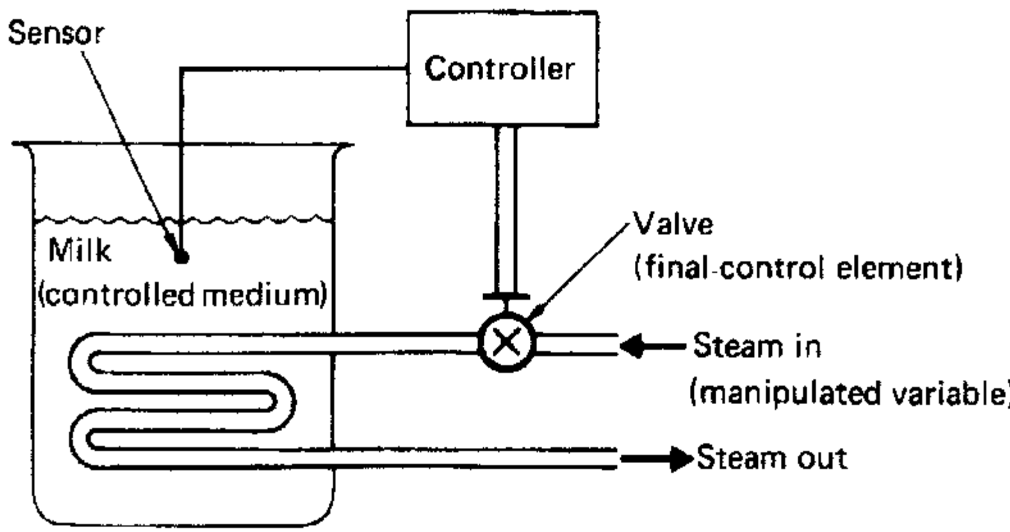
Process Control Systems

Control System Basics



Control Systems Have…

- One or more *controlled or dynamic variables*
- One or more *manipulated variables*
- One or more *disturbances*

3 Common Characteristics of Control Systems

- Measurement of the controlled variable
- Evaluation of the measurement by comparison to a set point. If measurement is different from set point, an error condition exits.
- Final Control Element adjusts the process to bring the controlled variable back to the set point value.

3 Basic Characteristics of Processes

- Process Load
- Process Lag
  - Capacitance
  - Resistance
  - Transportation Time
- Stability

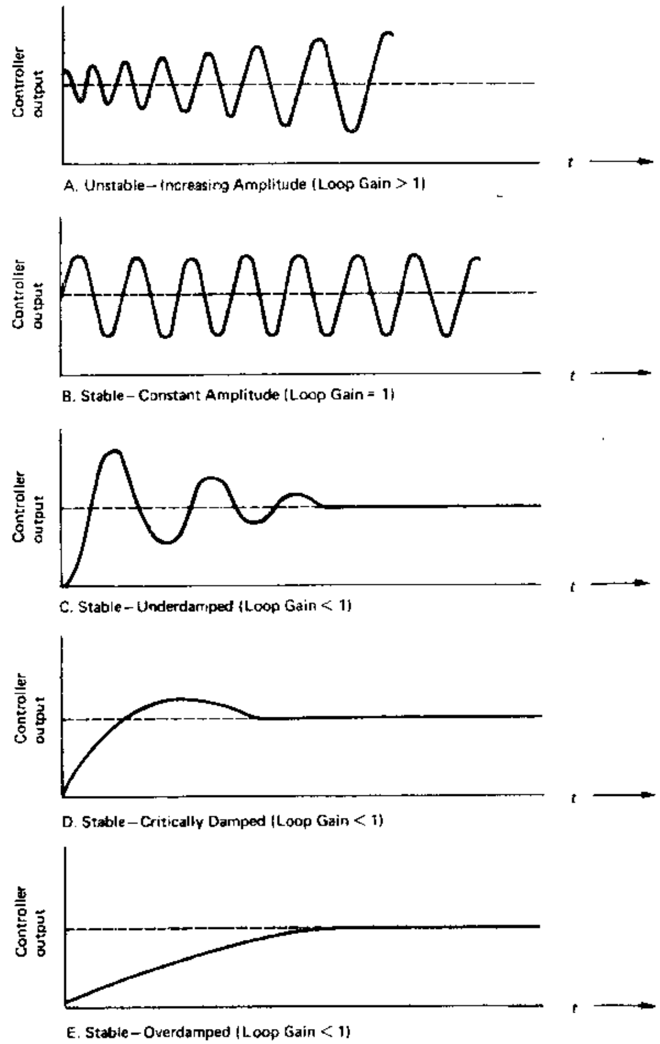
Process Load

- The total amount of control agent needed to keep the process in a balanced condition
- Disturbances to the process cause a change in the process load

Process Lag

- The time it takes the controlled variable to reach a new value after a process load change
  - *Capacitance* is defined as the ability of a system to store a quantity of material or energy
  - *Resistance* is defined as opposition to flow
  - *Transportation Time* (or Dead Time) is the time it takes for a change to move from one place to another in a process.

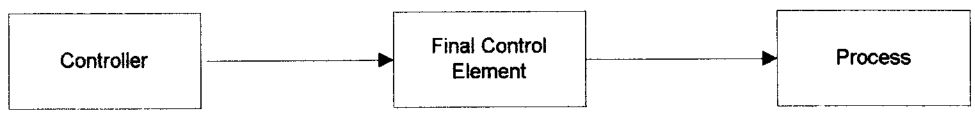
Stability


Controller output
t
A. Unstable – Increasing Amplitude (Loop Gain > 1)
Controller output
t
B. Stable – Constant Amplitude (Loop Gain = 1)
Controller output
t
C. Stable – Underdamped (Loop Gain < 1)
Controller output
t
D. Stable – Critically Damped (Loop Gain < 1)
Controller output
t
E. Stable – Overdamped (Loop Gain < 1)

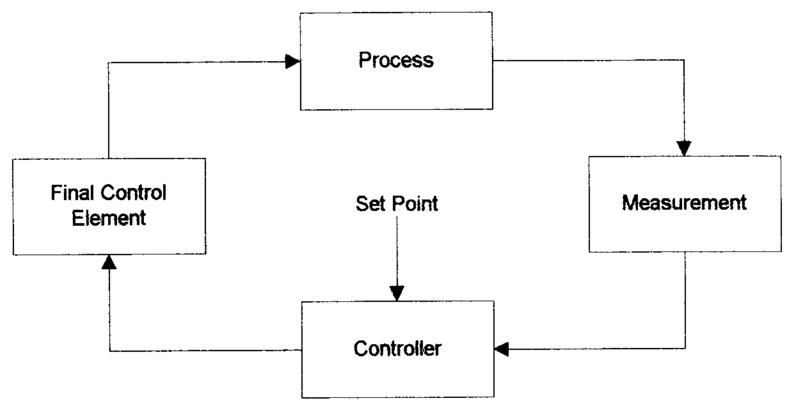
Types of Process Control

- Open-Loop Control
- Closed-Loop Feedback Control
- Closed-Loop Feedforward Control

