Industrial Automation

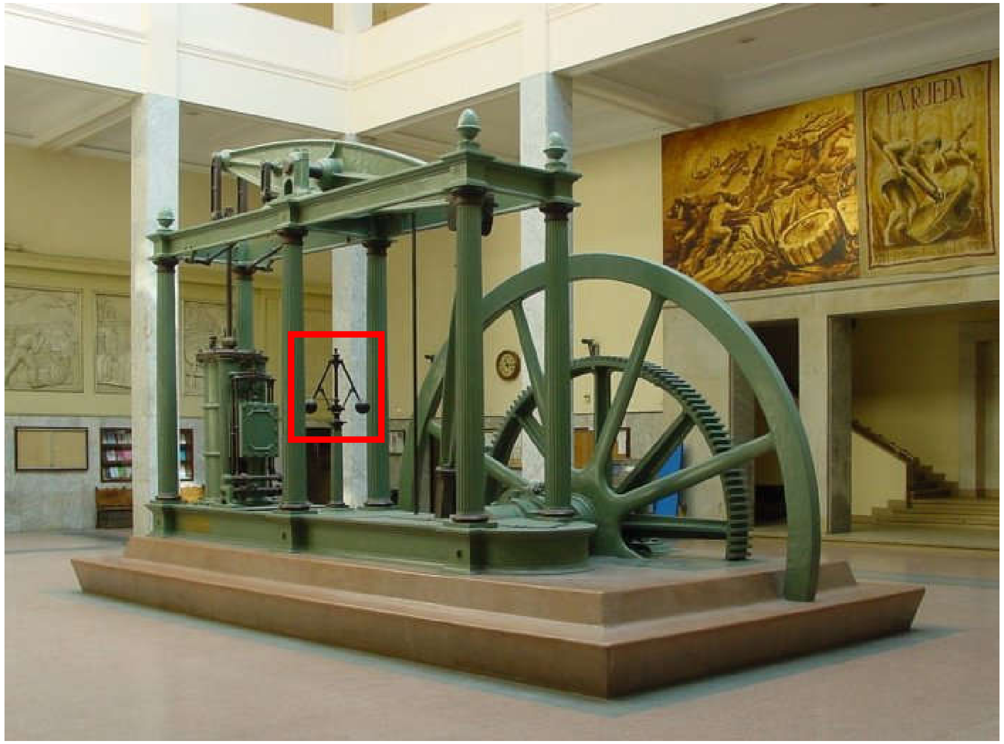
(Automação de Processos Industriais)

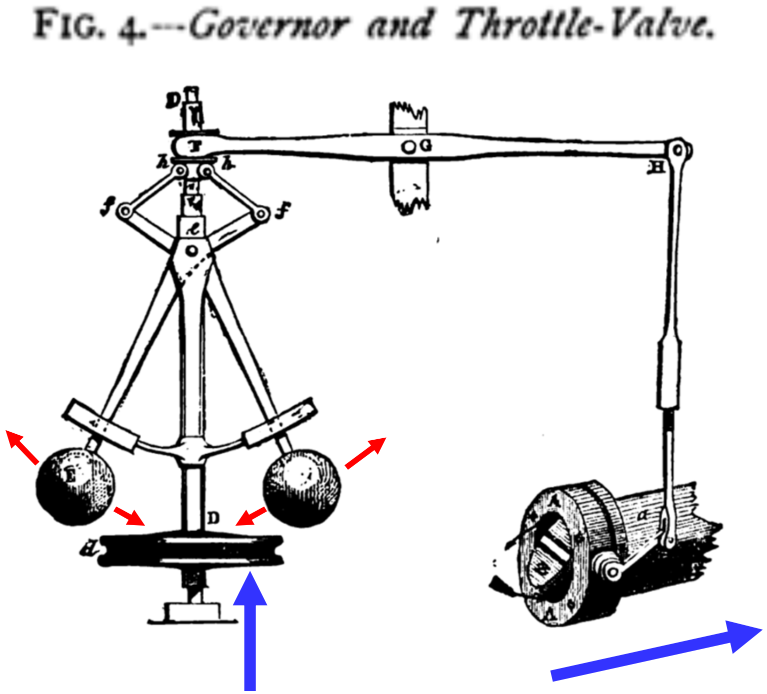
http://users.isr.ist.utl.pt/~jag/courses/api1920/api1920.html

Prof. Paulo Jorge Oliveira, original slides

Prof. José Gaspar, rev. 2019/2020

Industrial Revolution 1760/80 – 1820/40 (historians E. Hobsbawm, T. S. Ashton)



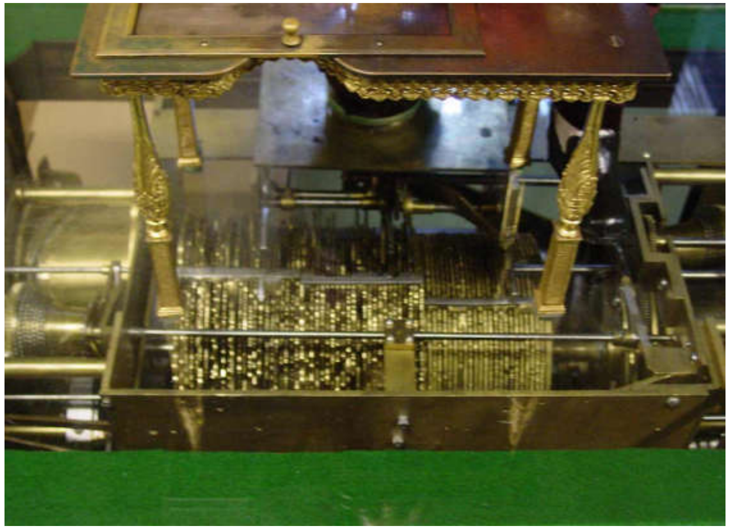


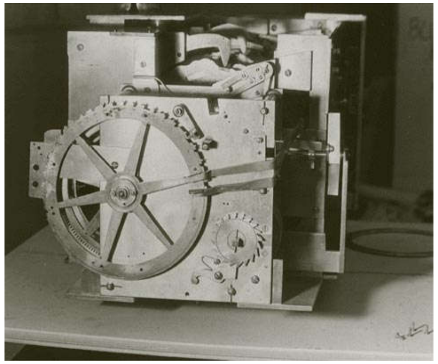
Air pressure implies proportional rotation (desired small flow)

Out flow regulates air pressure.

Steam engine and detail of the governor, James Watt's [Wikipedia].

A jewel: Maillardet's Automaton, 18th century, the largest known mechanical memory

