…
- Large and/or complex dynamics

LHC 4.5 K Cryogenics refrigerators

TPC gas system

LHC cooling towers



CO2 Cooling (MARCO)

CERN installations

Enormous number of PID based controllers: > **8000**

- LHC cryogenic control system: ~ **5000** PID controllers
- Cooling and Ventilation: ~ **870** PID controllers

PIDs tuned extremely conservative or initial parameters untouched

- Fine tuning systematically avoided

Implementation:

- **PLC**s (Programmable Logic Controller): > 400
- **UNICOS** (Unified Industrial Control System) framework.

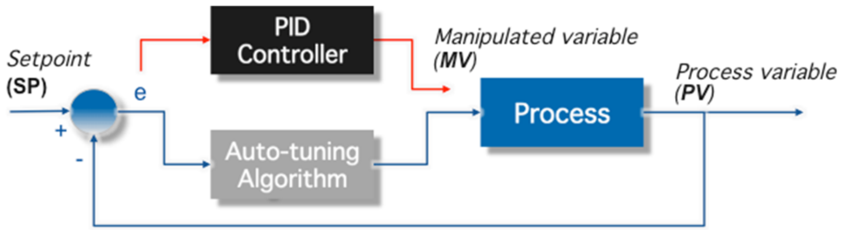
Unified
Industrial Control
System
UNICOS

PID auto-tuning

Create a tool to automatically find the PID parameters and tune the control loops always initiated deliberately by operators and/or control engineers.

Classification (one) on how the data is extracted from the plant

- **Open loop**: e.g. turn off PID and excite the process by changing the MV
- **Close loop**: e.g. tune online while the PID is working (SP is changed)



Open loop

Close loop

PID auto-tuning

Tuning methods

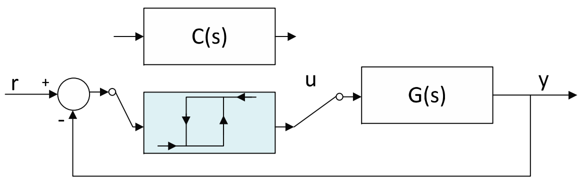
- Trial & Error
- Experimental based
- Model based analytical
- Automatic tuning: Auto-tuning methods
  - Relay Method
  - SIMC (*Skogestad* Internal Model Control)
  - IFC (Iterative Feedback Tuning)

The choice is not straight forward and depends mostly on the process knowledge

PID auto-tuning: [1] Relay

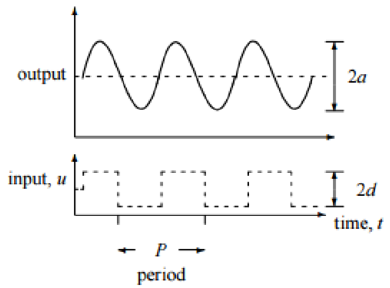
Astrom and Hagglund (1995)

The process is brought to oscillation by replacing the PID controller with a relay function. The ultimate Gain (**K_{cu}**) and the ultimate period (**T_u**) are determined



User parameters

- Maximal deviation of the control effort: MV
- Number of cycles to detect the ultimate condition



Advantages

Single action (vs. trial and error)

Little a priori knowledge of the process

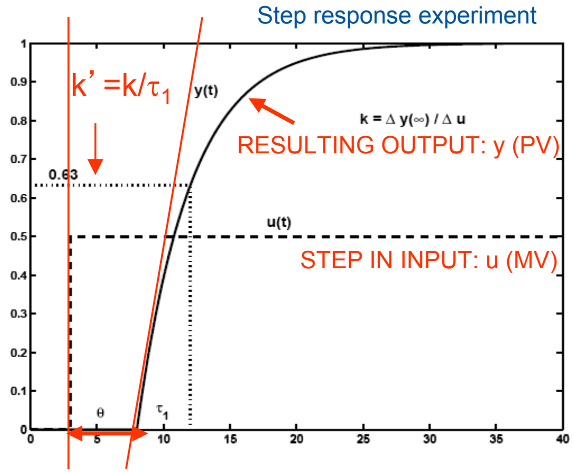
	Kc	Ti	Td
P	0.5 Ku		
PI	0.4 Ku	0.8 Tu	
PID	0.6 Ku	0.5 Tu	0.125 Tu

Disadvantages

Preferably to execute it under stable conditions

Process must be controllable with a P-controller.

