Control Systems

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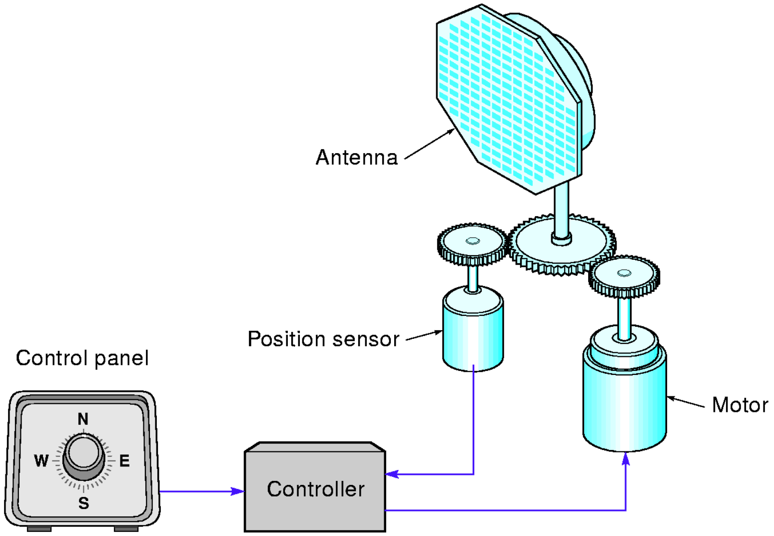
ME 475: Mechatronics

Example: An Antenna Positioning System



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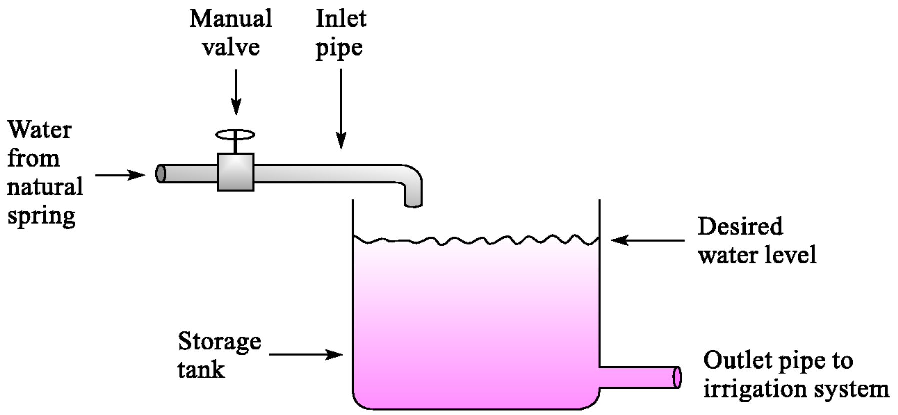
Importance

- A Control system is an interconnection of components forming a system configuration that will provide a desired system response.
- **Primary Reasons**
  - Power amplification
  - Remote control
  - Convenience of input form
  - Compensation for disturbances
- **Important Outcomes**
  - Increased productivity and lower product cost
  - Better and more uniform quality of product
  - Greater safety for operating personnel

Classifications

- Open-Loop System - output has no effect on control action.
- Closed-loop System - maintains a prescribed relationship between the output & some reference input by comparing them and using the difference as a means of control.
- Servomechanism - a feedback control system to control motion.
- Process Control Systems - a feedback control system where one or more process variables such as temperature, flow, liquid level etc are controlled.
- Batch Process - is a sequence of timed operations executed on the product being manufactured.
- Continuous Process - one or more operations are being performed as the product is being passed through a process.

Example: Manual Control System



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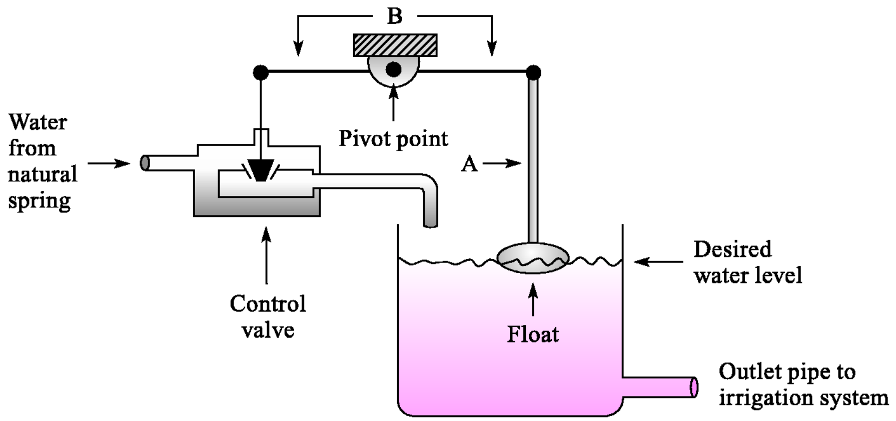
Example: Automatic Control System



