Lecture Notes

Fundamentals of Control Systems

Course coordinator: Assoc. Prof. Dr. Huynh Thai Hoang
Department of Automatic Control (DAC)
Faculty of Electrical & Electronics Engineering
Ho Chi Minh City University of Technology
Email: hthoang@hcmut.edu.vn

Instructor: Lecturers of Dept. of Automatic Control

Course objectives

- The course provides students with fundamental knowledge about classical control theory for analysis and design of feedback control systems.
- Students will study methods in time domain and frequency domain to analyze the stability and performance of control systems; and to design feedback control system satisfying desired performances.

Course outline

- Chapter 1: Introduction
- Chapter 2: Mathematical model of continuous systems
- Chapter 3: Analysis of system stability
- Chapter 4: Performances of control systems
- Chapter 5: Design of continuous control systems
- Chapter 6: Discrete control systems

Textbook

- Textbook: Lý thuyết điều khiển tự động, Nguyễn Thị Phương Hà và Huỳnh Thái Hoàng, NXB ĐHQG TPHCM

- Reference:
  - Katsuhiko Otaga, Modern Control Engineering, 3rd ed., Prentice Hall
  - Franklin, Powell, and Emami-Naeini, Feedback Control of Dynamic Systems, 6th ed., Prentice Hall, 2009
  - Farid Golnaraghi and Benjamin C. Kuo, Automatic Control Systems, 9th ed., 2009, Prentice Hall.
  - Richard C. Dorf and Robert H. Bishop, Modern Control Systems, 11th ed, Peason.

Course learning outcomes

- LO1: Establish mathematical model of linear control systems (10%)
- LO2: Analyze the stability of linear control systems (25%)
- LO3: Analyze the performance of linear control systems (15%)
- LO4: Design linear control systems to meet desired requirements (30%)
- LO5: Use computer software in analysis and design of control systems (10%)
- LO6: Conduct experiment to determine effects of changing input parameters on output of control systems (10%)

Teaching Plan and Grading policy

- Teaching plan:
  - Theory: 45 lecture hour (week 1 to week 15)
  - Lab: 15 lecture hour (week 6 to week 15)

- Grading policy:
  - Quizes: 10%
  - Group project or exercises 20%
  - Lab: 20%
  - Final exam: 50%

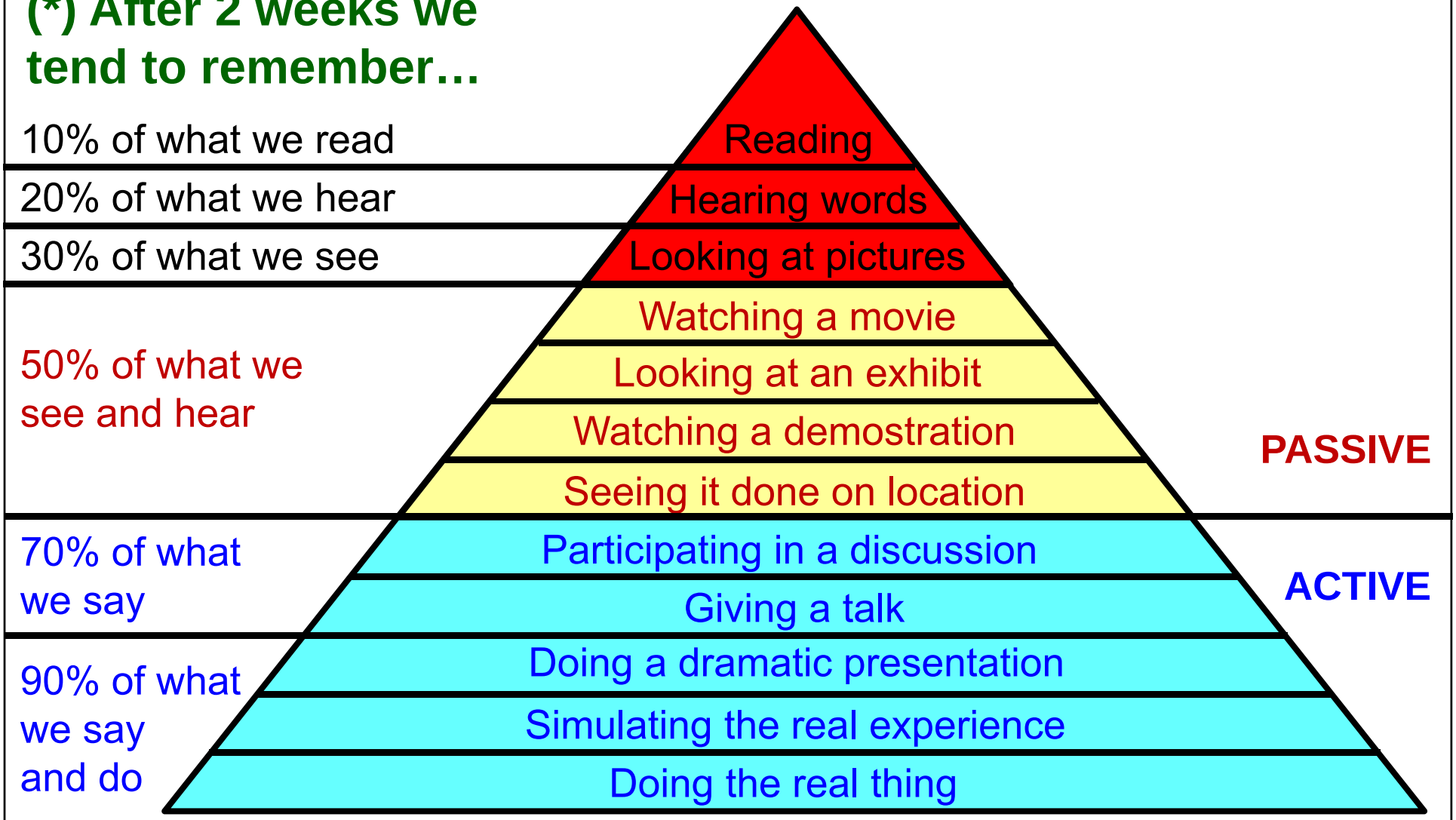
- Student are allowed to use hand-written references in the final exam.

Learning Outcome Assessment Plant

Assessment Method	Learning Outcomes						Total
	LO1	LO2	LO3	LO4	LO5	LO6	
Quizes	5%		5%				10%
Group project		10%		10%			20%
Final exam	5%	15%	10%	20%			50%
Lab					10%	10%	20%
Total	10%	25%	15%	30%	10%	10%	100%

How to learn the course? ACTIVE LEARNING

(*) After 2 weeks we tend to remember…



(*) Edgar Dale, "Audio-Visual Methods in Teching," Holt, Rinehart and Winston

Chapter 1

INTRODUCTION

Topics

- What is control system?
- Control principles
- Components of control systems
- Examples of control systems
- Review of complex variables and Laplace transform

What is control system?

Exercise

Find examples of control systems?

Exercise

Explain how a control system works?

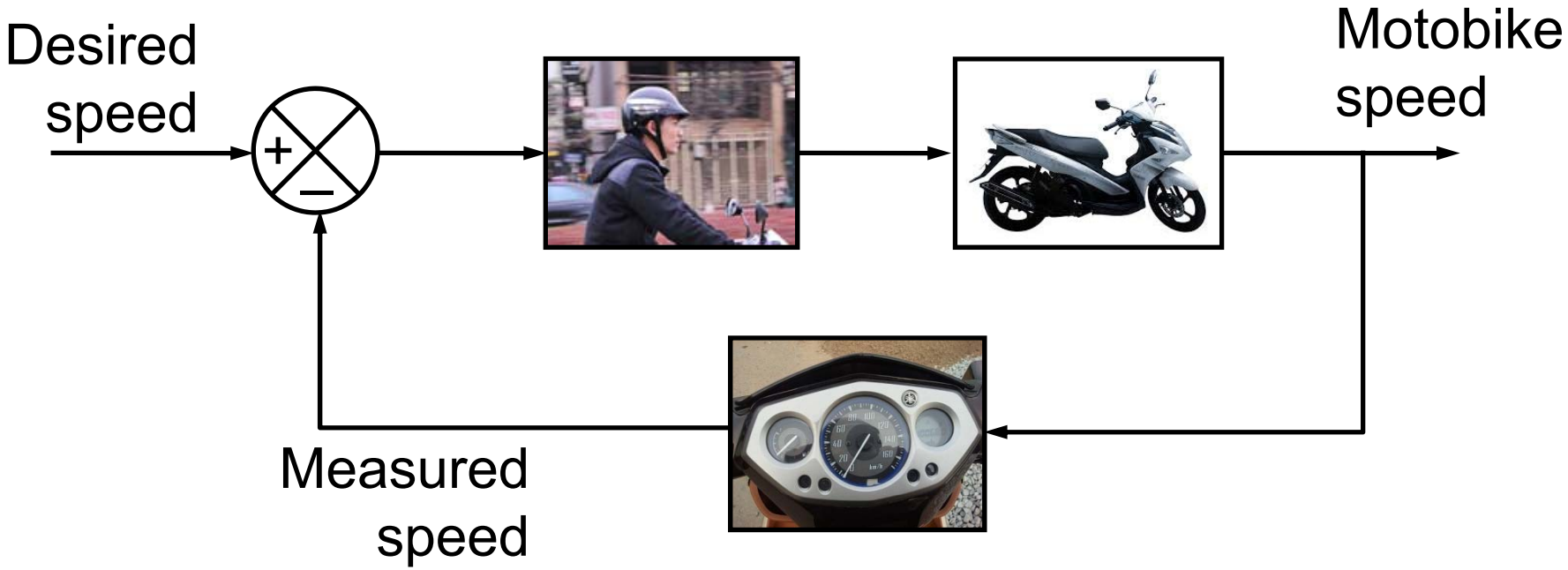
Example of a control process

- Activities in controlling a motobike with the objective to keep the motobike moving at constant speed
  1. reading velocimeter
  2. deciding to increase or decrease speed
  3. acting on the gas handle

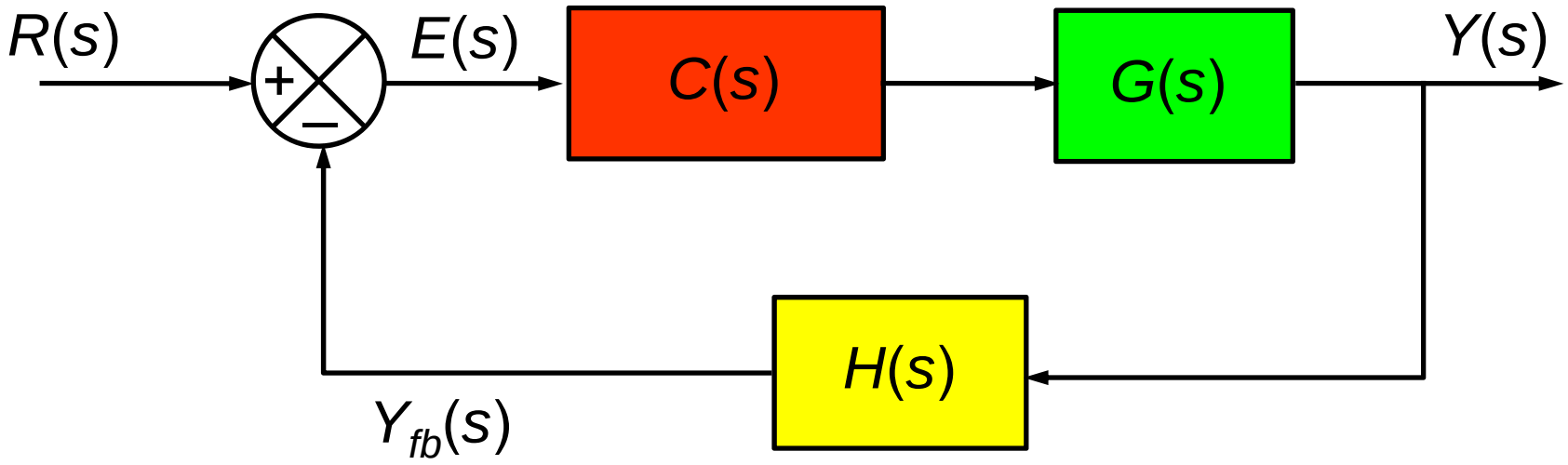
Definition of control concept

Control is the process of getting information, processing information and making decision, and acting on a system so that the system reponses as desired.

Control loop



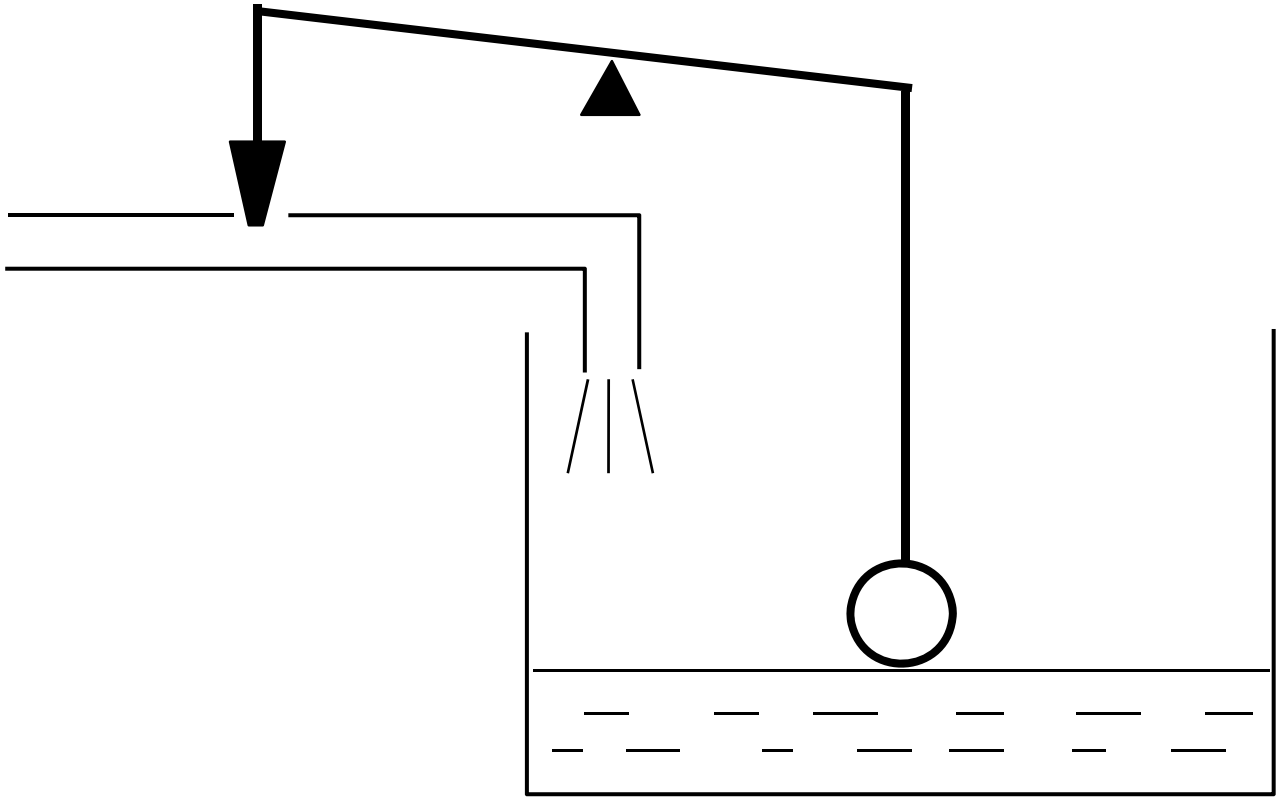
Components of a control system



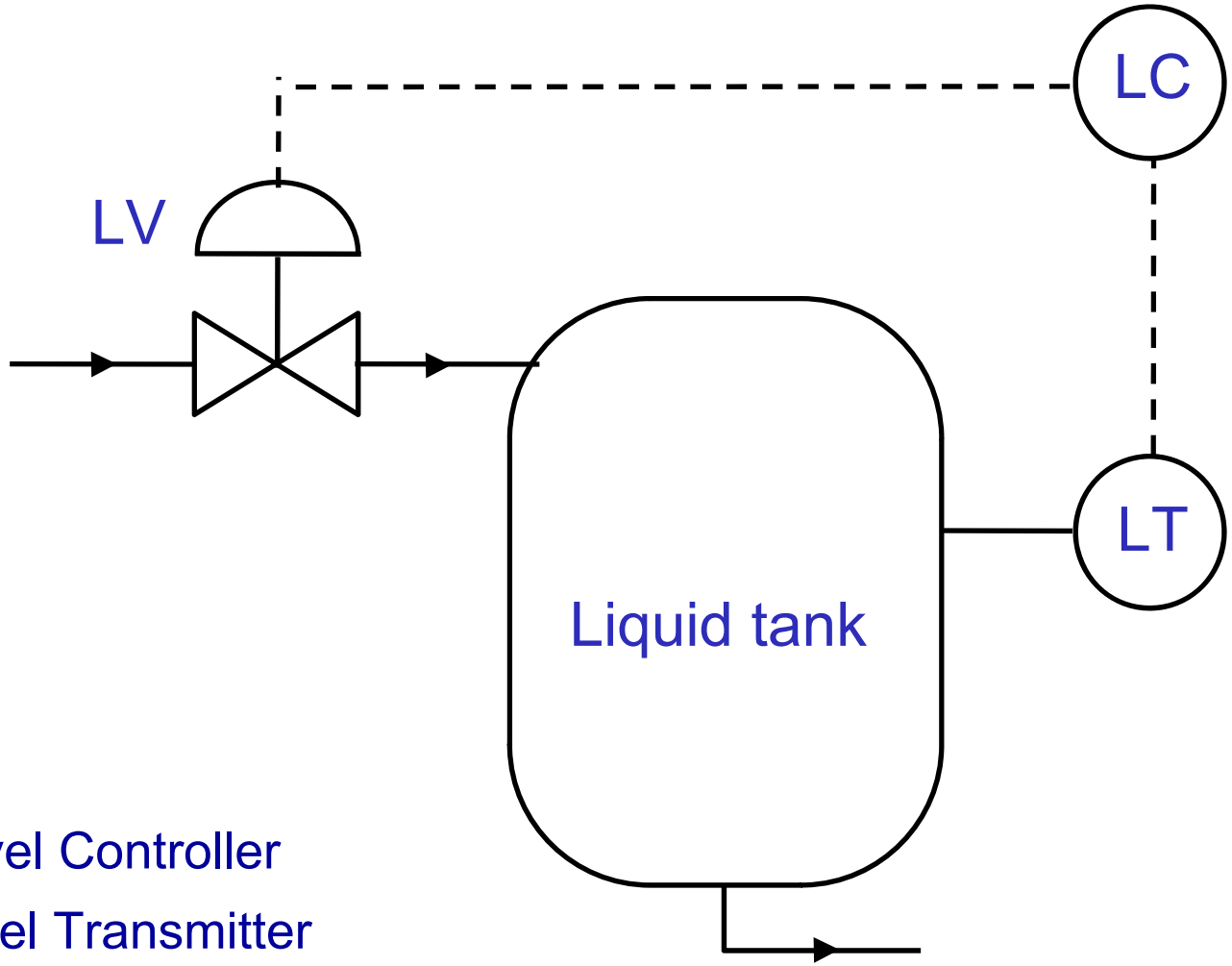
Notation:

- $C(s)$: controller
- $G(s)$: plant
- $H(s)$: sensor
- $R(s)$: setpoint
- $Y(s)$: controlled output
- $Y_{fb}(s)$: feedback signal
- $E(s)$: control error

A simple level control system



Level control system in industry



LC: Level Controller

LT: Level Transmitter

LV: Level valve

Speed control of steam engine

Why control?

- Increase productivity
- Increase quality
- Increase economic benefit

Plants

- Very diverse
- Class of systems:
  - Electrical
  - Mechanical
  - Thermal
  - Fluid
  - Chemistry
- Real systems consist of different kind of basic systems.

Sensors

- Temperature sensor
- Position sensor
- Velocity sensor
- Accelocity sensor
- Distant sensor
- Flow sensor
- Level sensor
- Pressure sensor
- Force sensor
- Color sensor
- ...

