1 Controllers

1.1 Outputs of the controllers

Controllers may differ by the number of outputs. In general number of those is greater than one. Moreover, functionally the same controllers can also have different types of the outputs.

Controller with two outputs

Controller has one input but 2 outputs (see Fig. 1 and 2),

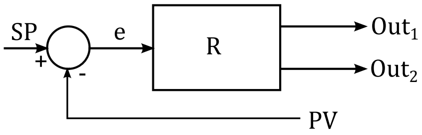
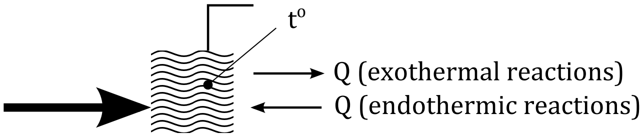


Figure 1: Controller outputs

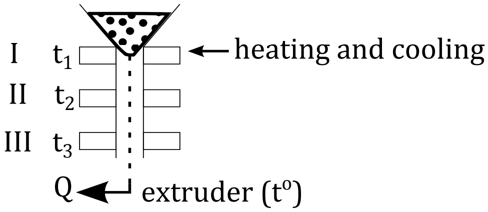
where, for example, Out_1 is for heating, and Out_2 - cooling.

Areas of use:

1. Chemical processes



2. Plastic casting and pressing (foundry)



Material flow interruptions can cause an overheating - cool the area!

Characteristics:

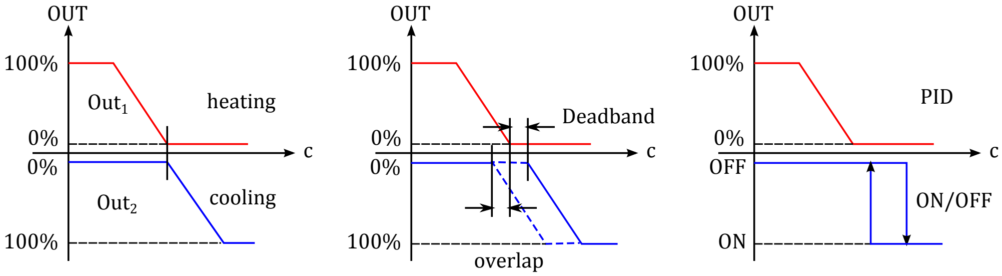


Figure 2: Characteristics of the controllers

Output: Alarm

$OUT = \{\mathrm{ON}, \mathrm{OFF}\}$, see Fig. 3.

Reacts when the signal comes out of the range, detects dangerous situations.

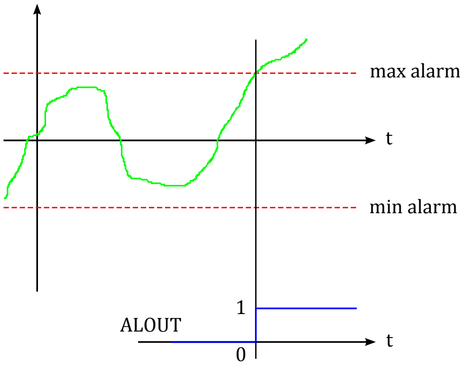


Figure 3: Alarm output

Alarm types:

Absolute alarms: if the alarmed value rises above or falls below a set value;

Deviation alarms: alarmed value exceeds a given deviation, plus or minus, from another value; from $e = SV - PV$ or PV

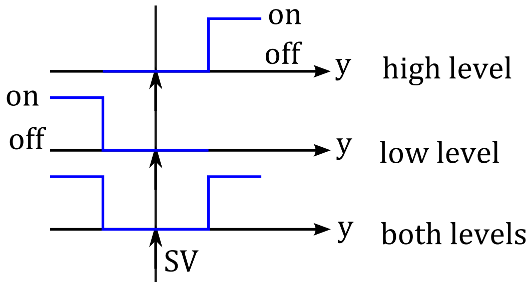


Figure 4: Alarm values

Alarm hysteresis H:

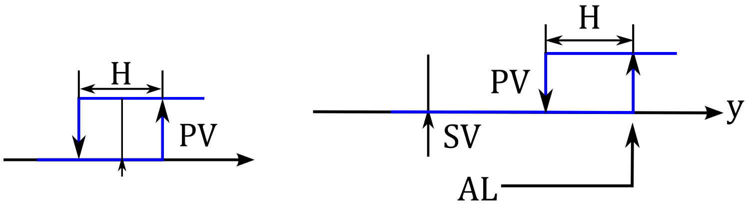


Figure 5: Hysteresis

prevents rapid changes and can be used as memory.