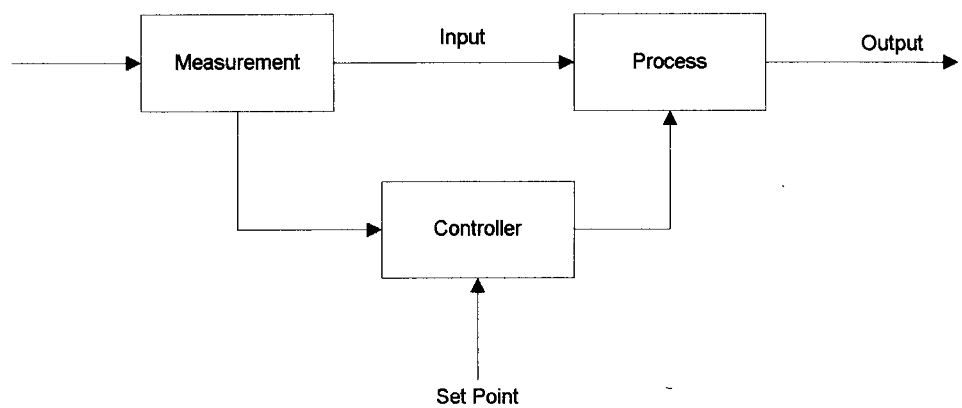
Open-Loop Control



Closed-Loop Feedback Control



Closed-Loop Feedforward Control



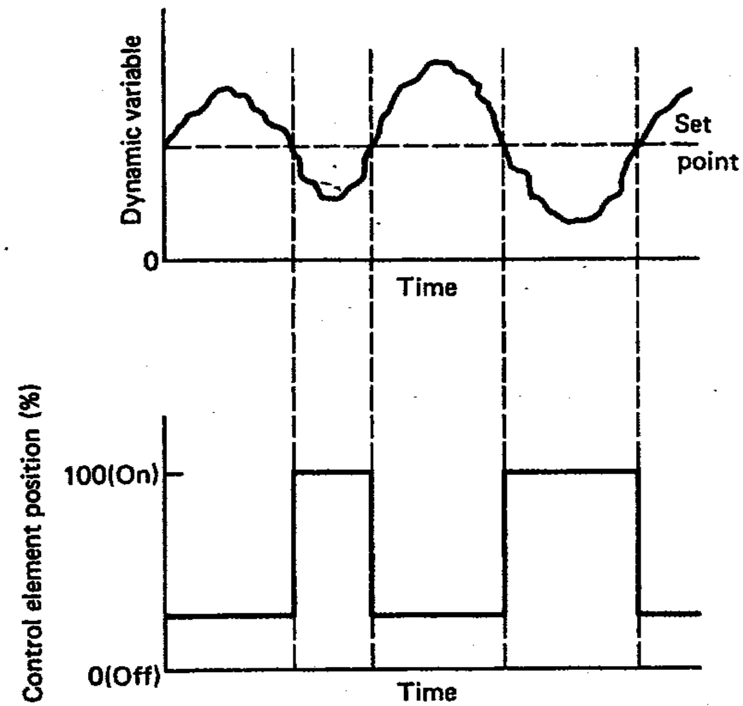
Basic Control Modes

- On-Off Control
- Proportional Control
- Proportional + Integral Control
- Proportional + Derivative Control
- Proportional + Integral + Derivative (PID)

On-Off Control

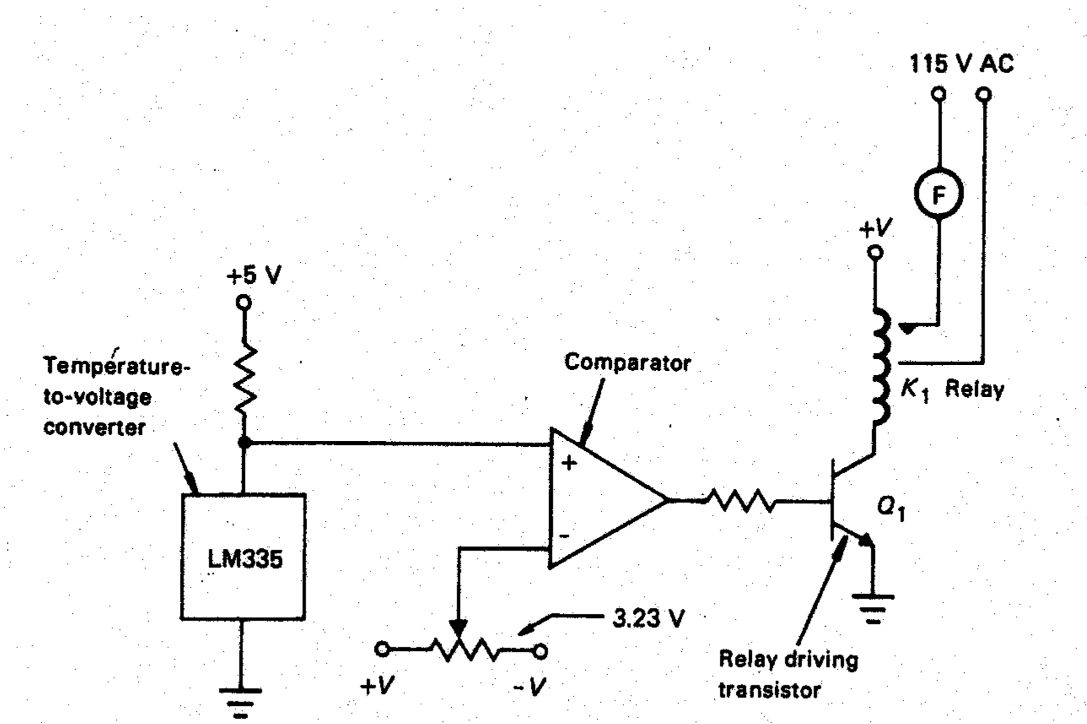
- As the name implies, the final control element is either ON or OFF
- Most popular method of control
- Very common in domestic applications