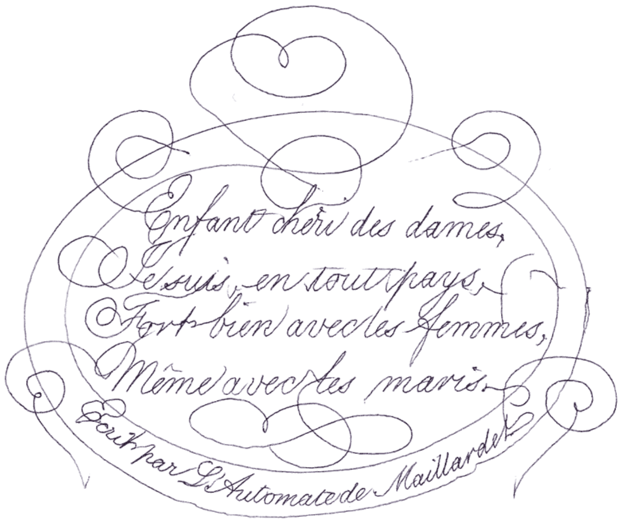


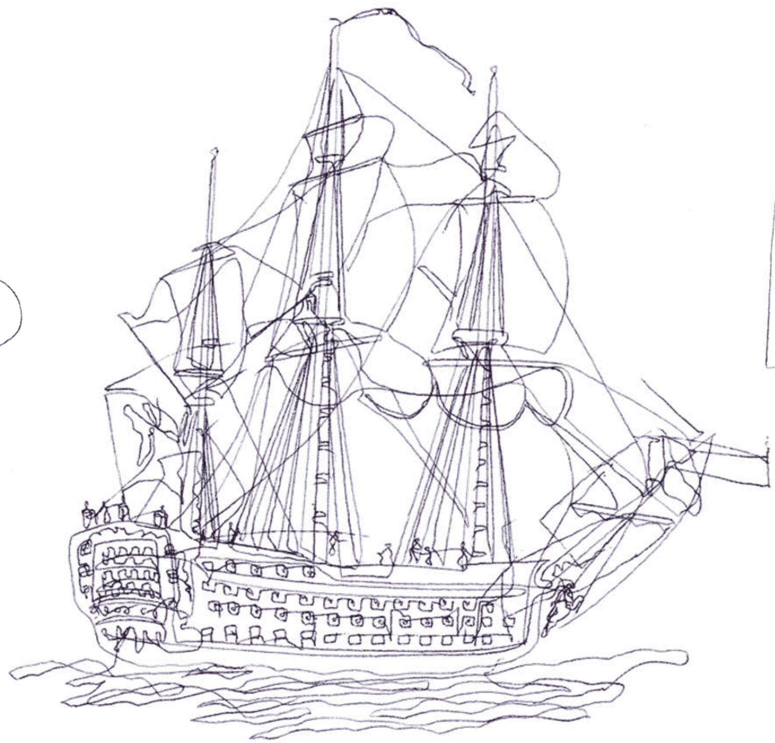


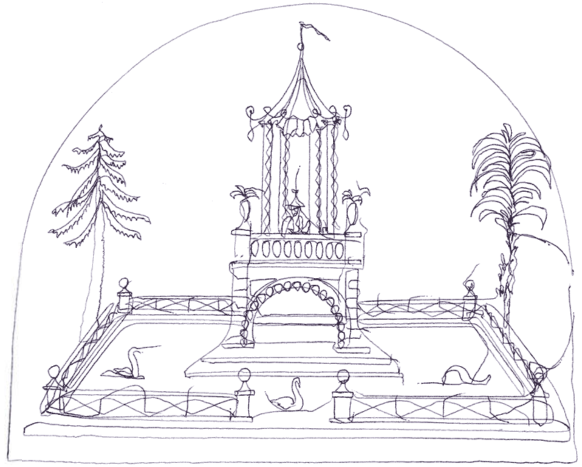
https://www.fi.edu/history-automaton

Maillardet's Automaton, 18th century: the largest known mechanical memory

Four drawings and three poems

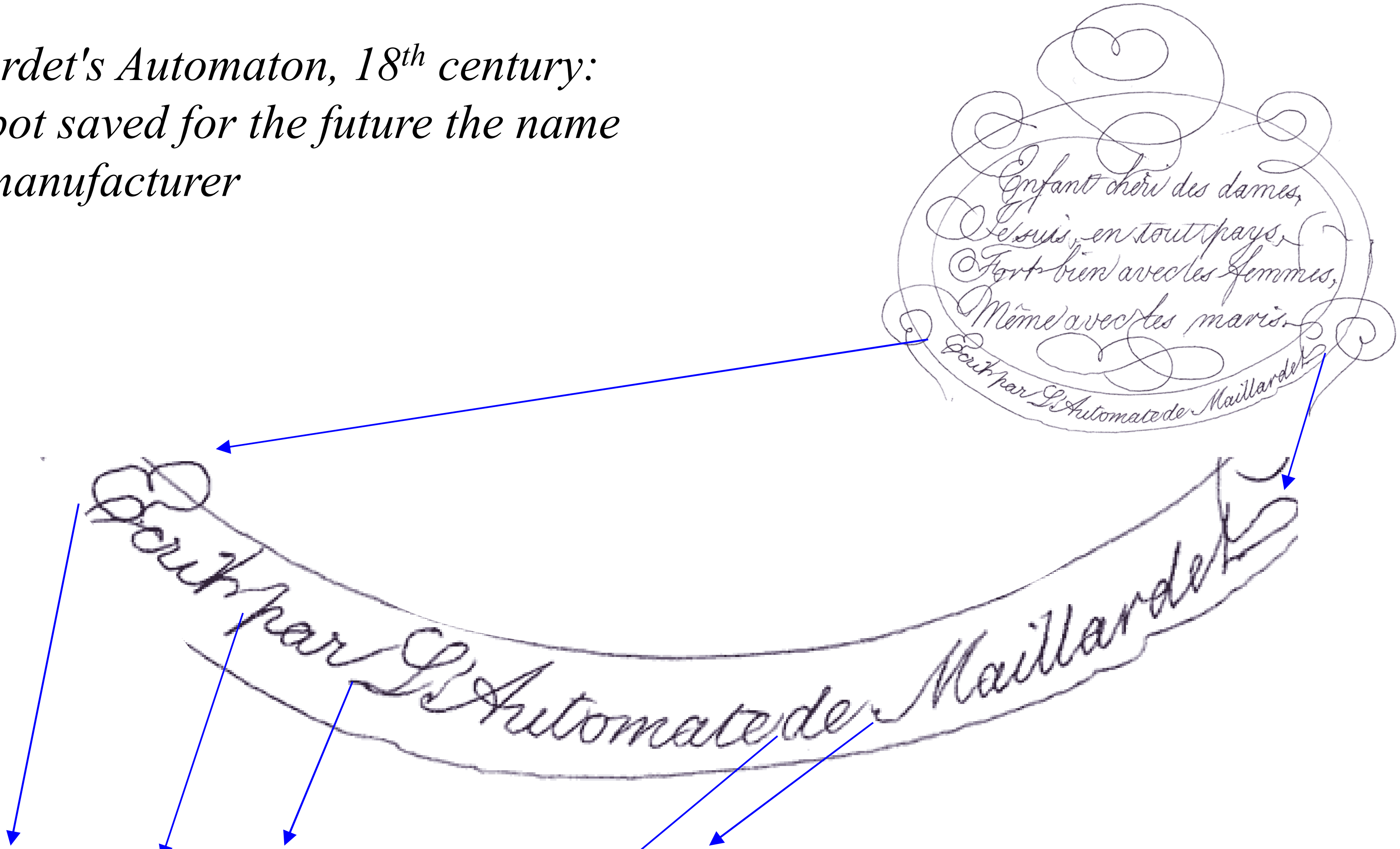






https://www.fi.edu/history-automaton

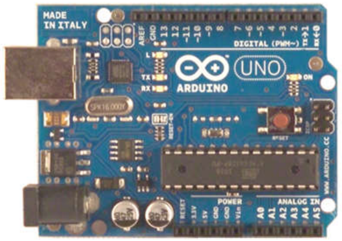
Maillardet's Automaton, 18th century: the robot saved for the future the name of its manufacturer



Ecrit par L'Automate de Maillardet

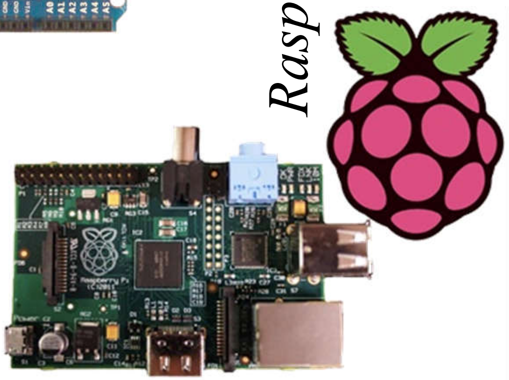
https://www.fi.edu/history-automaton

Microcontrollers

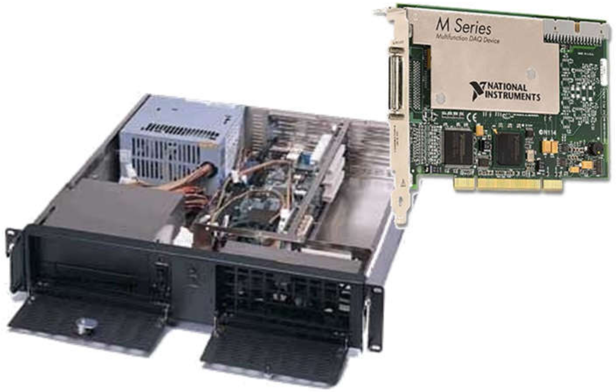


Arduino

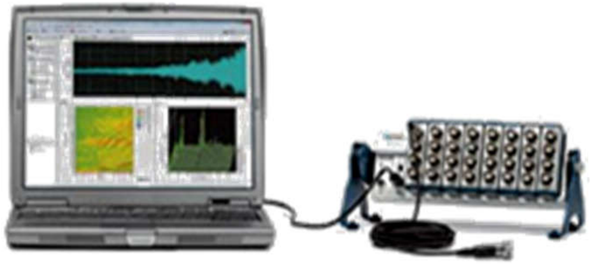
Raspberry-pi



Computer + IO

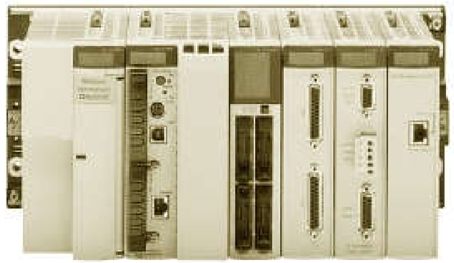


National Instruments AD/DA



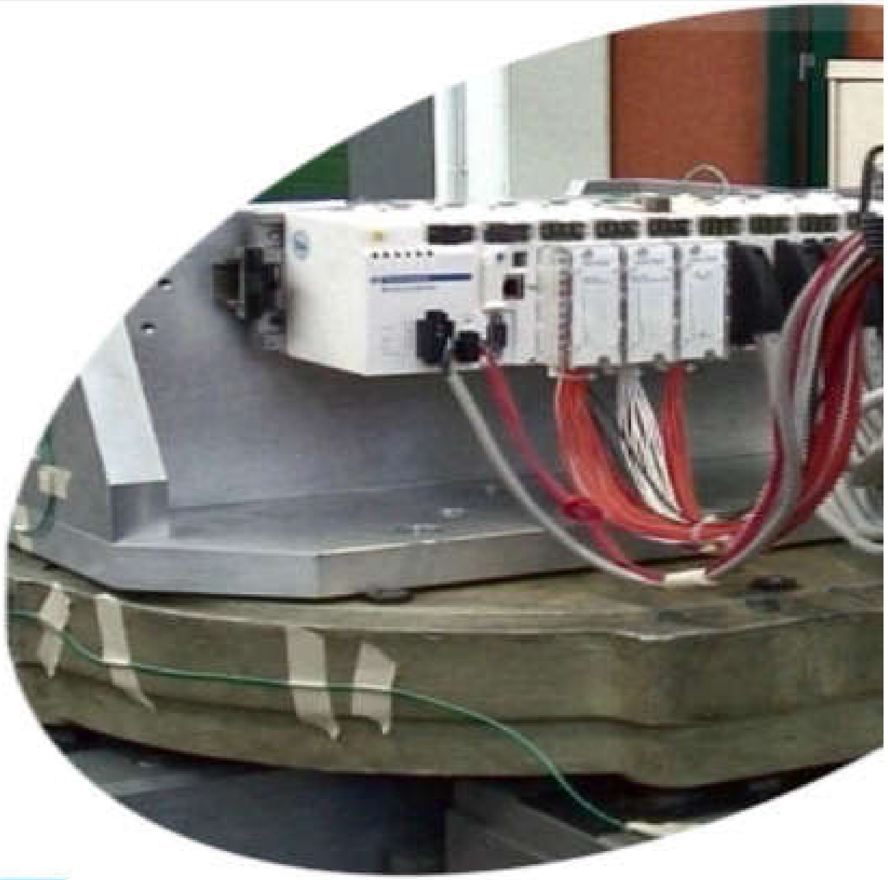
PLC

Premium P57



Many options for controlling real world devices! Why PLCs?

Robustness is not an Option



a brand of Schneider Electric

Telemecanique

Objectives of the course:

- ***Analysis*** *of systems for industrial automation.*
- *Methodologies for the* ***implementation*** *of solutions in industrial automation.*
- *Programming* ***languages*** *of PLCs (Programmable Logic Controllers).*
- *CAD/CAM and Computerized Numerical Controlled (CNC) machines.*
- ***Discrete Event Systems*** *Modeling.*
- ***Supervision*** *of Processes in Industrial Automation.*

Program at a glance:

1. Introduction to Automation [1 week]
Introduction to components and methodologies.

2. Introduction to PLCs [2 weeks]
Components of Programmable Logic Controllers (PLCs). Architecture, functional structure, IO.

3. PLCs Programming Languages [2w]
Standard languages (IEC-1131-3): Ladder Diagram; Instruction List and Structured Text.

4. GRAFCET (Sequential Function Chart) [1 week]
Norm, elements of the language, modelling.

5. CAD/CAM and CNC Machines [1 week]
Types of Computerized Numerical Controlled machines. Interpolation of trajectories. Flexible fabrication cells.

6. Discrete Event Systems [1 week]
Modeling of discrete event systems (DESs). Automata. Petri networks. State and dynamics of PNs.

7. Analysis of DESs [2 weeks]
Properties of DESs. Methodologies for the analysis: reachability graph and matricial equation.

8. DESs and Industrial Automation [1week]
Relations GRAFCET / Petri networks. Analysis of industrial automation solutions as DESs.

9. Supervision of Industrial Processes [2w]
Methodologies for supervision. SCADA. Synthesis based on invariants. Examples of application.

Assessment and grading:

- *2 Preliminary laboratory assignments - training purposes (0% of the final grade).*
- *2 Laboratory assignments (20%+20% of the final grade). Groups of 3 students.*
- *1 Seminar (20% of the final grade). Topics to be selected with each group.*
- *1 Exam (40% of the final grade).*