1.2 Physical outputs

Can be divided into two categories: relay and analogue outputs.

1.2.1 Analogue outputs

For example $OUT : I = 4 \ldots 20\ mA$.

Is used to control:

✓ Thyristor (Y13)[$\sim U = 0 \ldots 190\ V$];

✓ Positioner [$0 \ldots 100\ mm$];

✓ Frequency converters (for drive applications).

As $Out(\%) \leftrightarrow Out(mA)$, this type controllers frequently used in cascade control architectures.

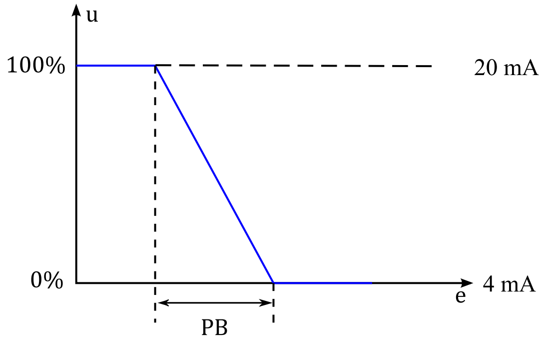


Figure 6: Analog current output

1.2.2 Relay Outputs

Relay / releeväjlundiga / релейный выход, which is used to operate a contactor or solenoid valve in heating and cooling applications. Additionally logic which is used to switch a solid state relay. The benefits are: long life, no maintenance and the ability to rapidly switch heaters which have a small thermal mass.

Time-proportional control, a form of pulse-width modulation, is a mathematical technique that allows a feedback controller to use an ON-OFF actuator as if it were a continuous actuator capable of generating control efforts anywhere between 0%–100%. Time-proportional control can achieve a proportional control response to process variation using a device with relay output by varying on and off times in a defined control period. The ON-OFF device is generally a simpler, less expensive control device.

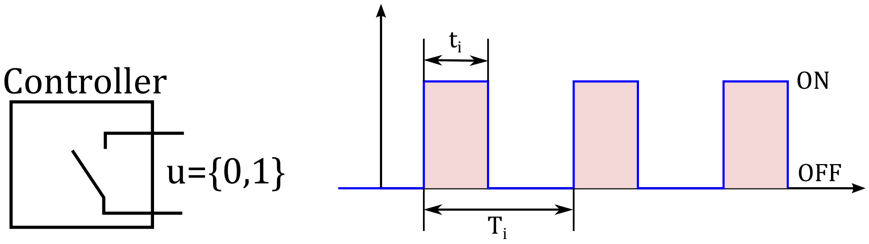


Figure 7: Contactor and PWM

$$0 \leq \frac{t_i}{T_i} \leq 1$$

Two cases:

1. $t_i = 0 \dots T_i$; $T_i =$ const.
2. $T_i = 0 \dots t_i$; $t_i =$ const.

The parameters used to program a time-proportional output include the sample period, the set-point, the proportional band, and the control direction. In case of PID controller sample period is called as Control Period CP and can be found in the settings of the controller.

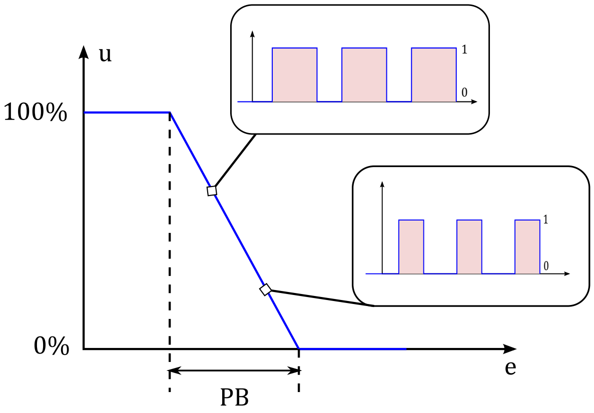


Figure 8: PID with relay output

The sample period should be set to approximately 1.5 times the amount of time that it takes for the system to react. Setting the control period too low will result in a second addition being made before the first is detected and will cause set point overshoot. Setting the sample period too high will delay the next addition and can prevent the set point being reached.