Controllers

- Mechanical controller
- Electrical controller
  - Analog controller
  - Digital controller
    - Microcontroller, DSP based control
    - Computer based control
    - Programmable Logic Controller (PLC)

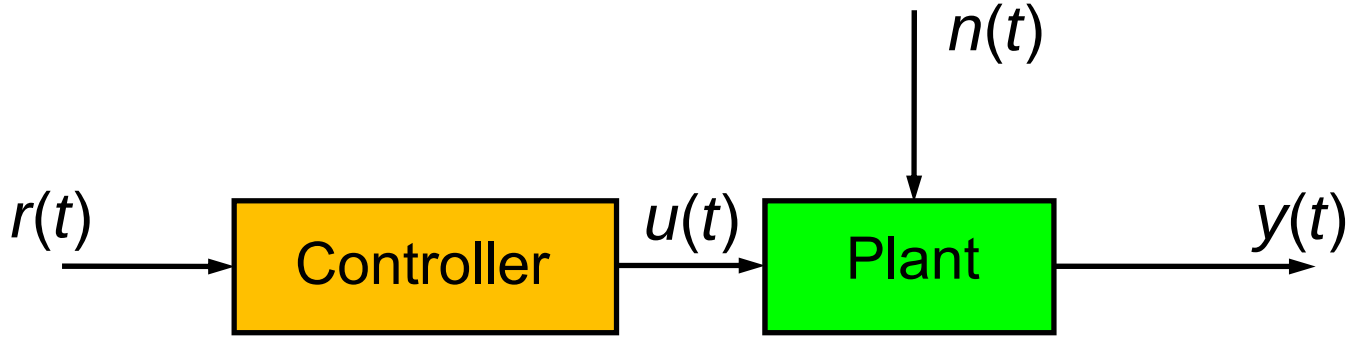
Basic problems in control

- System Analysis
- System Design
- System Identification

The course focuses only on system analysis and design

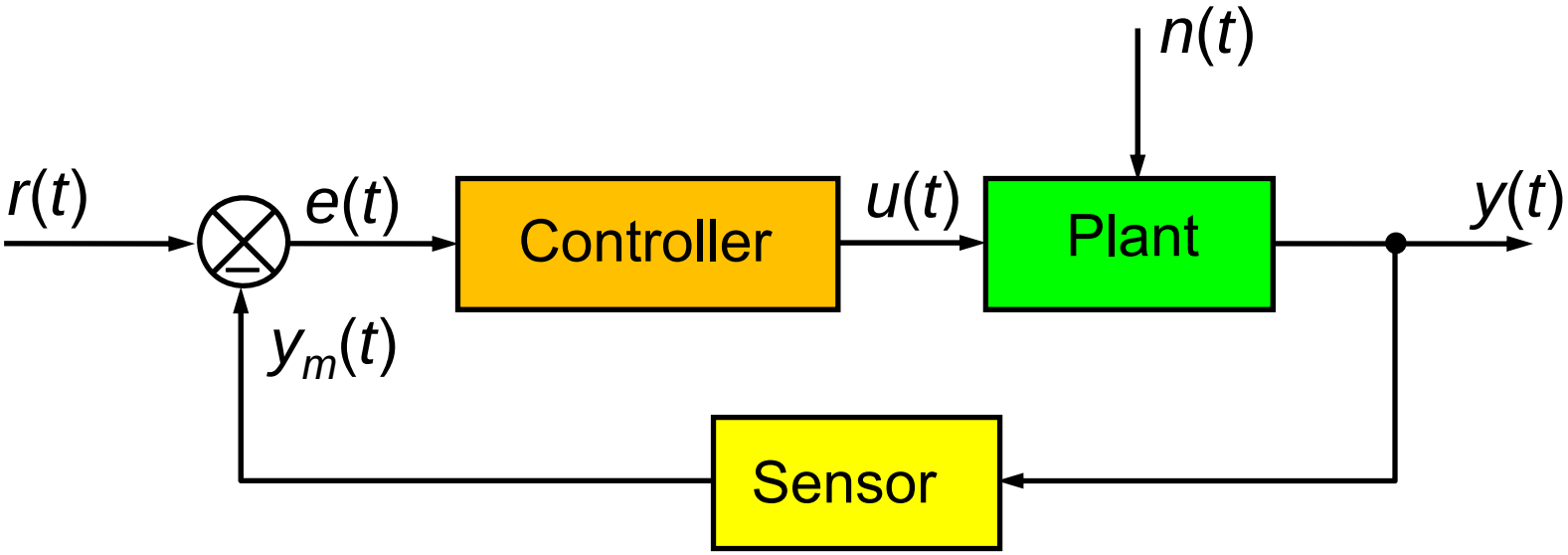
Control schemes

Open-loop control



- ★ Feedforward control
- ★ Control without feedback information

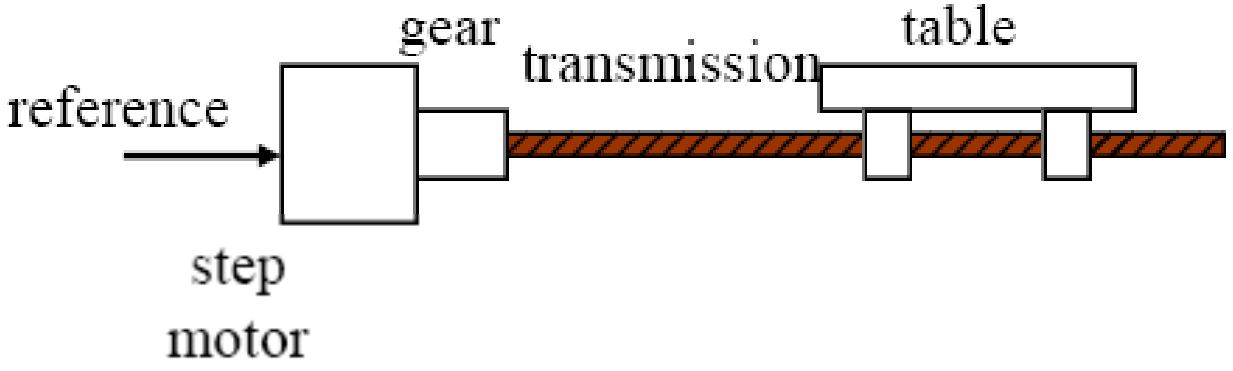
Closed-loop control

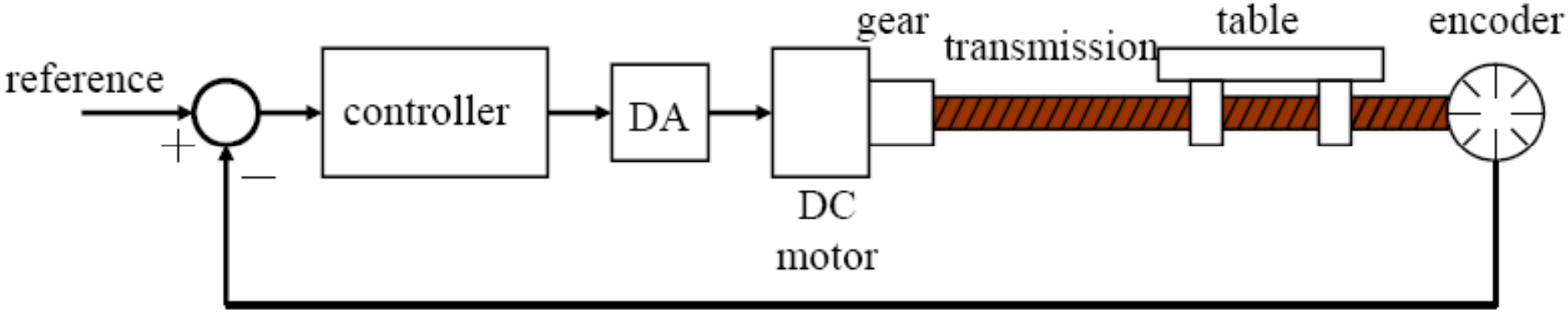


- ★ Feedback control
- ★ Need to measure system output

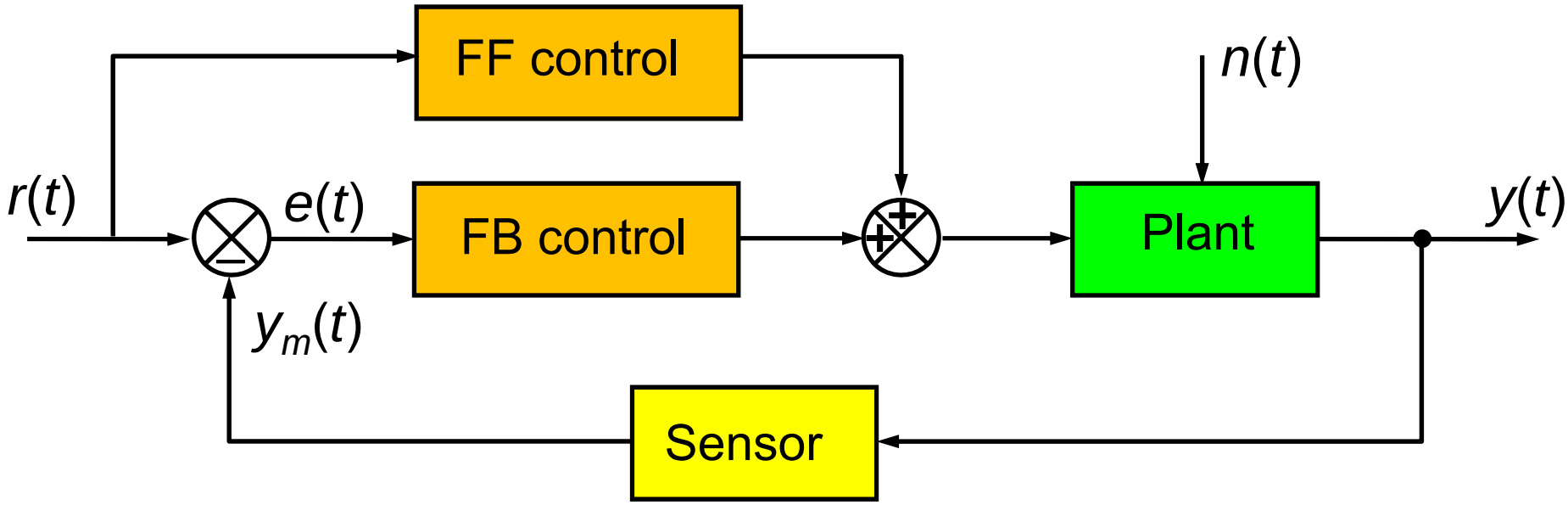
Exercise

- Open-loop or closed-loop control system?
  - Plant?
  - Sensor?
  - Controller?



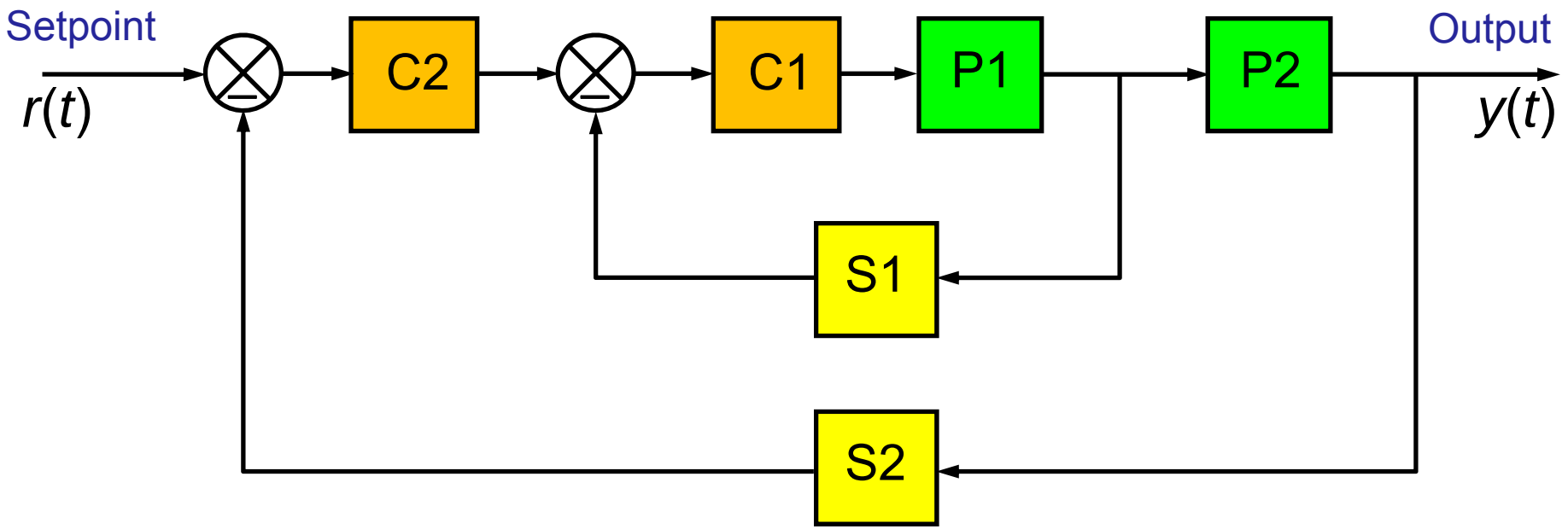


Feedback and feedforward control



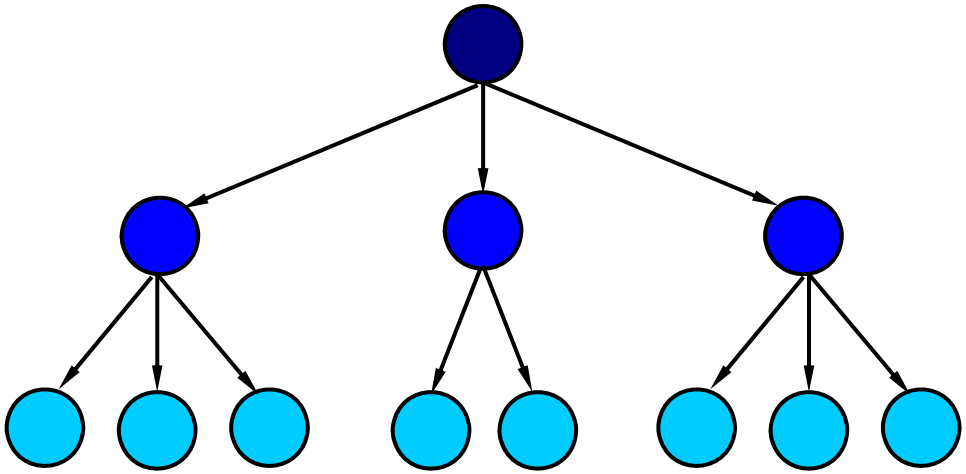
- This combined control scheme is widely used in industry

Multi-loop control system



- This control scheme is also refered as Cascade Control
- Multi-loop control is widely used in industry

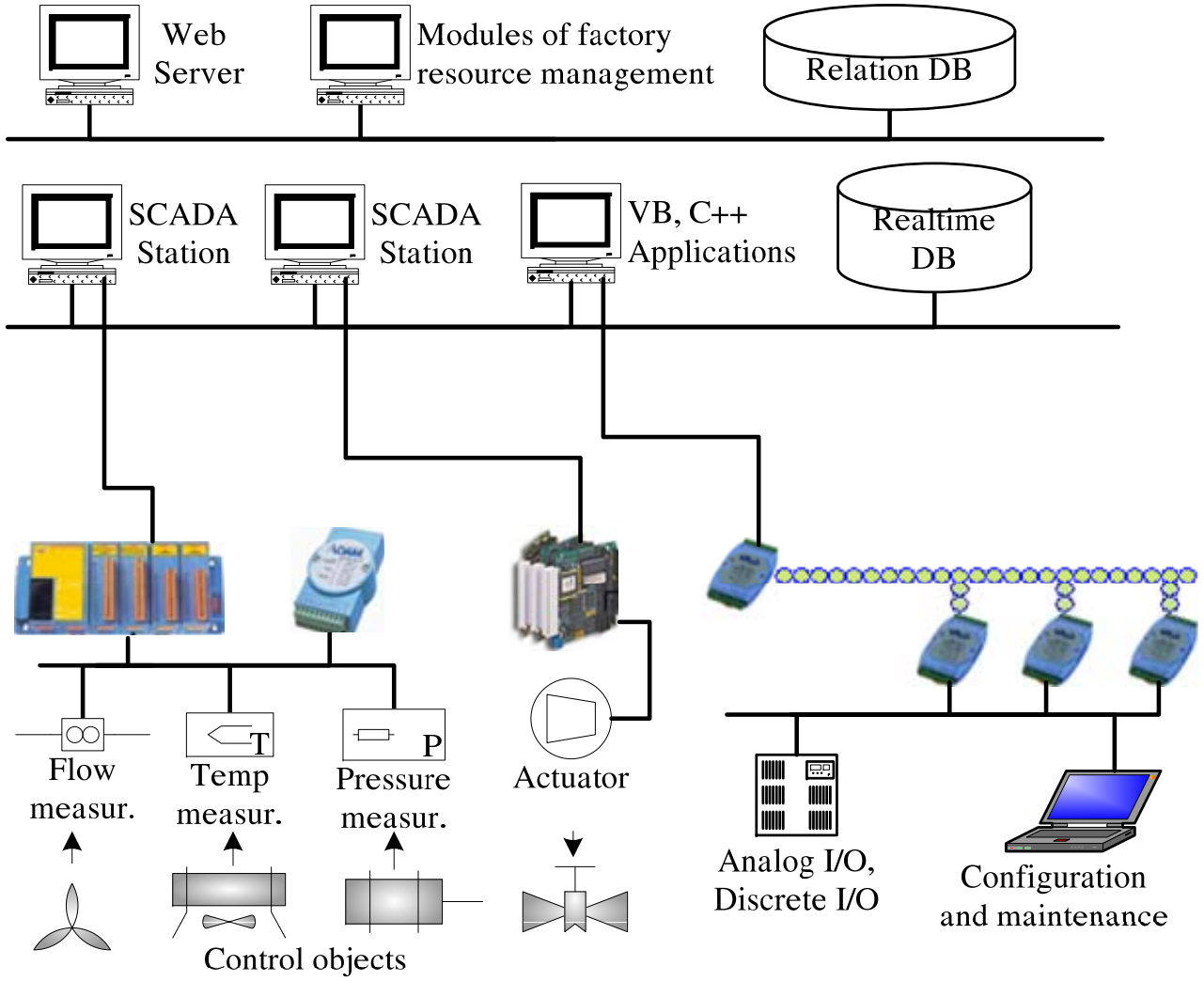
Hierachy control



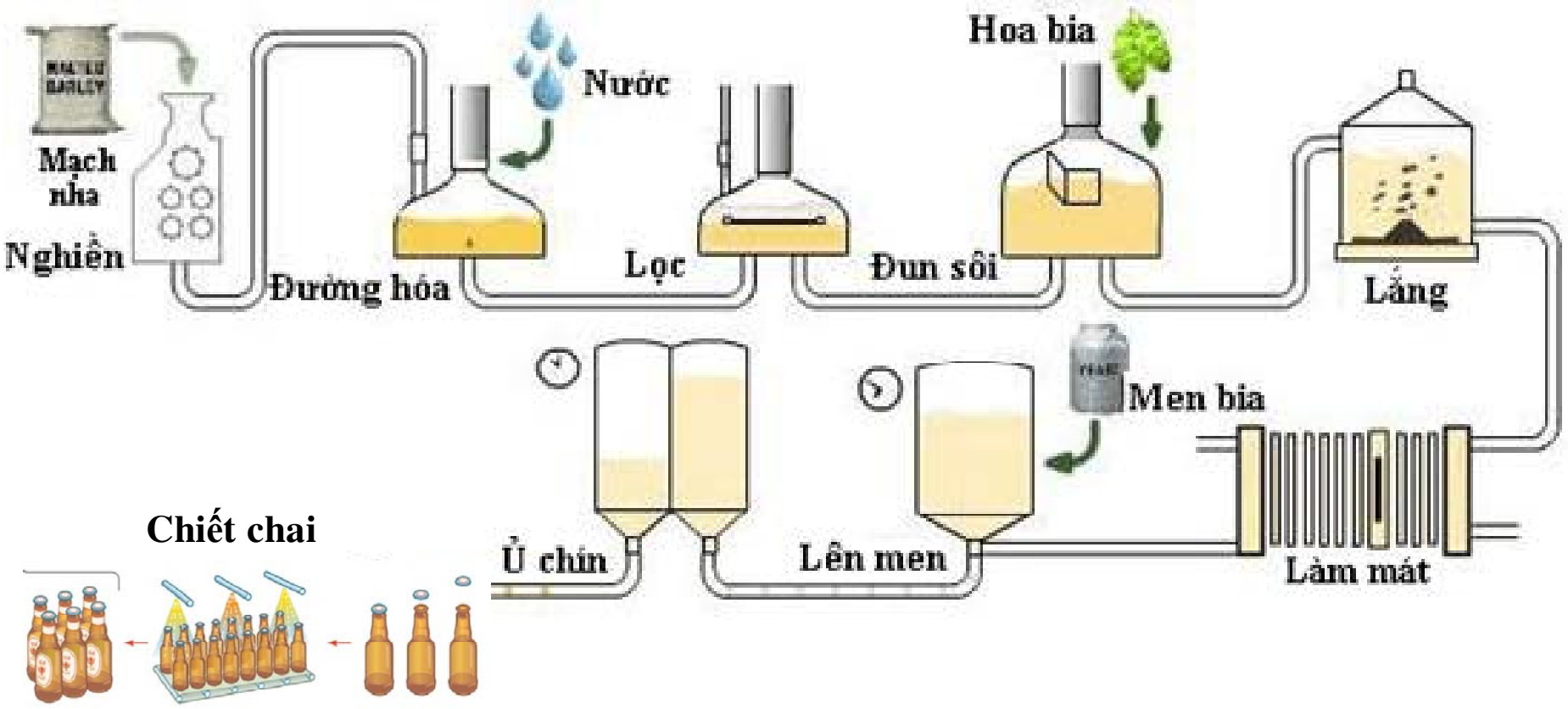
- Decentralized control
- Distributed control

Hierachy control

Example: SCADA (Supervisory Control And Data Acquisition)



Beer making process



Control system clasification

Control system classification

- Continuous system: All signals in the system are continous.

  Discrete system: There exists discrete signals in the system
- Linear system: The system satisfies the superposition principle.

  Nonlinear system: The system don’t satisfies the superposition principle.
- Time Invariant System: Parameters of the system don’t change over time.