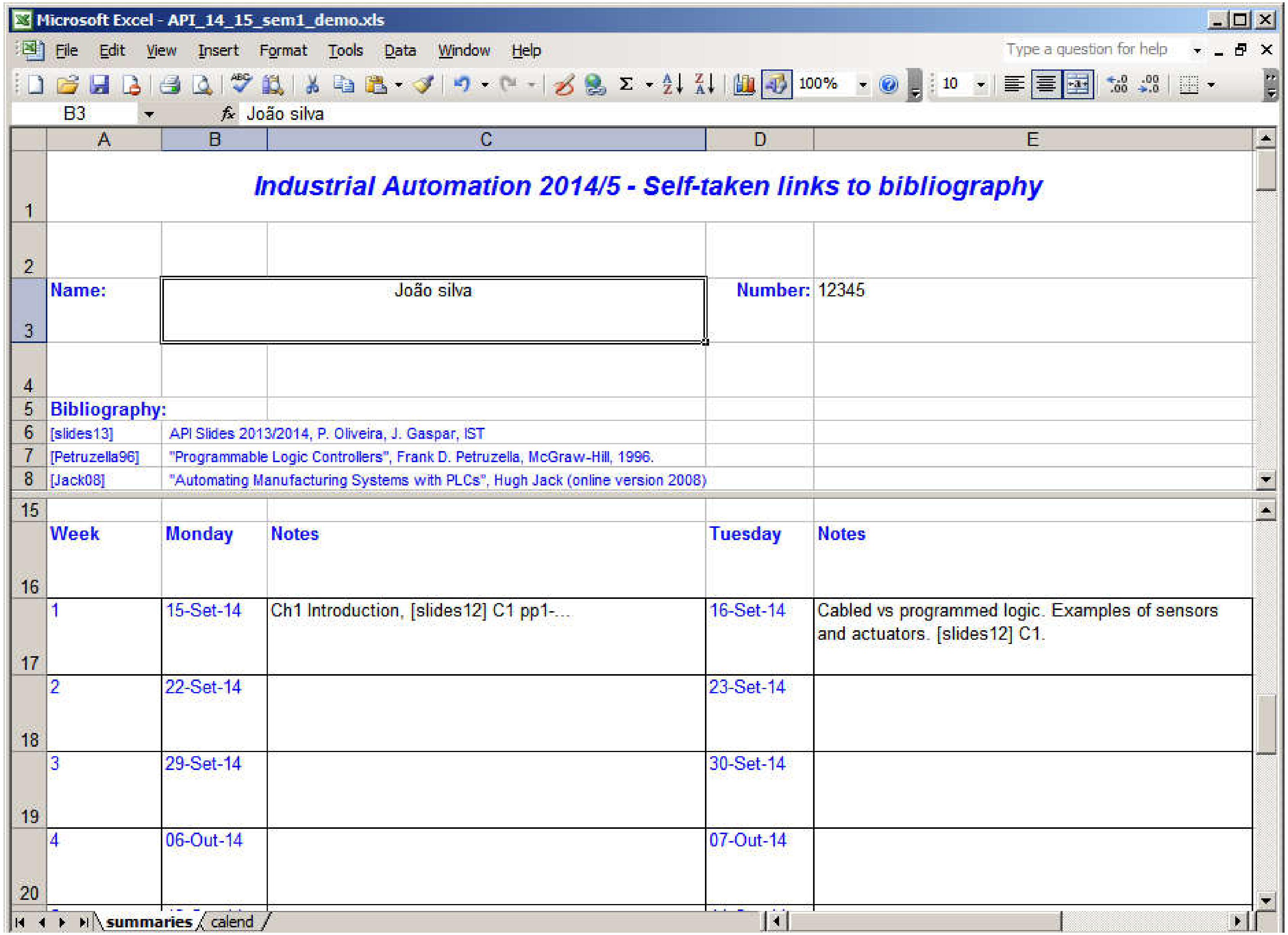
  Upon student choice, the second exam can be oral.

- *Minimum grade: 9.0/20.0 val. in each component.*

One extra value for students attending more than 70% of recitations and do short summaries of the classes.

Assessment and grading:

Short summaries of the classes



Download this XLS file from the webpage of the course.

Schedule (semester view, laboratories & exam):

Lab. registration [1]	First week
1st preliminary lab.	1 week
2nd preliminary lab.	1 week
1st lab. assignment	3 weeks
2nd lab. assignment	3 weeks
3rd lab. assignment	0.5h seminar (one date >= week 8) *20min presentation + 10min discussion*
Exams (do at least one)	3h, **08Jun** or **06Jul** 2020

[1] *Important: define the students' representative*

Schedule (week view, see also IST-GOP / fenix):

- Recitation classes

Monday	15.30 h – 17.00 h	Ea3
Friday	15.30 h – 17.00 h	Ea5

- Lab. Classes (once per week, choose one shift)

1st shift Monday	17.00h – 18.30h	LSDC4 (room 5.21)
2nd shift Thursday	09.30h – 11.00h	LSDC4 (room 5.21)
3rd shift	*to schedule if needed*	LSDC4 (room 5.21)

- Groups registration for the Laboratory

Bibliography :

--- References mostly found in the slides :

• **Automating Manufacturing Systems with PLCs**, Hugh Jack (available online).

• **Programmable Logic Controllers,** Frank D. Petruzella, McGraw-Hill, 1996.

• **Petri Net Theory and the Modeling of Systems**, James L. Peterson, Prentice-Hall,1981.

• **Supervisory Control of Discrete Event Systems**, Moody and Antsaklis, Kluwer Academic Publishers, 1998.

• **Discrete Event systems: Modeling and Performance Analysis**, Christos Cassandras, Aksen Associates, 1993 (newer book in 2008).

--- More references :

• **Computer Control of Manufacturing Systems**, Yoram Koren, McGraw Hill, 1986.

• **Petri Nets and GRAFCET: Tools for Modeling Discrete Event Systems**, R. David, H. Alla, New York : Prentice Hall Editions, 1992.

• **Supervisory Control of Concurrent Systems: A Petri Net Structural Approach**, Marian V. Iordache, Panos J. Antsaklis, Birkhauser, 2006

• **Modeling and Control of Discrete-event Dynamic Systems with Petri Nets and other Tools**, Branislav Hruz and MengChu Zhou, 2007.

• **Técnicas de Automação**, João R. Caldas Pinto, Lidel Ed. Técnicas Lda, 2010 (3ª Edição)

Industrial Automation

(Automação de Processos Industriais)

Introduction to Automation

http://www.isr.ist.utl.pt/~jag/aulas/api1920/api1920.html

Prof. Paulo Jorge Oliveira, original slides
Prof. José Gaspar, rev. 2019/2020

Industrial Automation is Necessary and is Happening

Consistent **production growth** in the last three centuries (since the Industrial Revolution)[1].

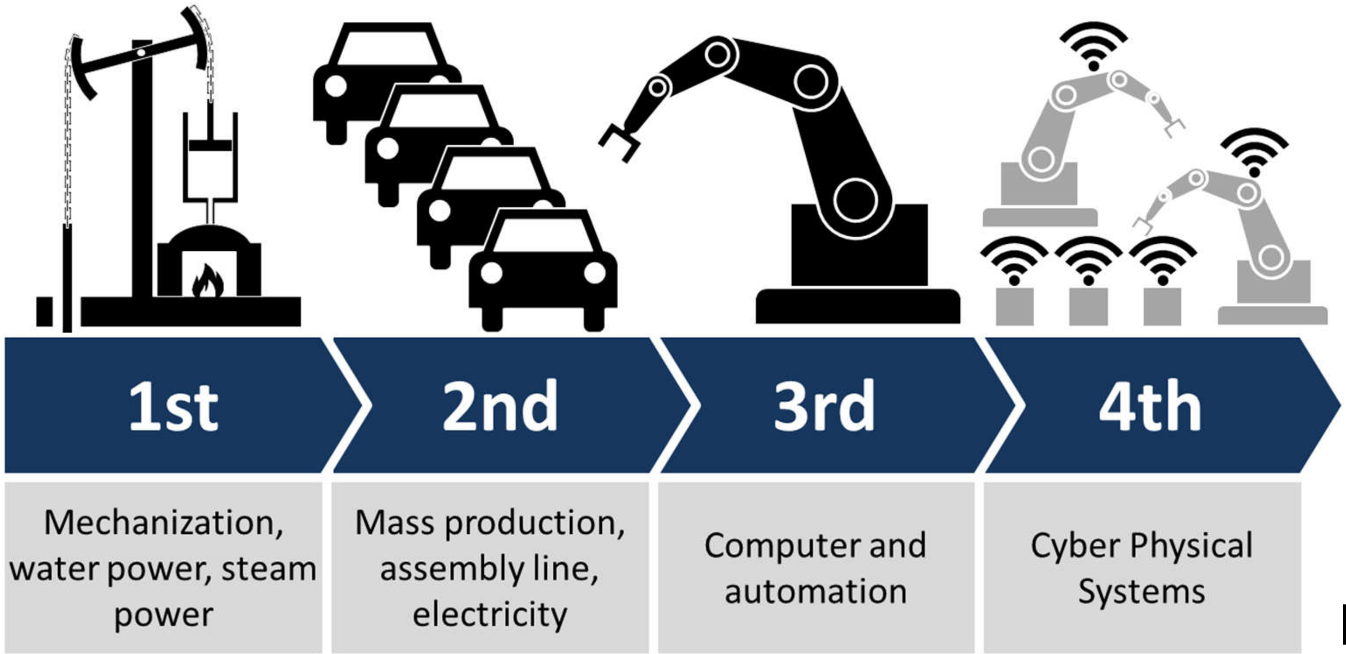
The production of **increasing amounts** of goods requires the storage and handling of large quantities of resources.

Need to use **automatic tools and systems**.

Automation was fostered by the invention of computers.

[1] Motivated by the continuous growth of the world population and migration to cities.

Industrial Automation - Industry 4.0



[Wikipedia]

1760-1840 Industrial Revolution

1913 Assembly line by Henry Ford

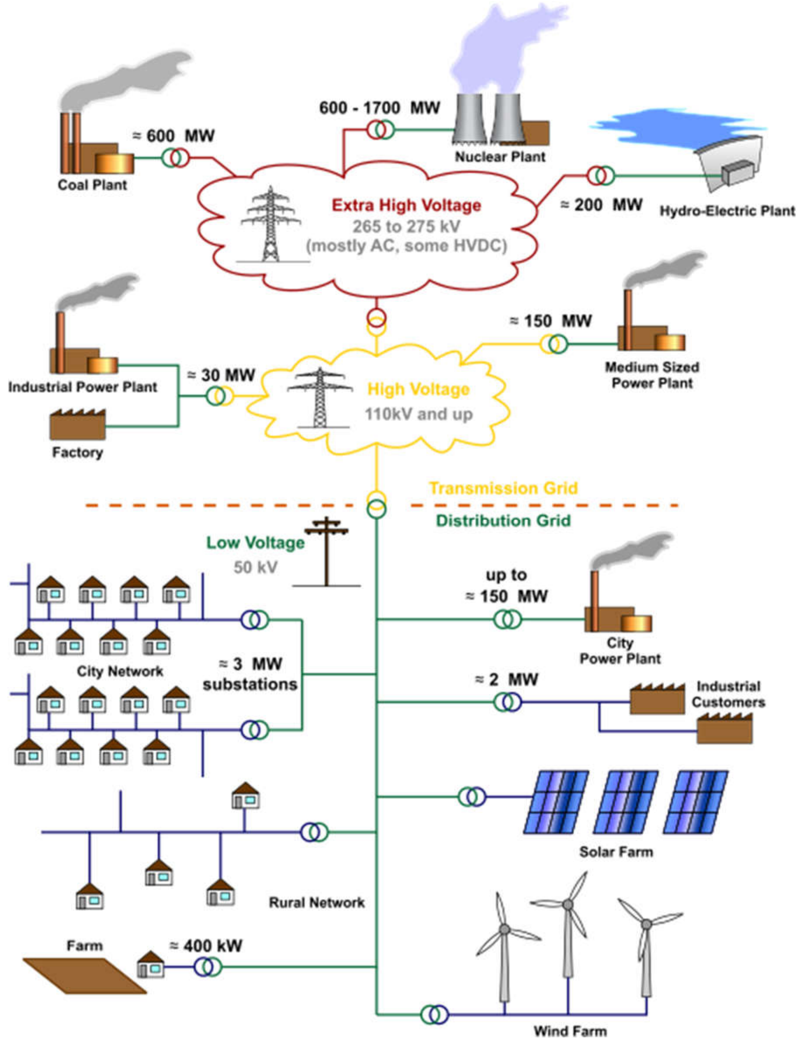
1955 NC/CNC 1968 Bedford / GM PLC

2011 Industry 4.0 term revived at the Hannover Fair

1807-1811 *French invasions, 1821 Independence of* ***Brasil***
1974-1975 *Independence of Guiné-Bissau, Moçambique, Cabo Verde, São Tomé e Príncipe,* ***Angola***

