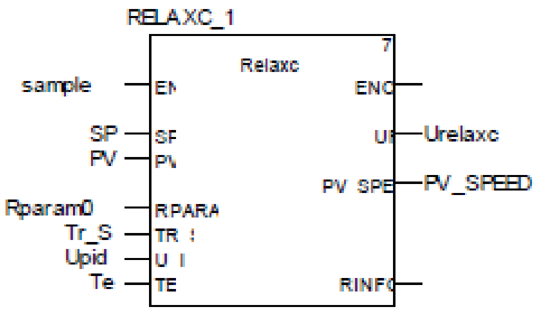


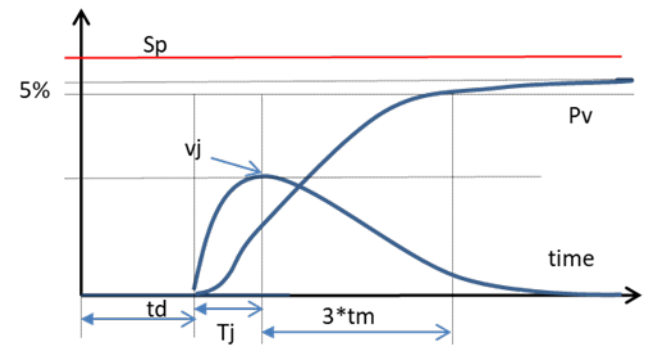
Relaxc

Critical Process Loop Control

Version 2

John Masse
30/03/2020

- Introduction
- Concept
- Keys to understand Relaxc
- How to tune relaxc
- Relaxc and Ziegler & Nichols
- References



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ℜelaxc : Next Generation Process Control

"Detailed Studies of the real work impel us, albeit reluctantly, to take account of the fact that the rate of change of physical systems depends not only on their present state, but also on the past history "

(Bellman –Cooke 1963)

77 years after Ziegler & Nichols and an impressive literature about the control theory, the controller *Relaxc* (Relax Controller) seems to bring an efficient way to control any process without effort.

The controllers proposed in the specialized literature are too complicated and time consuming to tune with a bad load disturbance rejection. The behavior of these controllers are not generally predicable without trial and error.

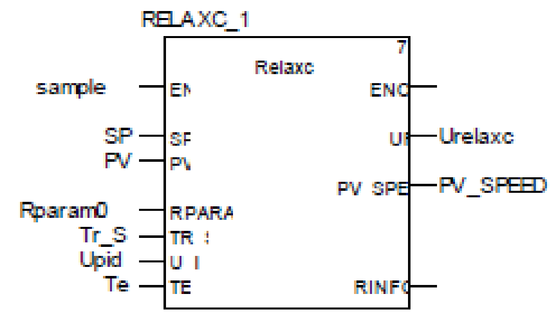
In addition, the mathematical structure of PID begins to show its limits despite all the mathematical approaches carried out in recent years.

It is not possible to predict the behavior of PID tuning or other method without modeling. It is a major drawback.

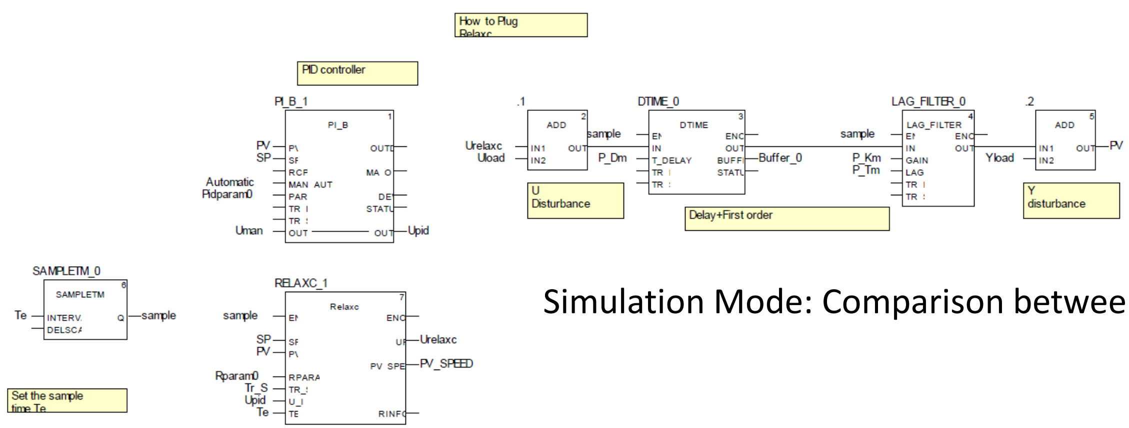
In these few slides, we try to explain this fact. We also show how Relaxc is easier to use and its remarkable effectiveness

Relaxc works under Expert control

- Library package compatible with all version of Control expert (EFB block)
- Library compatible with the following hardware - Modicon M340, Momentum, M580, Quantum, Premium.



A free trial, available *exclusively* via Schneider Electric™ Exchange (shop.exchange.se.com).
Includes full documentation (Practical Tuning Guide and Commissioning with EcoStruxure™ Control Expert)



Simulation Mode: Comparison between PID and Relaxc

Relaxc is also available under Simulink® (Trial version too).
This version allows to control your MATLAB® models, Amesim®, GtPower®, etc. or your owner simulator by co-simulation with Simulink.