On-Off Control

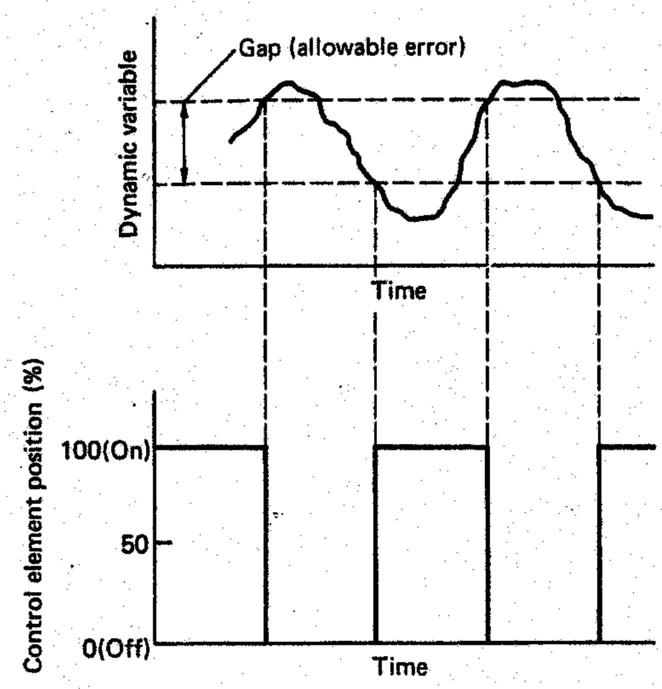


Plot of measured variable and final control element position versus time in on-off controller.