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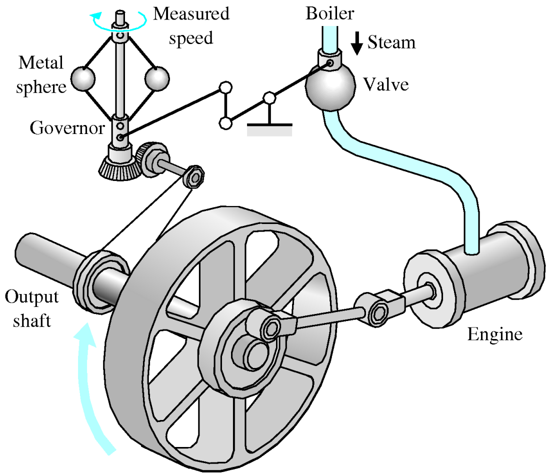
Example: Automatic Mechanical Control System



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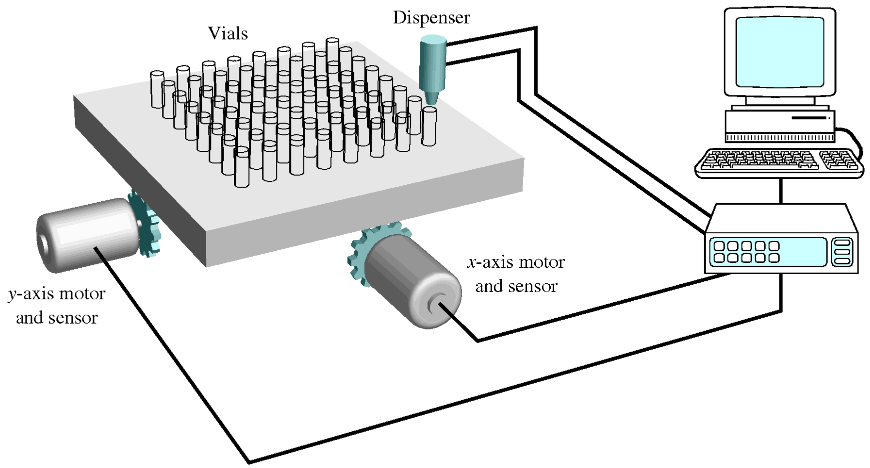
Watt's fly-ball mechanical governor

Example: Computer Based Control System



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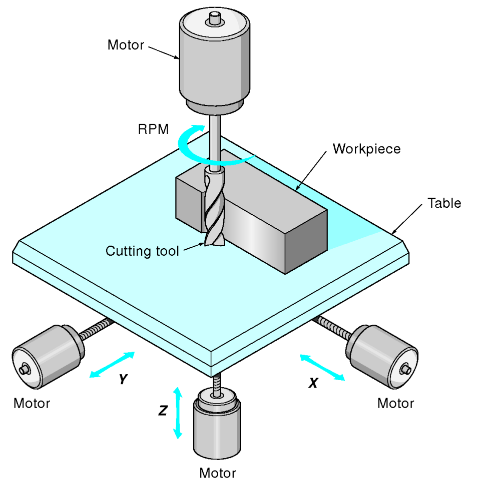
Automatic table and dispenser

Example: Servomechanism



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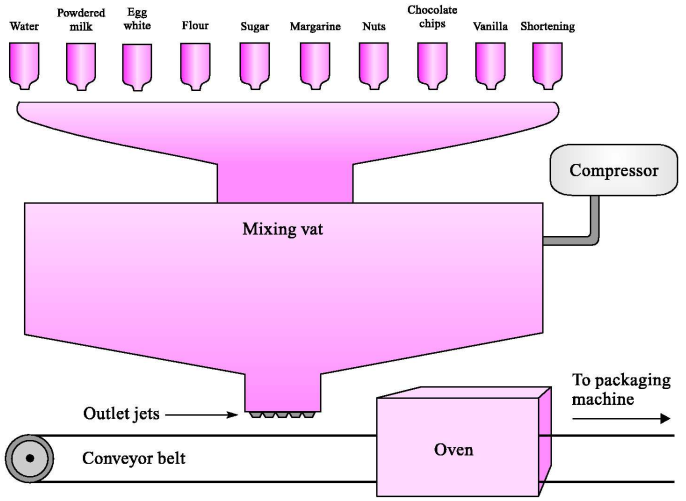
Numerical control milling machine

Example: Batch Processen in Cookie Machine



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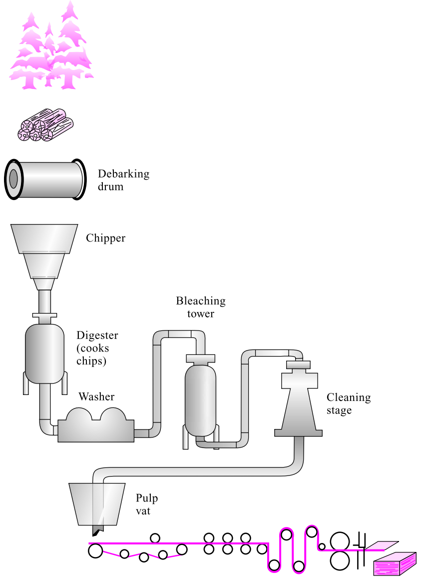
Example: Continuous Process Control in Paper Mill