  Time Varying System: Parameters of the system change over time.
- SISO system: Single Input Single Output system

  MIMO system: Multi-Input Multi-Output system

History of control theory

- Classical control
- Modern control
- Intelligent control

Classical control

- Mathematic models used in analysis and design control systems are transfer functions.
- Features:
  - Simple, easy to understand
  - Advantages: easy to apply to analysis and design SISO linear time – invariant system.
  - Frequency domain techniques.
- Analysis and design techniques:
  - Root locus.
  - Frequency response: Nyquist, Bode.
- Controllers:
  - Lead – lag controllers
  - PID (Proportional – Integral – Derivative)

Modern control

- Mathematical model used in analysis and design is mainly the state-space equation.
- Features:
  - Can be applied to nonlinear systems, time varying systems, multiple input- multiple output system.
  - Time domain technique
- Analysis and design method:
  - Optimal control.
  - Adaptive control.
  - Robust Control
- Controller:
  - State feedback controller

Intelligent control

- In principle, mathematic models are not required in design intelligent control system.
- Features:
  - Simulate / emulate biological intelligence system.
  - The controller is capable of processing uncertain information, learning, and handling large amounts of data
- Intelligent control techniques:
  - Fuzzy Control
  - Neural Networks
  - Genetic Algorithm
  - …

Course objective

- The course Fundamental of Control Systems mainly presents the classic method for analysis and design of SISO linear time invariant systems.
- The knowledge gained from the course help student to analyze and design control systems at the executive level.

Related courses

- To be able to design the control system at the implementation level, in addition to knowledge of automatic control theory, a designer needs to master the relevant knowledge, such as:
  - Circuits, Electronic circuits
  - Industrial Measurement
  - Digital system, Microprocessor
  - Computer based control system, ...

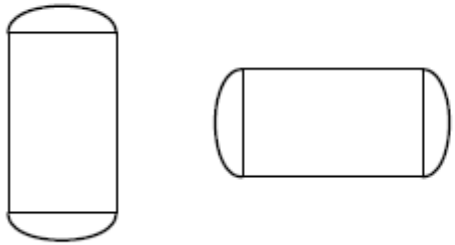
Graphic Symbols for Process Displays

Standard ISA 5.5

- The purpose of this standard is to establish a system of graphic symbols for process displays that are used by plant operators, engineers, etc., for process monitoring and control.
- The standard is intended to facilitate rapid comprehension by the users of the information that is conveyed through displays, and to establish uniformity of practice throughout the process industries.
- Resulting benefits are intended to be as follows:
  - A decrease in operator errors
  - A shortening of operator training
  - Better communication of the intent of the control system designer to the system users

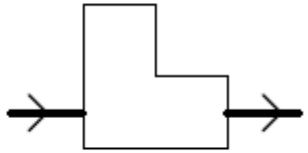
Symbol of process equipments

Pressure vessels

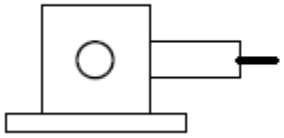


Centrifugal pump

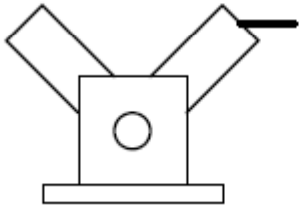
Positive-displacement pump



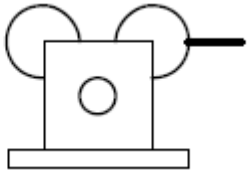
Single-stage reciprocating compressor



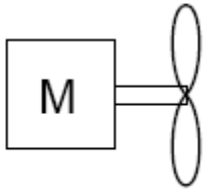
Dual-stage reciprocating compressor



Rotary screw compressor

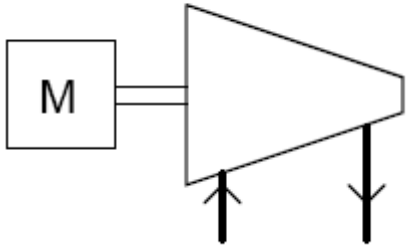


Motor-driven fan

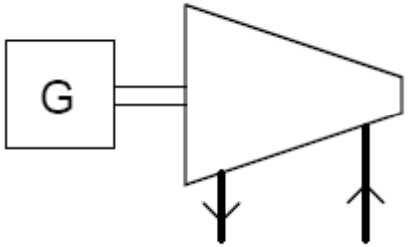


Symbol of process equipments

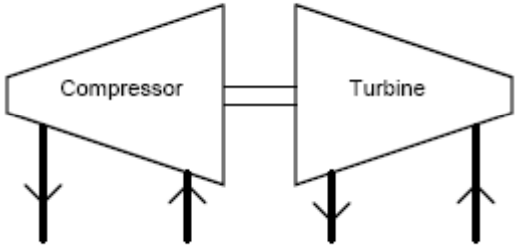
Motor-driven axial compressor



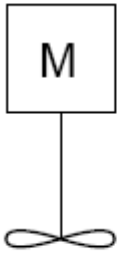
Turbogenerator



Turbocompressor



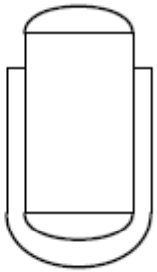
Mixer



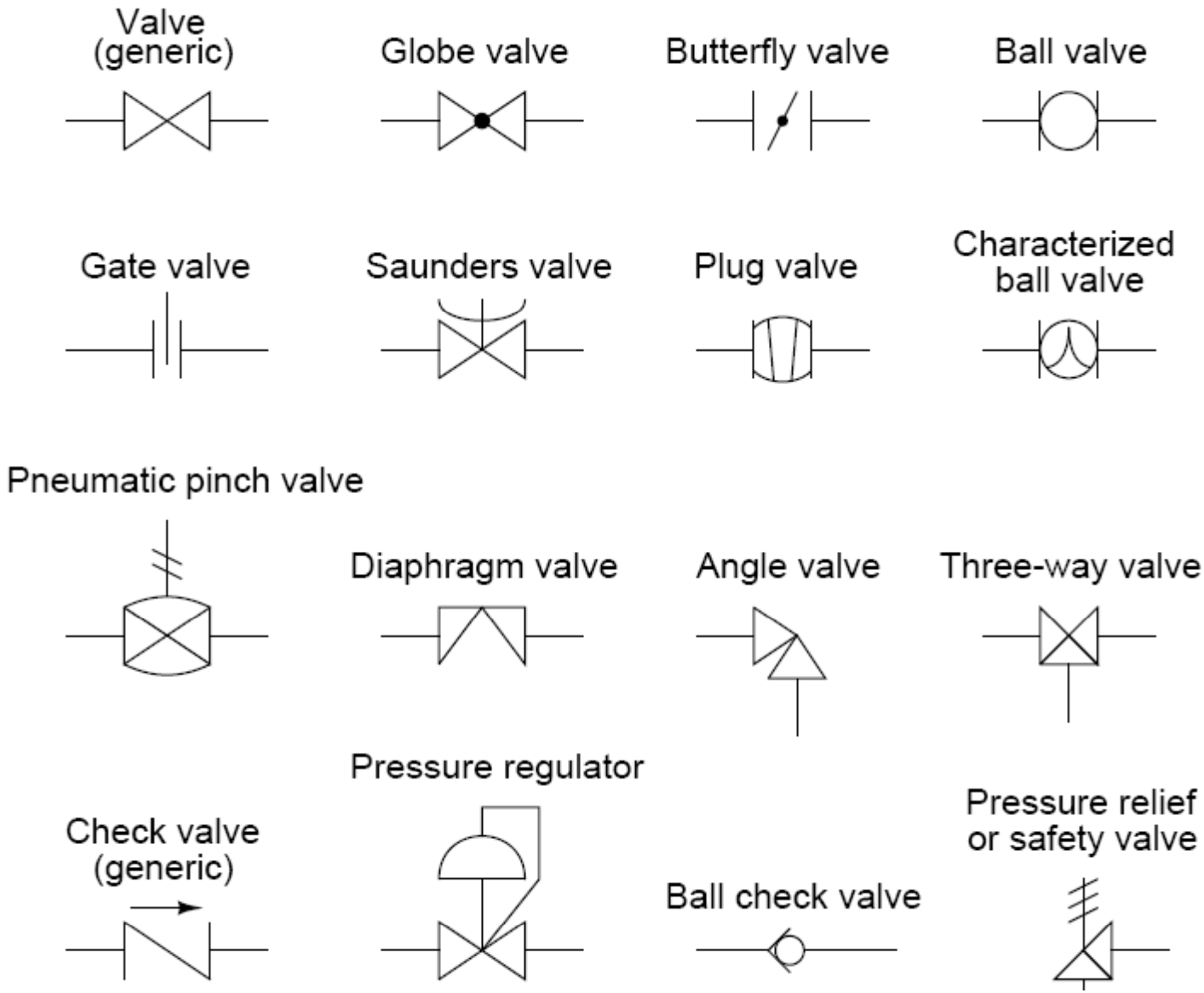
Conveyor belt

Shell-and-tube heat exchanger

Jacketed vessel

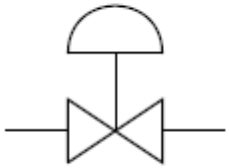


Symbol of valves

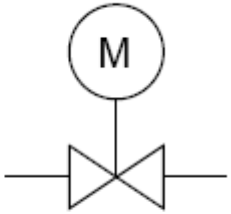


Symbol of control valves

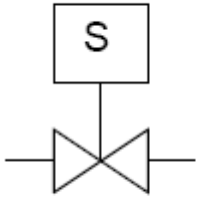
Diaphragm



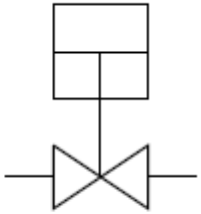
Electric motor



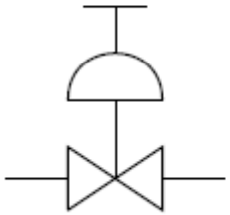
Solenoid



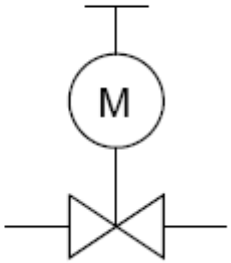
Piston



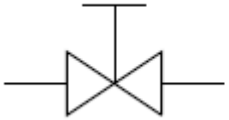
Diaphragm w/ hand jack



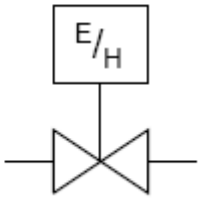
Electric motor w/ hand jack



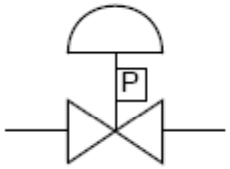
Hand (manual)



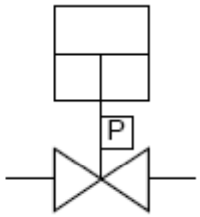
Electro-hydraulic



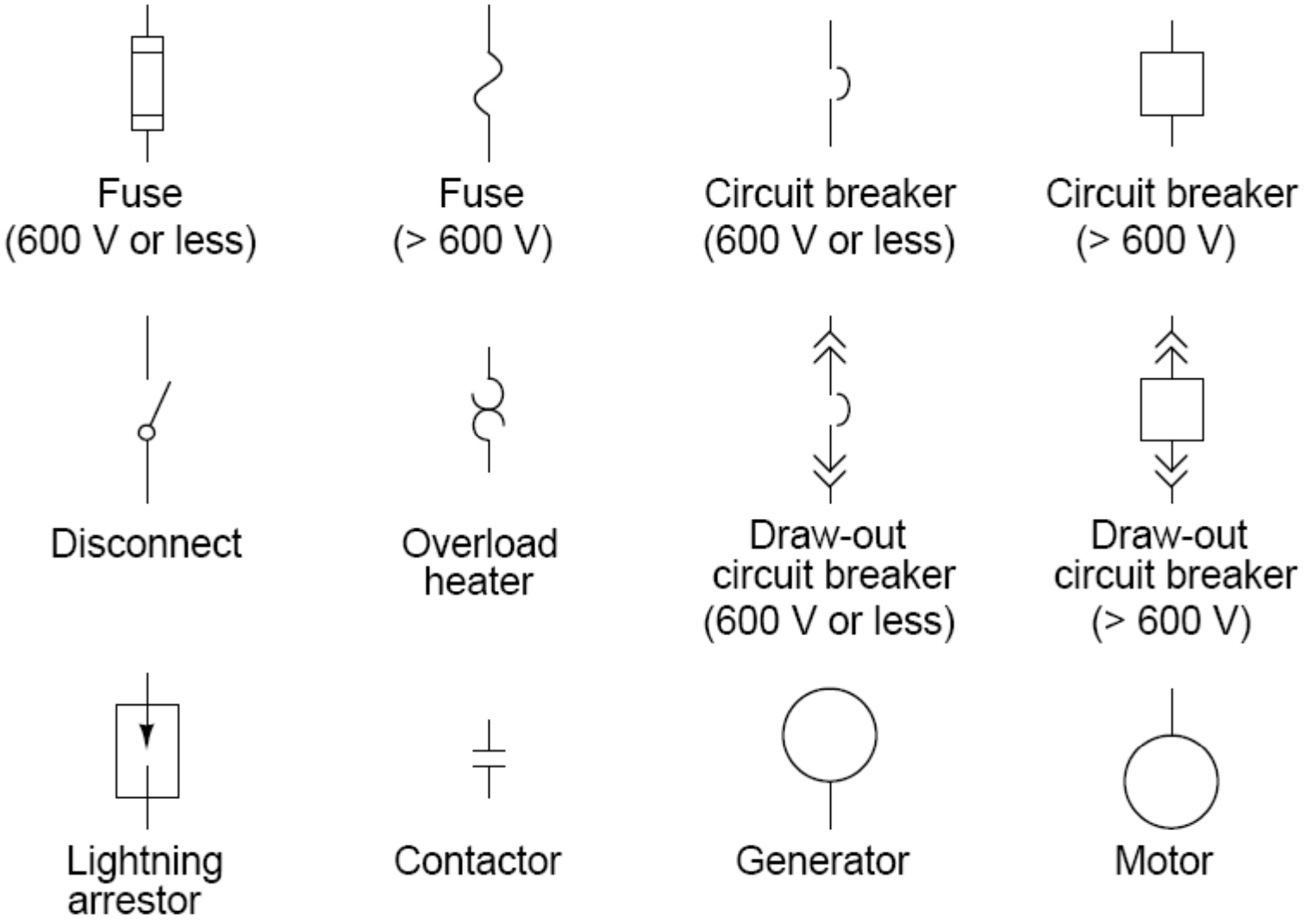
Diaphragm w/ positioner



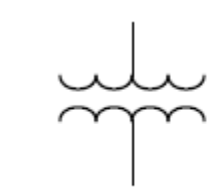
Piston w/ positioner



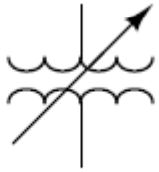
Symbol of electrial component (cont.)

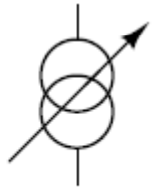


Symbol of electrial component (cont.)


Transformer

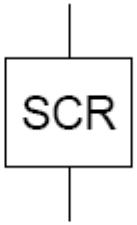

Transformer (alternate symbol)


Variable transformer


Variable transformer (alternate symbol)


Rectifier

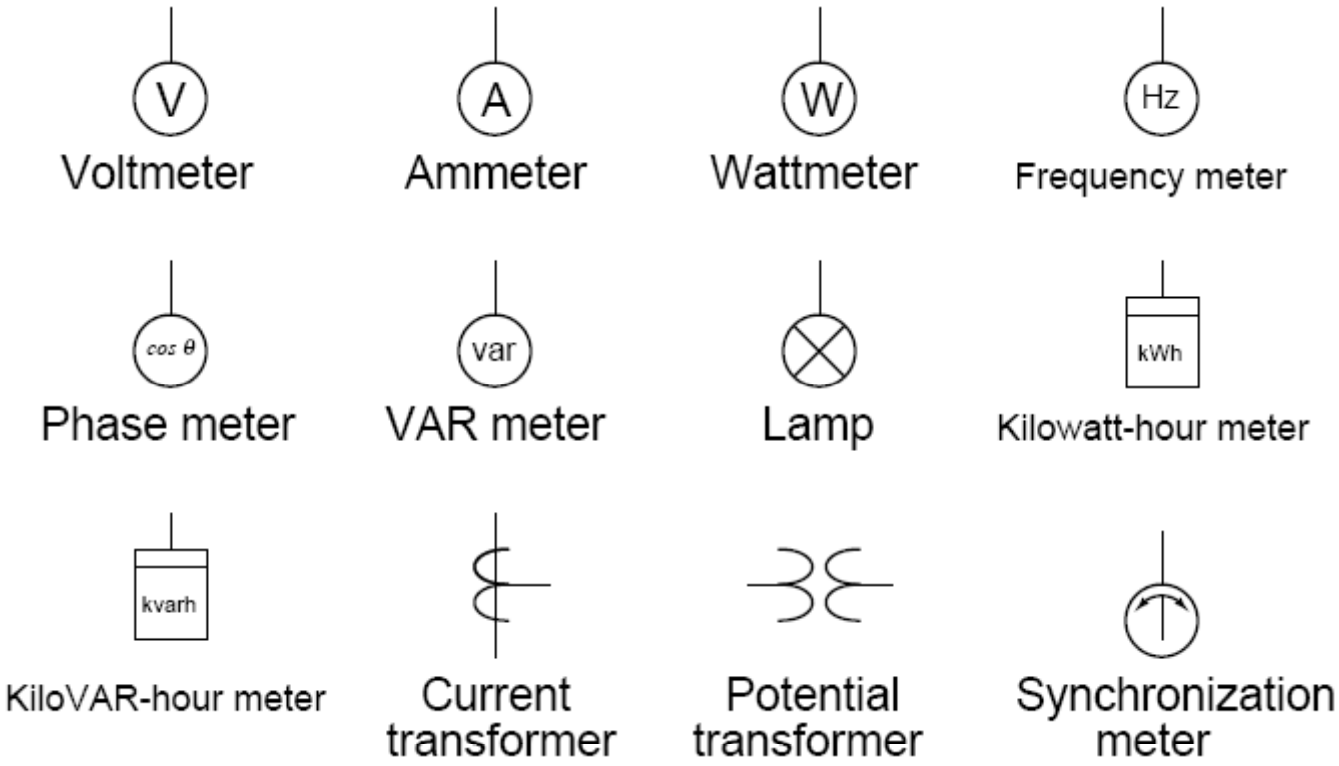

Inverter



DC motor drive

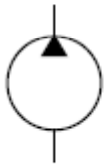
AC motor drive

Symbol of measurement equipment and indicator

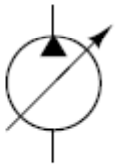


Symbol of power supply

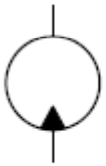
Hydraulic pump (fixed displacement)



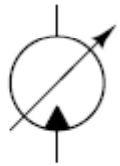
Hydraulic pump (variable displacement)



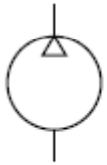
Hydraulic motor (fixed displacement)



Hydraulic motor (variable displacement)

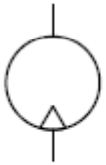


Air compressor (fixed displacement)

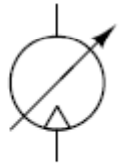


Air compressor (variable displacement)

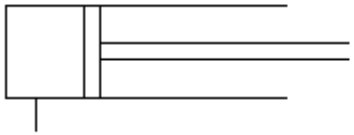
Air motor (fixed displacement)



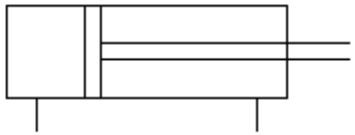
Air motor (variable displacement)



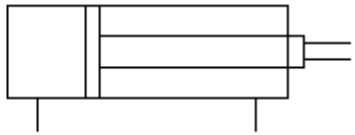
Cylinder, single-acting (ram)



Cylinder, double-acting



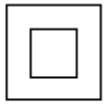
Cylinder, differential



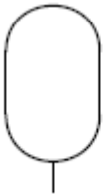
Symbol of power supply (cont.)

Electric motor

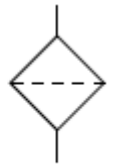
Combustion engine



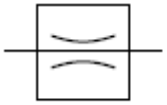
Accumulator



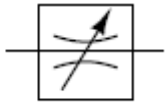
Filter



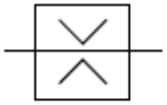
Fixed restriction, laminar flow



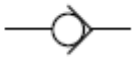
Variable restriction laminar flow



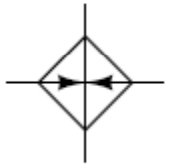
Fixed restriction, inviscid flow



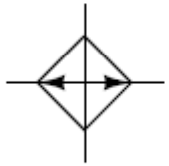
Check valve



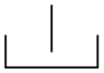
Fluid heater



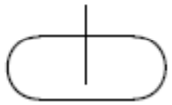
Fluid cooler



Open reservoir



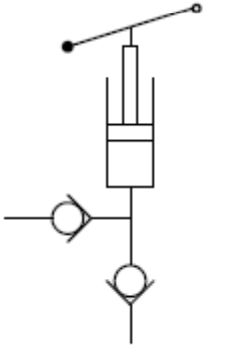
Closed reservoir



Symbol of power supply (cont.)