ℜelaxc : Performance and genericity

Relaxc allows to achieve optimal control performance for whatever the complexity of your processes is and without complex mathematic analysis:

- Improved asset sustainability
- Less process waste
- Lower energy costs
- Significantly reduced commissioning times

- ✓ Relaxc can be applied for tuning almost all kind of processes that include non-minimal phase, small and large pure delay, unstable processes, variable static gain, strongly non-linearities, constraints on MV (Urelaxc), speed saturation, discontinuities, load disturbances and more.

- ✓ With respect to all the family of PID, MPC (Model Predictive Control), adaptive or auto-tuning control, fuzzy logic, feed forward structure and all the other control laws, Relaxc provides faster commissioning time, improve rejection of perturbations and set point response.

Relaxc : A good alternative to improve industrial processes

Relaxc covers all the industrial fields where it is necessary to obtain quickly and effortlessly the best secure response for your processes.

Plant & Machine,
Power,
Building
Operation
Machine
Automation,
Marine,
Metals,
Minerals &
Cement,
Mining,
nuclear,
space industry,
Pharmacology,

Building,
Plant & Machine,
Power,
Building Operation,
Energy Efficiency,
Power Protection,
Power Quality,
Power Reliability,
Renewable Energy,
Oil & Gas,
Process Automation,
Smart Cities,
Solar & Energy Storage,
Water & Wastewater,
Biology,

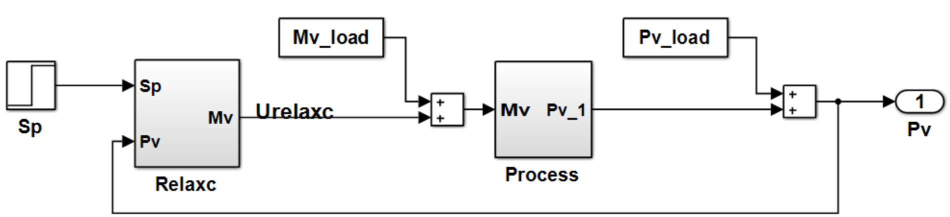
Safety,
Smart Design & Engineering,
Smart Operations,
Automotive,
Electricity Companies,
Food & Beverage,
Healthcare,
Life Sciences,
robotics,
microprocessor manufacturing,
avionics,
drone

$\Re$elaxc : One simple equation to control the transient response in closed loop of "almost" all types of processes

$$U_n = \Re_{(U_{n-1},\tau_{re})} + k_s(\tau_g \dot{e} + e)$$

Parameter	Data type	Description
tg	real	Time constant of the reference trajectory in seconds
tre	real	Relaxc time or reactivity time (delay+lag) in seconds
Ks	real	Speed convergence gain or throttle between the reference trajectory and PV

- $(\tau_g \dot{e} + e)$ is the generating function which allows to control the transient response
- $\Re$ the Reactivity or Relaxc function
- τ_g and τ_{re} are physical parameters.
- k_s is calculated by the formula $k_s = \frac{1}{v*\tau_g*(\frac{t_d}{\tau_{re}}+1)}$.



$\Re$elaxc : a concept promising and intriguing

(PID or Relaxc ?)

Mathematic problematic: To reduce the mathematic distance or effort between the tuning parameters of the controller and the plant.

$$PID \Rightarrow U = Kp\left(1 + \frac{1}{Ti * s} + Td * s\right)e$$

- ✓ My point of view : The coefficients of PID have not a physical meaning because it is a normalized convergence equation. Where we set the convergence time by a mixture of $\frac{Kp}{Ti}$ which fixes the inverse of the integral time, the velocity convergence fixed by $kp * Td$, and kp the gain applied to error .
- ➢ In these conditions, it is difficult to predict the transient response without a fastidious trial error, complex mathematic (if we arrive to identify correctly the process) or rules of thumb. The reason of these drawbacks is due to the fact that all the parameters interact between them and the control **U is explicit** and so, depends necessary of the mathematical structure of the plant. (See the difficulties (poor) to tune a PID and the impressive literature around PID, stability theory, frequency method, locus roots, closed loop study, etc.)

$$Relaxc \Rightarrow \quad U_n = \Re_{(U_{n-1}, \tau_{re})} + k_s(\tau_g \dot{e} + e)$$

- ➢ **It is necessary to change of paradigm:** In contrast with the other approaches, Relaxc is **an implicit** algebraic controller. The control **U of Relaxc is evaluated by numerical convergence with the speed ks**. This is why U does not depend of the mathematical structure of the process but just of **simple physical characteristics** (delay and maximal speed and its time). It is not necessary to get equations of the plant. Relaxc fits the plant and Relaxc becomes the plant, so, the parameters of Relaxc are the parameters of the plant. Thus, 5 tuning graphics rules cover a large part of industrial processes and to help Relaxc become the plant.

$\Re$elaxc ⟺ mimics the ⟺ ***Plant***

ℜelaxc : Principle

3 keys to understand the heart of Relaxc

- To fit the plant
- Take into account the reactivity time
- The Relaxc's parameters are directly identifiable and discernable.