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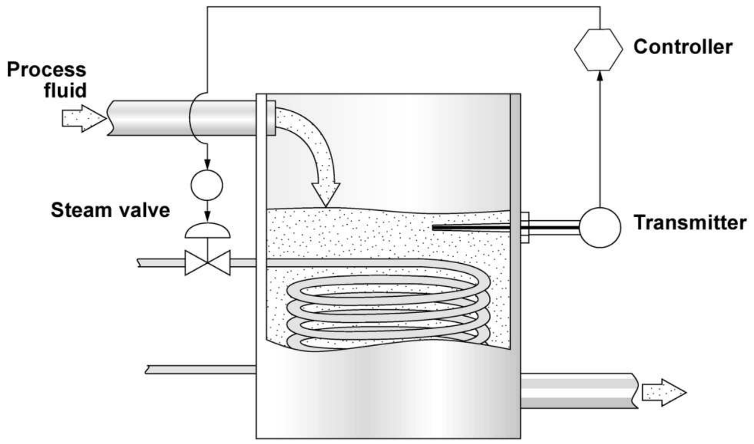
Feedback Contol



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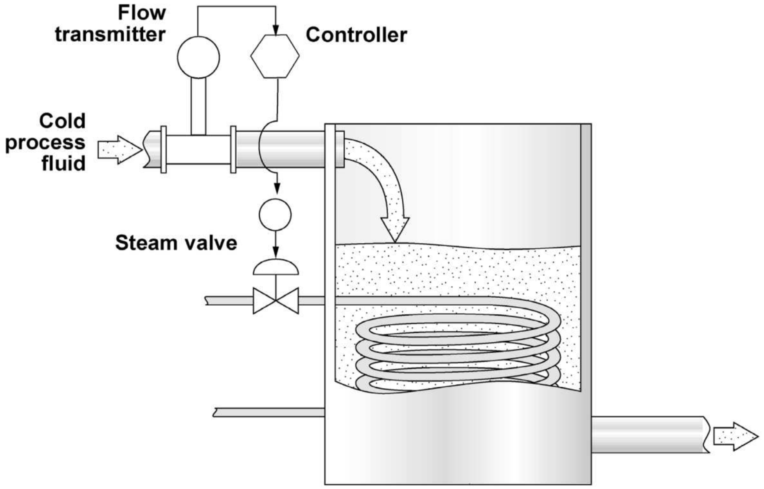
Feedforward Contol



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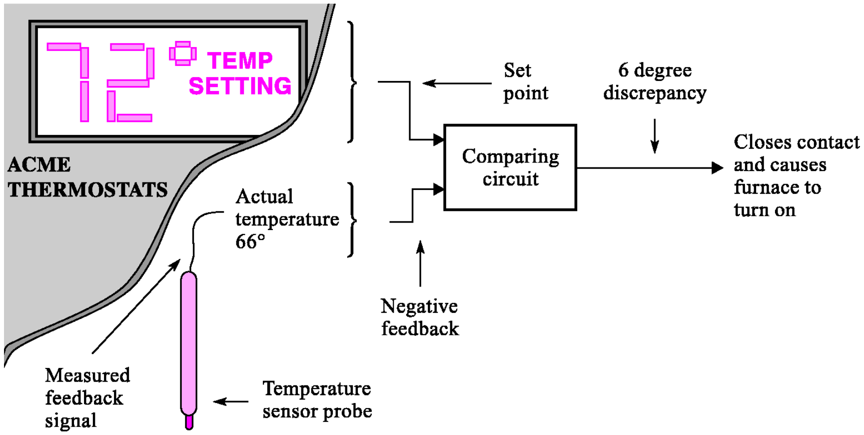
Example: Industrial Negative Feed-back Control



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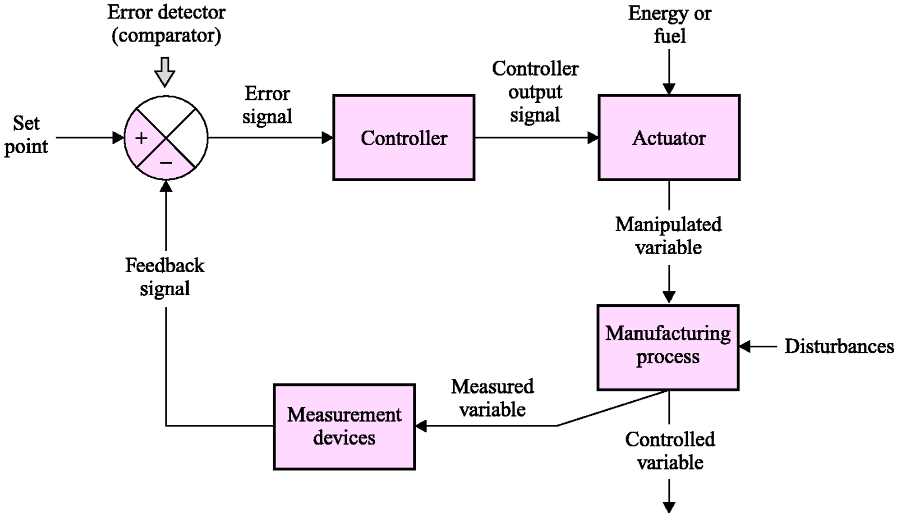
Elements of Closed-loop Control System