PID auto-tuning:[2] SIMC



Method based on an internal model (*Skogestad IMC*)
- Two phases: Process identification (first or second order) and application of tuning rules

Parameterization
- Desired performance: *Tight* vs. *smooth* control

Advantages
- Simplicity of parameterization

Disadvantages
- Applicable to processes without complex dynamics
- Stable processes: open loop test

$$K_c = \frac{1}{k'} \cdot \frac{1}{(\theta + \tau_c)}$$
$$\tau_I = \min(\tau_1, 4(\tau_c + \theta))$$

$k' = k/\tau_1$ = initial slope step response
$\tau_c \geq 0$: desired closed-loop response time (**tuning parameter**)
For robustness select : τ_c ¸ θ (gives $K_c \leq K_{c,max}$)
For disturbance rejection select : $K_c \geq K_{c,min} = u_{d0}/y_{max}$

PID auto-tuning: [3] IFT

Iterative Feedback Tuning (IFT): inspired in the iterative parametric optimization approach. Makes random perturbations on the SP. Minimize the current value of the measured value and a desired first order response.

Parameterization

- Just safeguards (thresholds)
- Desired 1st order response shape

$$J(\rho) = \frac{1}{2N}\left[a\sum_{t=1}^{N}(L_y \cdot \tilde{y}_t(\rho))^2 + l\sum_{t=1}^{N}(L_u \cdot u_t(\rho))^2 \right]$$