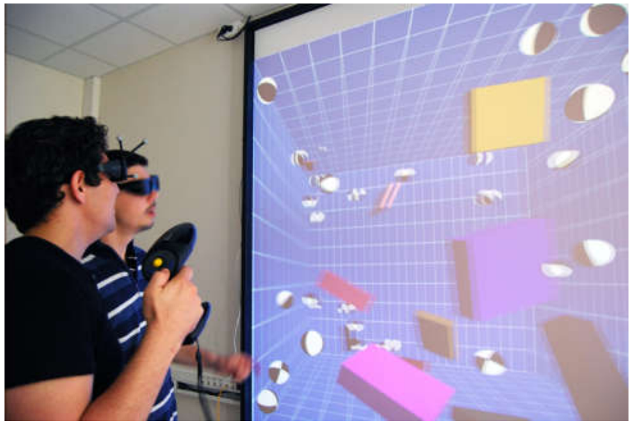
Industrial Automation - Industry 4.0

Cyber physical systems, Internet of things (IoT) and Visual computing



https://en.wikipedia.org/wiki/Electric_power_distribution

https://medium.com/datadriveninvestor/the-internet-of-things-90263f7b1249



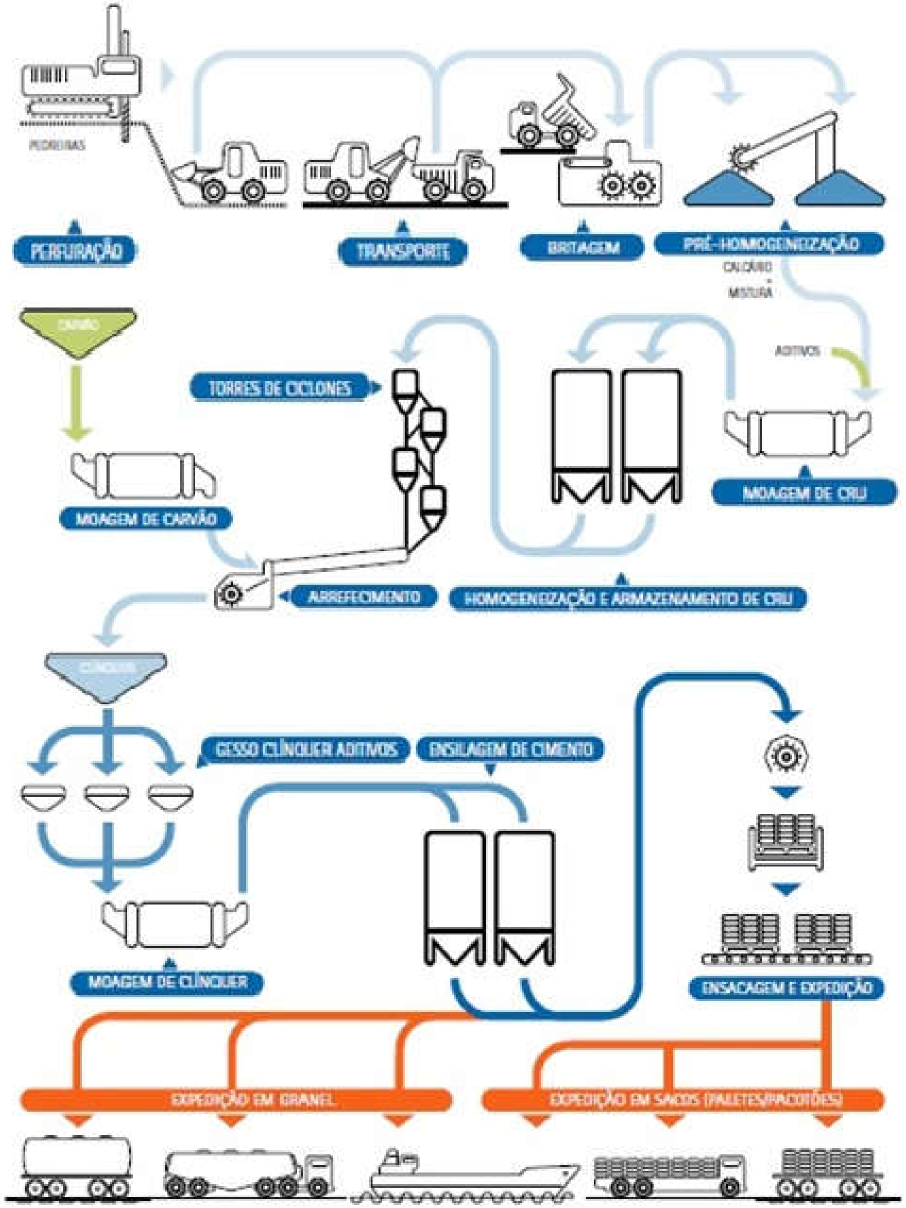
https://eisti.fr/en/formation/visual-computing-option

Industrial Process:

Making Cement

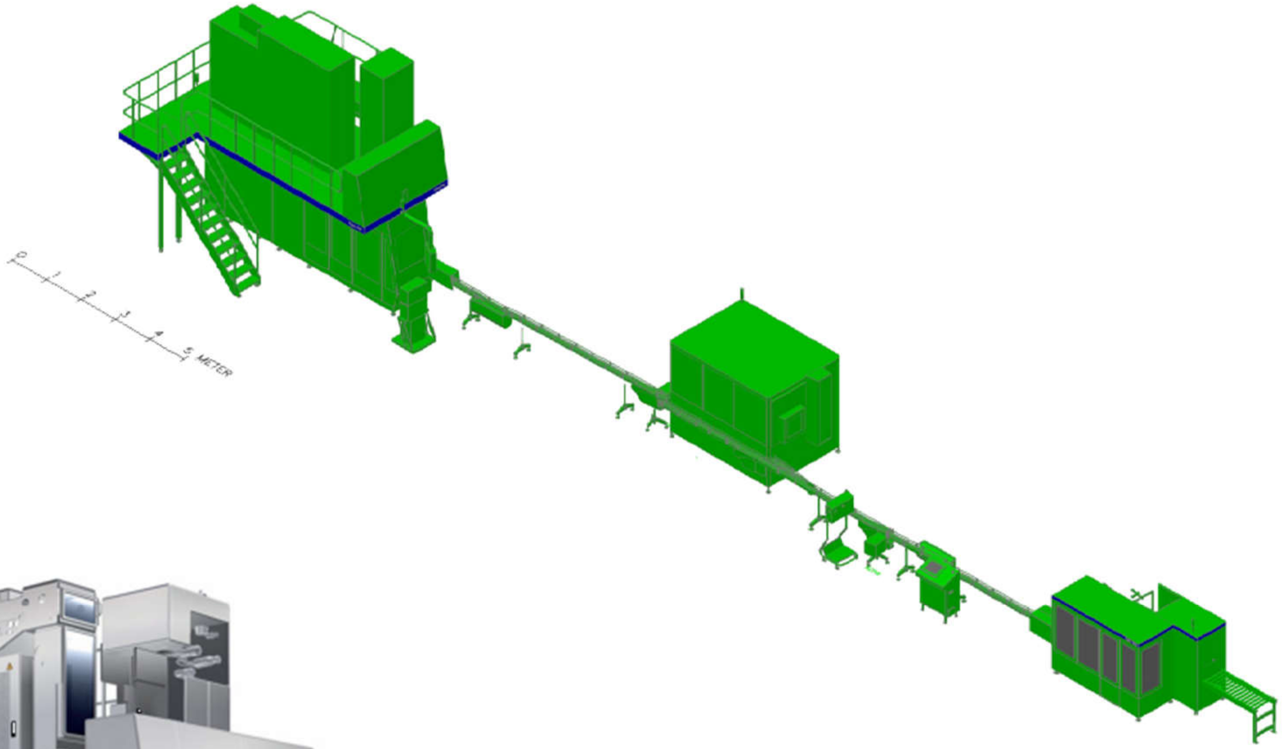
[Outão / Setúbal / Portugal]

Some systems are very ***large and complex*** *but still need to "work like a clock"*



Industrial Process:

Tetra Pak / Parmalat

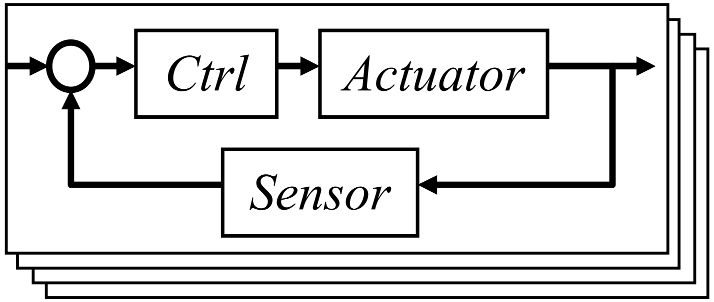


*Complexity handled with **modularity**.*
Filling machine, complete line:

- *200 ml slim 20000 TP/h*
- *Straw Applicator*
- *Beverage Carton Film Wrapper*
- *Conveyors*
- *Carboardpacker*

Complex Systems based on Local and Global Controllers

Subsystem +Subsystem +Subsystem + … + Global Controller = Automated Industrial Process



Other courses as e.g. Control

Subsystems sequencing, synchronization, …

Start and stop digital (binary) signals and events.

The subject of this course.

Ch. 1 – Introduction to Automation [1 week]

1.1 Introduction to **components** in industrial automation.

1.2 **Cabled** logic versus **programmed** logic versus **networked** logic.

1.3 Introduction to **methodologies** for problem modeling. Methodologies of work.

1.1 Components used in industrial automation

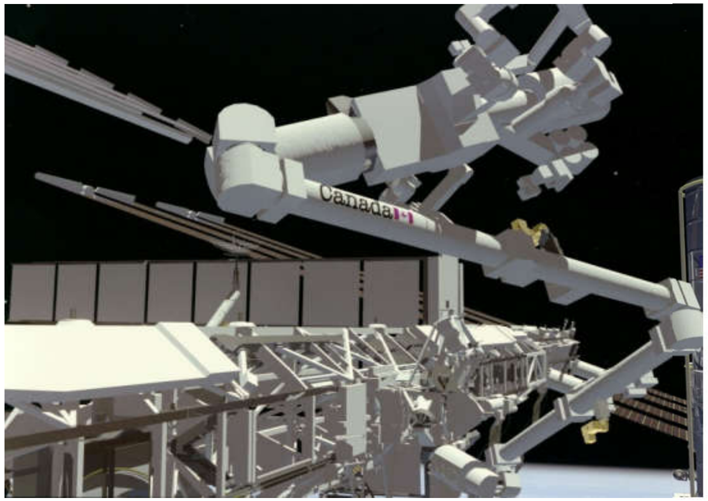
Robotic Manipulators
– generic load, unload, handle, work