For thermal objects control the cycle time must be short enough to allow the thermal mass of the load to smooth out the switching pulses. 20 seconds is typical. Systems with a small thermal mass will need shorter cycle times than can be provided with a relay up to 2 seconds [1, 2].

Features:

1. Simple, cheap

   binary $\{0, 1\}$ cheap actuator.

2. Conditions for controlled object

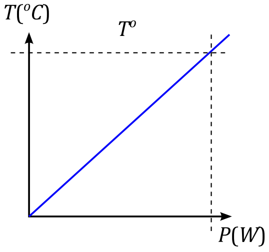
   object time constant $T >> T_i$;

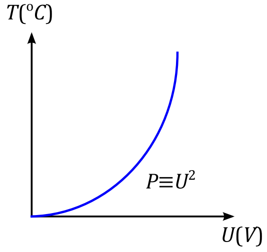
   pulse signal does not pass through the object $\Delta y <<$.

3. Linearizes the controlled system.

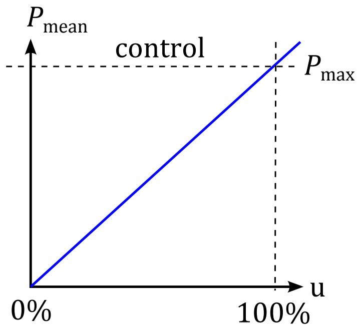
Thermal objects

$$\Delta T \equiv \Delta P$$





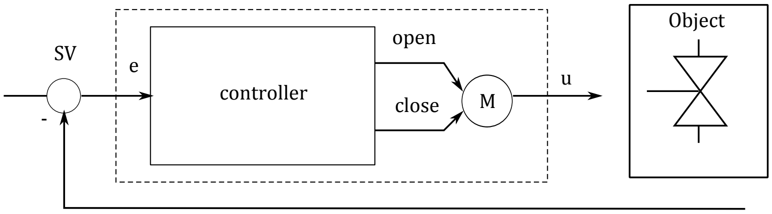
- ✓ Control by power $P, P \sim U^2$;
- ✓ Control by voltage U - invert $\sqrt{u}$.



$$\bar{P} = P_{max}\frac{u(\%)}{100(\%)} \tag{1}$$

controller output is proportional to the given mean power

1.2.3 Position-proportional controller



Actuator with a motor: motor with constant speed (asynchronous motor - cheap and reliable).

	3 operational modes		
	FF	FB	Stop
speed	+s	-s	0
open	1	0	0
close	0	1	0

Motor control signal: $\{+s,-s,0\}$

Output signal u: mechanical movement 0%…100%

Tracking system (positioner)

Keeping motor output y on desired value x, so $y \approx x$

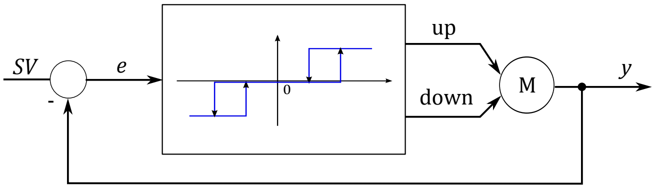


Figure 9: Step tracking system

Motor works as integrator.

Motor control signal dy/dt.

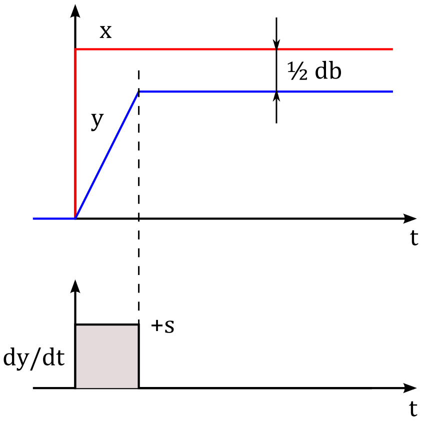


Figure 10: System reaction

Continuously changing signal.
Next error:

- Inside the range $\pm db/2 \ldots \pm (db/2 + \Delta)$
- Error sign
  - $y < x$, if $dx/dt > 0$ - rising
  - $y > x$, if $dx/dt<0$
- Output signal y changes with a mean speed $\frac{d}{dt}y = \frac{t_i}{T_i}s$