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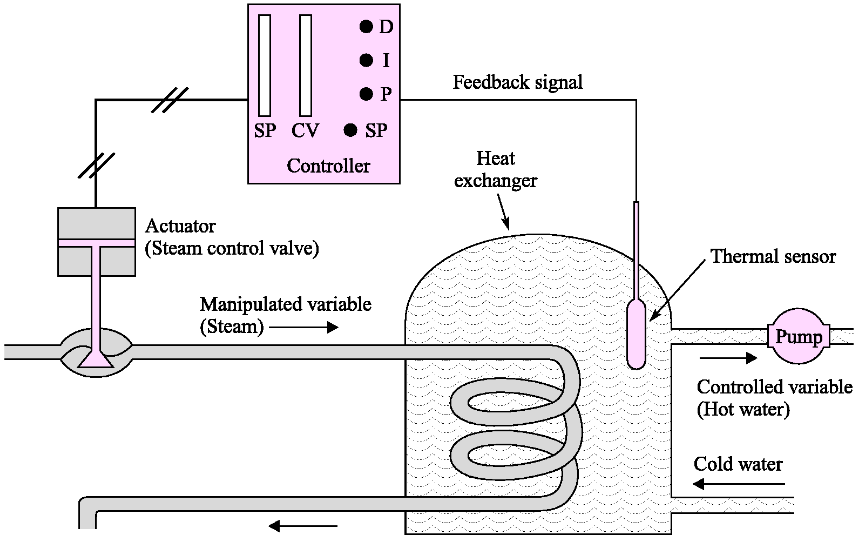
Example: Industrial Temperature Control System



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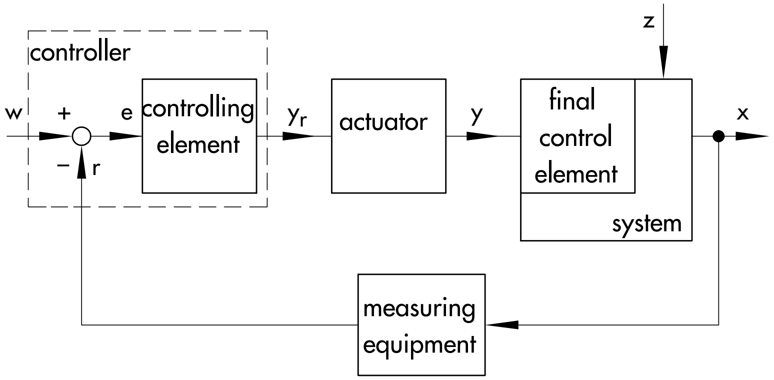
Block Diagram & Abbreviations



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w : reference variable

y : manipulated variable

r : feedback variable

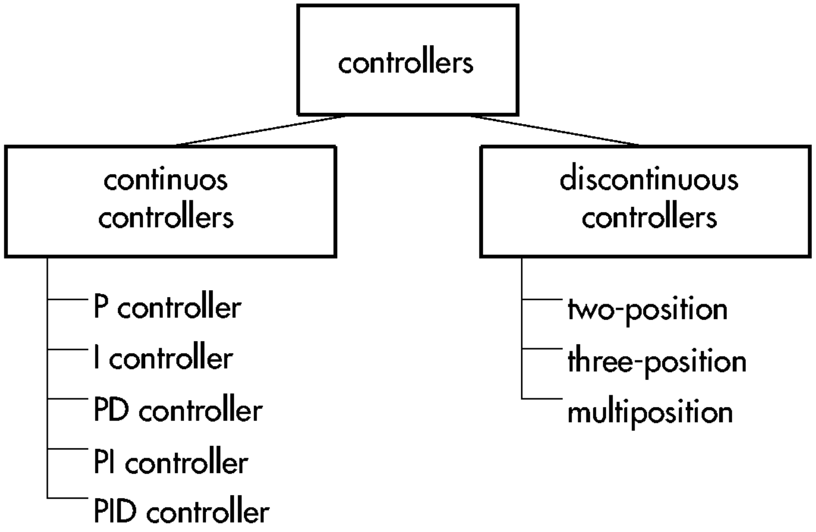
y_r : controller output variable

x : controlled variable

z : disturbance variable

e : error ($\equiv w - r$)