Computerized CNC Machines
– specialized workers

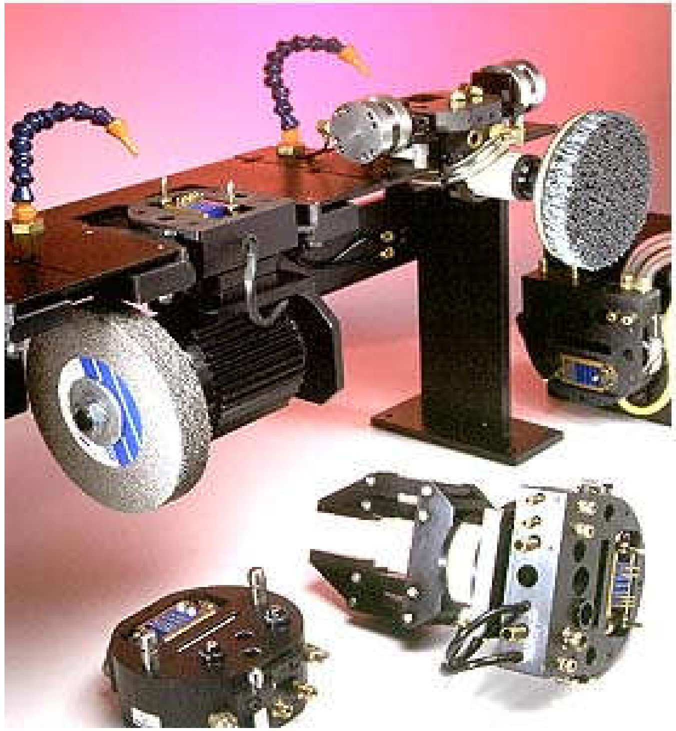
Handling materials
– specialized load and unload

How it is done:
– Low level actuation and sensing
– Motors and sensors, local and global integration

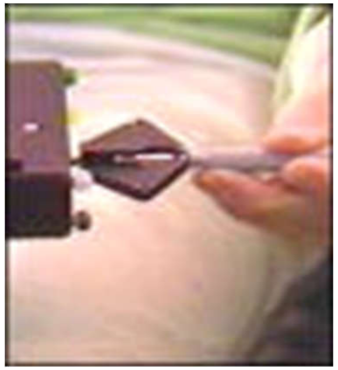
Robotic Manipulators



Robotic Manipulators - End Effectors



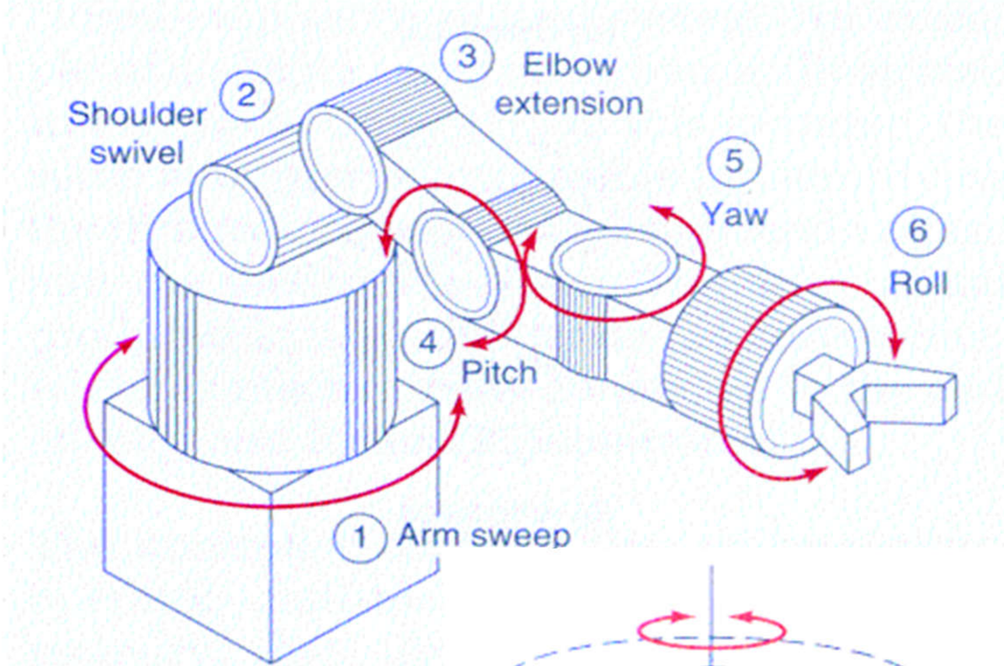





Robotic Manipulators

Major characteristics:

- Number of degrees of freedom
- Types of joints (prismatic/revolution)
- Programming tools and environments (high level languages, teach pendent, ...)
- Workspace
- Accuracy, reliability
- Payload and robustness



Workspace, examples:

- Spherical
- Cylindrical
- …

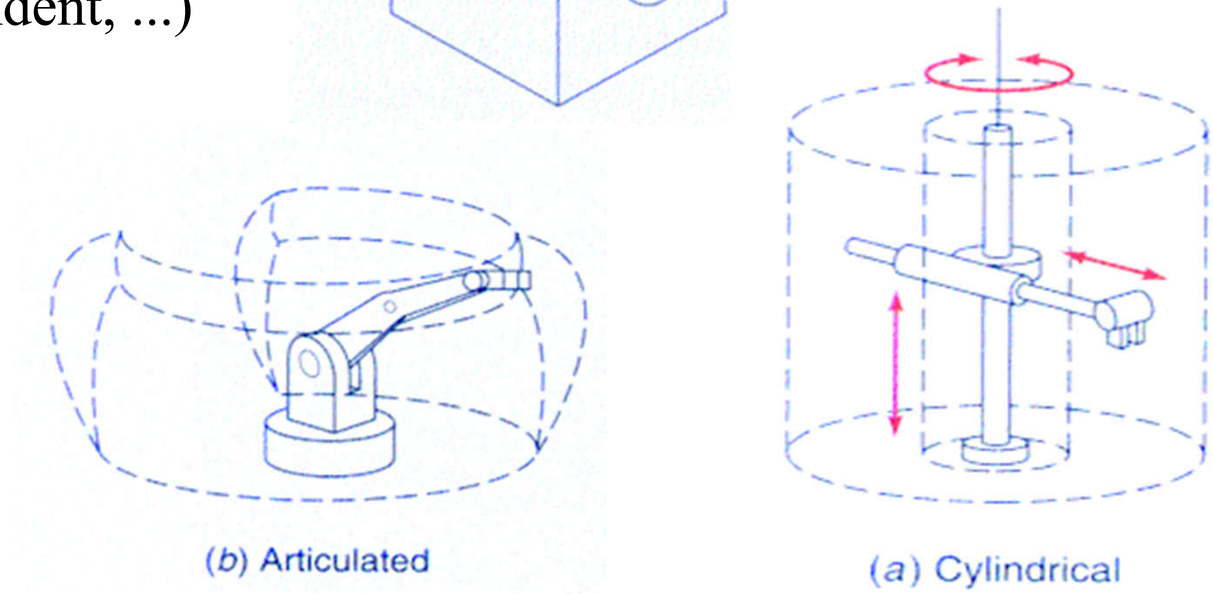
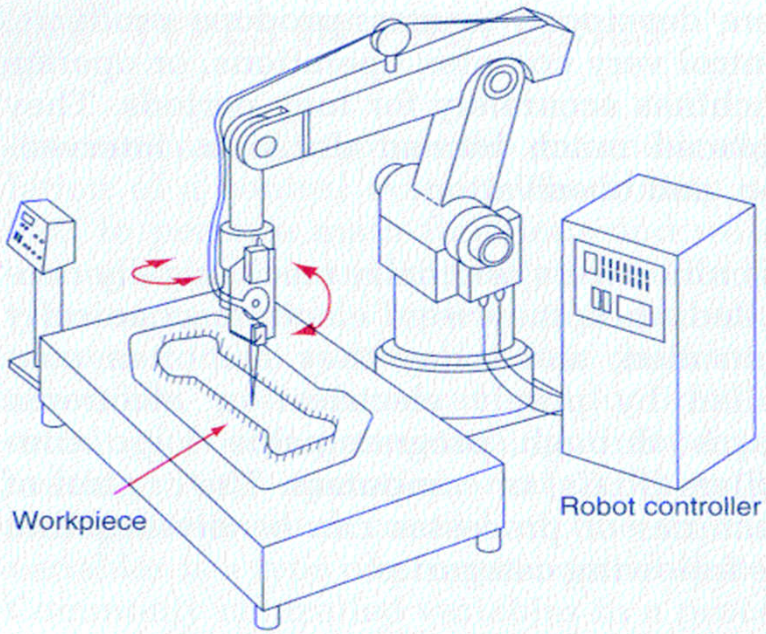


Fig. 15-23 Robot work envelope.

Robotic Manipulators

Central problems to address and solve:

- Direct / Inverse kinematics
- Trajectory generation / Trajectory following
- Coordinate frames where tasks are specified
- Level of abstraction of the programming languages



Industrial robot used in an individual item process

Fig. 14-3
Individual product production.

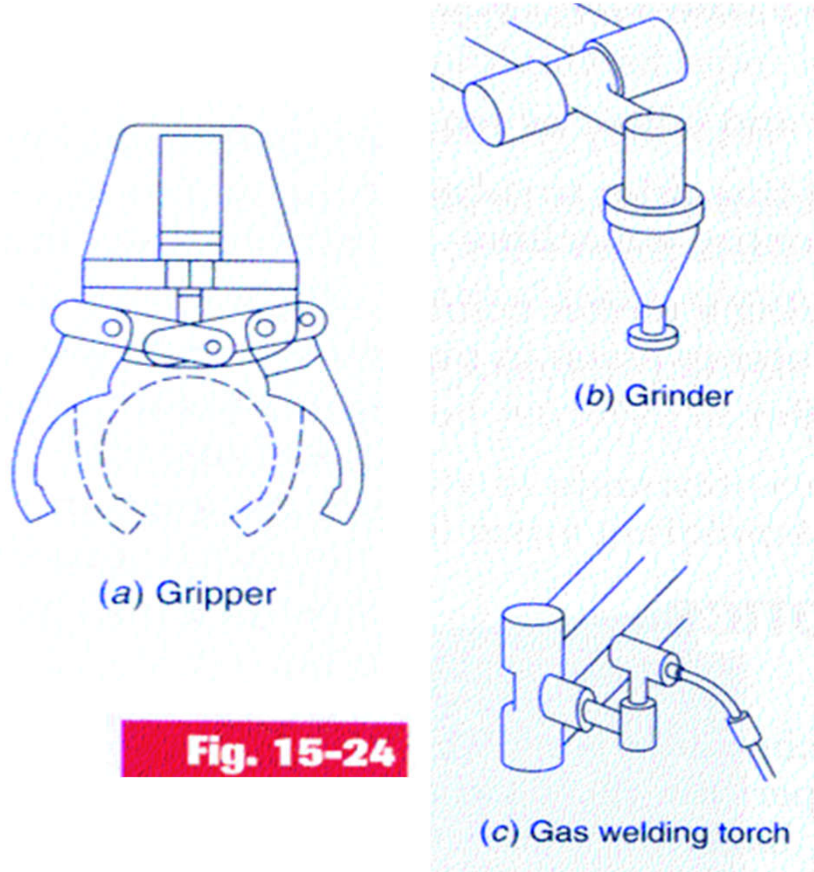


Fig. 15-24

Use in Flexible Cells of Fabrication:

it is required that the manipulators have correct interfaces for the **synchronization** and inputs for **external** commands.

Robotic Manipulators

Riding an ABB IRB 6600 Robot 1 [Youtube]

API Note: please understand the power, and do not do this; keep always the safety!