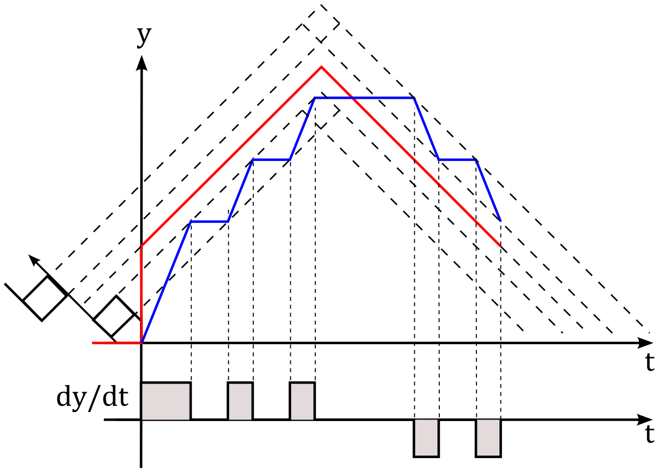


Figure 11: Continuously changing signal

Motor parameter: T_m

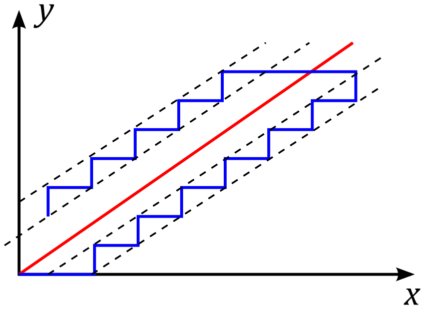
motor travel time $0\% \ldots 100\%$ range in T_m [s]

speed $s = \frac{100[\%]}{T_m[s]} = \text{const}$

pulse length t_i

$t_i = \frac{T_m[s] \cdot \Delta[\%]}{100\%}$ output changes by the Δ

- I/O characteristics:



$$y = x \pm (db/2 + \Delta)$$

Internal feedback

Feedback of the motor signal y is onerous, make a change.

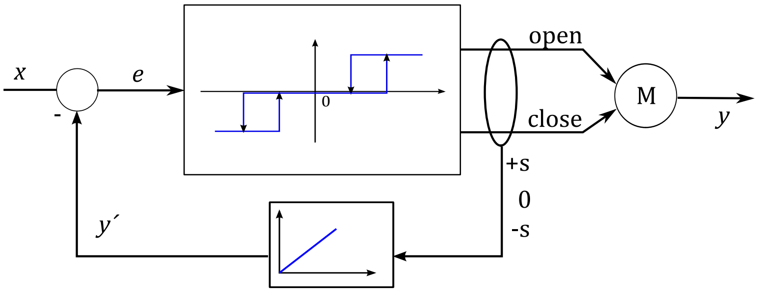


Figure 12: Internal feedback

Motor: integrator features are known;

Motor model: integrator simulates the motor behavior, generates signal $y' = y$.

Controller: PID + tracker

Tracking accuracy is defined by db, Δ parameters.

If pulse length t_i is smaller:

1. More precise tracking,
2. More often switching of the motor,

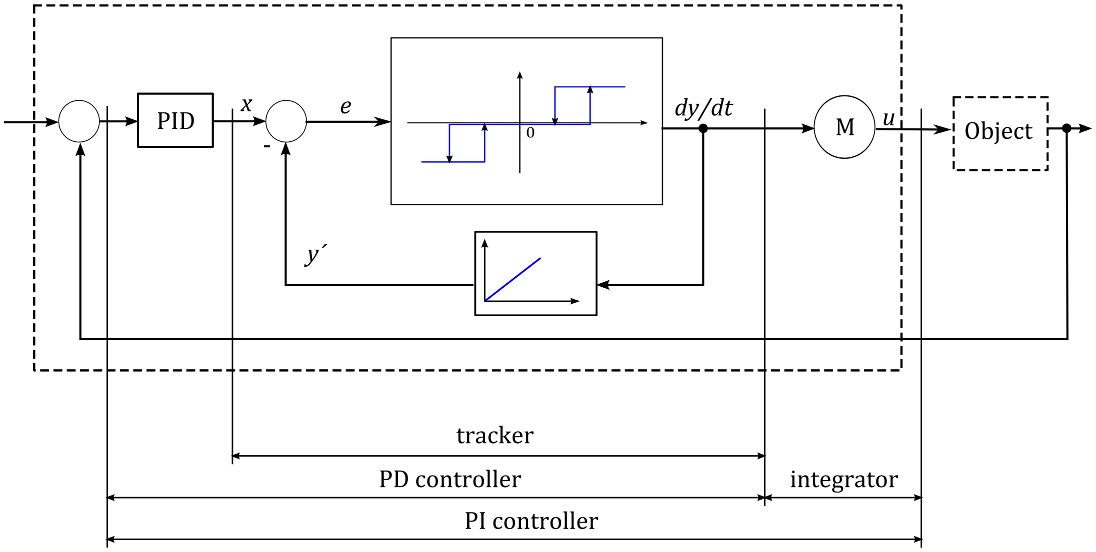


Figure 13: General system

3. Same mean speed.

Problems:

1. Motor inertia on start and stop

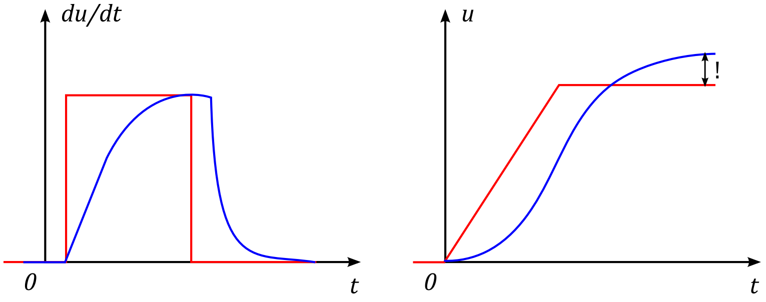


Figure 14: Motor inertia

2. Damped oscillations in tracking actuator chain
    - if *db* is small then motor does not stop and error of other sign $\pm e$ appears.

Controller parameters are:

✓ PID: K_c, T_i, T_d;

✓ Motor parameter T_m;

✓ Relay parameters db, Δ.

2 System performance

System Requirements (objectives).

Performance evaluation.

2.1 Control loop

What is the influence of the reference and disturbance signals on the output of the system?

Control loop: $r(t), d(t) \rightarrow y(t)$

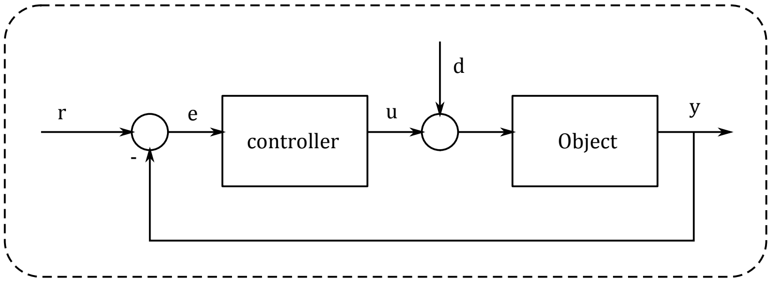


Figure 15: Control loop

To choose a controller type your need:

1. Model of the object/process or test data.
2. System requirements.

How to describe the desired behavior of a closed loop system?

How comparable system is? What is numerical value of the system performance?

Requirements (goals)→ actual (results)

- What is changing $r(t), d(t), W_o, \ldots$? - reason
- How is changing (step, random,...)?

- What is observed $y(t), e(t), \dots$? -conclusion
- How to evaluate the change by numeric value (max, standard deviation, integral,...)?

What system features are important?

Requirements must be: measurable, unambiguous, understandable.

2.2 Simple performance measures [3]

When we apply control actions to the system the reaction of the system can be obtained. Measuring some parameters of the system output one can analyze the performance of the control actions.