$$\rho^* = \underset{\rho}{\operatorname{argmin}} \; J(\rho)$$

$$\tilde{y}_t = y_t - y_d$$

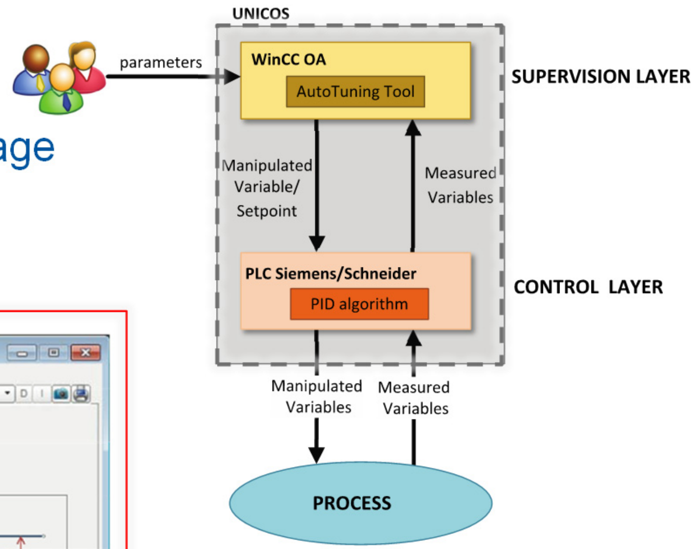
Advantages

- close loop method with minimal disturbances
- model free

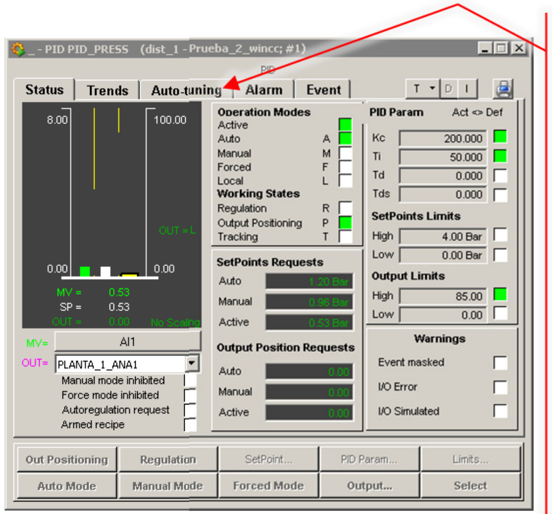
Disadvantages

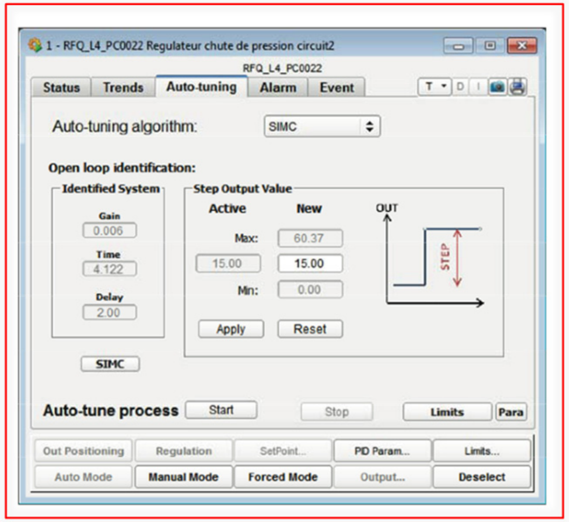
- A local minima could be found

UNICOS Implementation



- Algorithms in the *WinCC OA* SCADA: Scripting language
- The **PLC** maintains the PID algorithm untouched
- HMI inside the PID controller faceplate

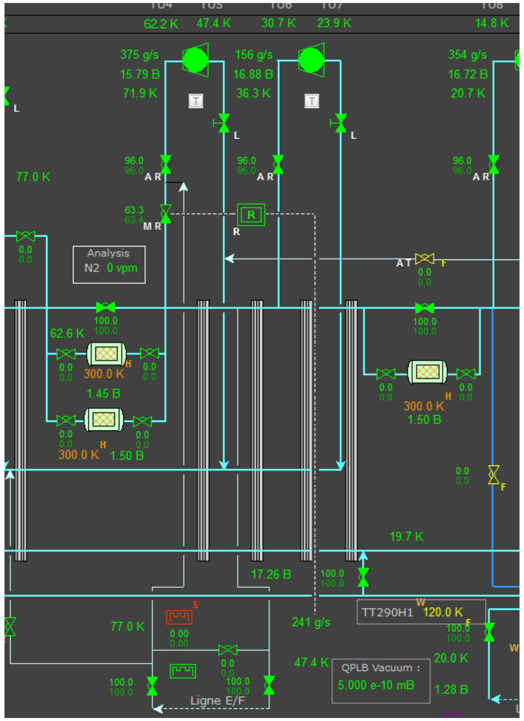




Experimental results (Ghe Flow control)

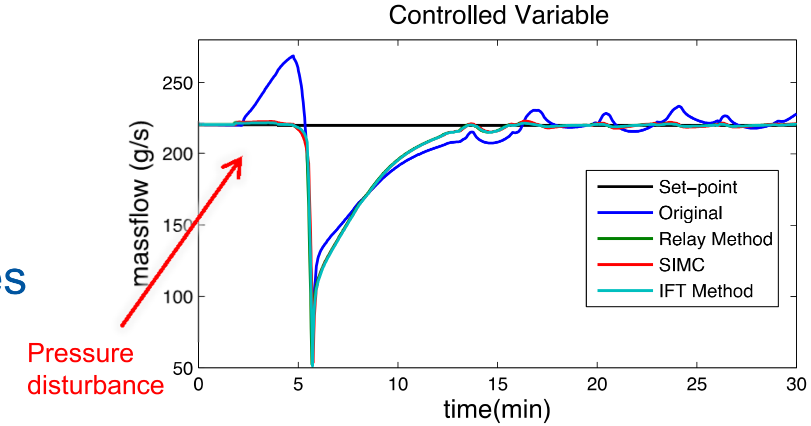
Use case: Cryogenics flow control: PI control [*Simulation*]

Gas helium circulating to maintain the thermal shielding of the LHC superconducting magnets at 80 K.