Computerized Numerical Controlled (CNC) Machines

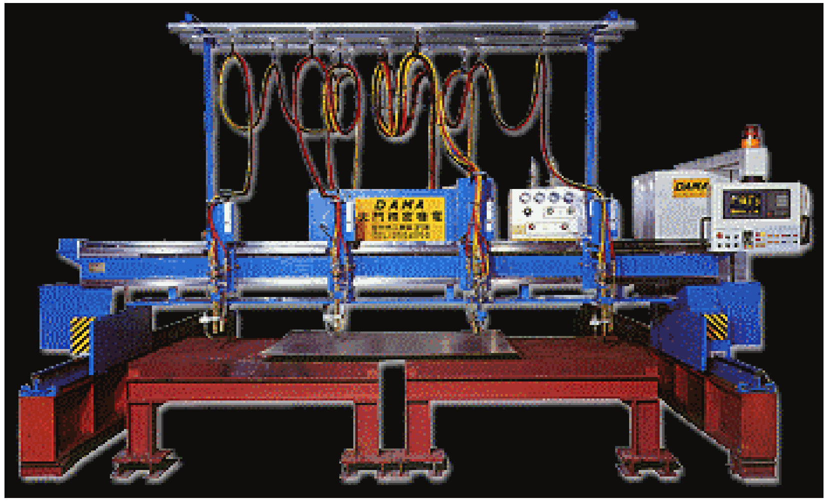
Major characteristics:

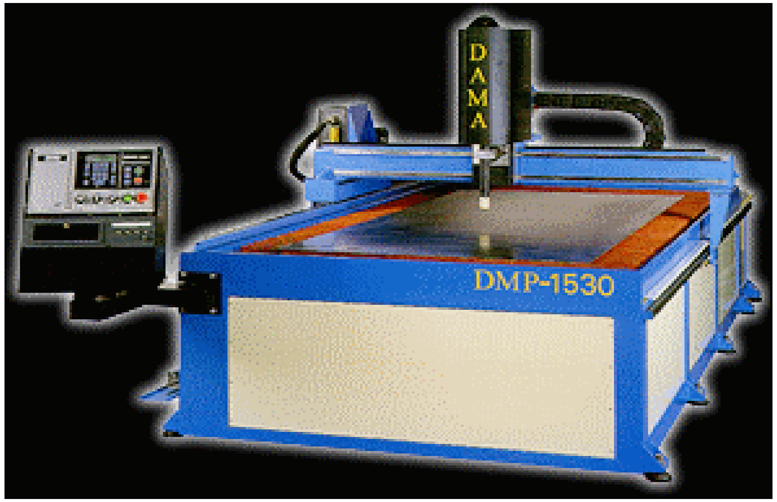
- Number of degrees of freedom
- Interpolation methods
- Load/unload automation, and also in tool change
- Programming (high level languages, teach pendent, ...)
- Workspace
- Accuracy, reliability
- Payload and robustness
- Interface
- Synchronization with exterior

Examples:
Milling, Lathes, ...

MITSUI SEIKI Machining Center

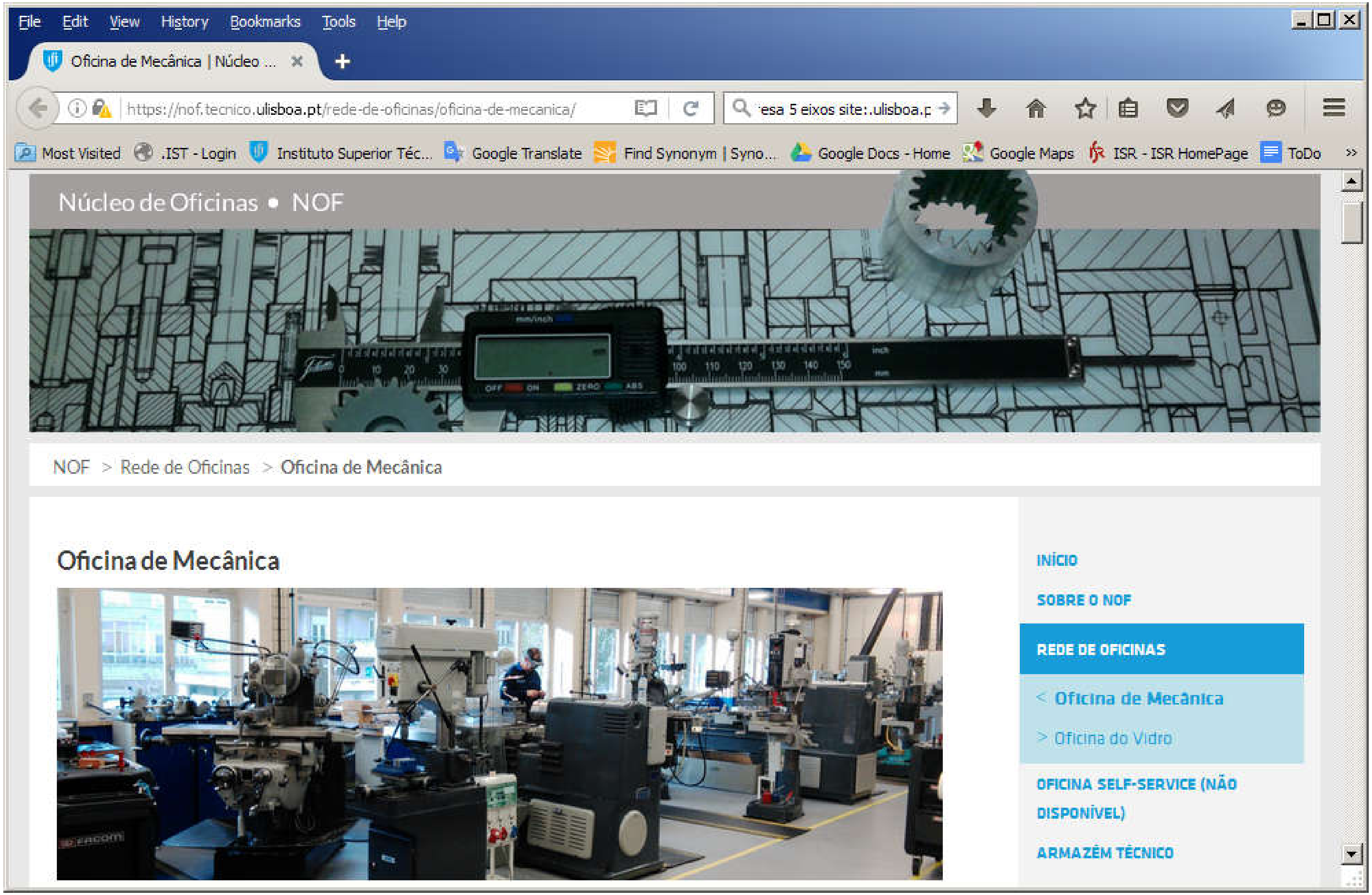
Computerized Numerical Controlled (CNC) Machines





Compact CNC plasma cutting machine
Effective cutting :1.5 m X 3 m
Plasma torch cutting capacity up to 5cm (mild steel), Gas torch option allows up to 10cm.

Computerized Numerical Controlled (CNC) Machines



Solutions for Handling materials

For transport

Major characteristics:

- Load / unload automation
- Accuracy, reliability
- Payload and robustness
- Interface
- Synchronization with exterior

Conveyors, wheels on the ground

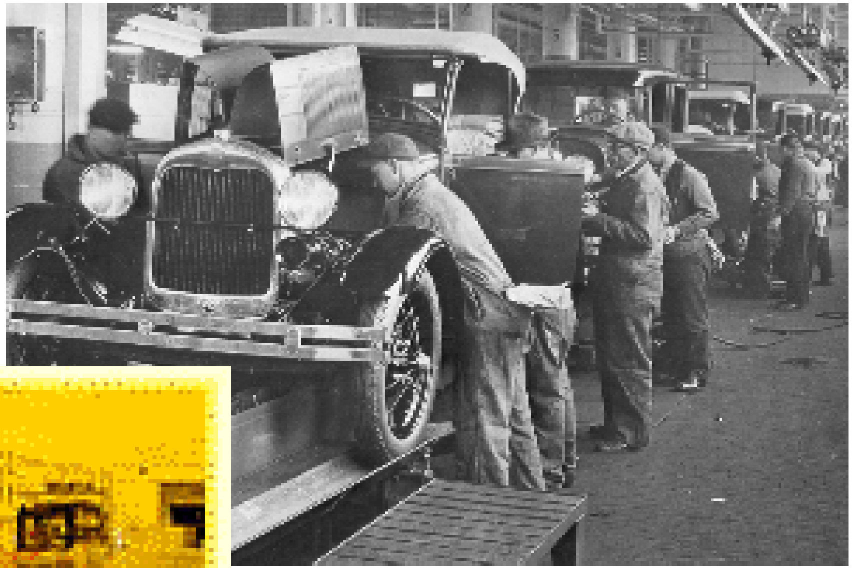
Automatic Guided Vehicles (AGVs)

Major characteristics:

- Load/unload automation
- Accuracy, reliability
- Payload and robustness
- Interface
- Synchronization with exterior

Automatic Guided Vehicles (AGVs)

Example of fleet operating in industry



Automatic Guided Vehicles (AGVs)

Kiva Systems Inc
- warehouse automation
- used by Staples, Toys R Us, ...
- 2012 bought by Amazon ($775 million)

AGVs (Automatic Guided Vehicles)

Kiva Systems Inc, warehouse automation

Ch. 1 – Introduction to Automation [1 week]

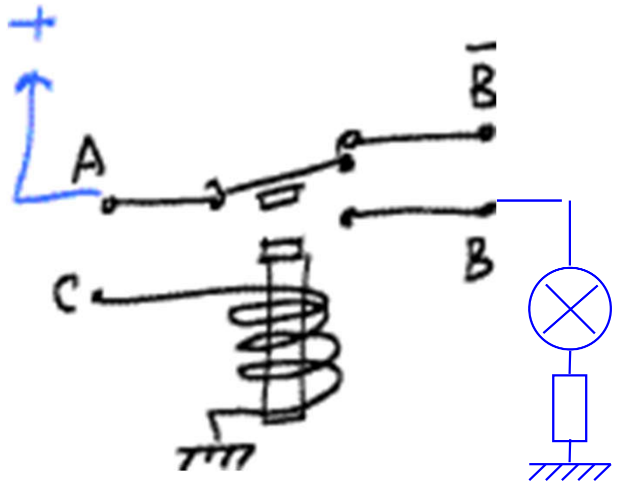
1.1 Introduction to **components** in industrial automation.

1.2 **Cabled** logic versus **programmed** logic versus **networked** logic.

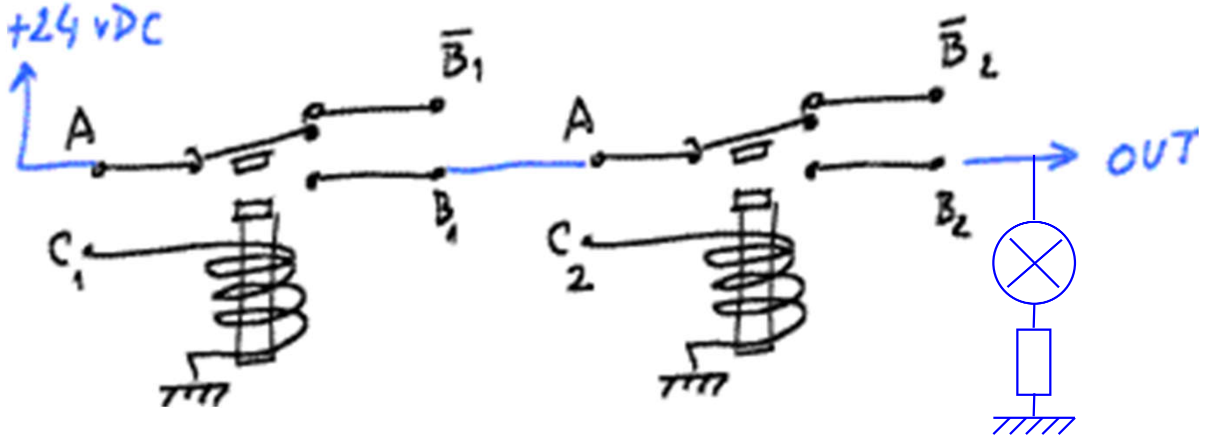
1.3 Introduction to **methodologies** for problem modeling. Methodologies of work.