Various spool valve "box" symbols

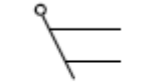
Hand pump



Solenoid actuator

Pressure actuator

Lever actuator

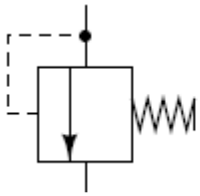


Roller actuator

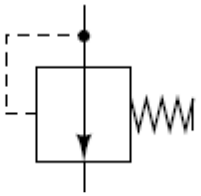
Button actuator

Return spring

Pressure relief (shunt regulator)

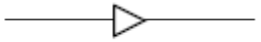


Pressure regulator (series)

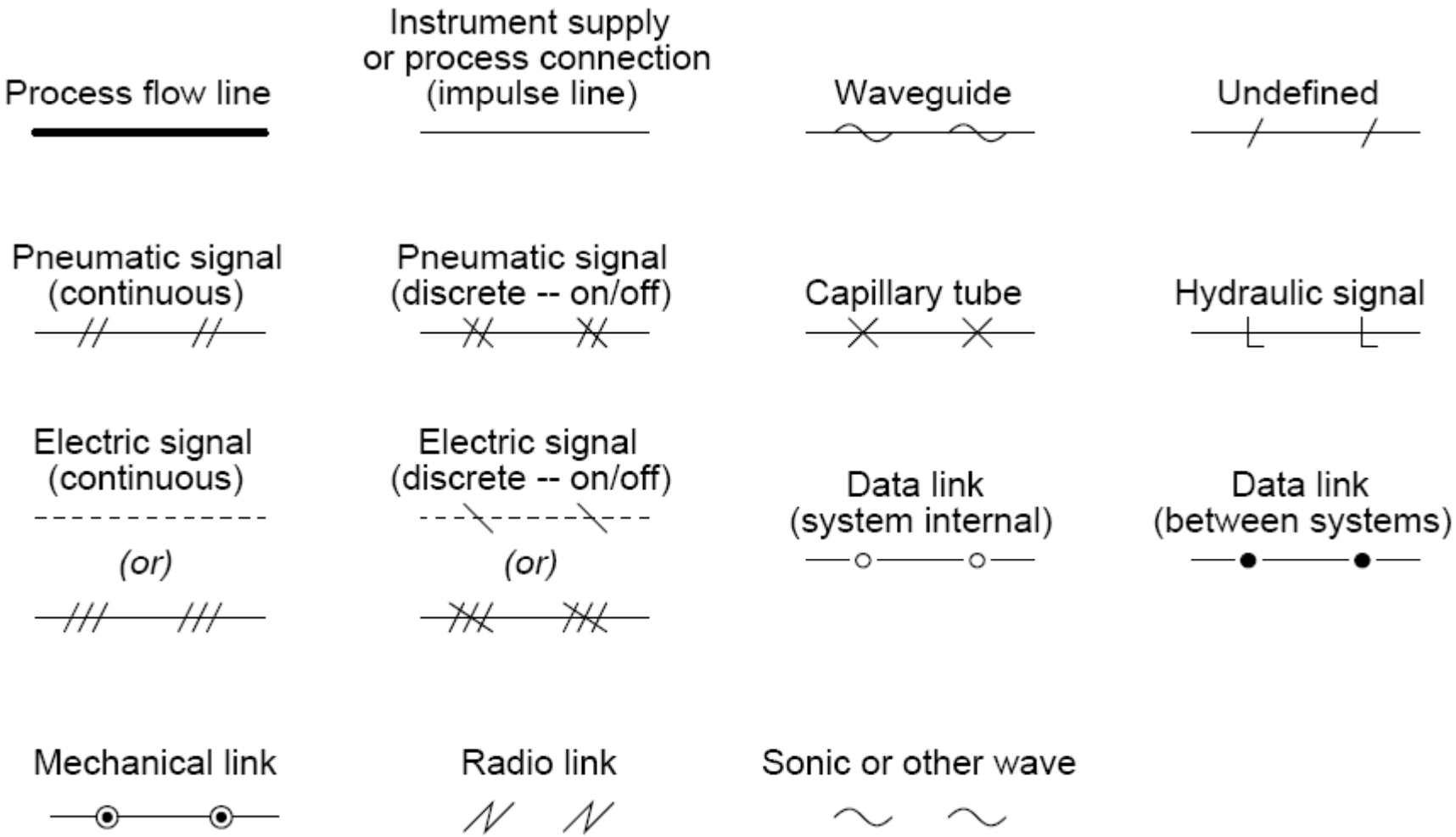


Hydraulic line

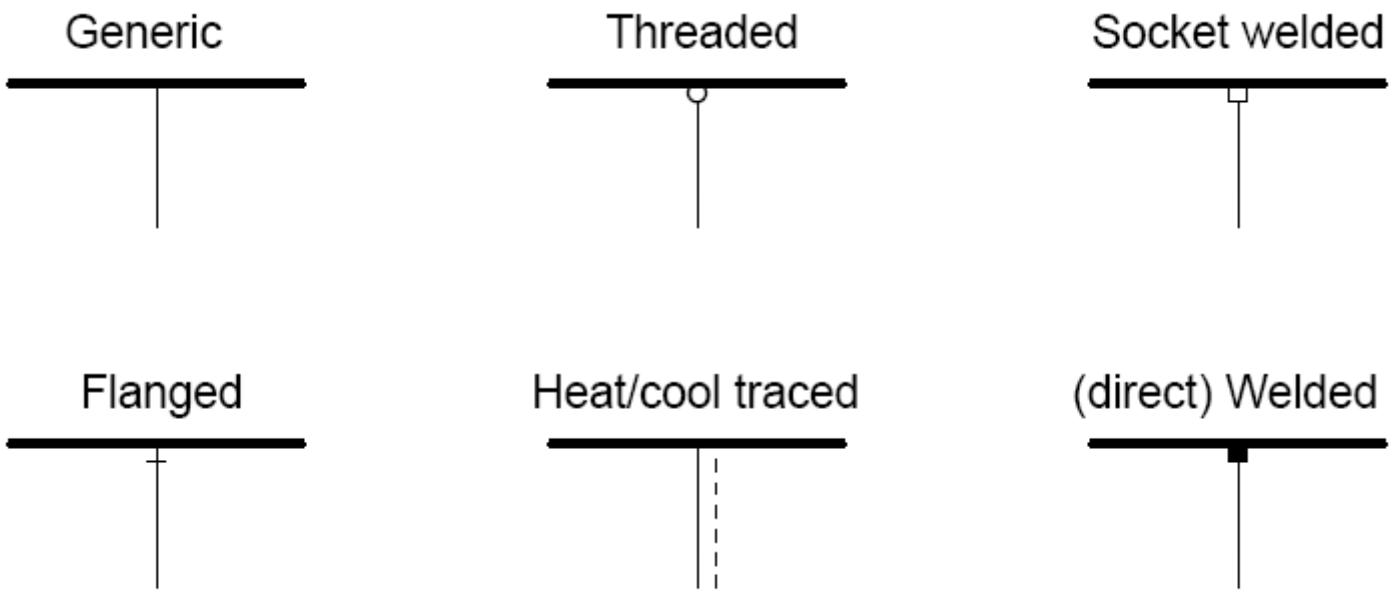
Pneumatic line



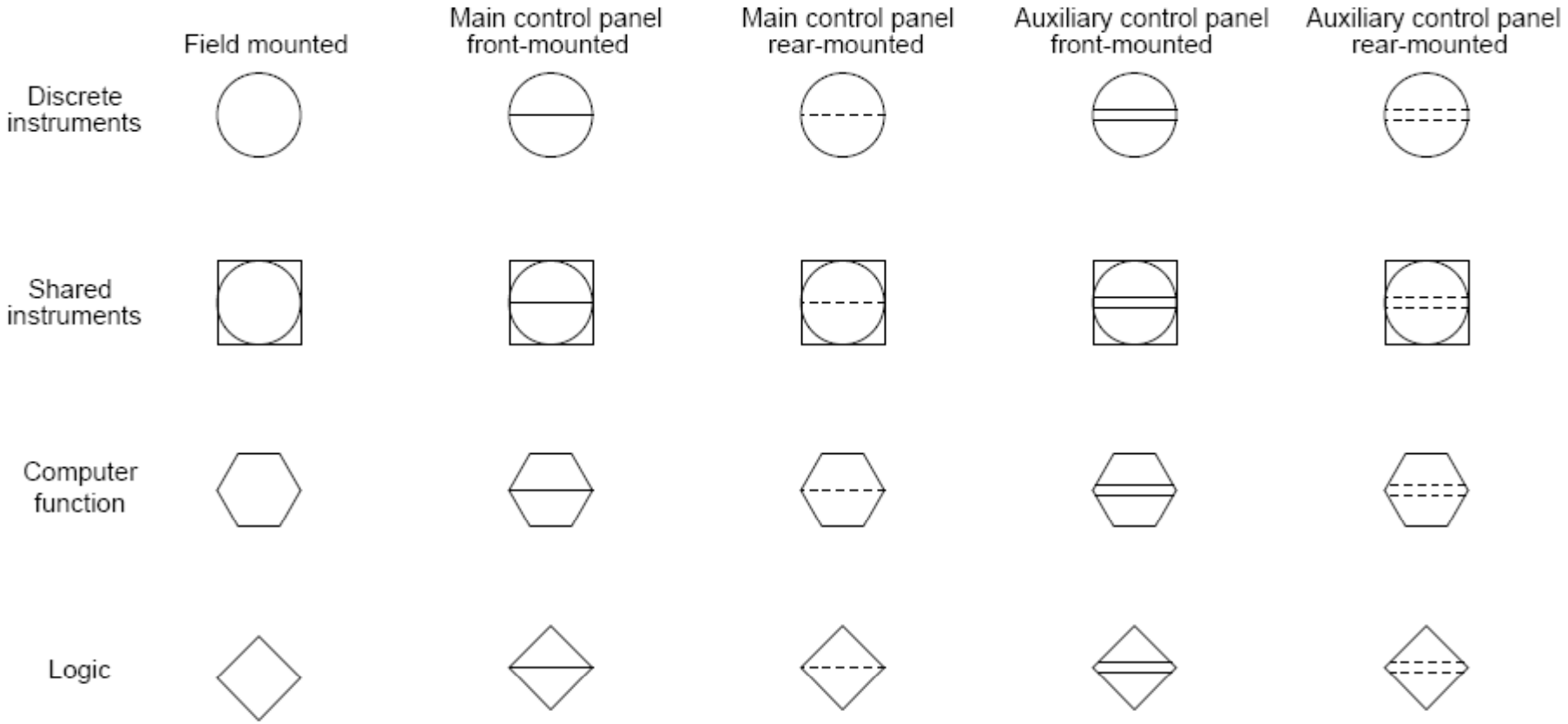
Symbol of signals



Symbol of connection

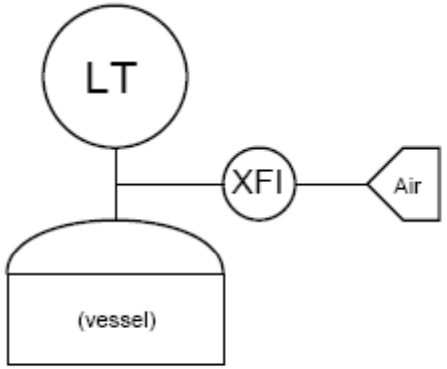


Symbol of measument equipment

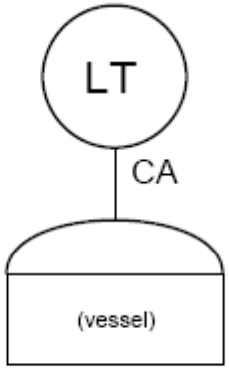


Symbol of level measurement equipment (cont.)

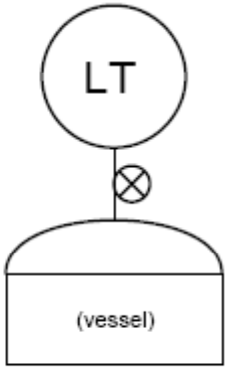
Bubbler (dip tube)



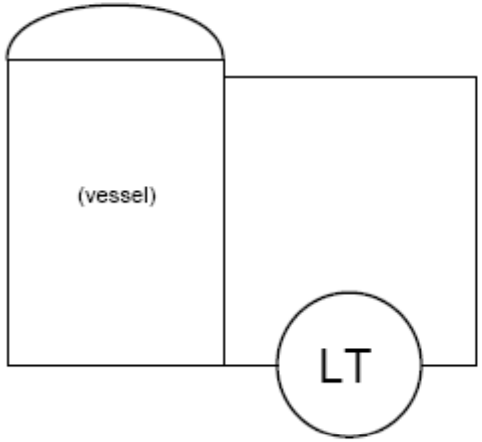
Capacitive



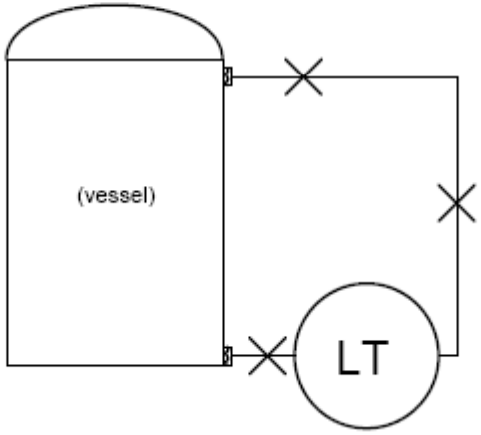
Tape-and-float



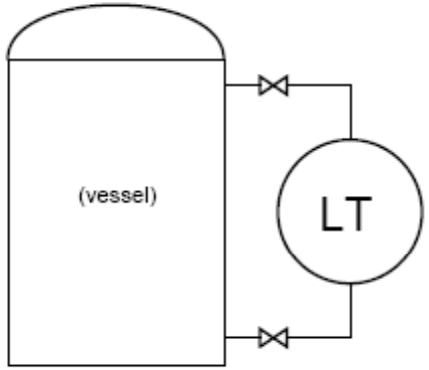
Hydrostatic



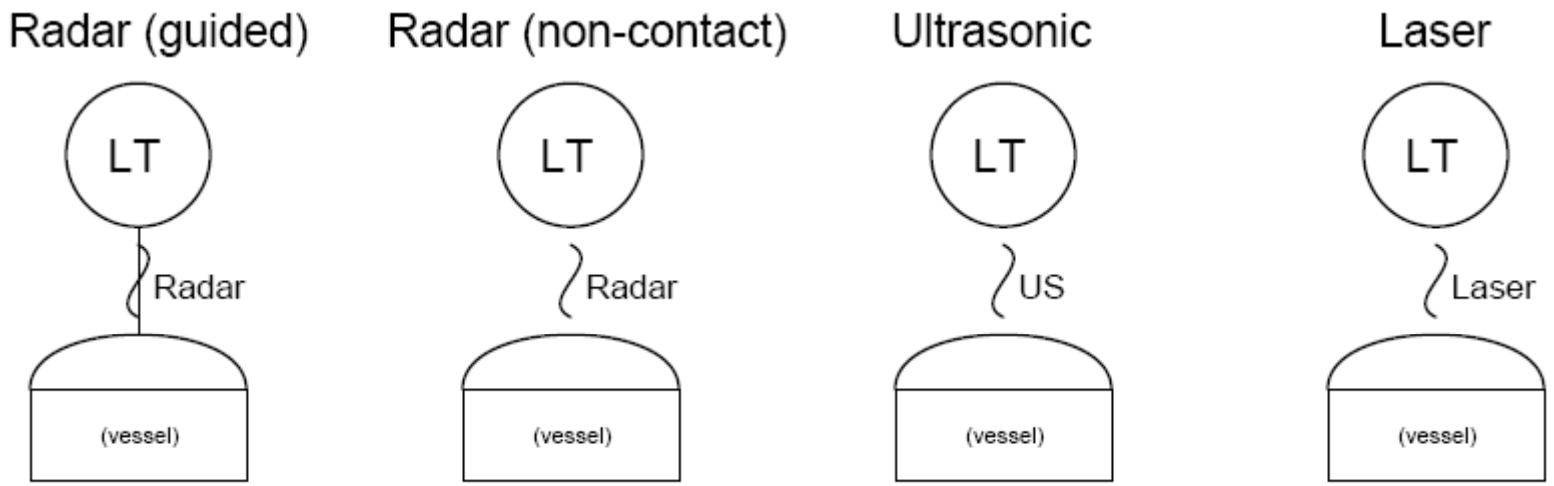
Hydrostatic (w/ seals)



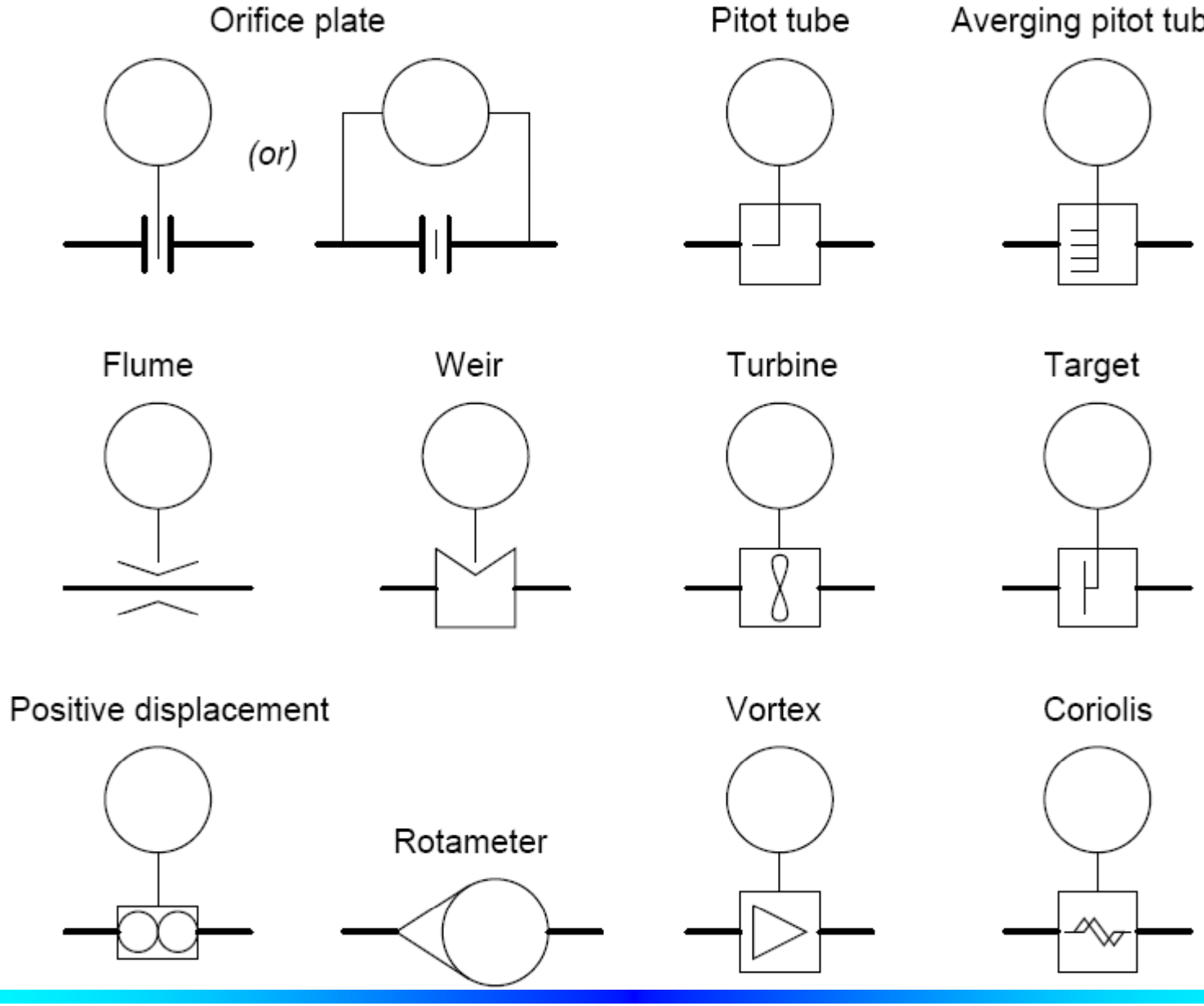
Displacer



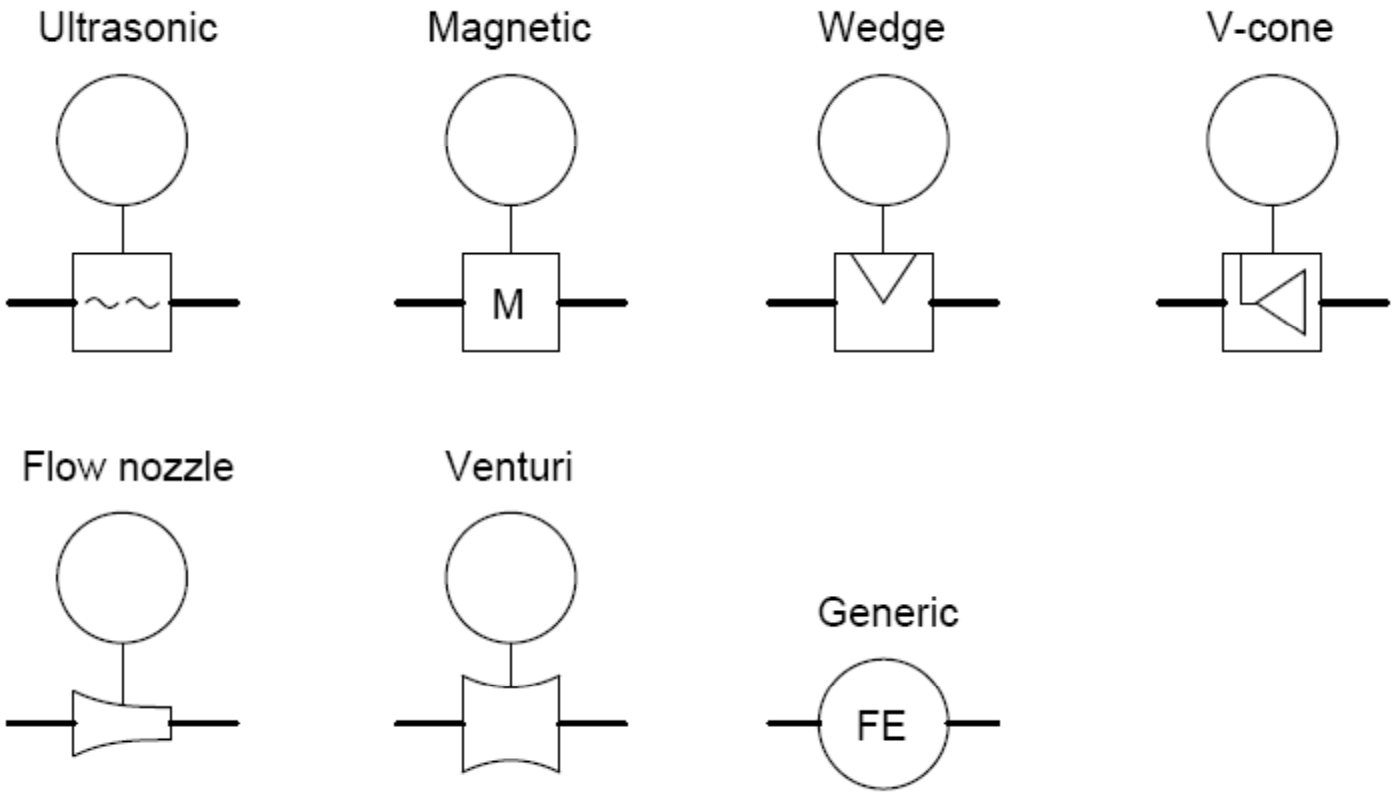
Symbol of level measurement equipment (cont.)