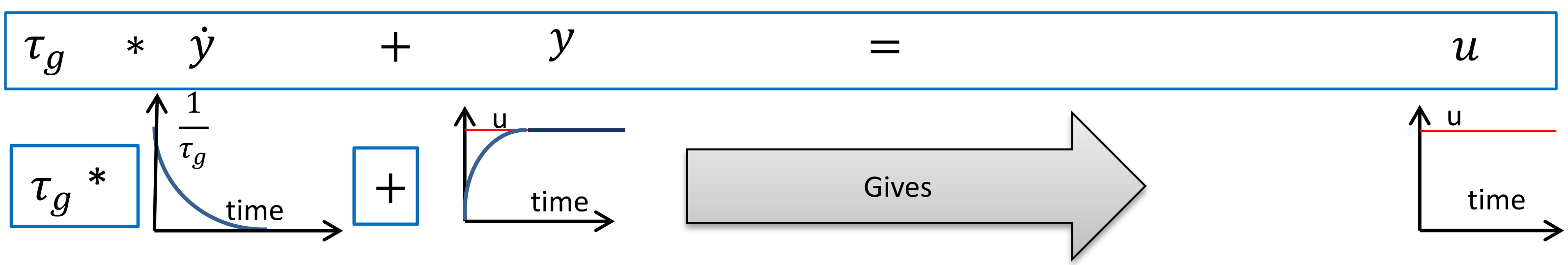
Relaxc is not a PID

1^{st} Key - To fit the plant

- The generating trajectory allows to fit plant. Relaxc becomes the plant.
- In the family of generating functions we choose a first order because we don't want overshoot.
- τ_g is the time constant that the plant can secure or in other word τ_g is time constant of the plant in "closed loop" or time of disturbance rejection and the time constant of the reference trajectory.

➢ If we know u

➢ If we know or impose $\dot{y}$ and y then we can **compute/deduce** $\boldsymbol{u = \tau_g * \dot{y} + y}$



To fit the plant through Relaxc allows to reduce the error between y (the reference trajectory) and ym the plant . $e = y - ym$ In order to do that we Introduce in Relaxc the term $k_s(\tau_g \dot{e} + e)$ with k_s a speed convergence weight (Throttle).

2^{nd} key : Solving Relaxation time equation: The heart of Relaxc

- In mechanic or physic when we want to balance two algebraic variables with a steady error equal at zero the Physics says ex: conservation angular momentum $J\frac{dw}{dt} = C1 - C_2$, or mass flow $\frac{dP}{dt} = \frac{1}{C}(qe - qs)$
- In our case , it is necessary also to manage the pure delay and the gap time. In Zero order hold (ZOH) context, we introduce a novel **discrete derivative operator** $\dot{\ddot{U}}$ as following $\dot{\ddot{U}} = k_s(\tau_g \dot{e} + e)$ with $\dot{\ddot{U}} = U_n - \Re_{(U_{n-1}, \tau_{re})}$ with $\Re$ the relax function with the relaxc time constant τ_{re}. Thus ,we obtain the main and simple equation of relaxc that embeds a first order generating function.

$$\dot{\ddot{\boldsymbol{U}}} = \boldsymbol{k_s}(\boldsymbol{\tau_g}\dot{\boldsymbol{e}} + \boldsymbol{e})$$

Algebraic notation to discrete time

$$\boldsymbol{U_n} = \Re_{(\boldsymbol{U_{n-1}}, \boldsymbol{\tau_{re}})} + \boldsymbol{k_s}(\boldsymbol{\tau_g}\dot{\boldsymbol{e}} + \boldsymbol{e})$$

- k_s weight constant (named also Throttle) allows to connect and to unify all parts of the relaxc equation (reactivity and reference trajectory) and the plant with its speed (v) :

  k_s is given by the simple formula $\boldsymbol{k_s} = \frac{\boldsymbol{1}}{\boldsymbol{v} * \boldsymbol{\tau_g} * (\frac{\boldsymbol{t_d}}{\boldsymbol{\tau_{re}}} + \boldsymbol{1})}$

- Property : at t=0 $U_o = k_s * u_{sp}$ with u_{sp} the set point. Useful to set the first step of the control U_o.

- If we have not delay $(\tau_{re} = 0)$ the equation becomes $\boldsymbol{U_n} = \boldsymbol{U_{n-1}} + \boldsymbol{k_s}(\boldsymbol{\tau_g}\dot{\boldsymbol{e}} + \boldsymbol{e})$

3rd key : The parameters of Relaxc are identifiable and discernable

$$F(s) = \frac{s + a + \varepsilon}{(s + a)(s + b)(s + c)}$$

- **Identifiability** : A parameter is identifiable if it belongs to the equation.