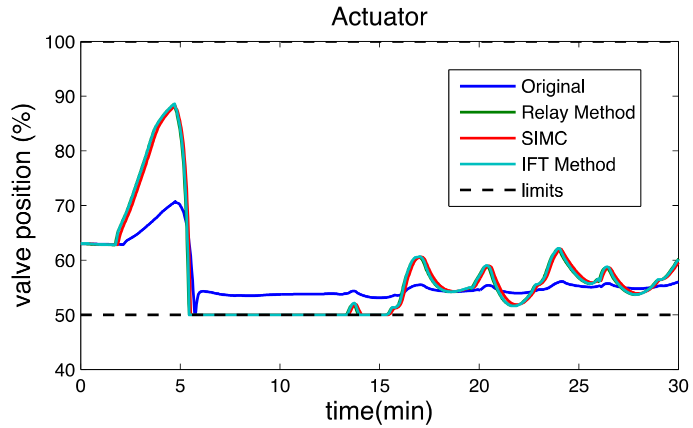


GHe Flow control

- Found too sluggish with oscillations and overshoots when disturb by pressure changes
- Three auto-tuning methods tested: Relay, SIMC, IFT

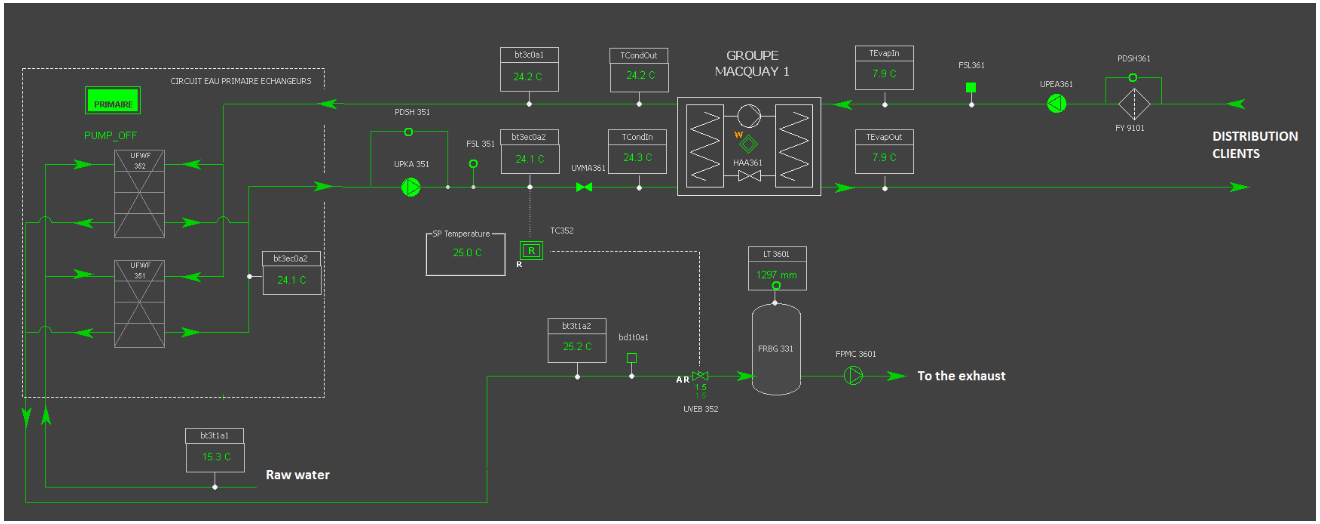


Tuning	Kc	T_i	Overshoot	Oscillation
Original	1	200	22 %	6 %
Relay	9	12	0.5 %	1 %
SIMC	4.5	7	1 %	1.3 %
IFT	13	11	0.5 %	0.5 %



Experimental results (HVAC process)

- Use case: chilled water production unit providing water at 5º C for LHC
- Maintain at 25º C the condenser output temperature of a chiller
- PI controller: desired temperature deviation within 1º C