Symbol of flow measurement equipment

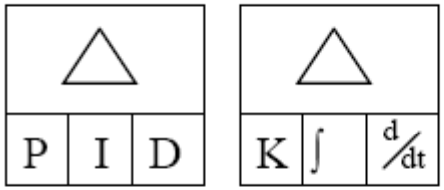


Symbol of flow measurement equipment (cont.)

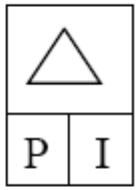


Symbol of function blocks

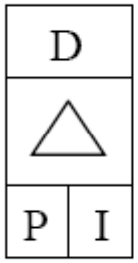
PID controllers



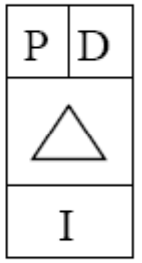
PI controller



D-PI controller



PD-I controller

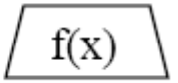


Manual adjust

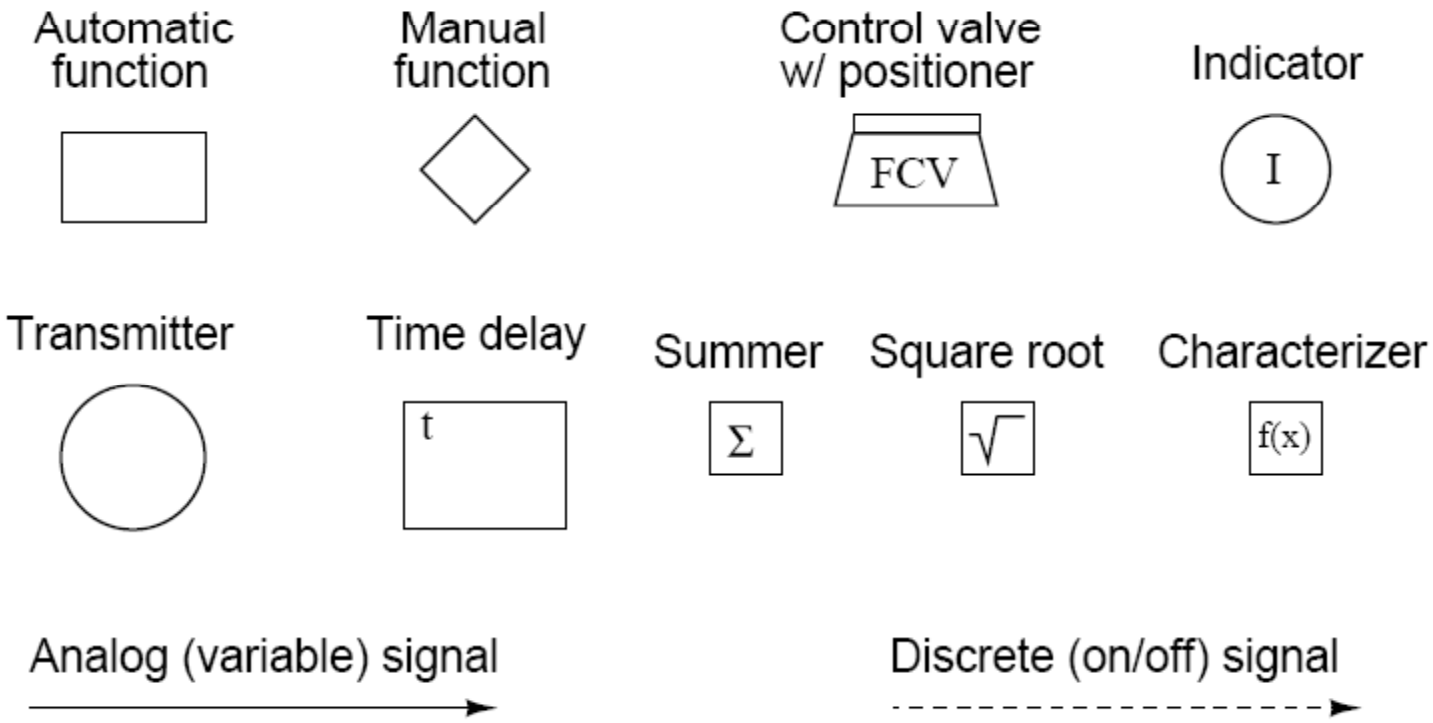
Manual transfer

Control valve

Characterized control valve



Symbol of function blocks



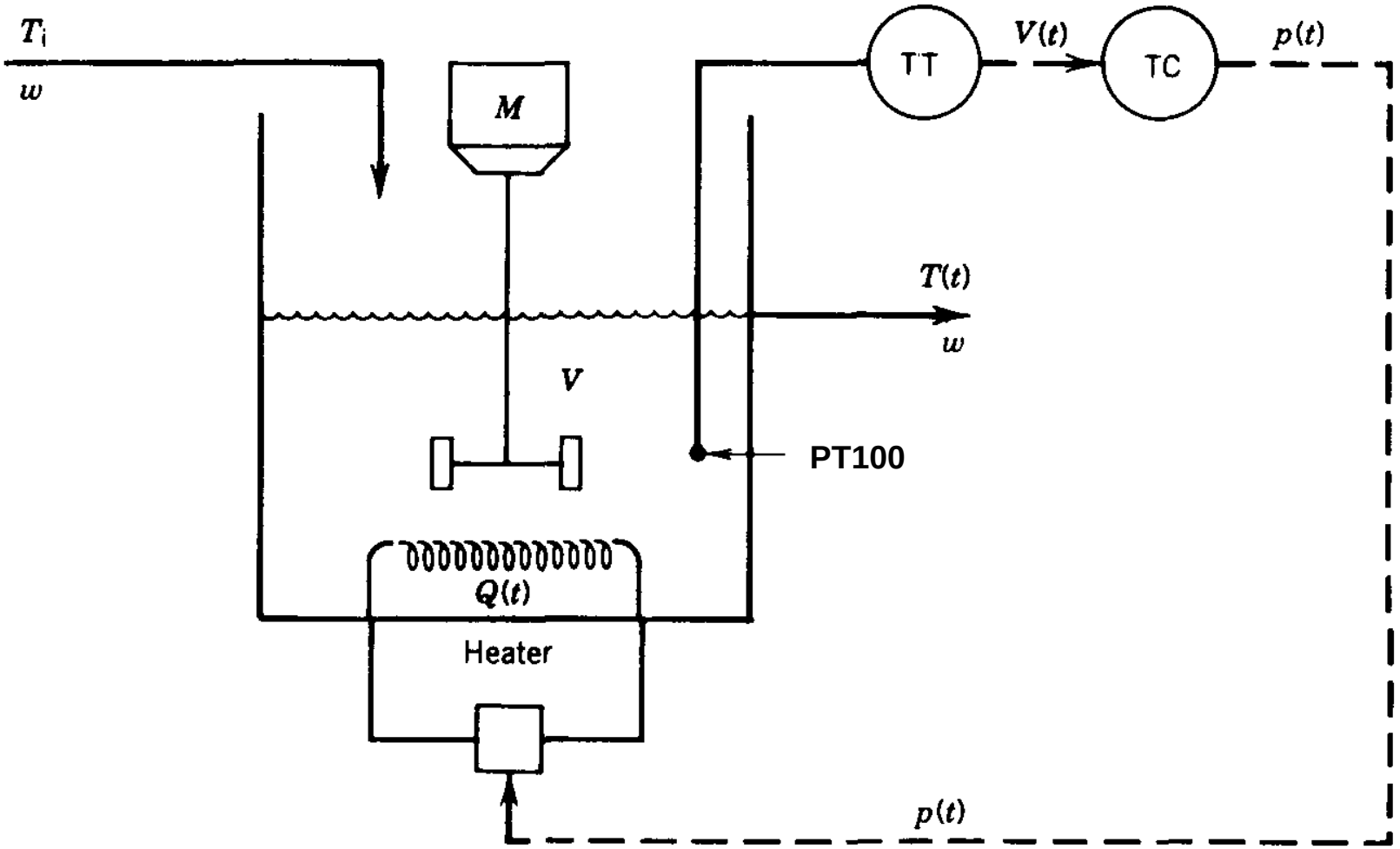
Equipment Identification Label

First letter (4)			Succeeding letters (3)		
Measured or initiating variable		Modifier	Readout or passive function	Output function	Modifier
A	Analysis (5, 19)		Alarm		
B	Burner, Combustion		User's Choice (1)	User's Choice (1)	User's Choice (1)
C	User's Choice (1)			Control (13)	
D	User's Choice (1)	Differential (4)			
E	Voltage		Sensor (Primary Element)		
F	Flow Rate	Ratio (Fraction) (4)			
G	User's Choice (1)		Glass, Viewing Device (9)		
H	Hand				High (7, 15, 16)
I	Current (Electrical)		Indicate (10)		
J	Power	Scan (7)			
K	Time, Time Schedule	Time Rate of Change (4, 21)		Control Station (22)	
L	Level		Light (11)		Low (7, 15, 16)
M	User's Choice (1)	Momentary (4)			Middle, Intermedi-ate (7, 15)
N	User's Choice (1)		User's Choice (1)	User's Choice (1)	User's Choice (1)
O	User's Choice (1)		Orifice, Restriction		

Equipment Identification Label

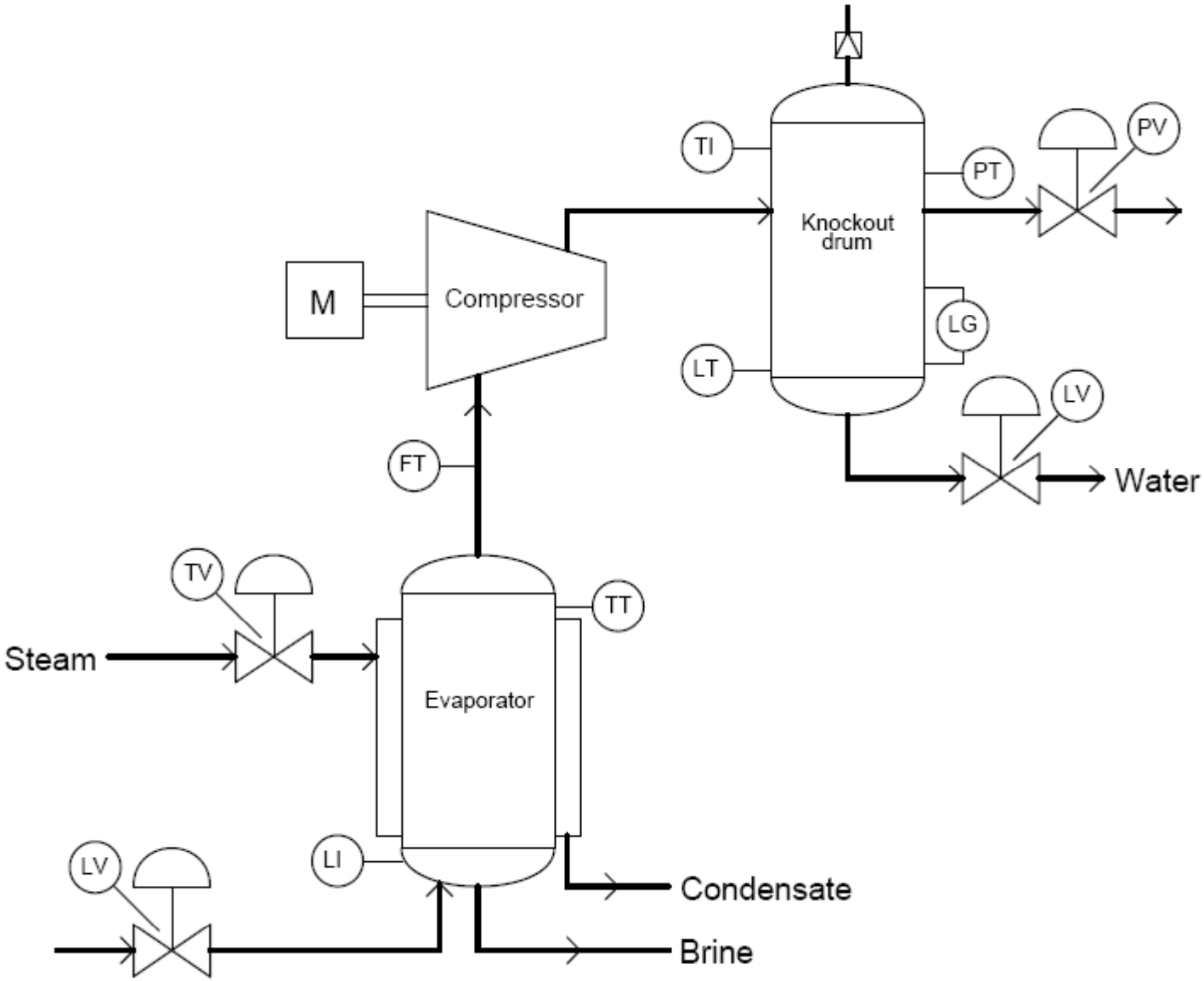
First letter (4)			Succeeding letters (3)		
Measured or initiating variable		Modifier	Readout or passive function	Output function	Modifier
P	Pressure, Vacuum		Point (Test) Con-nection		
Q	Quantity	Integrate, Totalize (4)			
R	Radiation		Record (17)		
S	Speed, Frequency	Safety (8)		Switch (13)	
T	Temperature			Transmit (18)	
U	Multivariable (6)		Multifunction (12)	Multifunction (12)	Multifunction (12)
V	Vibration, Mechanical Analysis			Valve, Damper, Louver (13)	
W	Weight, Force		Well		
X	Unclassified (2)	X Axis	Unclassified (2)	Unclassified (2)	Unclassified (2)
Y	Event, State or Presence (20)	Y Axis		Relay, Compute, Convert (13, 14, 18)	
Z	Position Dimension	Z Axis		Driver, Actuator, Unclassified Final Control Element	

Control process diagram – Example 1

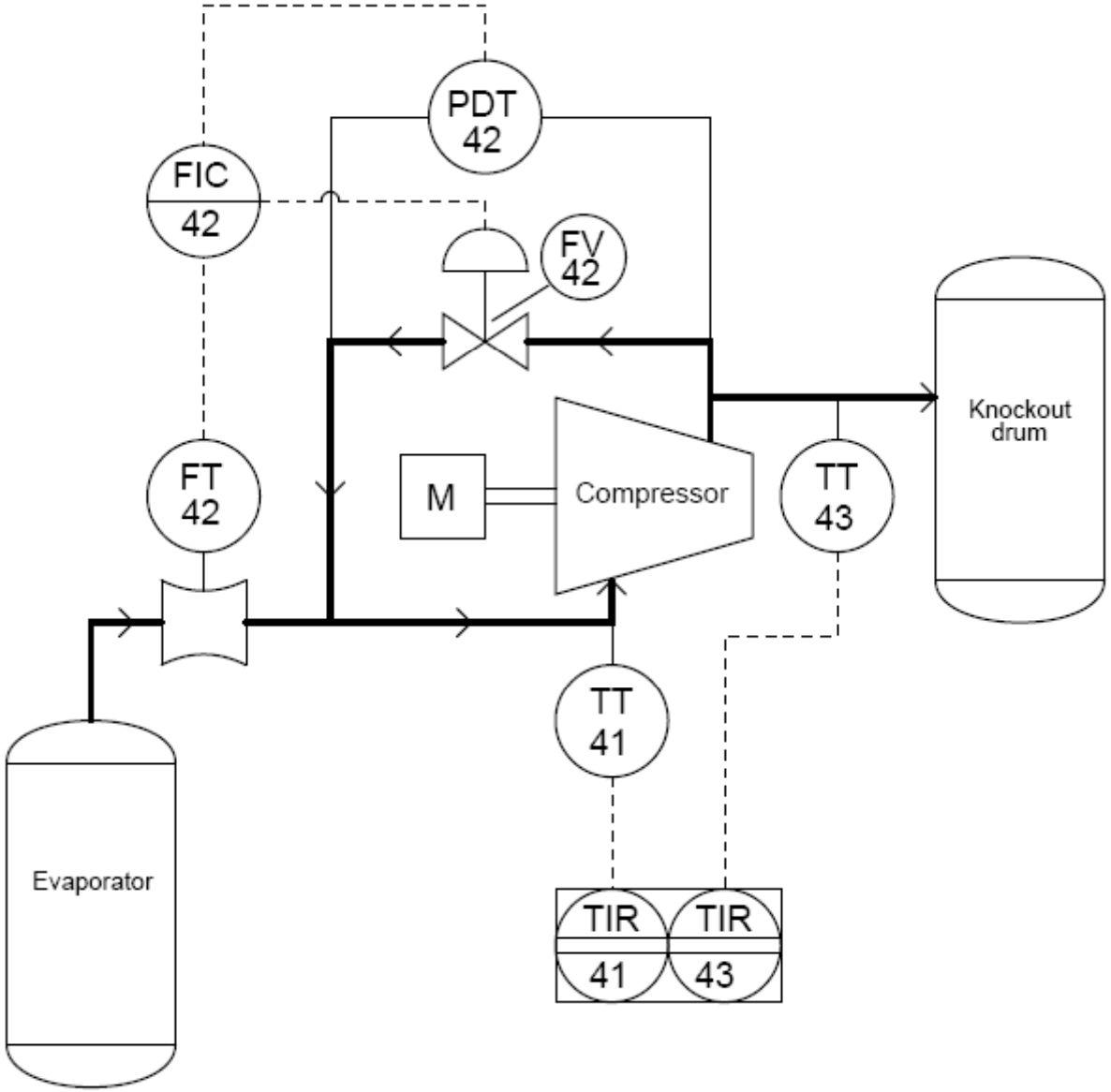


Schematic diagram of a temperature feedback control system for a stirred-tank heater. – – –, Electrical instrument line; TT, temperature transmitter; TC, temperature controller.