Control Modes



controllers

continuos controllers
- P controller
- I controller
- PD controller
- PI controller
- PID controller

discontinuous controllers
- two-position
- three-position
- multiposition

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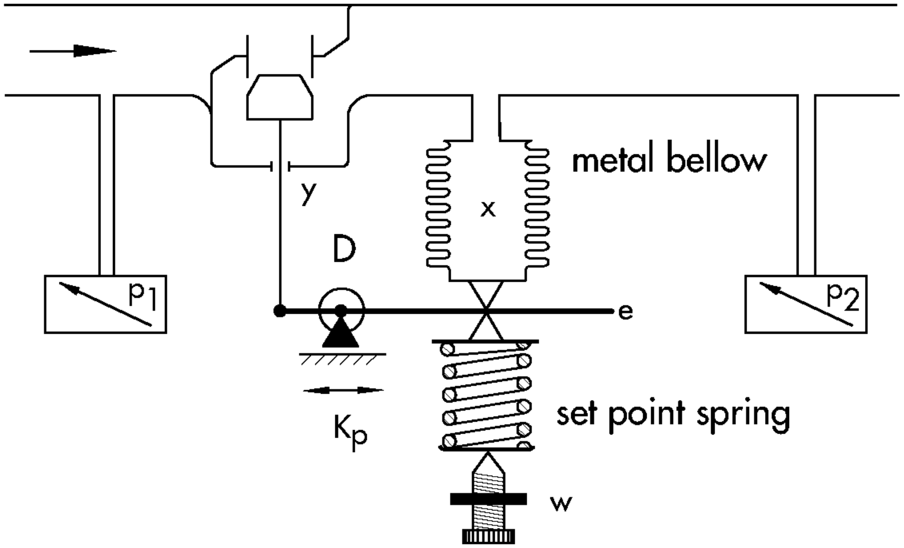
Proportional (P) Controller



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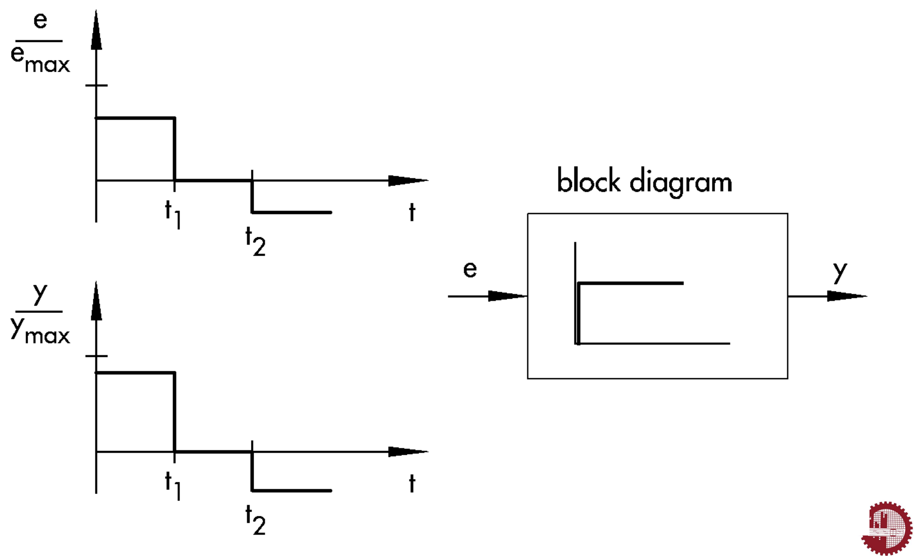
In proportional (P) mode, linear relationship between the controller output and the error exist in proportional band (PB).

$$y = K_p e + y_o \qquad K_p = \frac{100}{PB}$$

- K_p = proportional gain between error and controller output
- y_o = manipulated variable at operating point

- If error is zero, output is a constant equal to y_o.
- In case of error, for every 1% of error, a correction of K_p% is added or subtracted from y_o, depending on error sign.
- There is a band of error about zero of magnitude PB within which output is not saturated at 0% or 100%.
- When a load changes, a permanent residual error occurs.

Dynamic Behavior of a P Controller



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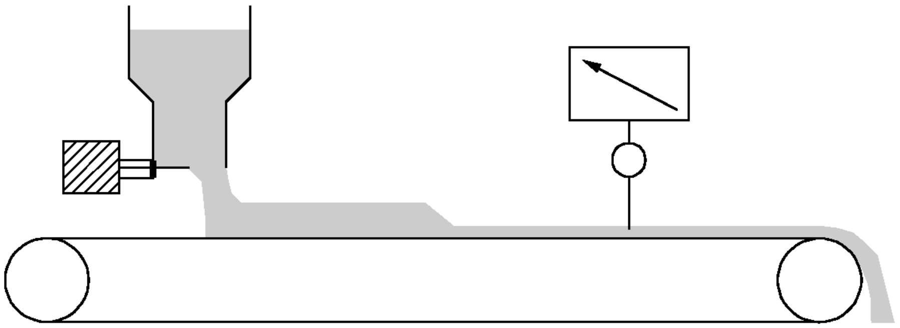
Controlled system with dead-time