On-Off Control

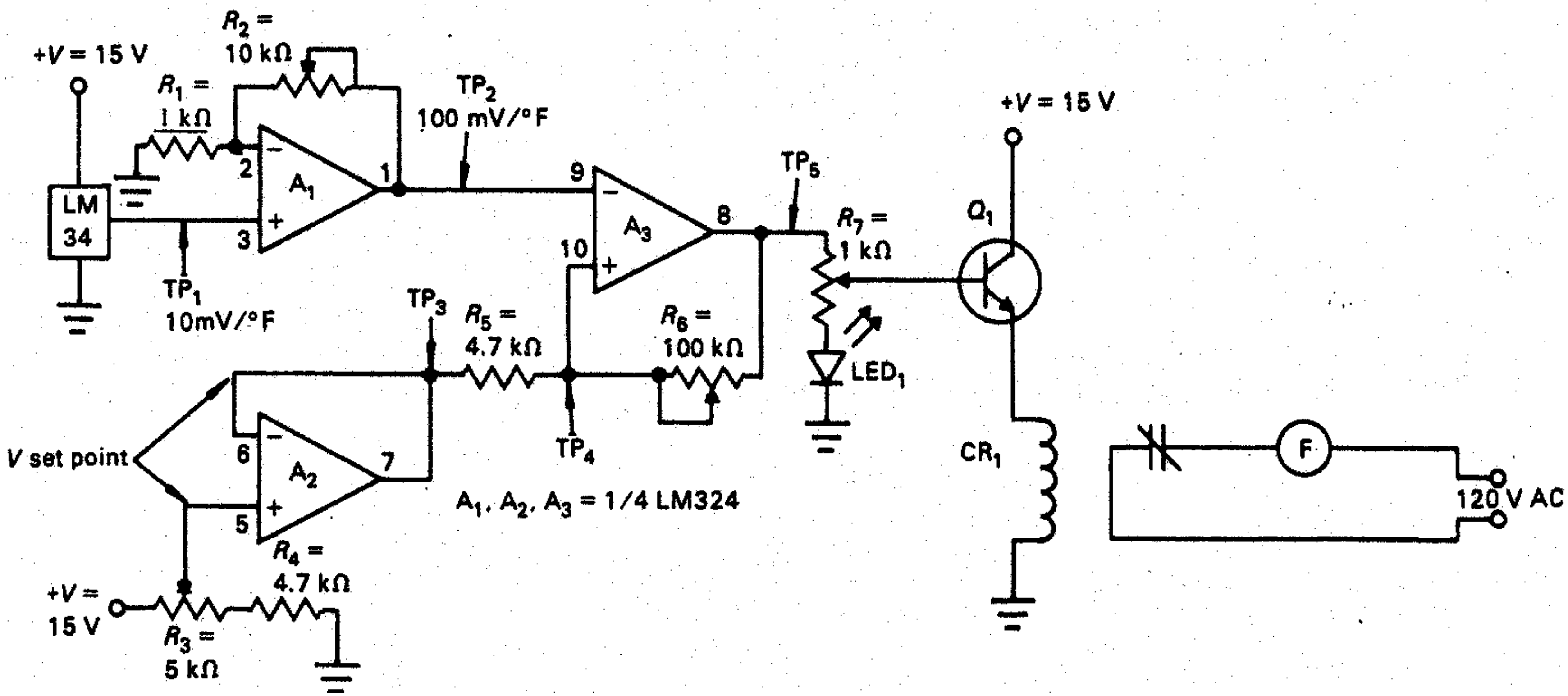


Differential-Gap Control

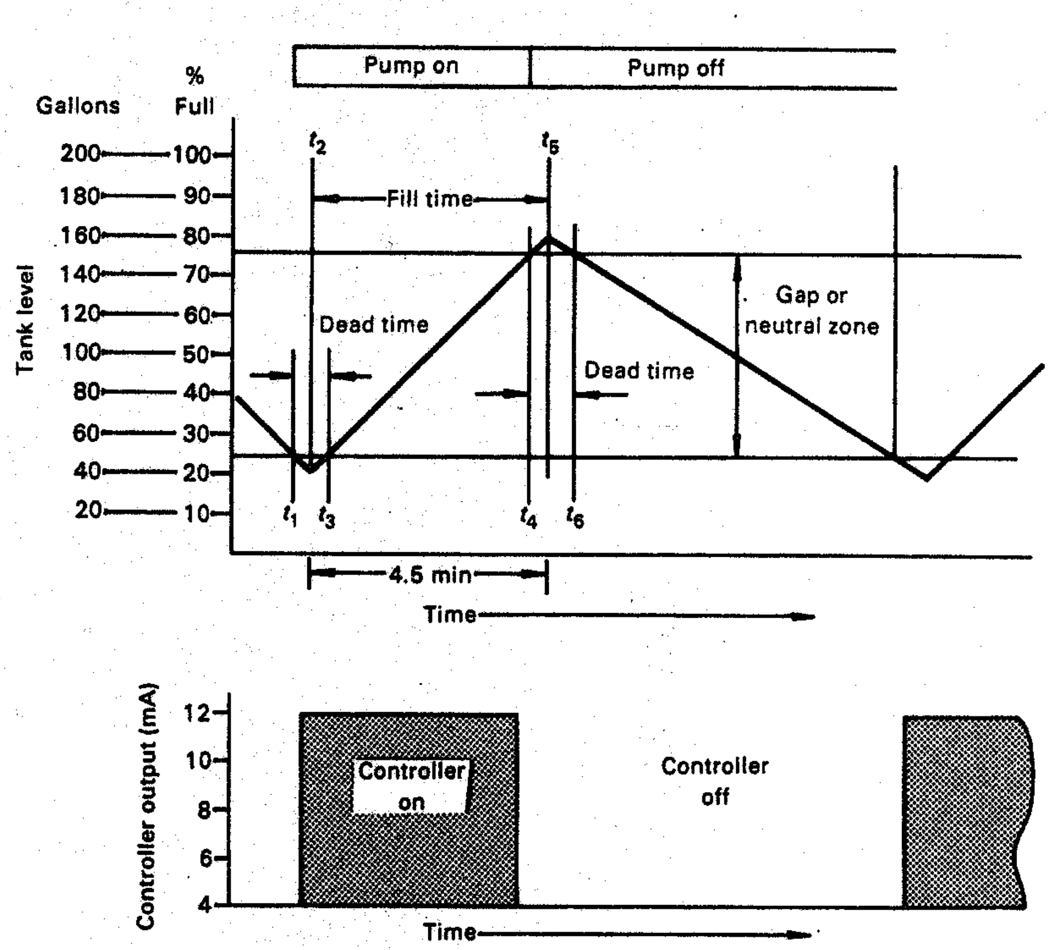


Plot of measured variable and final control element position versus time in a differential-gap controller.

Differential Gap Controller



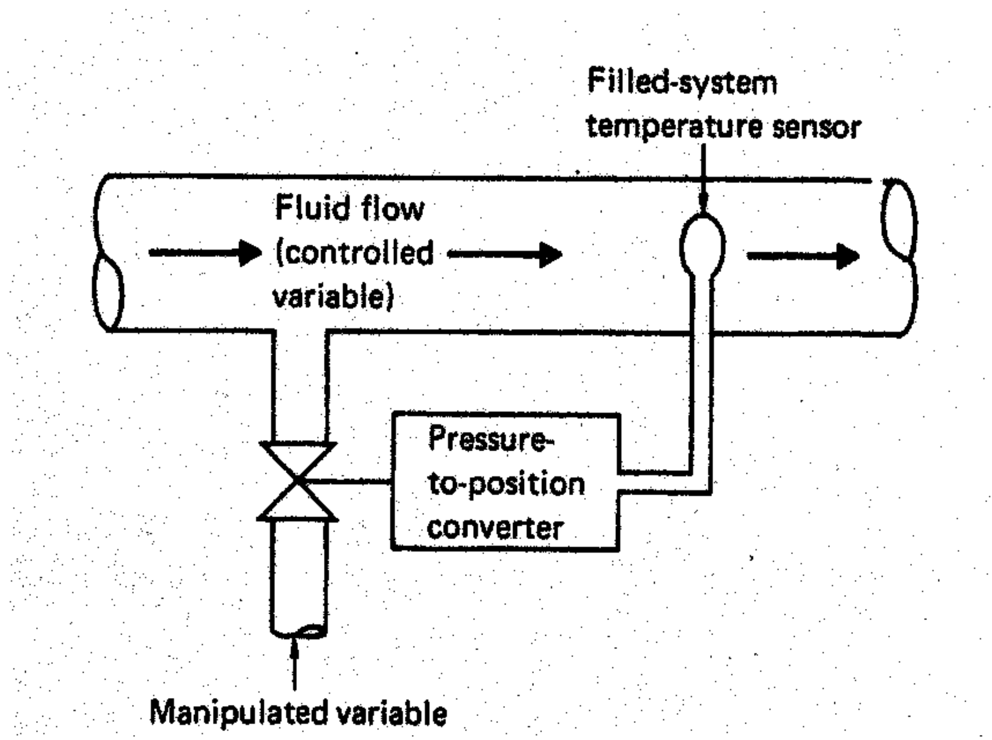
Differential Gap Controller Action: Tank Filling



Proportional Control

- In proportional control, the final control element is purposely kept in some intermediate position
- Term is usually applied to any type of control system where the position of the final control element is determined by the relationship between the measured variable and the setpoint.

Proportional Control



Controller Gain

$$\text{controller gain} = \frac{\Delta \text{output}}{\text{setpoint} - \text{measurement}}$$

Proportional Band

- Proportional Band is the amount of change in the dynamic variable that causes a full range of controller output
- In other words, proportional band is equal to the range of values of the dynamic variable that corresponds to a full or complete change in controller output.

Proportional Band

- Normally expressed as a percentage:

$$\%\ \text{proportional band} = \frac{1}{\text{gain}} \times 100$$

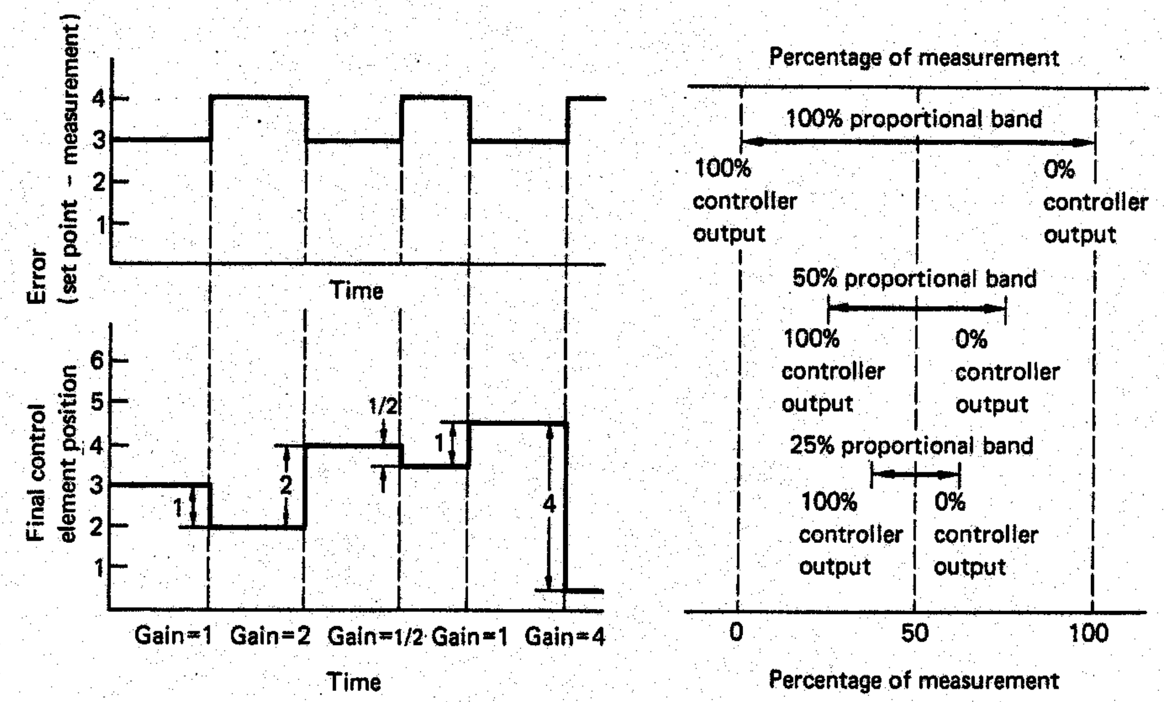
Then we have:

$$\text{gain} = \frac{100}{\%\ \text{proportional band}}$$

Determining Controller Output

$$\text{output} = \frac{100}{\%\ \text{proportional band}} \times (\text{set point - measurement}) + \text{bias}$$