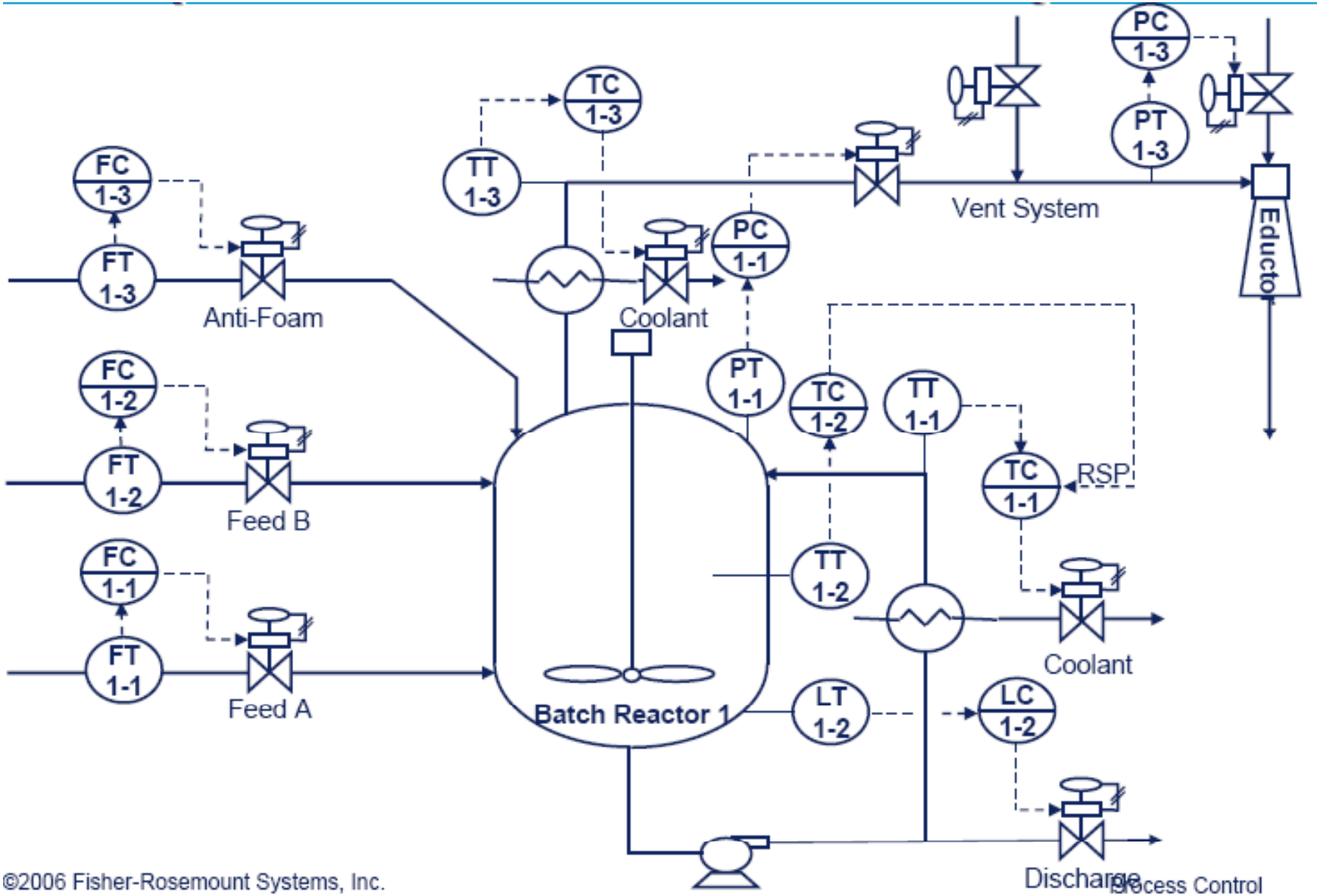
Control process diagram – Example 2



Control process diagram – Example 3



Control process diagram – Example 4



Applications of control systems

Applications of control theory

Feedback control can be found in many applications:

- Production system: cement plants, sugar mills, ...
- Industrial processes: temperature, flow, pressure, speed, ...
- Mechatronics: robot arms, computer numerical control (CNC), ...
- Information systems
- Power generation and transmission
- Transportation systems: cars, trains, aircraft, spacecraft, ...
- Military equipments
- Measurement
- Home appliances: air conditioners, televisions, refrigerators, washing machines, cameras, rice cookers, ...
- Medical equipments

Temperature control

- Temperature control plays an important role in many manufacturing systems: production of cement, ceramic tiles, pulp and paper, rubber and plastic, oil and gas, food and beverage,…

Cement factory

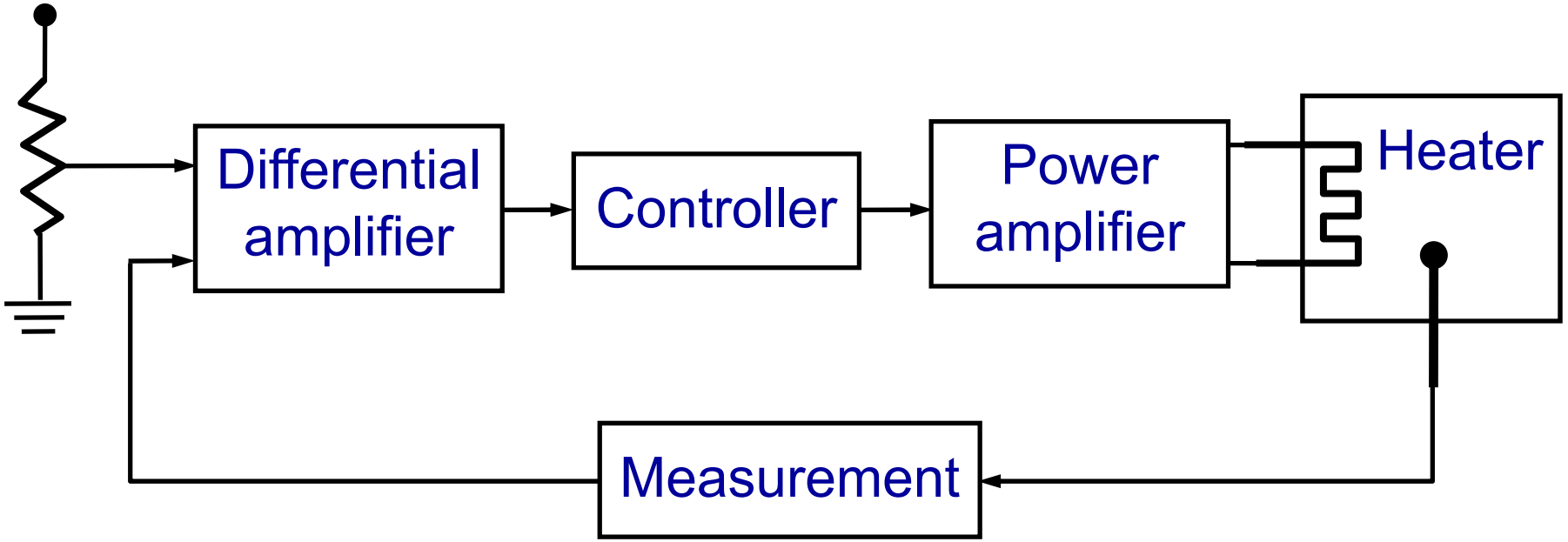
Paper factory

Examples of temperature control

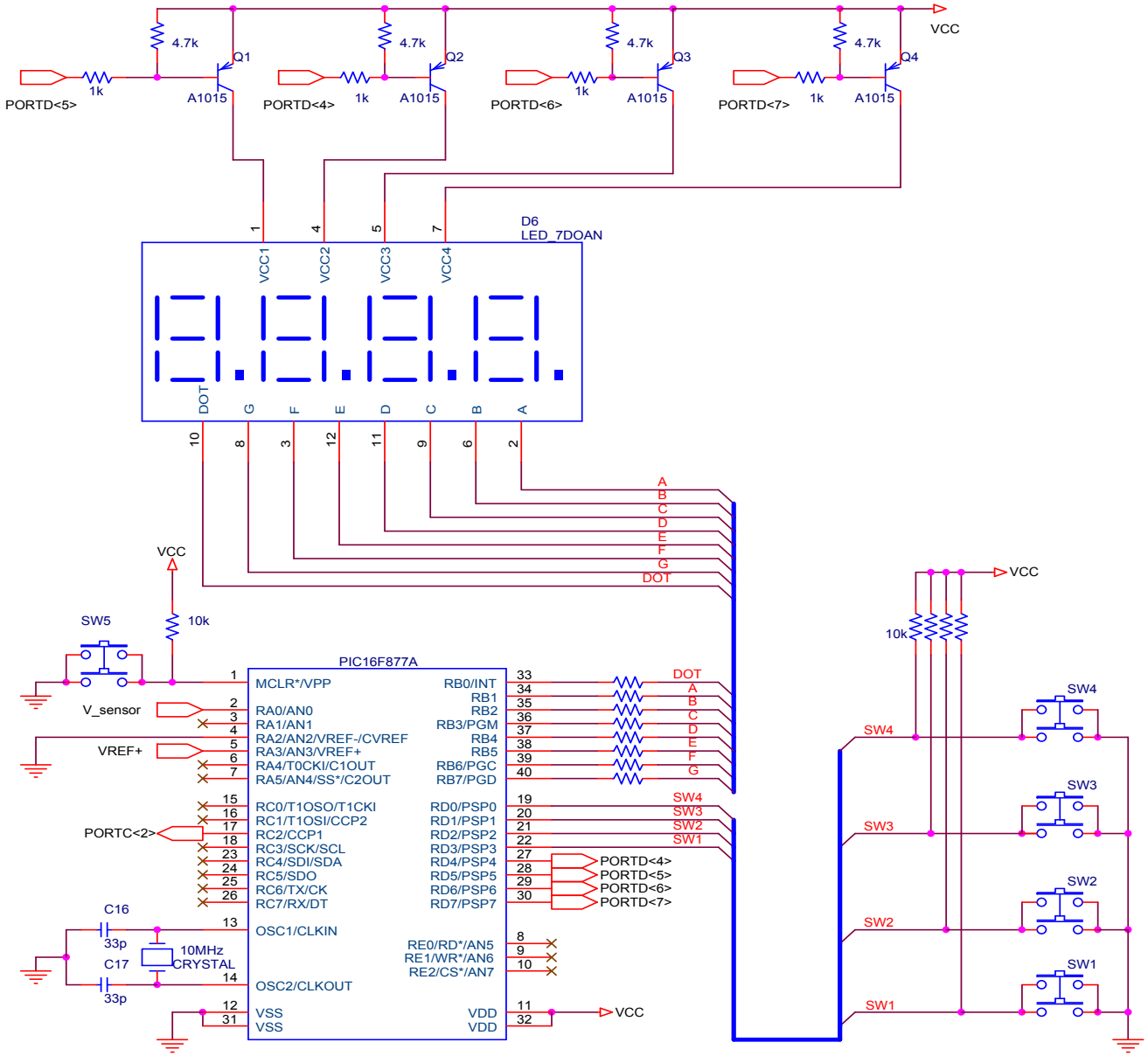
- Agricultural product drying system (coffee, cashew nut, black pepper,…)

Agricultural product drying system

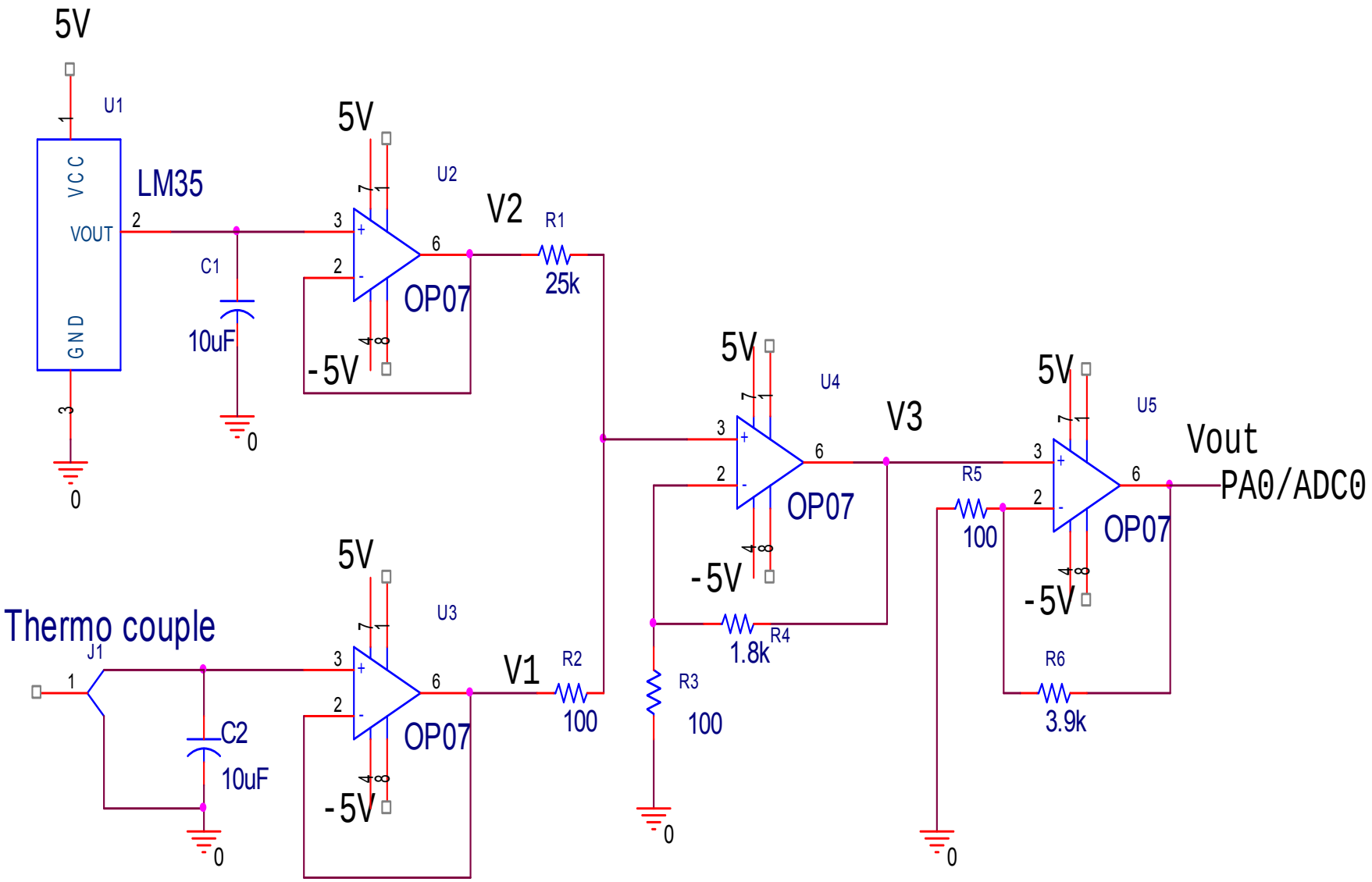
Block diagram of a temperature control system



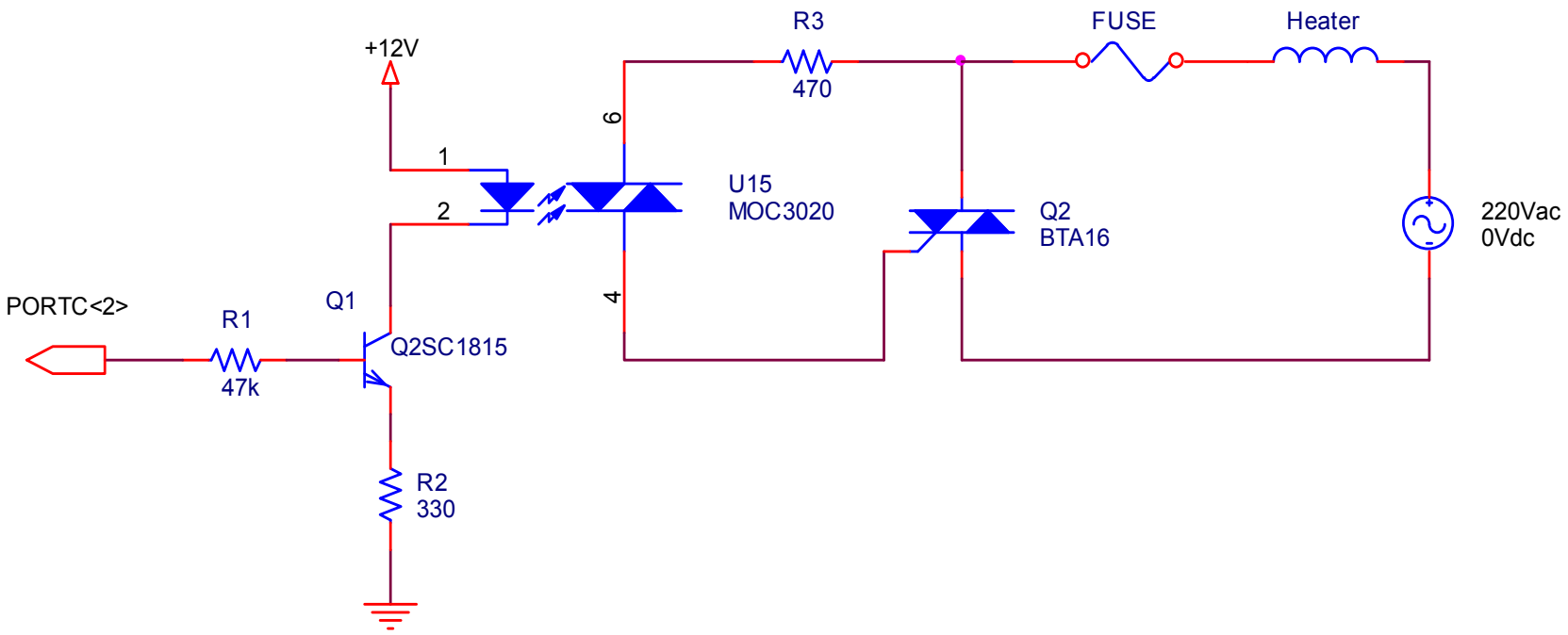
Temperature controller and user interface



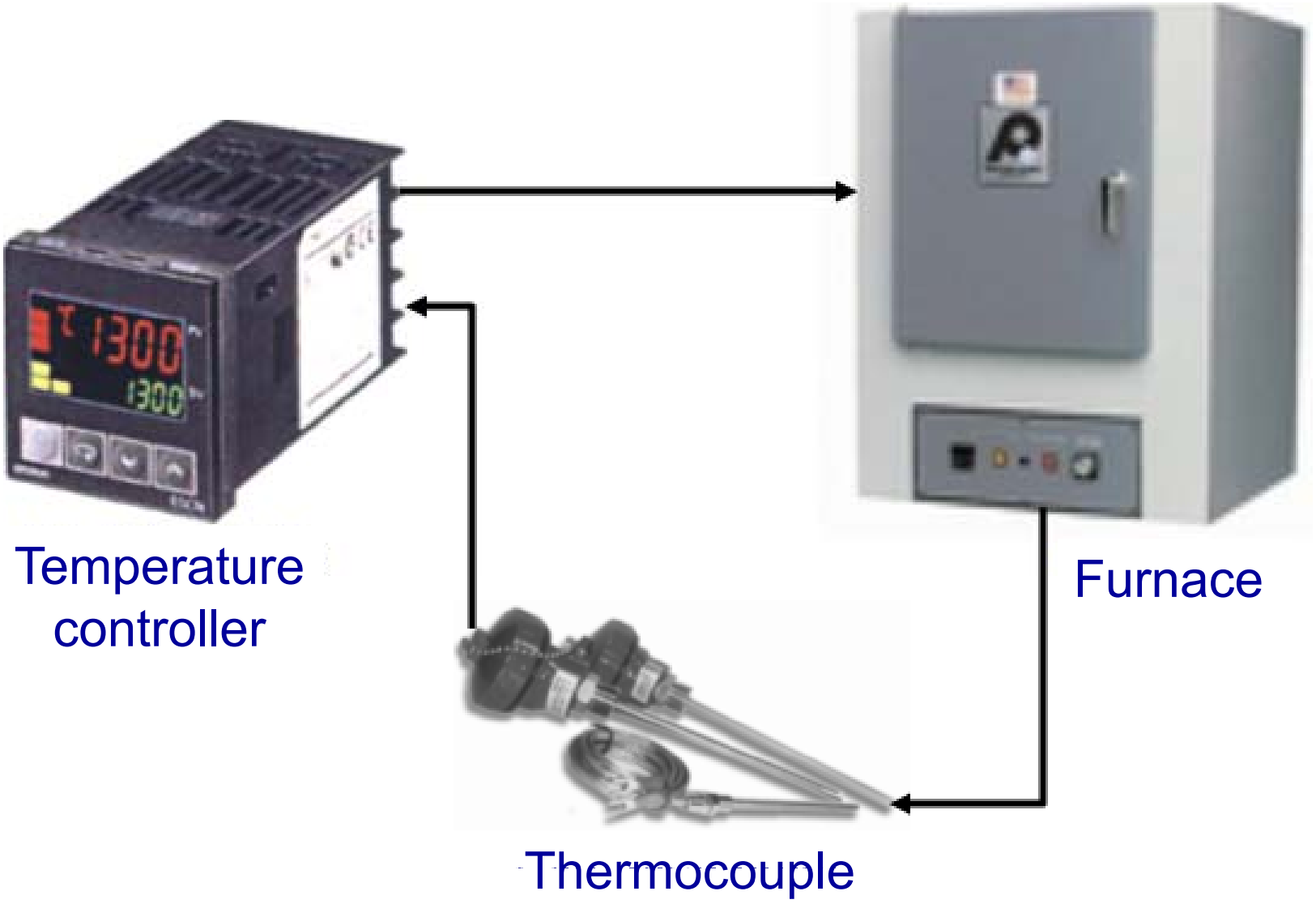
Temperature measurement using thermocouple