For example :

In F(s), if ε=0 , the parameter a is not fully identifiable because F(s) becomes $F(s, \varepsilon=0) = \frac{1}{(s+b)(s+c)}$

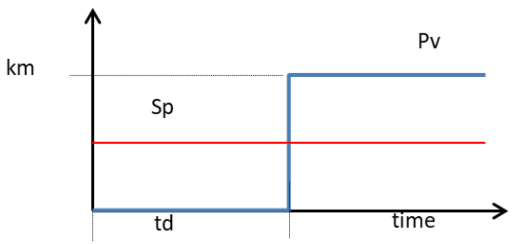
- **Discernibility** : A parameter is discernable, if we can identify them without confusion (The parameters have not to be interchangeable)

In F(s) the parameters *b* and *c* are not discernable because we can switch *c in b and b in c* and we obtain the same result for F(s) but the values of *b and c* become wrong. It is necessary to write F(s) in canonical form to identify correctly the thrust value of b and c . The canonic form is $F(s) = \frac{1}{s^2+(b+c)s+bc}$ and to identify *(b+c)* and *b*c*

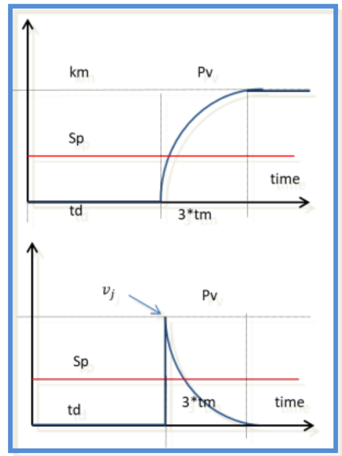
- The identifiability provides the raison why it is necessary to stimulate the process with an appropriate excitation: Step method, relay feed back, impulse response , auto tuning, noise, etc. to identify the dynamical characteristics of the process.
- The coefficients of Relaxc by its mathematical nature of Relaxc are **directly identifiable** and **discernable** with respect to the **dynamical characteristics of the plant** (delay, gap time, max speed and time where they occurs). It is not the case for PID.

So, it is easy to connect Relaxc to plant's responses.

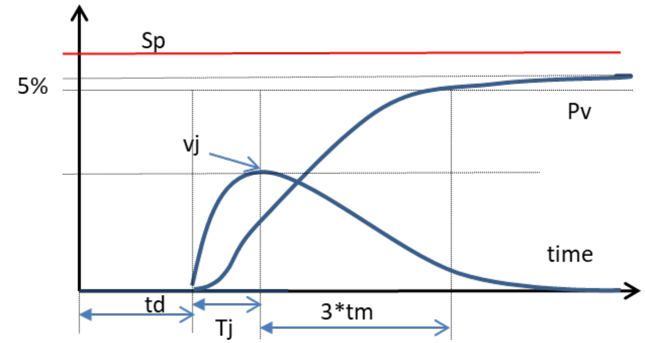
ℜelaxc : 5 *simple graphic rules to tune the world*



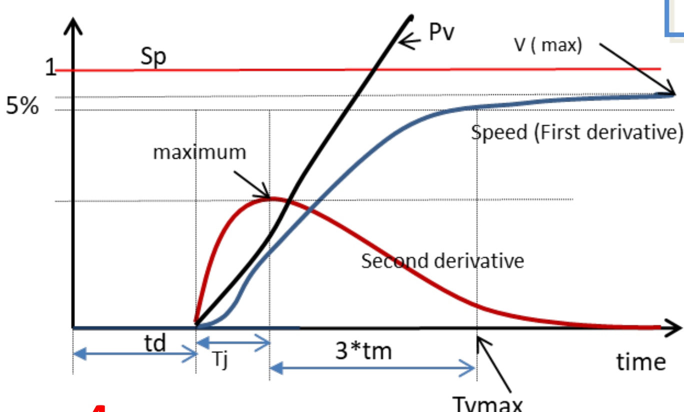
1 Pure delay



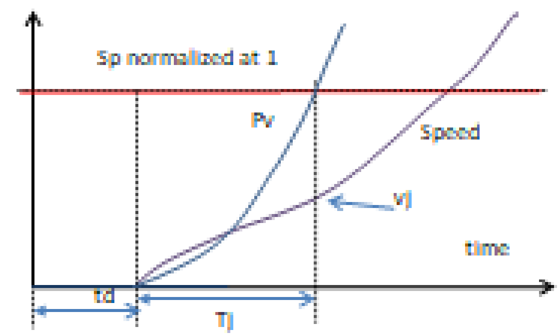
2 First order



3 Second order (and more)



4 Integrating (and more)



5 Unstable process

For each case, it is necessary to identify *td the pure delay*, the time lag *Tj*, *tm* and *vj* (speed).
Remark: it is not necessary to identify the gain of the process to evaluate the coefficients of Relaxc.

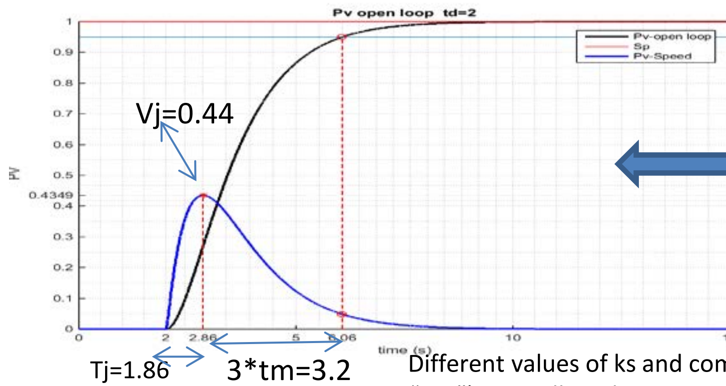
ℜelaxc : Graphic tuning example

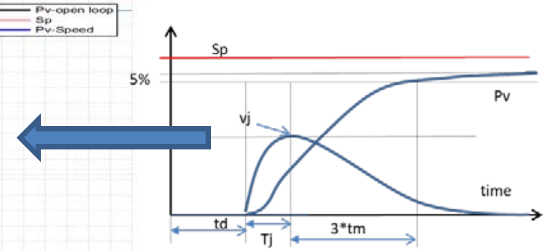
- The process of second order and more with small and large pure delay.