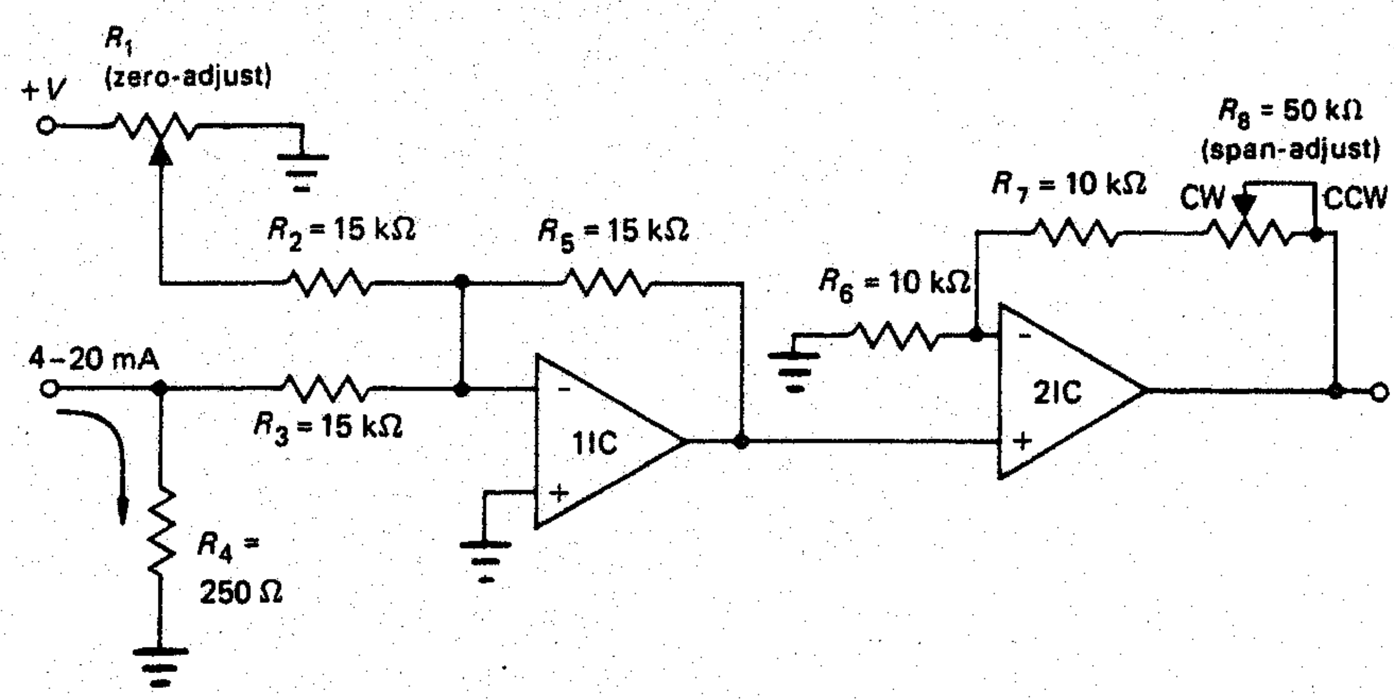
Gain & Proportional Band



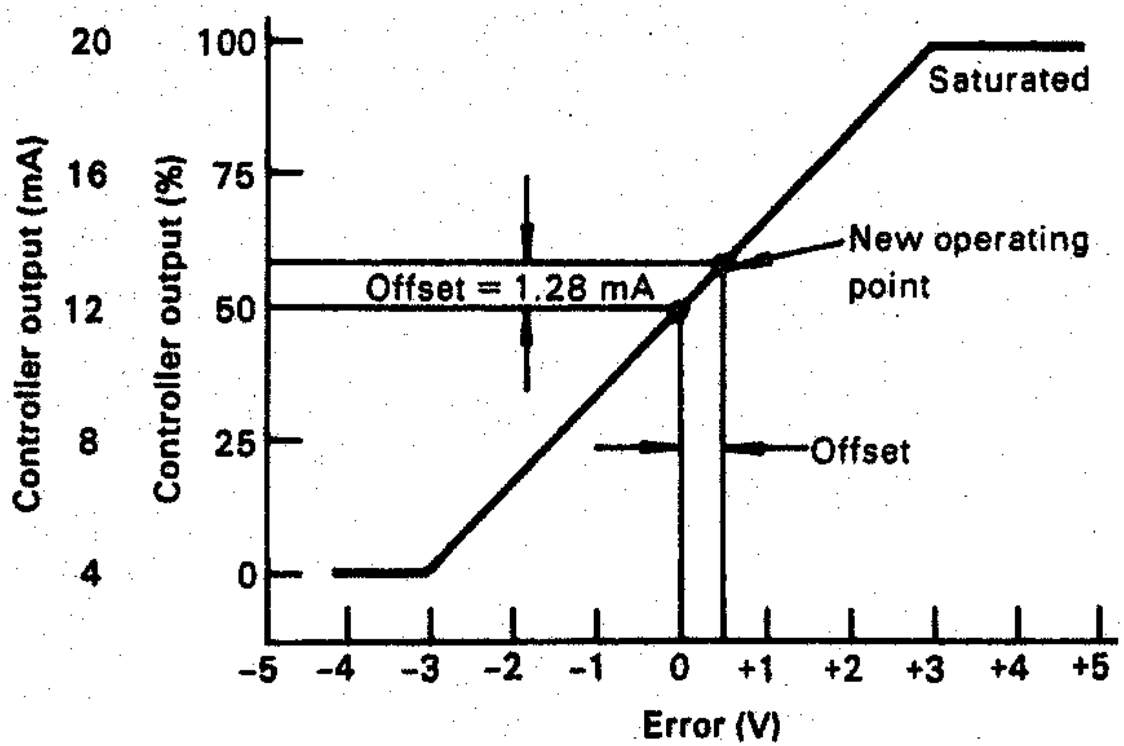
A. Effect of Gain Change on Input-Output Relationships

