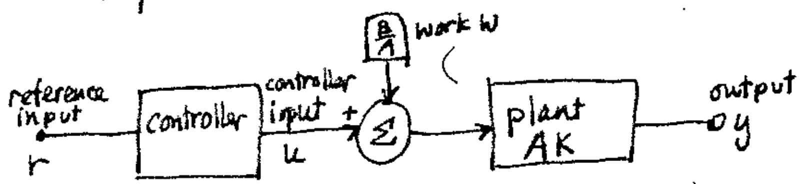
# Control

for a certain process(plant) there is an input and an output.
control is the process of making a system variable adhere to a particular value, the reference value.

open-loop : system does not measure output, and there is no compensation of that output to make it conform to the desired output.

closed-loop : system uses <u>feedback</u>, which is measuring a control variable and returning the output to influence the value of the variable.

<u>open loop</u> :




k= steady state gain

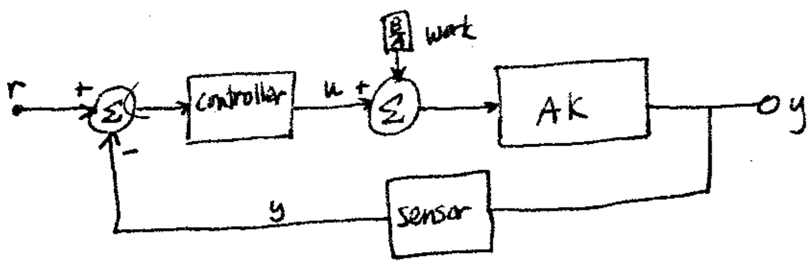
$$u = Kr$$

$$y_{ss} = Au = AKr \qquad (w=0)$$

$$y_{ss} = AKr + BW$$

$\boxed{\text{feedback}}$

<u>closed loop</u>:




$$u = K(r-y)$$

$$y_{ss} = \frac{AK}{1+AK} r \qquad (w=0)$$

$$y_{ss} = \frac{AK}{1+AK} r + \frac{B}{1+AK} w$$

system errors can be made less sensitive with feedback than they are in open loop systems by a factor of $1+AK$

as $AK >> 1$, $y_{ss}(c.L.) = r + W$

sensitivity to gain changes:

if $A \rightarrow A + \delta A$

$$\frac{\delta y}{y} = S \frac{\delta A}{A}$$

where $S$ is the sensitivity. good if it's small.

for open-loop (O.L.):

$$\frac{\delta y_{OL}}{y_{OL}} = \frac{\delta A}{A} \qquad S = 1$$

for closed-loop (C.L.)

$$\frac{\delta y_{CL}}{y_{CL}} = \frac{1}{1+AK} \frac{\delta A}{A}$$

since $AK$ is large (usually), sensitivity decreases to variations in plant gain $A$.

<u>proportional feedback</u>

feedback control signal is made to be linearly <u>proportional</u> to the error in the measured output

$u(t) = Ke(t)$

$$\frac{U(s)}{E(s)} = D(s) = K$$

(LaPlace transform stuff to get to s-plane)
$D(s)$ is the controller transfer fcn.

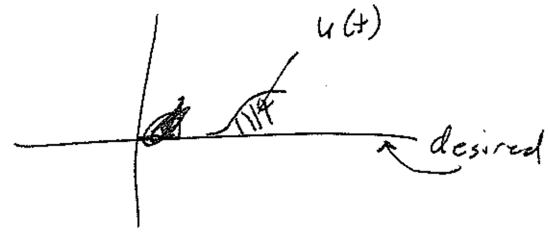
Proportional controller can be viewed as an amplifier with a "knob" to adjust the gain up or down.

<u>advantages</u>: reduces error responses to disturbances
increases speed of response

<u>disadvantages</u>: still allows for a non-zero steady-state error
has large transient overshoot
may have a steady-state offset (droop) in response to a constant reference input
may not be entirely capable of rejecting a constant disturbance
for higher order systems, large values of the proportional feedback gain will typically lead to instability.

large $K$ reduces errors, but leads to decreased damping ratio (more overshoot)
there is a limit on how much the errors can be reduced with P only.

## Integral Control :




$$u(t) = \frac{K}{T_I} \int_{t_0}^{t} e(\eta)\, d\eta$$

$$D(s) = \frac{K}{T_I s} \qquad \text{(LaPlace Transform)}$$

$T_I$ is the integral or reset time.

$\frac{1}{T_I}$ is a measure of the speed of the response and is the reset rate.

$y_{ss} = r$ no error (when $w = 0$)

<u>but</u>, very small damping ratio – response become oscillatory
response slows down, stability is decreased.

<u>PI</u> : $u(t) = K\left[ r - y + \frac{1}{T_I} \int_0^t (r-y)\, d\eta \right]$

$e = r - y$

$K$ = proportional gain

still get oscillatory action

by choosing $K$ and $T_I$, the designer can independently control certain coefficients (doesn't really mean anything to us.)

$\Rightarrow$ result is better transient response and greater reduction of errors.

## Derivative feedback :

$u(t) = K T_D \dot{e}(t)$

proportional to the rate of error – no good for steady-state errors!

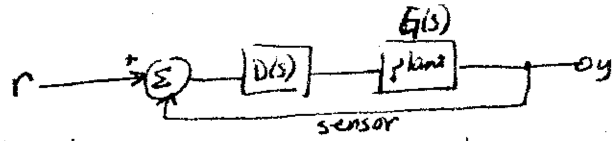
$D(s) = K T_D s$

$T_D$ is called derivative time

damping is increased (faster response)
stability is improved.

<u>but</u> can't be used alone.
exhibits an anticipatory response (faster)

## PID :




linear combination of controls proportional to error, time integral of error, and time rate of change of error

good error reduction with good stability and damping.

$D(s) = K\left(1 + \frac{1}{T_I s} + T_D s\right)$ $\quad\quad u(t) = K\left[e(t) + \frac{1}{T_I}\int_0^t e(\eta)\,d\eta + T_D \dot{e}(t)\right]$

adjusting $K$, $T_I$, $T_D$ is called <u>tuning the controller</u>

$K\uparrow$, $\frac{1}{T_I}\uparrow \implies$ errors $\downarrow$, stability $\downarrow$

$T_D\uparrow$, $\implies$ stability $\uparrow$

Ubiquitous in the process-control industry and is the basic ingredient in many control systems.

## feed-forward


put sensor right after load (before plant).

improved performance can be obtained if this information is fed forward to the controller

good for chemical processes — can change process conditions in response to feed conditions