$$H = \frac{e^{-2s}}{(1+0.7s)(1+1.0s)}$$

Graphic identification of the parameters (Rule 3)		
Te	10 ms	Sample time
td	2 s	Pure delay
Tj	0.86	Time lag
tlag	Tj/3=0.86/3=0.29	Time lag constant
vj	0.44	Process Speed (Normalized step)
tm	3,2/3=1.07	Estimation of Process Time constant

Relaxc Parameters		
tre	td/3+tlag=2/3+0.29= 0.95	Relaxc time (s)
τ_g	Min(tm,3*tre)=1.07	Time constant of the reference trajectory in seconds (s)
ks	$ks < \frac{1}{v*\tau_g*(\frac{td}{tre}+1)}$=0.29	We assume: α=2.3 we choose v≅2.3*vj (see practical tuning of relaxc)





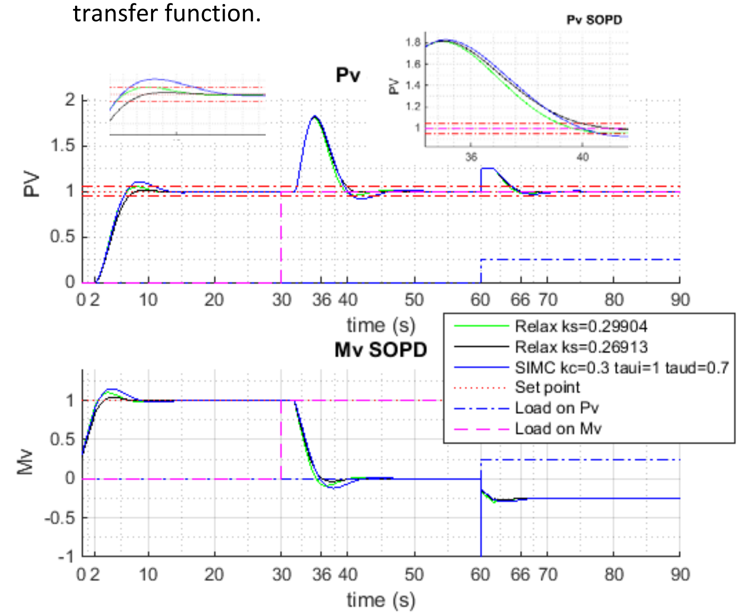
Even with a large time rise (ks low(0.26)) the Relaxc's active disturbance rejection is better than SIMC and without overshoot.

Graphic tuning gives directly the good value of ks (the steady state is constraint between 1.05 and 0.95).

The useful parameter Ks allows to tune the response and U0 as we want.

The forecast of the time rise is Td+3*τ_g=5 idem for the time rejection.

Different values of ks and comparison with SIMC (continuous "PID") controller where it is necessary to know exactly the plant's transfer function.

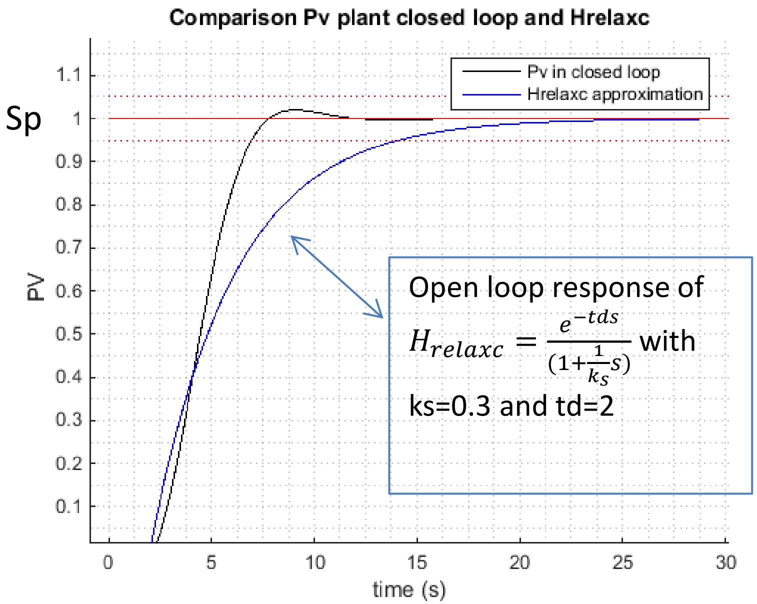


ℜelaxc : Other useful properties

- **Predictive maintenance:** For second order case it is possible with the value of k_s and $H_{relaxc} = \frac{e^{-tds}}{(1+\frac{1}{k_s}s)}$ to predict the behavior of relaxc closed loop on $H = \frac{e^{-2s}}{(1+0.7s)(1+1.0s)}$

✓ $\tau_s = \frac{1}{k_s}$ becomes the closed loop time constant and $U_{relaxc} = k_s$*Sp.