B. Effect of Proportional Band Change on Controller Output and Measurement

Proportional Controller



Offset in Proportional Control



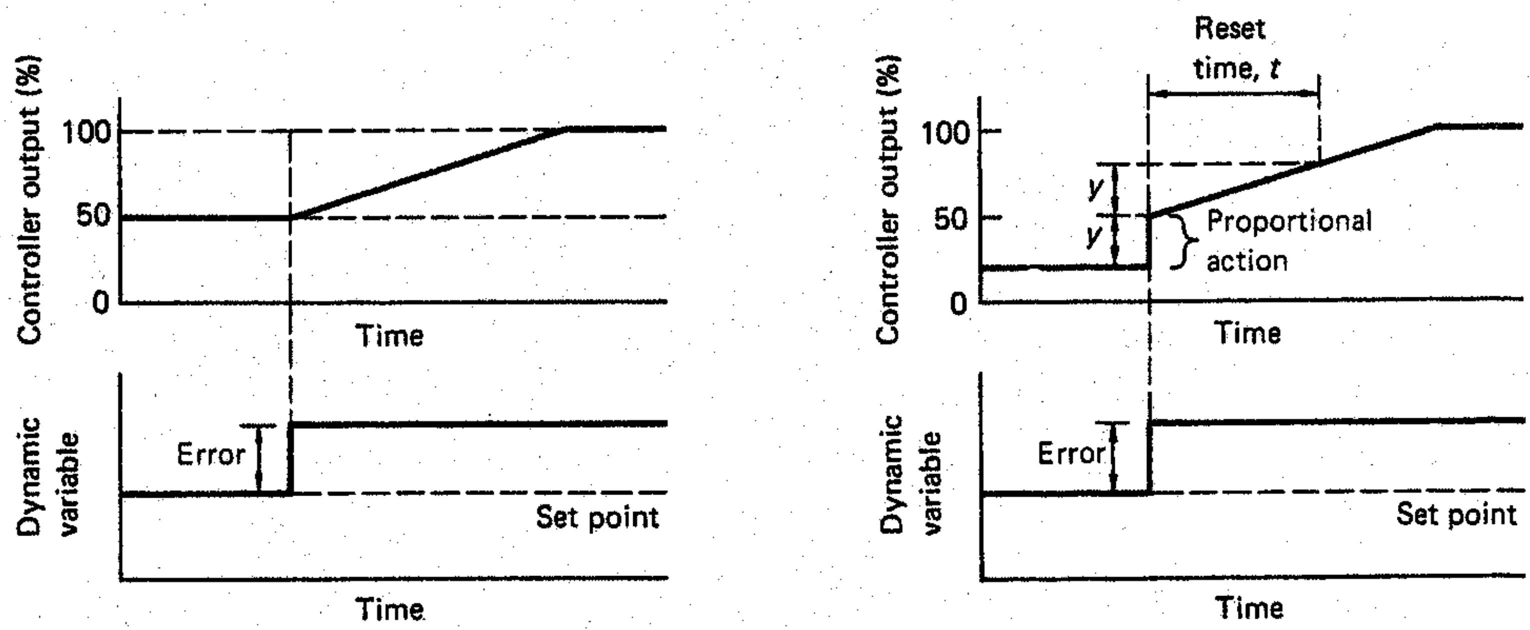
Offset in Proportional Control

$$\Delta \text{offset} = \frac{\%\ \text{proportional band}}{100} \times \Delta \text{measurement}$$

Proportional + Integral Control

- Integral control may be referred to as "Reset"
- Often used in conjunction with proportional control to reset the offset caused by proportional control
- Integrates any difference between the measurement and the set point, changing the controller output until the error is zero.