1.2 Cabled Logic

One Relay



Two Relays making one AND gate

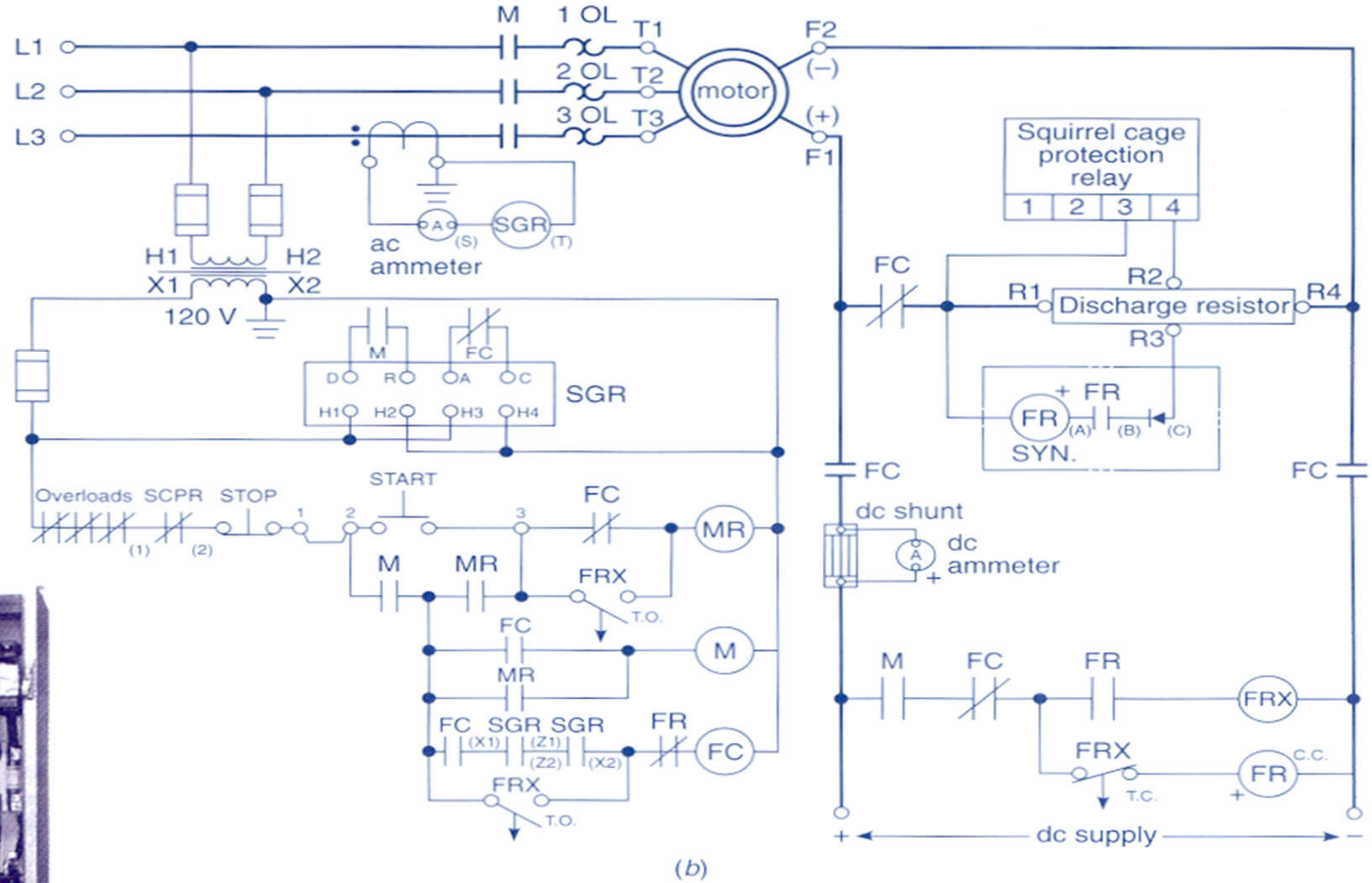


$$B = C$$

$$\overline{B} = \overline{C}$$

$$B_2 = C_1 \wedge C_2$$

1.2 Cabled Logic versus ...



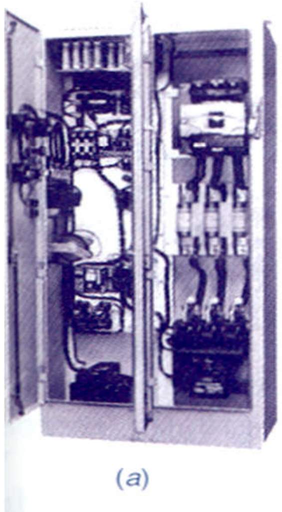
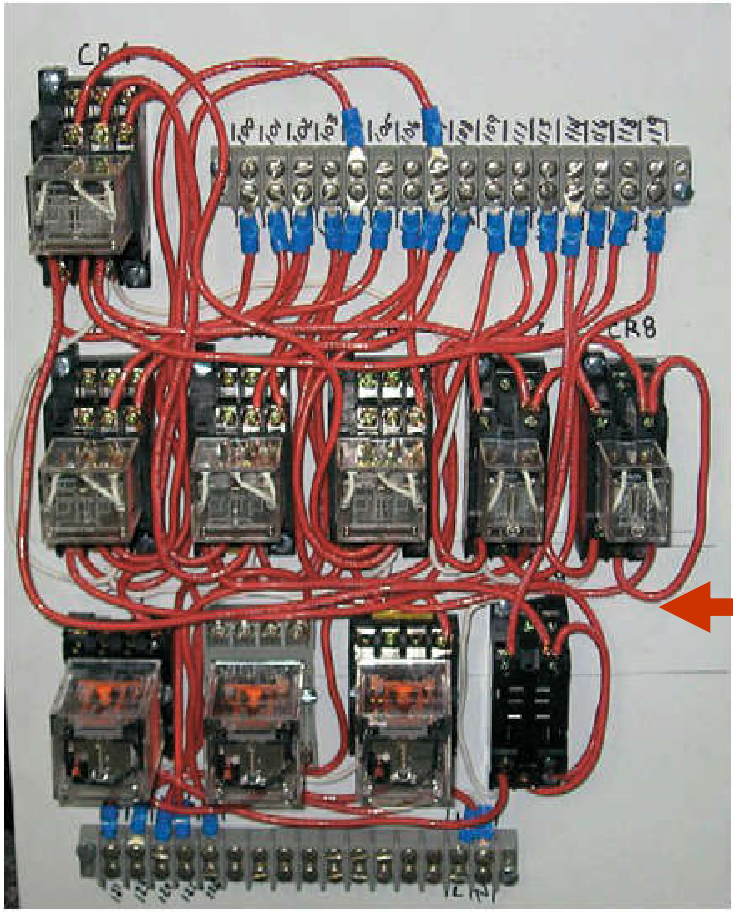


Fig. 1-2
(a) Typical hard-wired controller panel. (b) Typical hardwired diagram. (Courtesy of Allen-Bradley Company, Inc.)

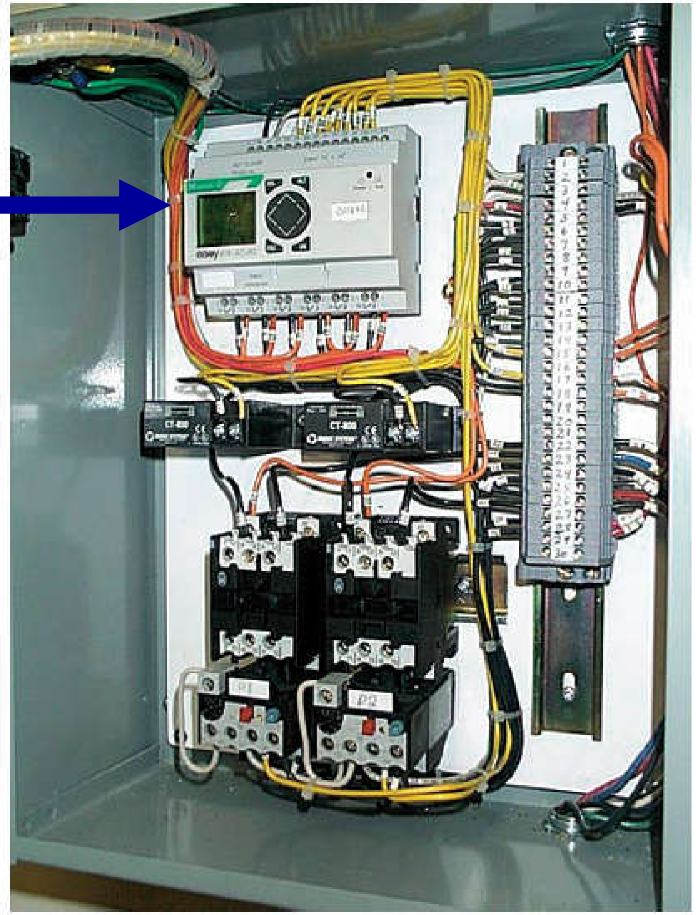
Cabled Logic versus ...

... versus Programmed Logic …

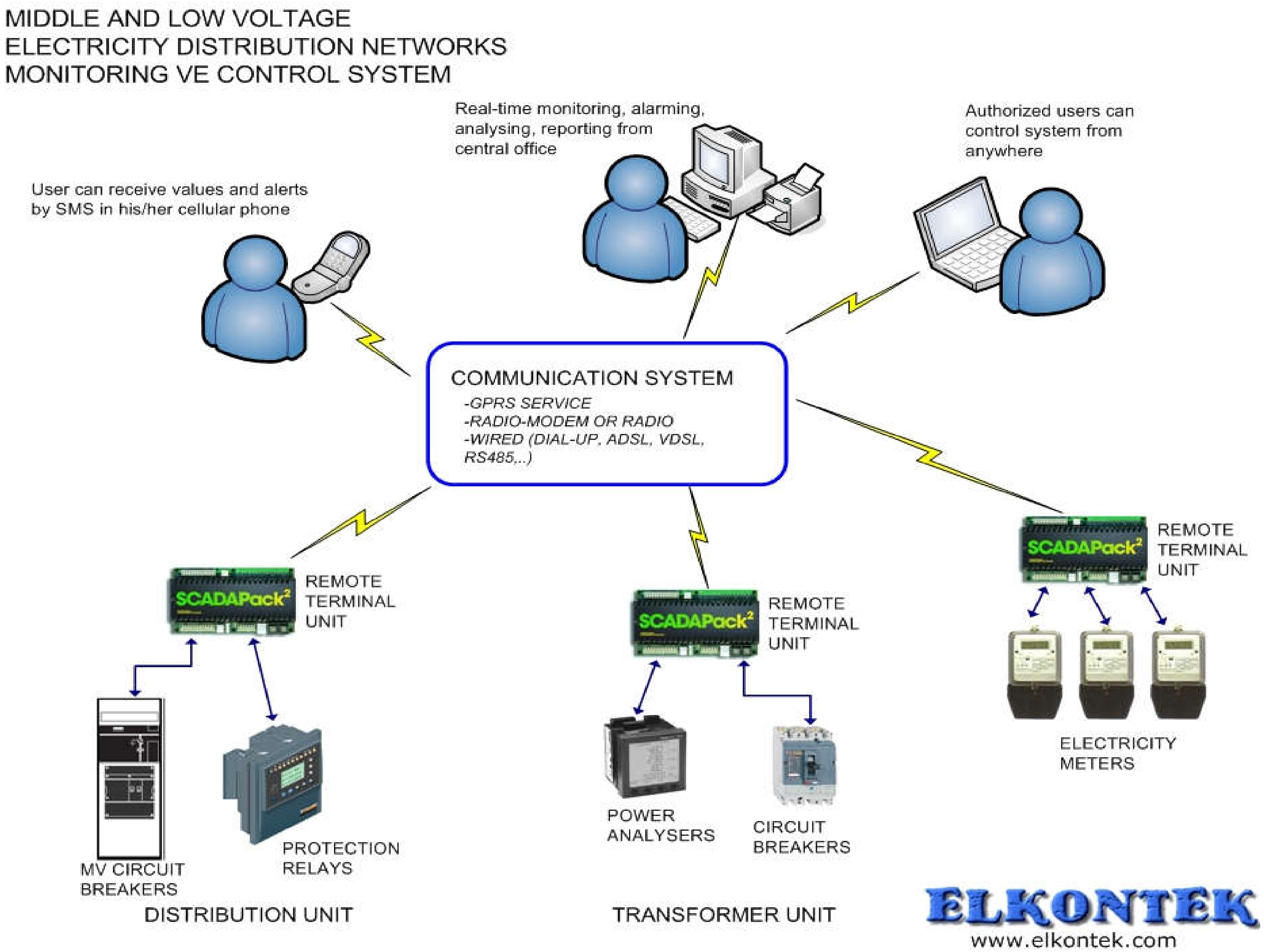


PLC control panel

Relay control panel



... versus Networked Logic



Ch. 1 – Introduction to Automation [1 week]