✓ It is useful to manage a time confidence interval in the transient response closed loop in order to do diagnosis or fault detection or process engineering design.



- **Auto tuning :** All the graphic tuning rules presented in these slides can be seen as auto tuning methodology if we identify automatically the necessary physical characteristics and an appropriate excitation of your choice.

Similar to all auto tuning methods, it is necessary to have minimum information about the process behavior (first, second or more order, integrating, unstable) in order to apply the good rule and determine the gain on ks.

The advantages of this Relaxc auto tuning are: we don't need to know or to identify the mathematic model process to find the coefficients. And we have no limitation with the pure delay value with respect to the dynamic of the process.

APPEDGE

Relaxc : Experiment case - Split Range

In a split range control loop, output of the controller is split and sent to two or more control valves. In most split range applications, the controller adjusts the opening of one of the valves when its output is in the range of 0 to 50% and the other valve when its output is in the range of 50% to 100%.

- **Goal** :

The first objective is to control the flow without overshoot and undershoot,

The second objective is to control this process without to build a physical modelling, complex identification. i.e. To tune the controller with the graphics rules.

- **Device :**

Schneider Modicon M340 controller

Unity pro with the controller *Relaxc* block inside,

Constraint on the Control: U works with the constraints [0:100]%,

Q(flow)max= 5000 liter/h

- **Difficulties** :

The process is strongly non linear (pump and pneumatic valves). The process's behavior oscillates between 1 order or 2 order. With a classical structure of control, nobody found a good tuning PID to control this process with reasonable time response and without overshoot on all the operational range.

The gain of the system is non-linear: the dynamic changes with respect to the set point. Cavitation phenomenon appear when we use a Huge step of set point. Speed saturation.

- **Constraints :**

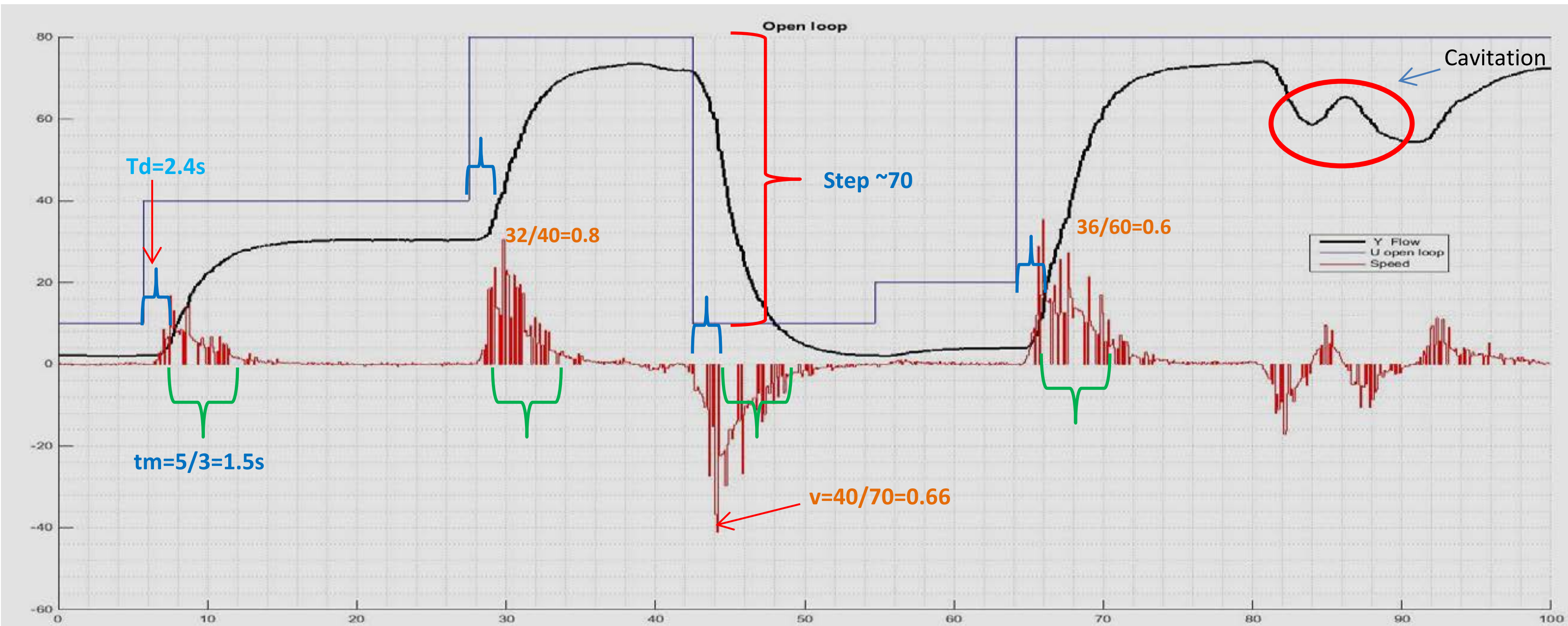
We do not have much time to tune the controller. Compressed air leaks. Difficulties to get a good quality of the derivative response.