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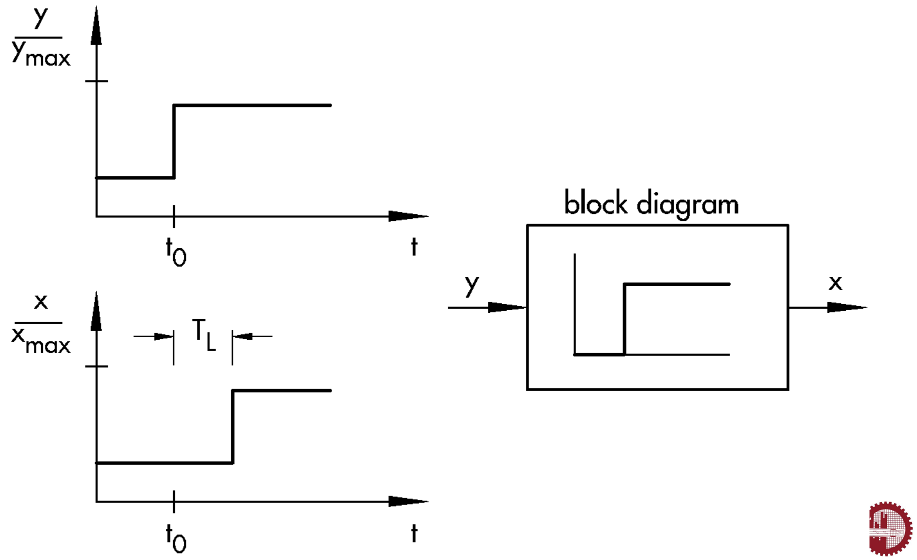
Dynamic controlled system with dead-time



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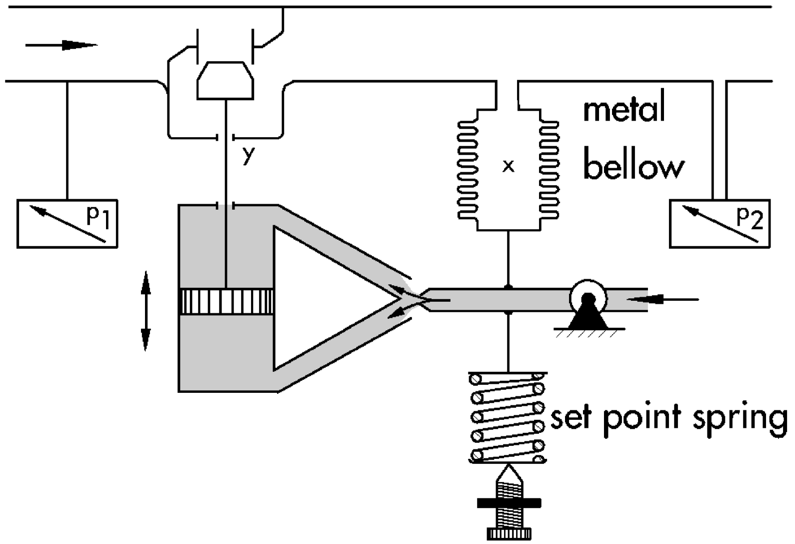
Integral (I) Controller



- Integral control action is used to fully correct system deviations at any operating point. As long as the error is nonzero, the integral action will cause the value of the manipulated variable to change.
- In I control mode, the value of the manipulated variable is changed proportional to the integral of the error e

$$y = K_I \int e \; dt + y(0) \qquad \text{with :} \quad K_I = \frac{1}{T_n}$$

- The higher the integral action coefficient K_I, the greater the integral action of an I controller.
  - No steady state error
  - Sluggish response at low K_I
  - At high K_I, the control loop tends to oscillate/may become instable

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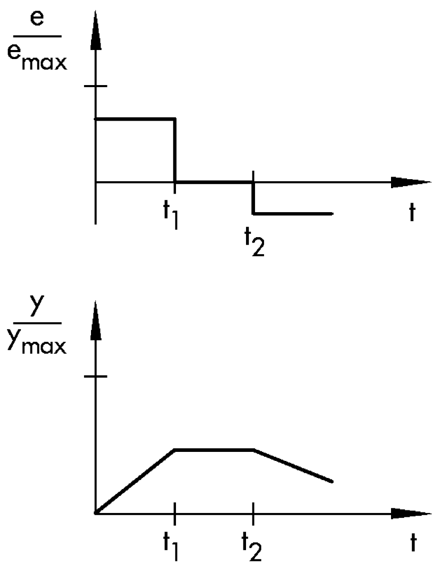
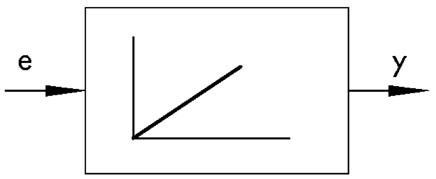
Dynamic Behavior of an I Controller



block diagram



Derivative (D) Controller

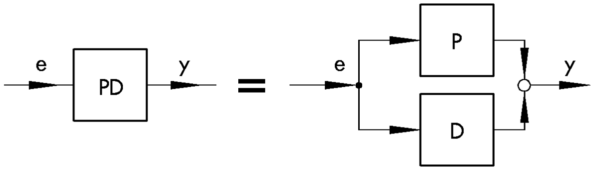
- D controllers generate the manipulated variable from the rate of change of the error and not - as P controllers - from their amplitudes.
- These react much faster than P controllers: even if the error is small, derivative controllers generate - by anticipation - large control amplitudes as soon as a change in amplitude occurs.
- A steady-state error signal, however, is not recognized by D controllers, because regardless of how big the error, its rate of change is zero.
- Therefore, derivative-only controllers are rarely used in practice. They are usually found in combination with other control elements, mostly in combination with proportional control.