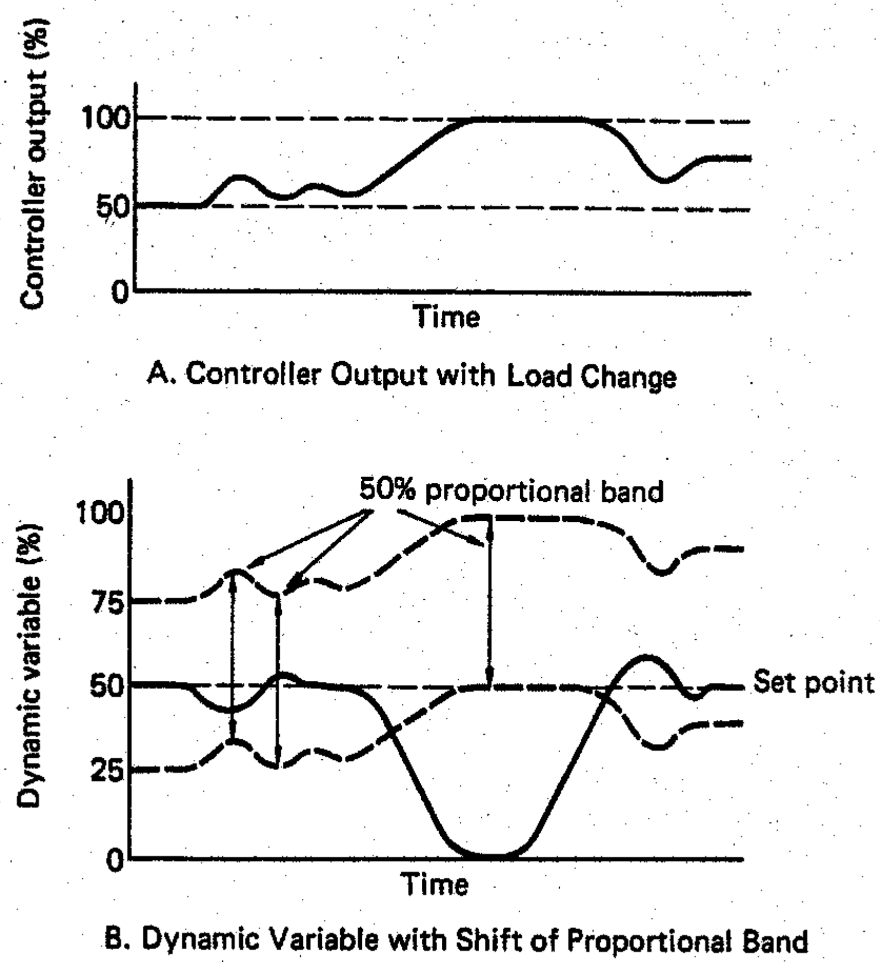
Controller Responses



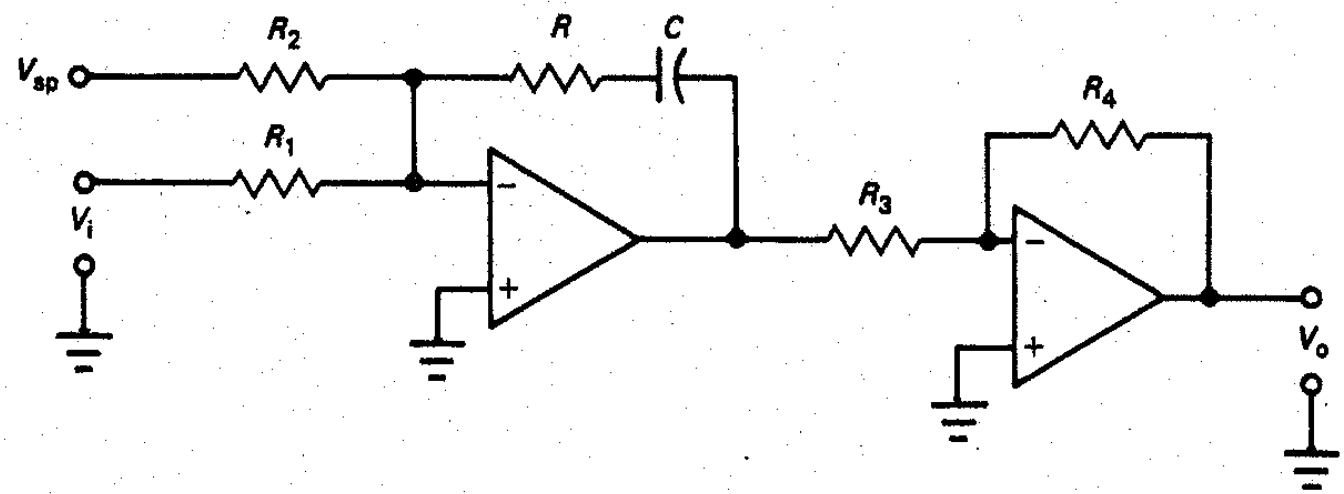
A. Pure Integral Controller (Open Loop)