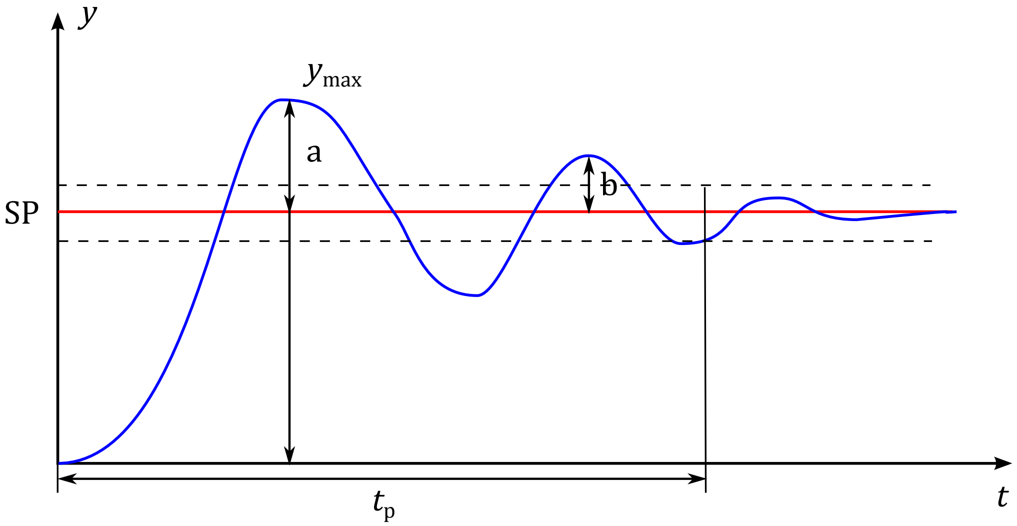


Figure 16: Control criteria

2.2.1 Overshoot

Overshoot is formally defined for the case where the process makes a transition from one operating level to another, see Fig. 16.

$$\sigma(\%) = \frac{y_{max} - SP}{SP} \cdot 100\% \tag{2}$$

2.2.2 Decay Ratio

The decay ratio reflects the rate of decay of the sinusoidal component of the response. The decay ratio is the ratio of the second peak overshoot b to the first peak overshoot a (see Fig. 16)

$$\psi = \frac{b}{a} \tag{3}$$

In process control, the decay ratio is the most commonly applied performance measure. Furthermore, the preferred value is almost always 1/4. The term "quarter - wave damping" is sometimes used to refer to responses whose decay ratio is 1/4. This response will have a significant first overshoot, followed by a small second overshoot.

This criterion can be also used as a response to other changes: response to change in load or disturbance and response to “bump” in the set point.

2.2.3 Settling time

Settling time t_p is the time required for the system to attain equilibrium after a change in one or more of its inputs. To quantify the settling time numerically, one has to introduce a tolerance for a variable to be considered as having attained its equilibrium value. When the input is a step change in the set point, the tolerance is typically 2% or 5%. As indicated in Fig. 16, the tolerance introduces a band about the final value. The settling time t_p is the time required for the response to come within that band and to remain within that band thereafter.

Simple performance measures are widespread because they are easy to apply, however, their limitations must be understood. Small amount of information needed for such methods gives the possibility that two very different responses could have the same value of a simple performance measure. This has implications for controller tuning.

2.3 The integral criteria [3]

The integral criteria address the deficiencies of the simple performance measures, but at a price.

An integral criterion is a performance measure that is based on the integral of some function of the control error and on possibly other variables (such as time).

The three most commonly used integral criteria are as follows:

- Integral of the absolute error (IAE);
- Integral of the square error (ISE);
- Integral of time and absolute error (ITAE).

The smaller the value of the integral criterion, the better the performance of the control loop. Thus, when used as the basis for tuning a PID controller, the objective is to determine the values of the tuning parameters K_c, T_i, T_d that minimize the selected integral criterion.

2.3.1 Integral of the absolute error

$$IAE = \int_0^\infty |E| \ dt$$

2.3.2 Integral of the square error

$$ISE = \int_0^\infty E^2 \ dt$$

The integral of the square error (ISE) penalizes for large errors more than for small errors. Often the response has a smaller initial overshoot, but cycling does not decay rapidly.

2.3.3 Integral of time and absolute error

$$ITAE = \int_0^\infty |E|t \ dt$$

The objective of the integral of time and absolute error (ITAE) is to penalize for even small errors that occur late in time. That leads to responses with a short settling time.

Determining the values of the tuning coefficients K_c, T_i, T_d that minimize the selected integral criterion is an iterative endeavor.

Given starting values for the tuning coefficients, each iteration consists of the following:

1. Obtain a process response to the input change of choice (such as a step change in set point).
2. Evaluate the integral criterion.
3. Select new values for the tuning coefficients.

   This procedure is repeated until the tuning coefficients that minimize the integral criterion of choice are found.

Such tests are only feasible on simulations, never on the real process.

An integral criterion does a much better job of quantifying the nature of the response. Every point on the response contributes to the value of the integral criterion. Simple performance measures depend on only one or two points on the response.

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