PD Controller

- In PD controllers with proportional-derivative control action, the manipulated variable results from the addition of the individual P and D control elements:

$$y = K_p \; e + K_D \, \frac{de}{dt} + y_o$$

- The control response for steady-state error in PD controllers is just as it occurs in P controllers. Due to the immediate control action whenever there is a change in the error signal, the control dynamics is faster than with P controllers.



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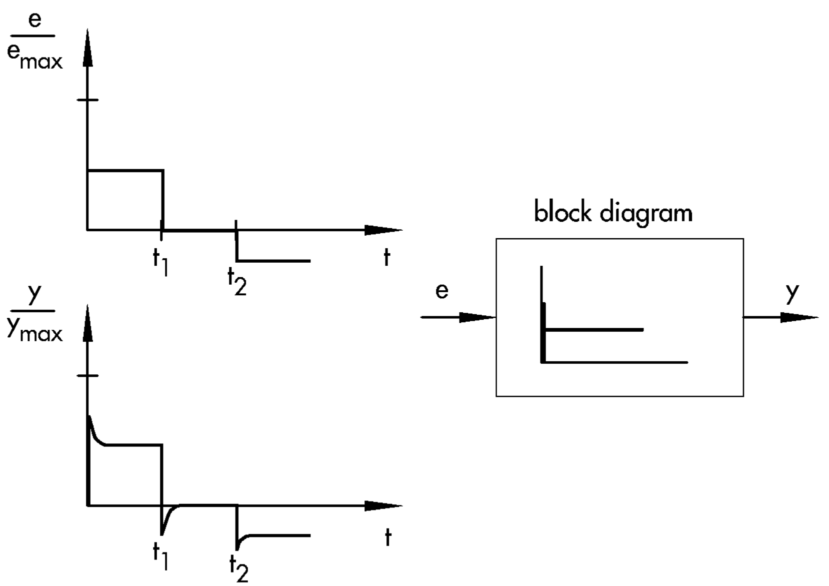
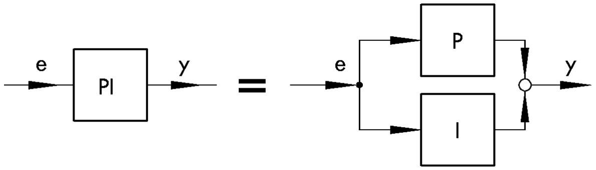
Dynamic Behavior of a PD Controller



PI Controller

- PI controllers are often used in practice. If properly designed, they combine the advantages of both controller types (stability and rapidity; no steady-state error), so that their disadvantages are compensated for at the same time.
- The manipulated variable of PI controllers is calculated as follows:

$$y = K_p\ e + K_I \int edt \qquad \text{with : } K_I = \frac{K_p}{T_n}$$



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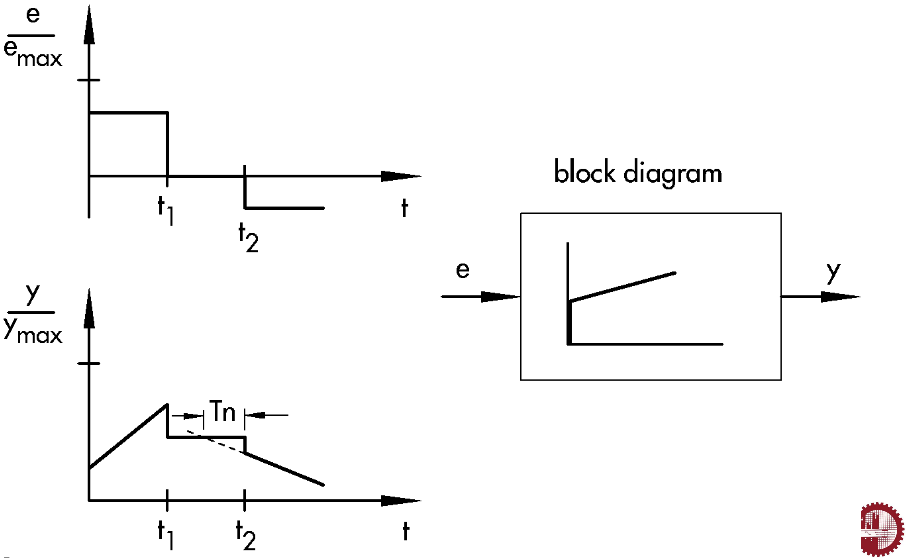
Dynamic Behavior of an PI Controller