- **Hypothesis :** We assume that the split range process can be seen as a first order. i.e. **we put all the lack of knowledge in only one parameter : the value of a pure delay (td)**

Figure 1: Split range equipment

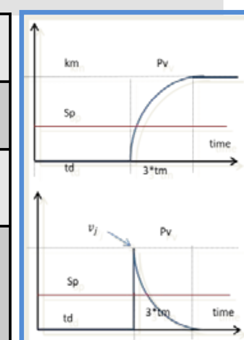
The first order's graphic tuning rule (more simple than the second order's graphic tuning rule) allow to control effortless a wide class of processes with efficiency and robustness in the real world.

ℜelaxc : Split range: tuning with step response and the first order tuning rule (N°2)



Graphic identification of the parameters (Rule 2) (First order)		
Te	20 ms	Sample time
td	2.4 s	Pure delay
v	Min 0.66 & max **0.8** (may be more)	Process Speed normalized (we choose max secure speed **v=1**)
tm	1.5s	Estimation of the Process Time constant : for this process

Relaxc Parameters		
tre	td/3=2.4/3=**0.8s**	Relaxc time (s)
τ_g	Min(tm,3*tre)=**1.5s**	Time constant of the reference trajectory in seconds (s)
ks	$ks = \frac{1}{v*\tau_g*(\frac{td}{tre}+1)}$=**0.17**	If we choose vmin, it is necessary to reduce ks =0.25 to 0.17 if we don't want overshoot into the range[0;30]



ℜelaxc / PID : Split range

APPEDGE

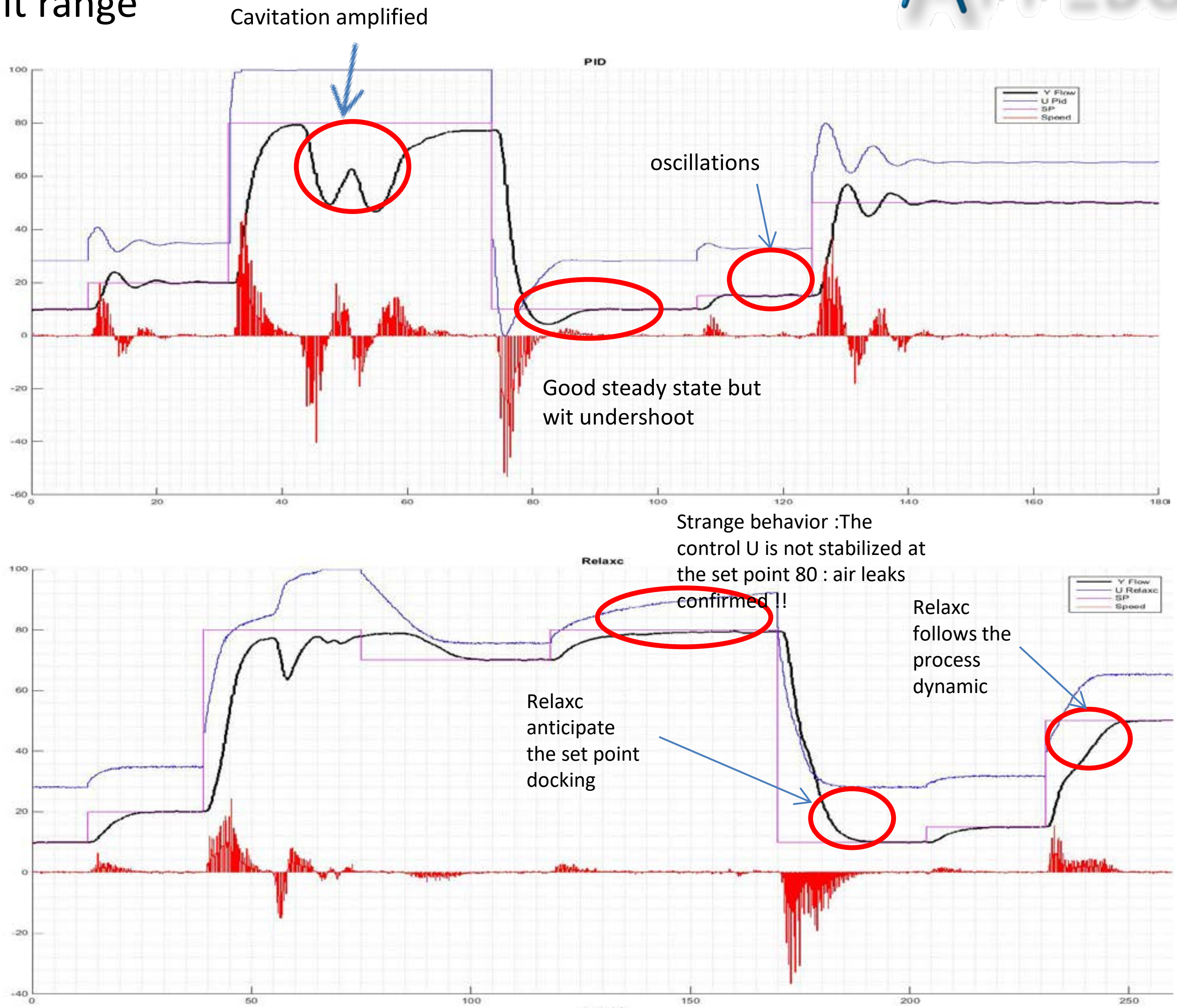
We use a classical PI with *Kp*=0.8 and Ti=2s without nothing else.