Power circuit

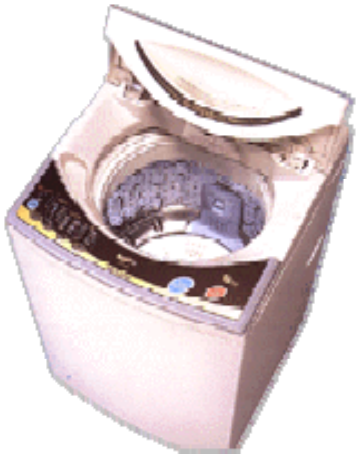


An industrial temperature control system



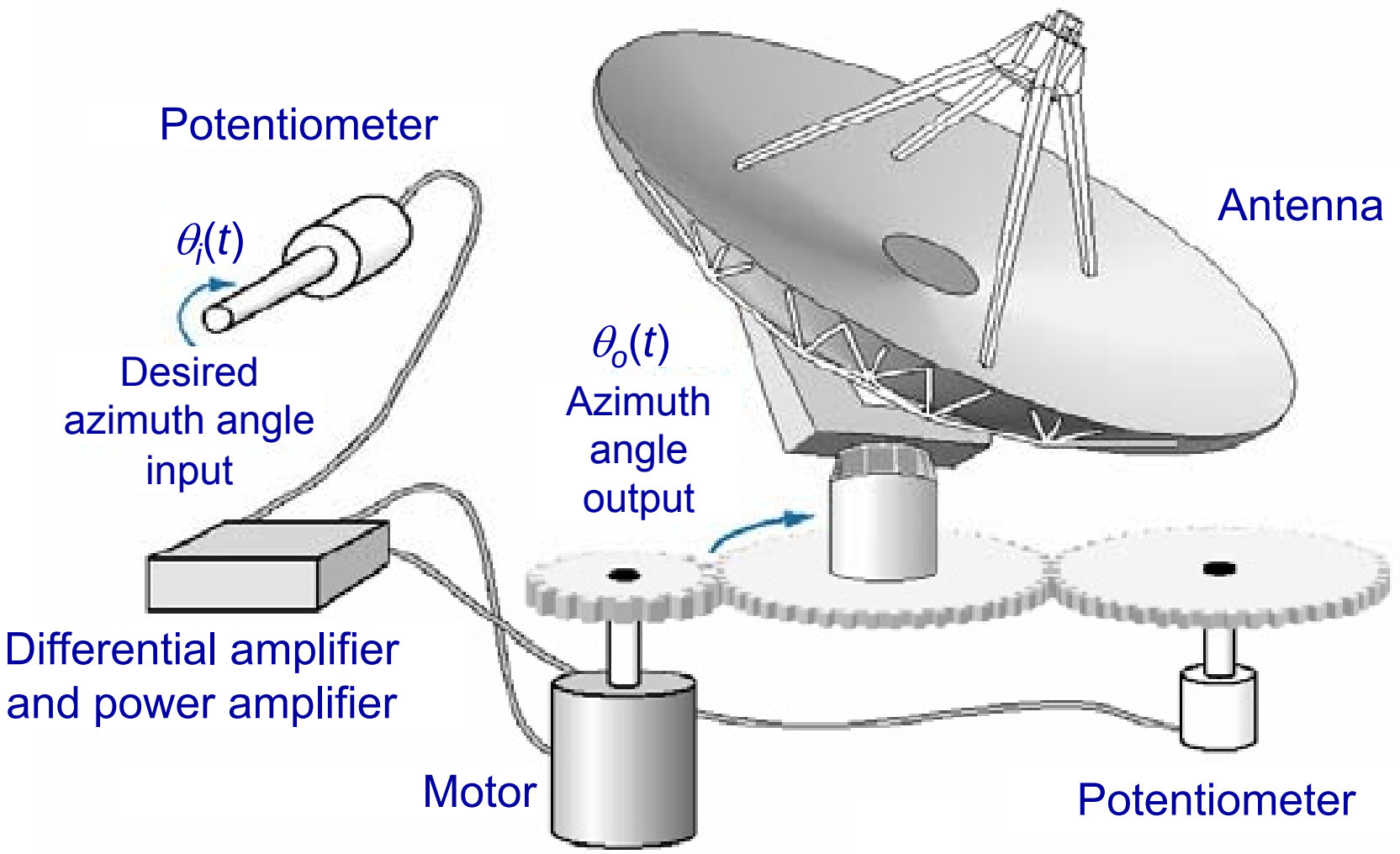
Motor control

- Motors (DC, AC) are one of the most common actuators used machinery and manufacturing factory.
- Three basic control problems: speed control, position control, torque control

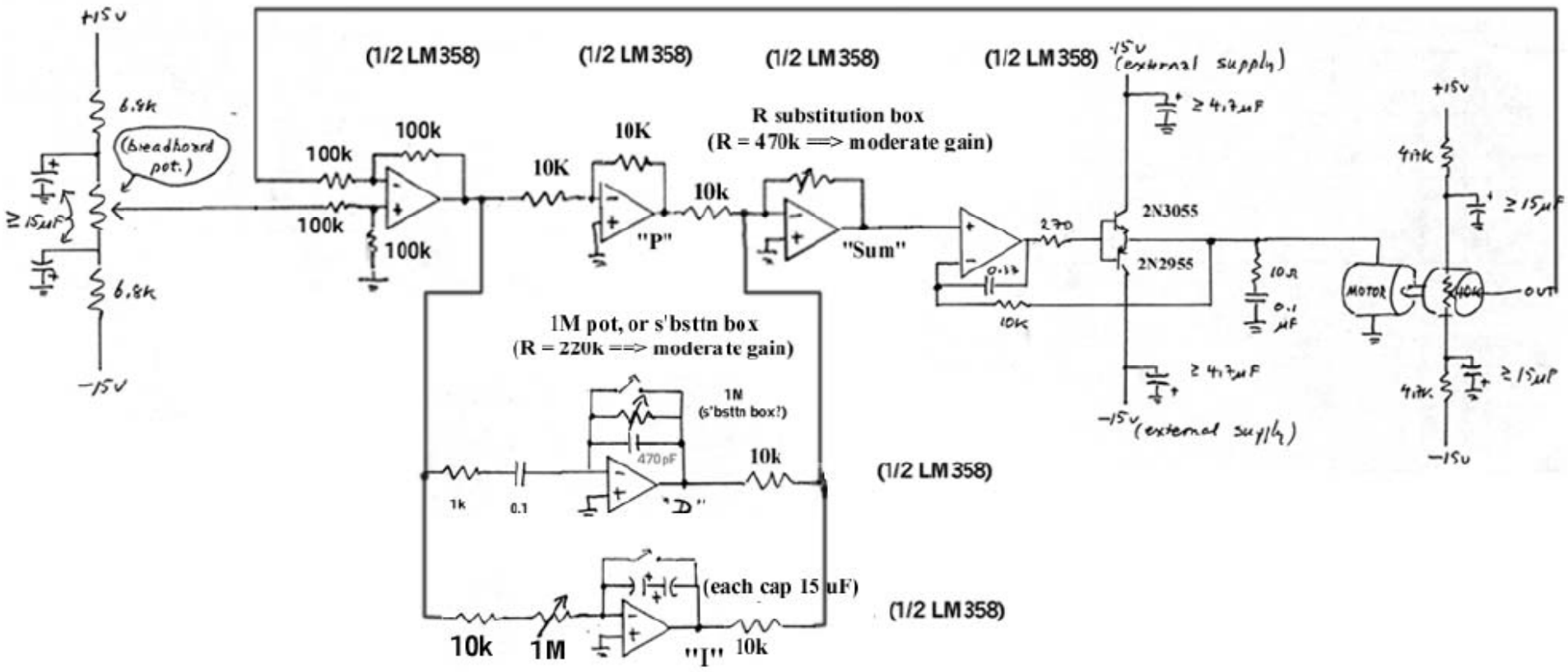




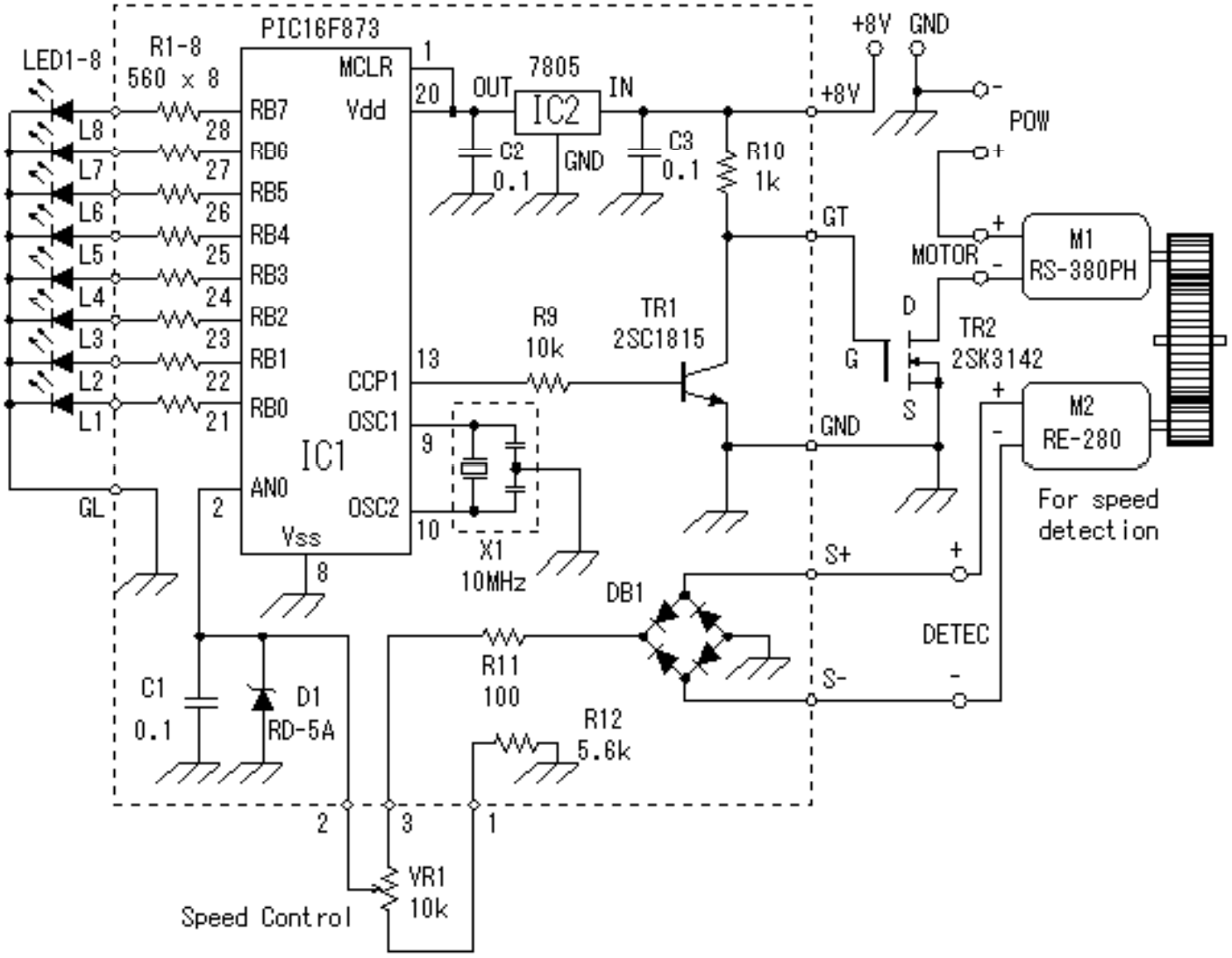
Antenna position control



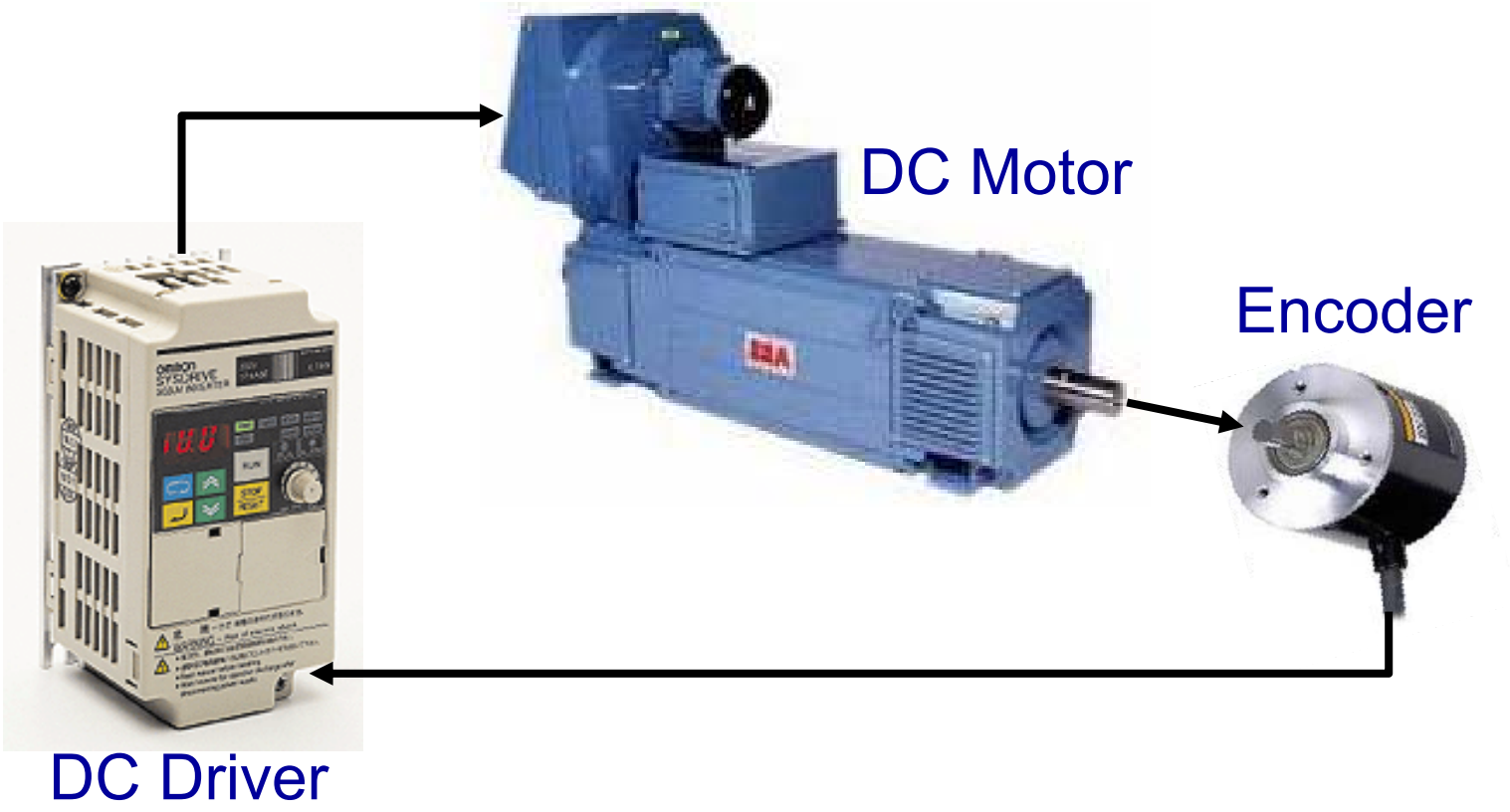
Analog PID control of DC motor



Digital PID control of DC motor



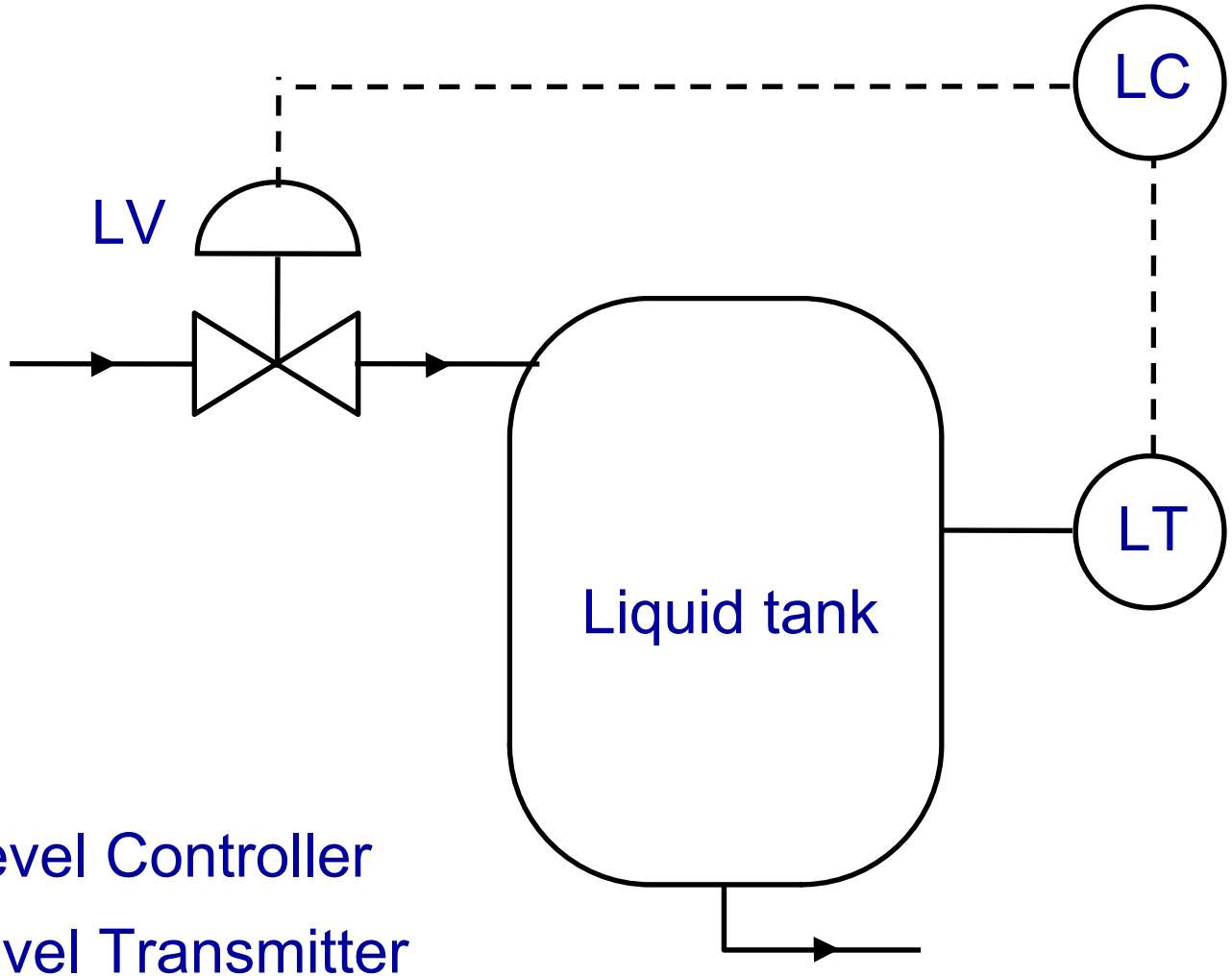
An industrial DC motor control system



Level control

- Level control can be found in industrial processes such as food and beverage, waste water treatment,…
- Level control, flow control
- Sensor:
  - Level sensor: presure sensor, capacitor sensor, ultra sonic
  - Flow sensor: ultra sonic