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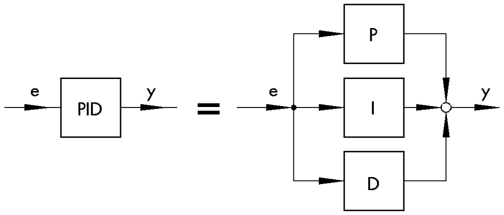
PID Controller

- If a D component is added to PI controllers, the result is an extremely versatile PID controller. If properly tuned, this controller causes the controlled variable to reach its set point more quickly, thus reaching steady-state more rapidly.
- The manipulated variable of PID controllers is calculated as follows:

$$y = K_p\ e + K_I \int edt + K_D \frac{de}{dt}$$



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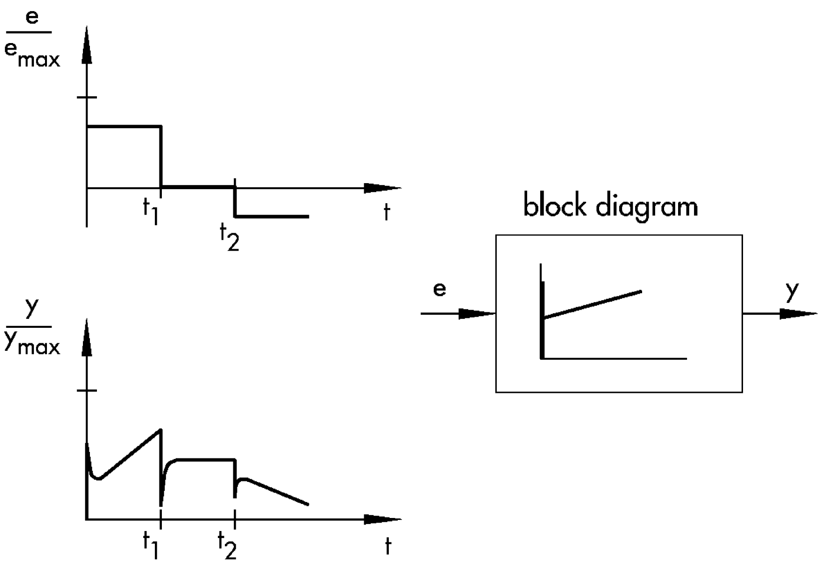
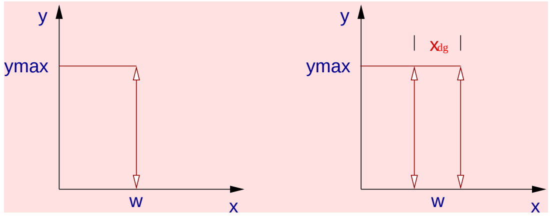
Dynamic Behavior of an PID Controller



Two-position (ON/OFF) Controller

The simplest version of a discontinuous controller is the two-position controller which has only two different output states, for instance 0 and y_{max}. For a simplest two-position controller, oscillations occur about the set-point. In virtually any practical implementation, there is a neutral zone where no change in the controller output occurs.



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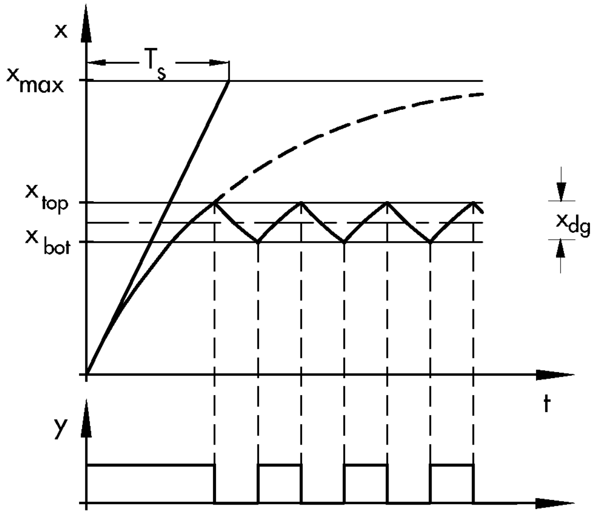
Switching characteristics of the two-position controller (without and with a neutral zone of width x_{dg}

Response of an ON/OFF Controller



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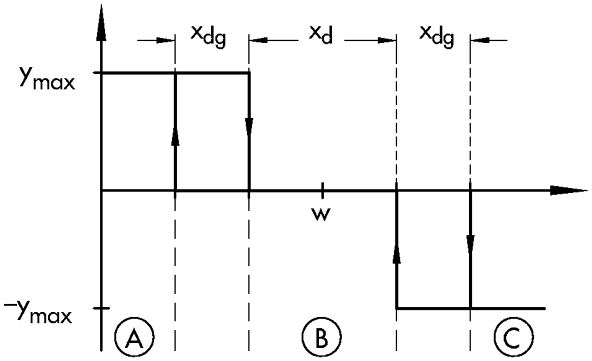
Three-position Controller

Three-position controllers can assume three different switching states. In a temperature control system, these states are not only ’off’ and ’heating’ as in a two-position controller, but also ’cooling’.



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