The PID figure shows as planned that dynamic change with level of flow and we see the process saturation at 80%. The oscillations increase with respect to the set point level. We obtain a good result for the time rise and the response time for a step between 10% and 15% but somewhat oscillating. But it is not acceptable for the other set point range

We don't know exactly that we have to choose to *Kp*, Ti and *Td* (derivative term).(May be to use a lookup table)

For relaxc, we see that the simple graphic tuning method gives a secure methodology to control directly (one shoot) the process without overshoot on the all operating set point. Relaxc works well even if we have air leaks and some difficulties to measure the speed.

Question ? : With a softer PID tuning we can't control the overshoots everywhere on the operational range and so , without degraded disturbance rejection time response .

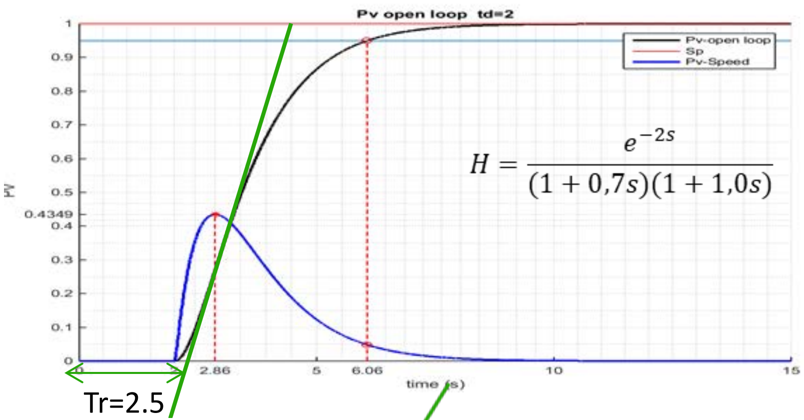


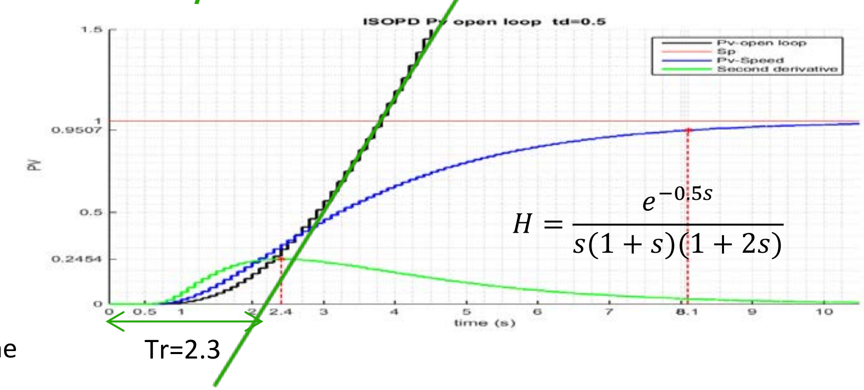
ℜelaxc and Ziegler&Nichols.

The graphic methodology of *Relaxc* seems to be close to the methodology of Ziegler and Nichols (and vice versa) to identify some physical process characteristics. But Ziegler and Nichols (ZN) applicate Its graphics tuning to PID.

But it is may be interesting to superpose these 2 methods on second order + delay and integrator + lag + delay and to compare the value of tre an Tr (Zn's delay time).

Plant	**Tr**	tre
Second order+delay	2.5	0.95
Integrator +lag+delay	2.3	2.53





- The speed is the same for Relaxc and ZN
- For the second order or more we don't use Zn to determine tre when we have a large pure delay. The response will be to sluggish (tre too large)
- For an integrator, $tre \approx Tr$ the ZN whatever the delay ZN can be acceptable to determine tre but a little bit small. We will have an little bit overshoot. If we set 2* Tr = τ_g + tre It possible may be to find the plant equation where ZN works.

The ZN's drawback is to determine a tangent line at the inflection point of the curve. As we have seen, it is difficult to apply that on the noisy split range curve.

To measure the speed max's time is more reliable and more accurate as proposed by the methodology of Relaxc. But it rests to find τ_g and ks. The relaxc graphics tuning is more complet and generic than the graphic rule of ZN.

We stop the comparison at this level because Relaxc is not a PID

ℜelaxc: Conclusion

Maximum performance in a single block

- ✓ Relaxc opens a new skyline in the world of the industrial controllers and allows to save commissioning time.(Quicker secure commissioning than PID)
- ✓ The best ways to verify these fact is to try It and may be, to adopt it.

References:

- trial version

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https://www.appedge.com/Relaxc/Appedge_relaxcdemov1.zip

- documentation

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https://www.researchgate.net/publication/339843638_Commissioning_Relaxc_for_Modicon_Controllers_Schneider_Electric

- Experiment cases

https://www.researchgate.net/publication/335652545_Relaxc_vs_Real_processes

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