Level control system in industry

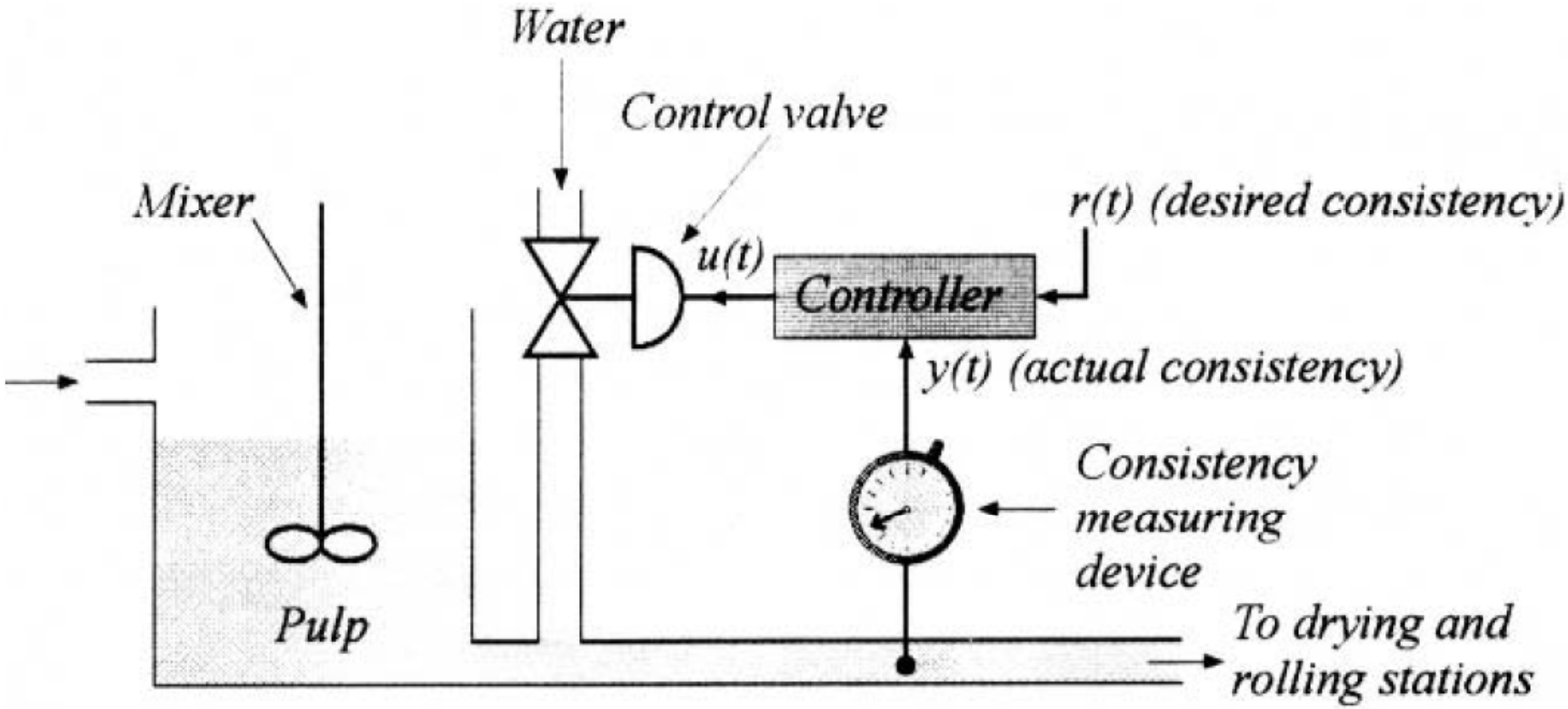


LC: Level Controller

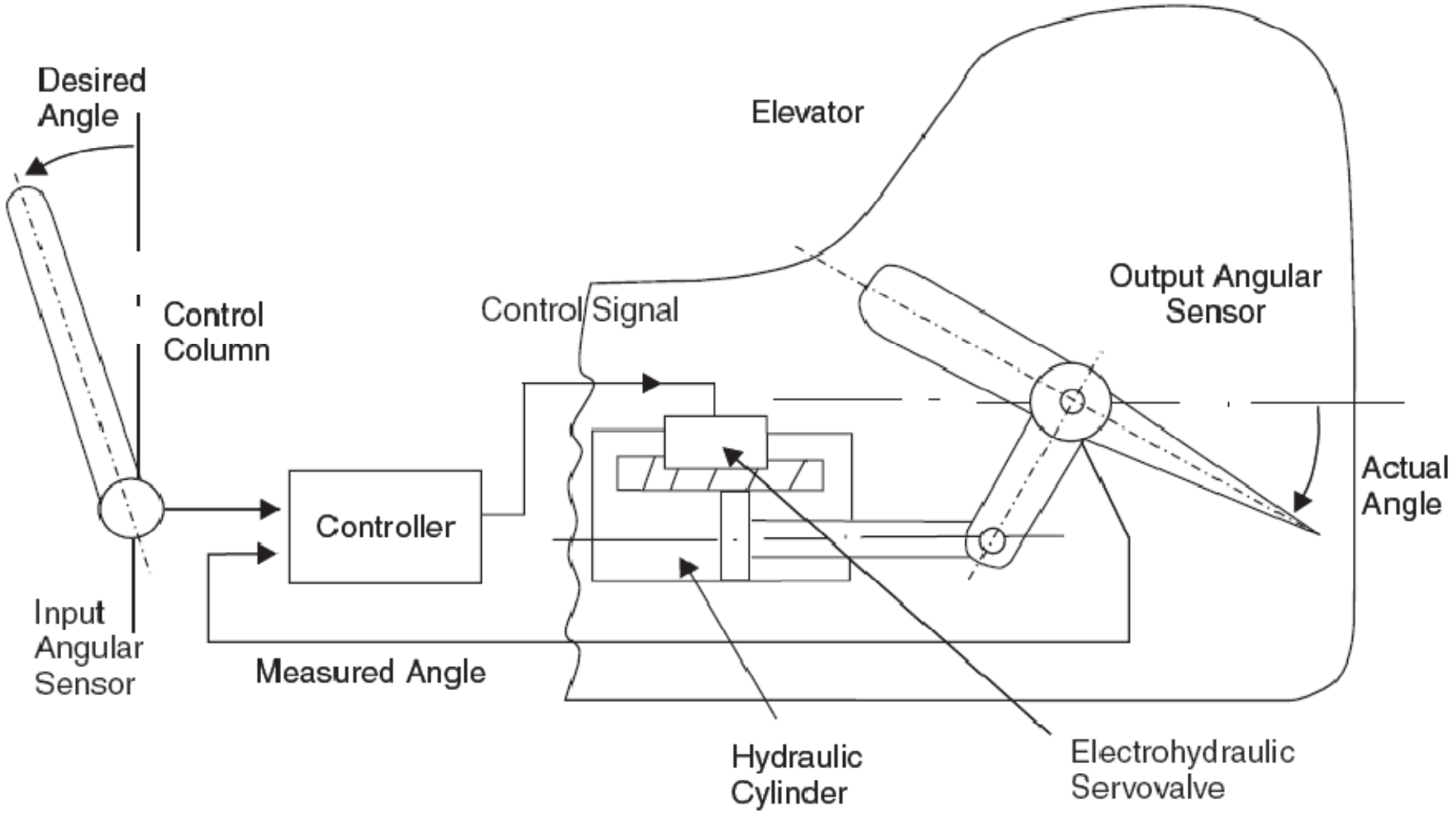
LT: Level Transmitter

LV: Level Valve

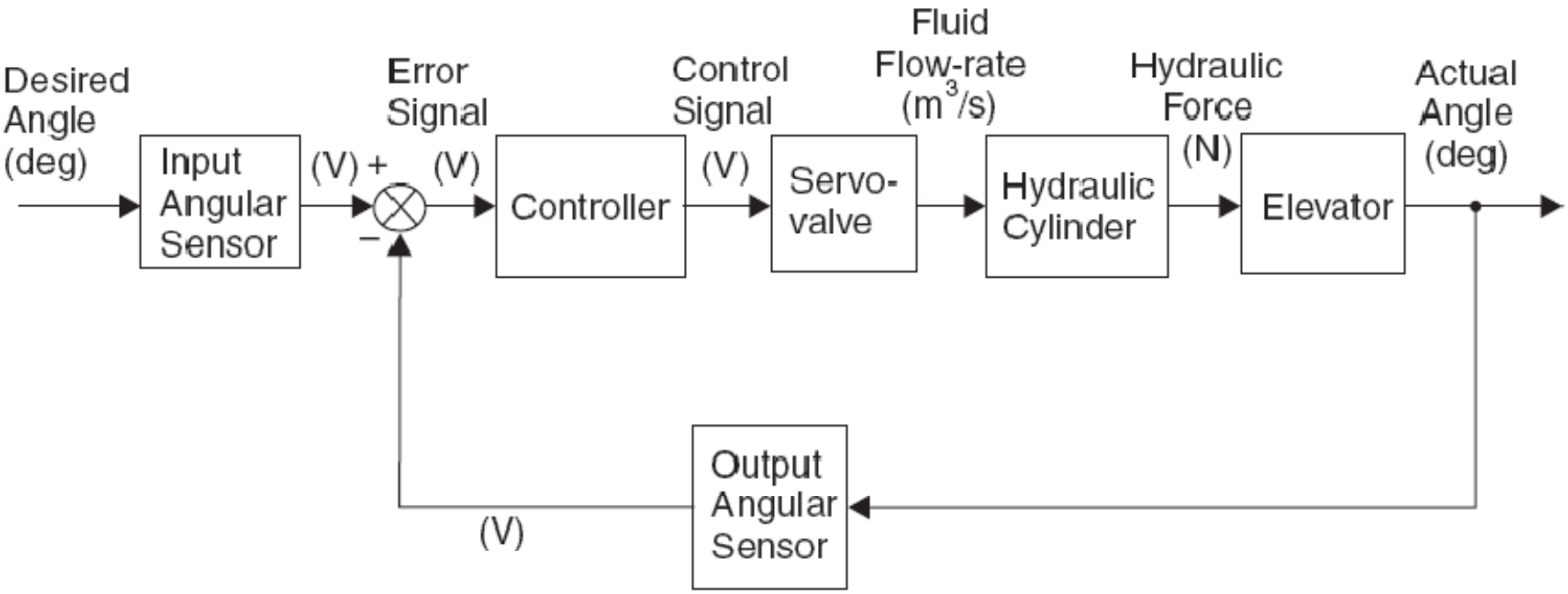
Pulp concentration control



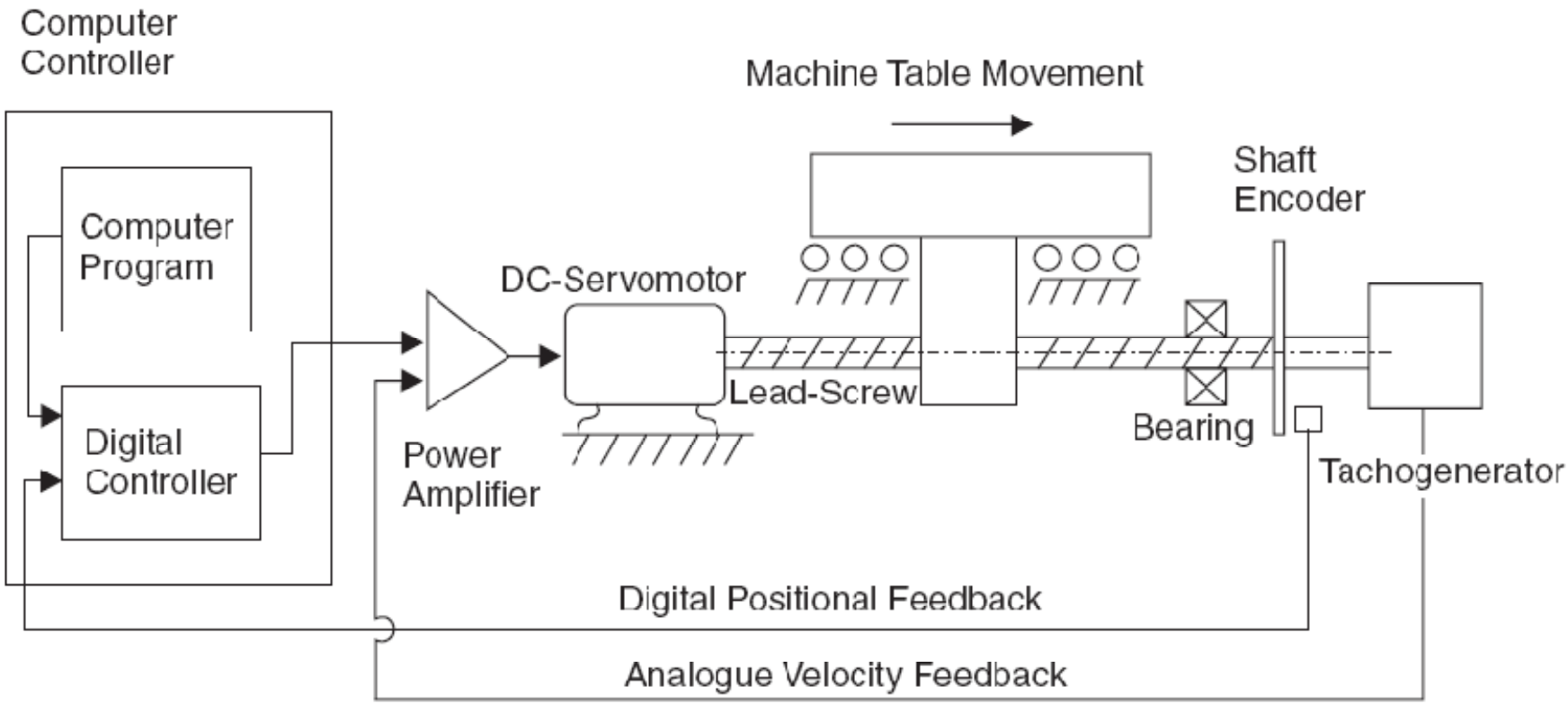
Pitch angle control



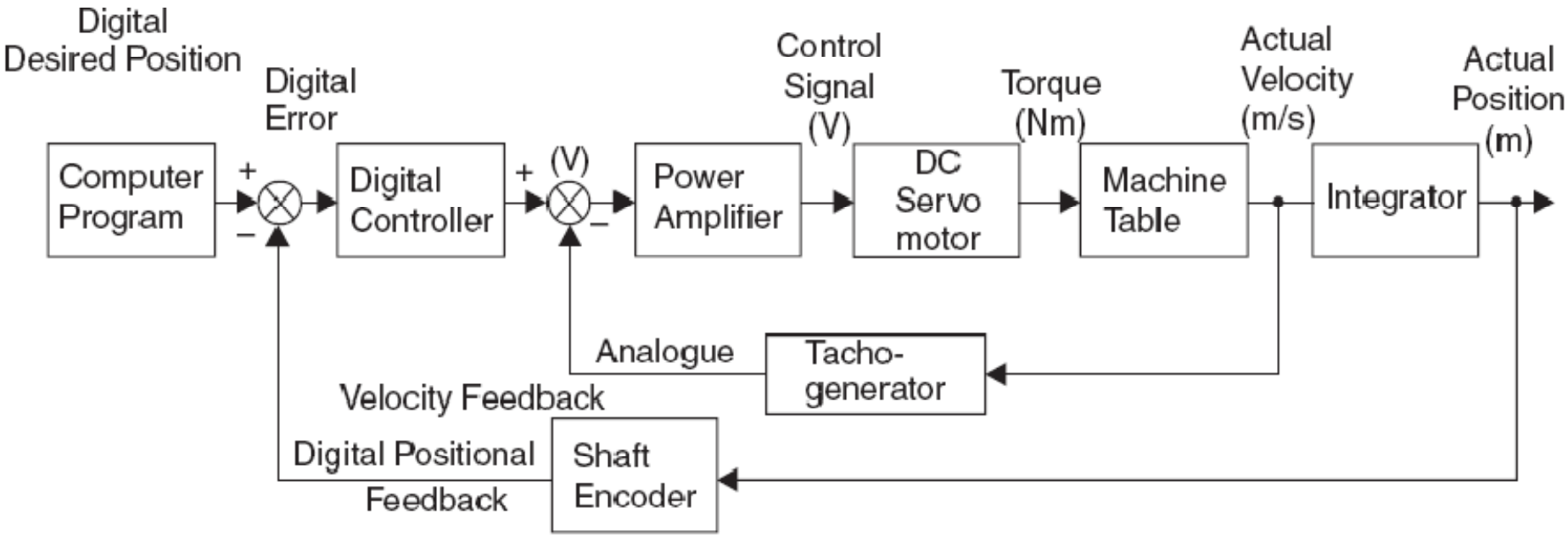
Block diagram of pitch angle control system



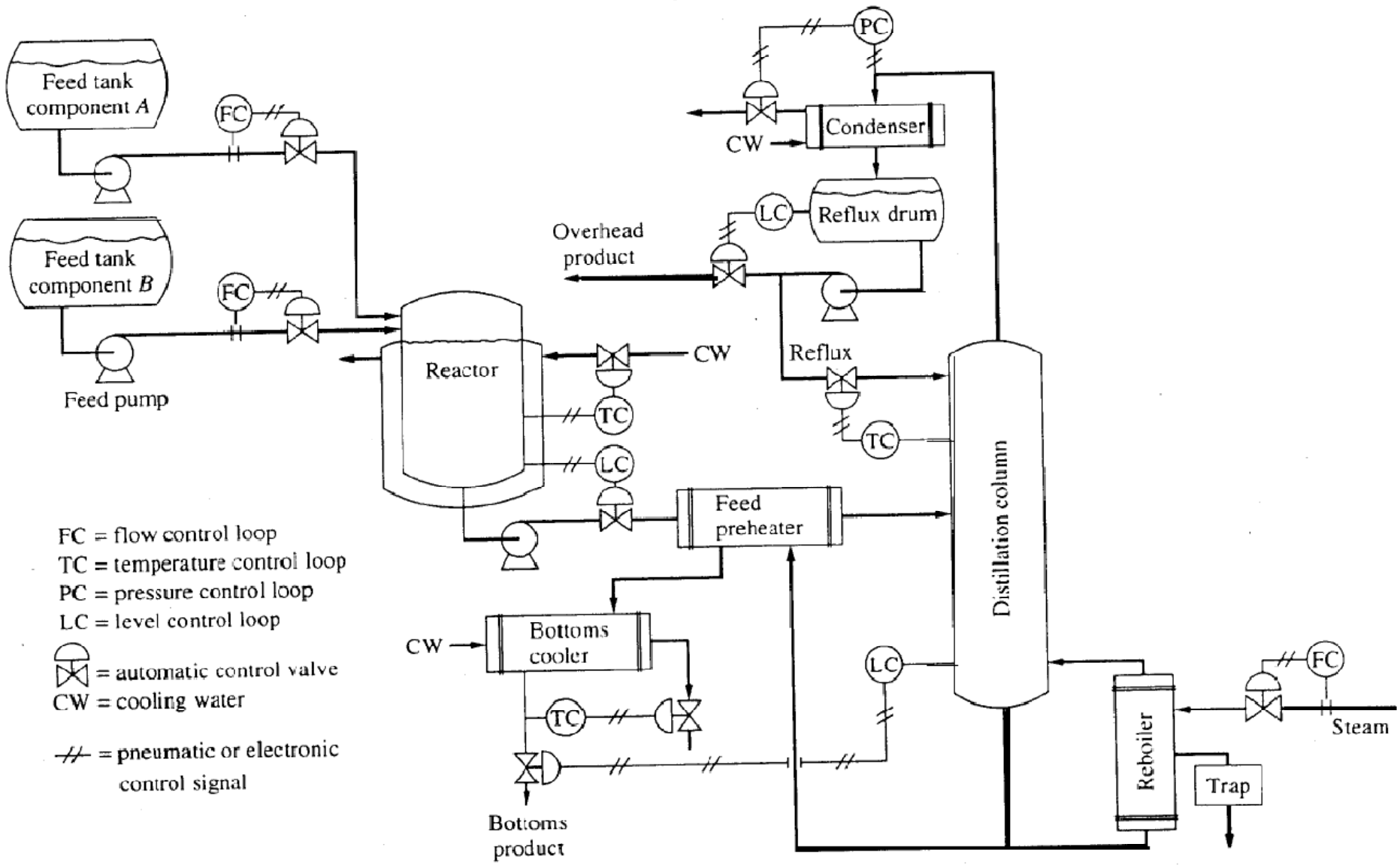
CNC diagram


Computer
Controller
Computer
Program
Digital
Controller
Machine Table Movement
Shaft
Encoder
DC-Servomotor
Lead-Screw
Bearing
Power
Amplifier
Tachogenerator
Digital Positional Feedback
Analogue Velocity Feedback

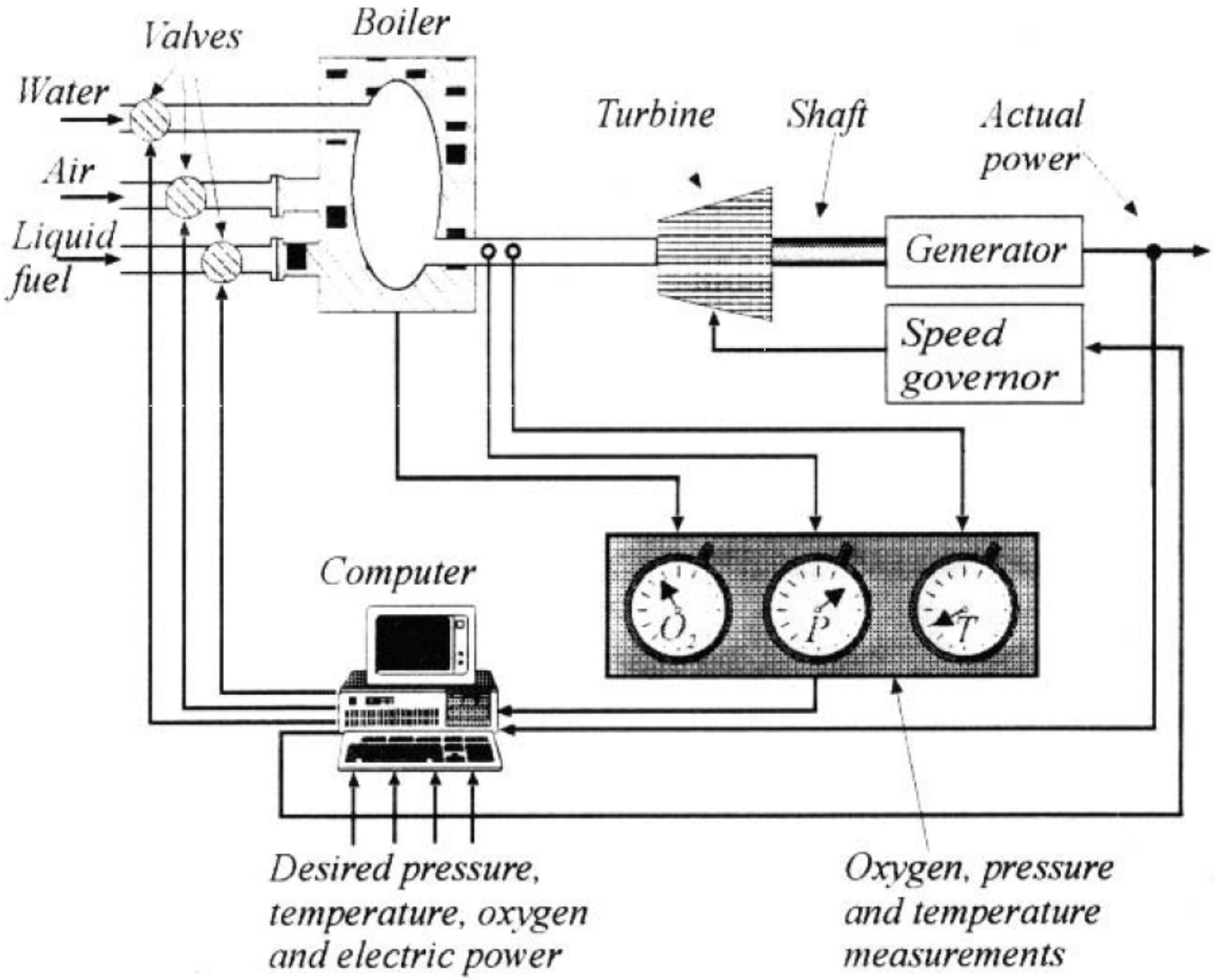
Block diagram of CNC control system



Distillation Process



Steam Power Generator



Review of complex variables and matrix theory

Review

- Complex variables: Appendix B, Feedback Control of Dynamic Systems, Franklin, Powell, and Emami-Naeini, 6th ed., Prentice Hall, 2009
- Matrix theory: Appendix C, Feedback Control of Dynamic Systems, Franklin, Powell, and Emami-Naeini, 6th ed., Prentice Hall, 2009