B. PI Controller (Open Loop)

Proportional Band in PI Control



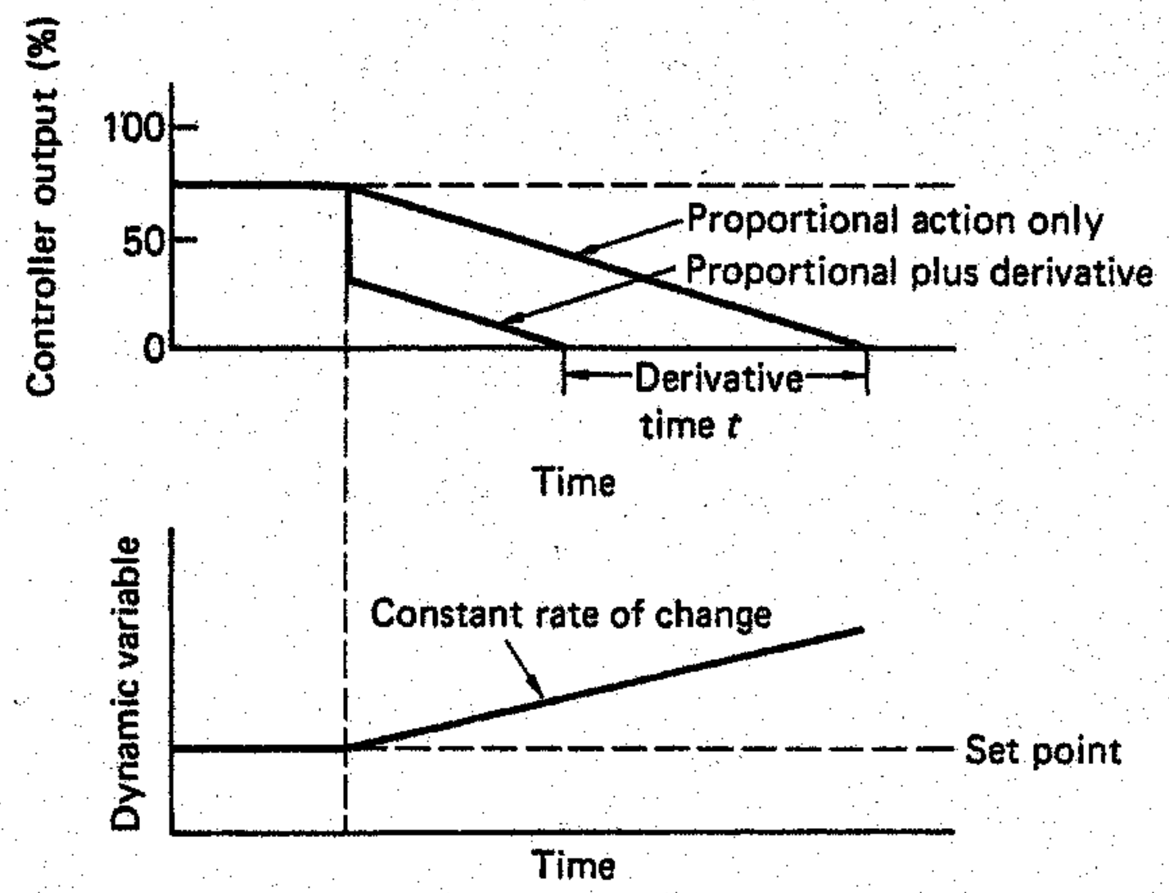
PI Controller



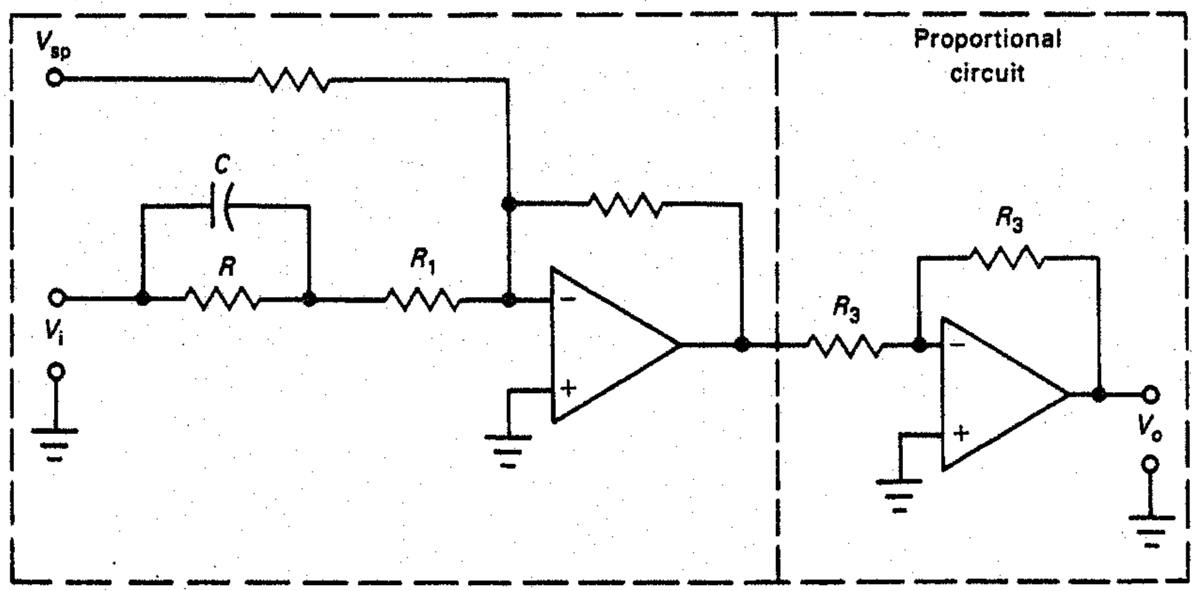
Proportional + Derivative Control

- Used in systems where errors may change very rapidly
- This situation is especially true in processes that have small capacitance
- Often referred to as “Rate”

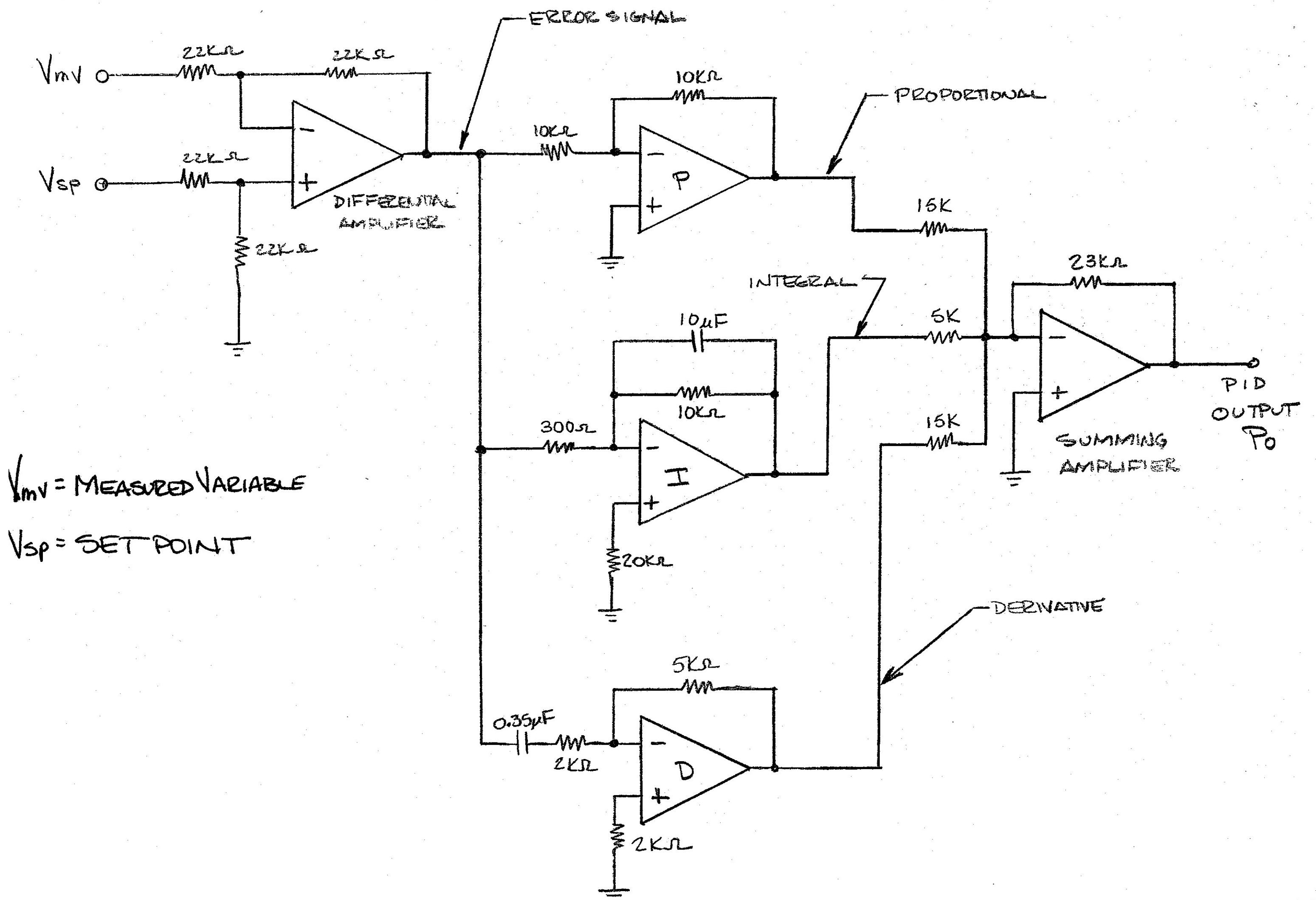
PD Response


Controller output (%)
100
50
0
Proportional action only
Proportional plus derivative
Derivative time t
Time
Dynamic variable
Constant rate of change
Set point
Time

PD Controller



PID Controller



ISA Standard (Dependent Gains)

Derivative of Error:

$$CV = K_c\left[(E) + \frac{1}{T_i}\int_0^t (E)dt + T_d\,\frac{d(E)}{dt}\right] + Bias$$

Derivative of PV:

$$CV = K_c\left[(E) + \frac{1}{T_i}\int_0^t (E)dt + T_d\,\frac{d(PV)}{dt}\right] + Bias \quad (E = SP - PV)$$

$$CV = K_c\left[(E) + \frac{1}{T_i}\int_0^t (E)dt + T_d\,\frac{d(PV)}{dt}\right] + Bias \quad (E = PV - SP)$$

Independent Gains

Derivative of Error:

$$CV = K_p(E) + K_i \int_0^t (E)dt + K_d \frac{d(E)}{dt} + Bias$$

Derivative of PV:

$$CV = K_p(E) + K_i \int_0^t (E)dt + K_d \frac{d(PV)}{dt} + Bias \quad (E = SP - PV)$$

$$CV = K_p(E) + K_i \int_0^t (E)dt + K_d \frac{d(PV)}{dt} + Bias \quad (E = PV - SP)$$