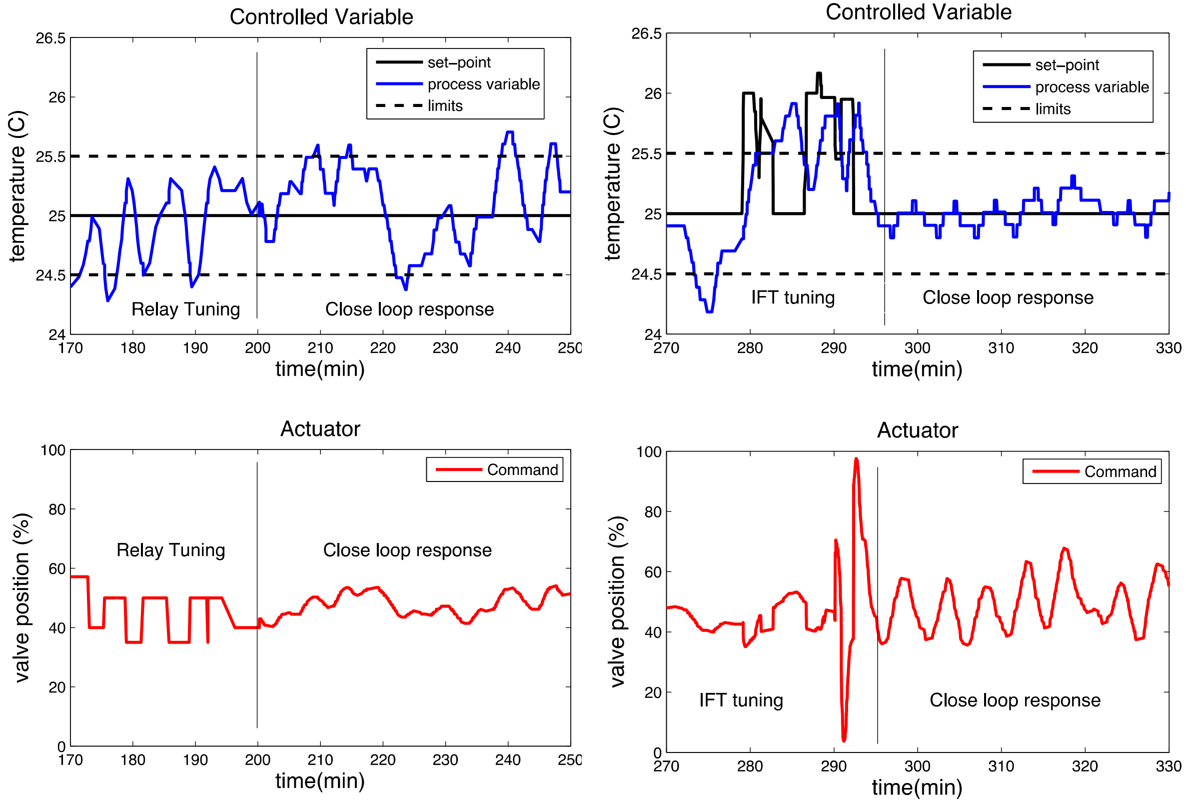


HVAC control

Operation team reported instabilities on a regulation loop action on a control valve

Results: Relay vs. IFT

Tuning	Kc	T_i	$\|\Delta y\|$	$\|\Delta u\|$
Original	8	0.5	2 °C	100 %
Relay	8.3	311	1.3 °C	10 %
IFT	50.9	5666	0.5 °C	20 %



Conclusions

- PID auto-tuning is not a dream. **Feasible** to implement
- Fully-integrated implementation: UNICOS
- Flexible solution: Open to new methods
- Improvement of plant availability and engineering time
- **Operator acceptance**

Acknowledgements

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University of Valladolid.
UVA, Valladolid (Spain)

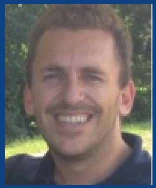
CERN

www.cern.ch

Unified Industrial Control System

UNICOS

UNICOS (**UN**ified **I**ndustrial **C**ontrol **S**ystem) is a CERN-made framework to develop industrial control applications
http://www.cern.ch/unicos



Enrique Blanco: automation engineer, PhD in systems and process engineering. Head of the process control section (industrial controls group) in the engineering dpt. at CERN

Native integration advantages

Easy integration

- Avoid data extraction & third party tools (off line analysis)
- External connections
- Customized to our environment (event driven data, Customized scaling)

Ease operation

- Same philosophy & look and feel
- Ease parameterization
- Fully control and safe operation (boundaries)

Flexible and evolutive

- Easy integration of new algorithms