1.1 Introduction to **components** in industrial automation.

1.2 Cabled logic versus **programmed logic** versus networked logic.

1.3 Introduction to **methodologies** for problem modeling. Methodologies of work.

Relay or Ladder diagram, design methodology:

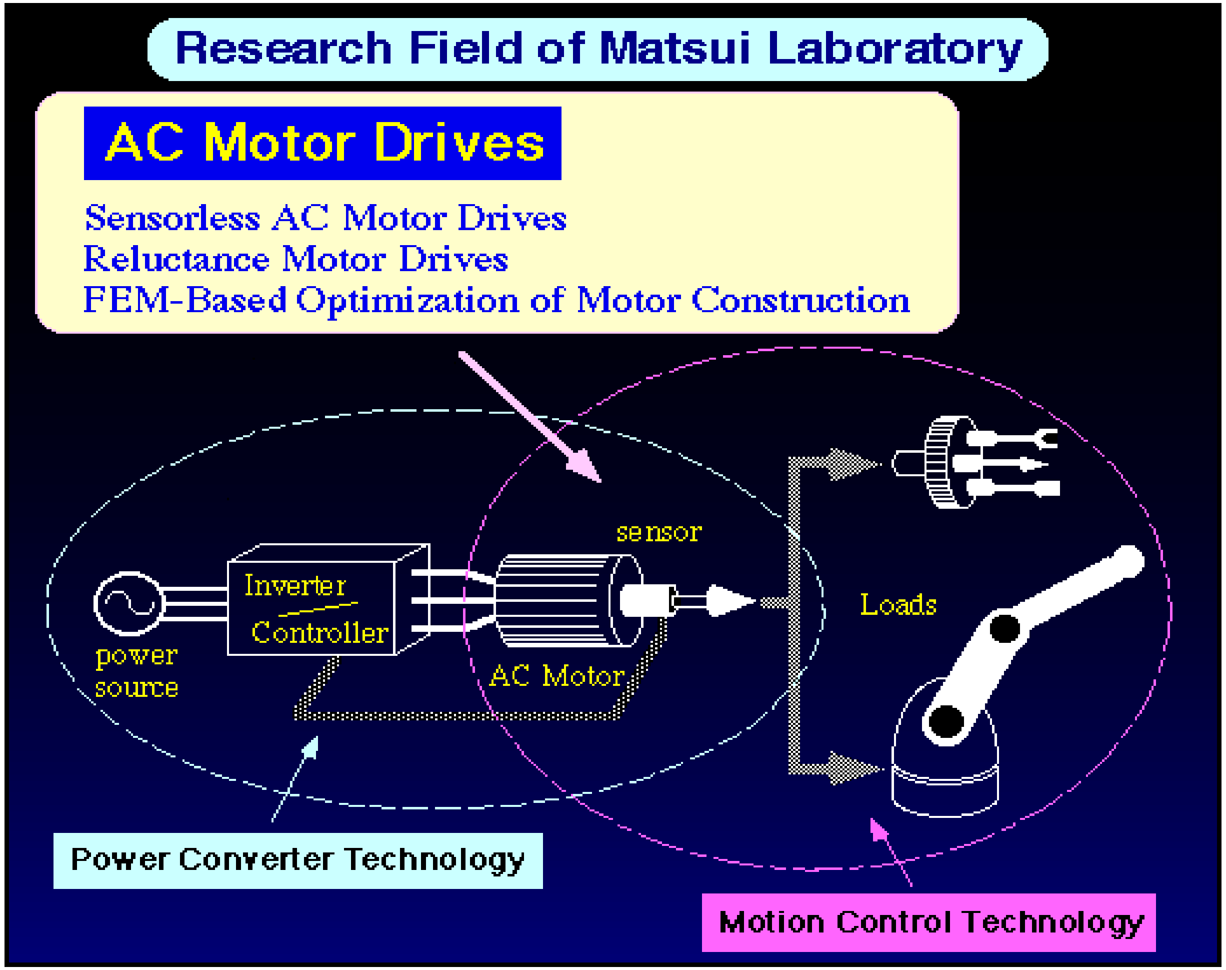
- identify the main hardware, **actuators & sensors**, to build the system
- break the system into **subsystems**; tune hardware selection
- **integrate** hardware, logic and sequencing, locally and globally.

Actuators
Motors
Solenoid valve
Command relay
Pneumatic cylinder / Electro pneumatic

Sensors
Pressure switch
Temperature sensors
Proximity sensors

Ref: Programmable Logic Controllers, Frank D. Petruzella, McGraw-Hill, 1996.

Example of AC motor, with driver



Actuation

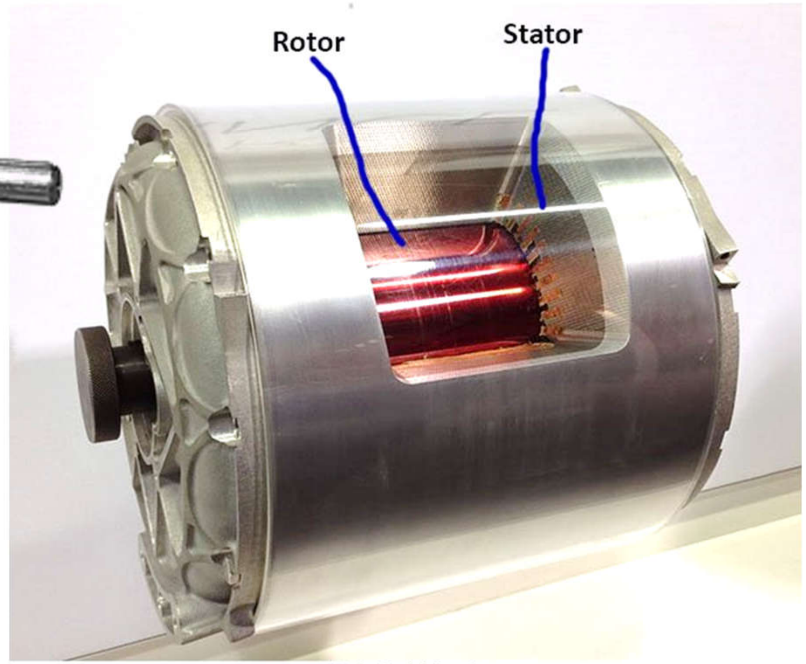
Motors

Major characteristics:

- Type of start
- Type of control
- Accuracy, reliability
- Payload and robustness
- Interface with exterior
- Synchronization







Tesla Model S motor

Solenoid Valve

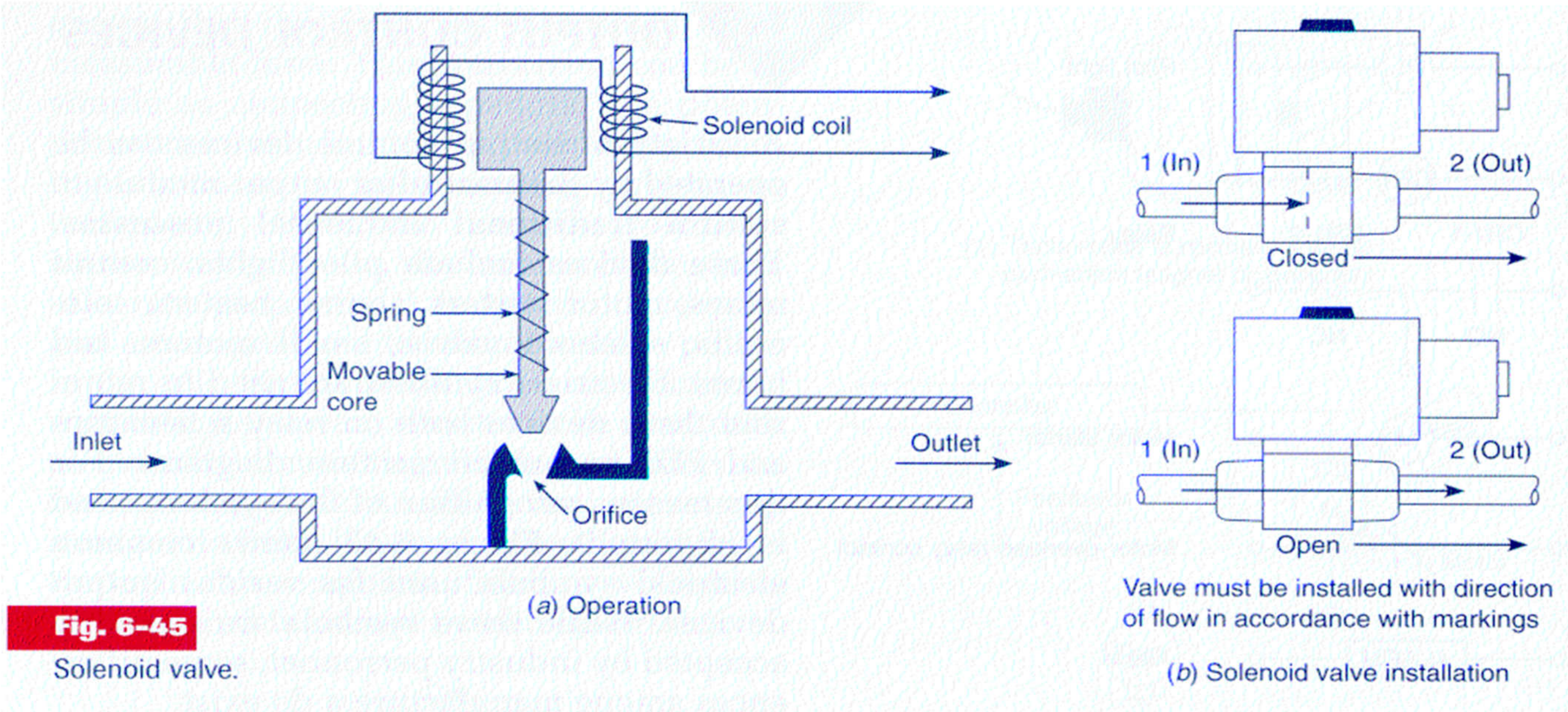


Fig. 6-45
Solenoid valve.

Command Relay

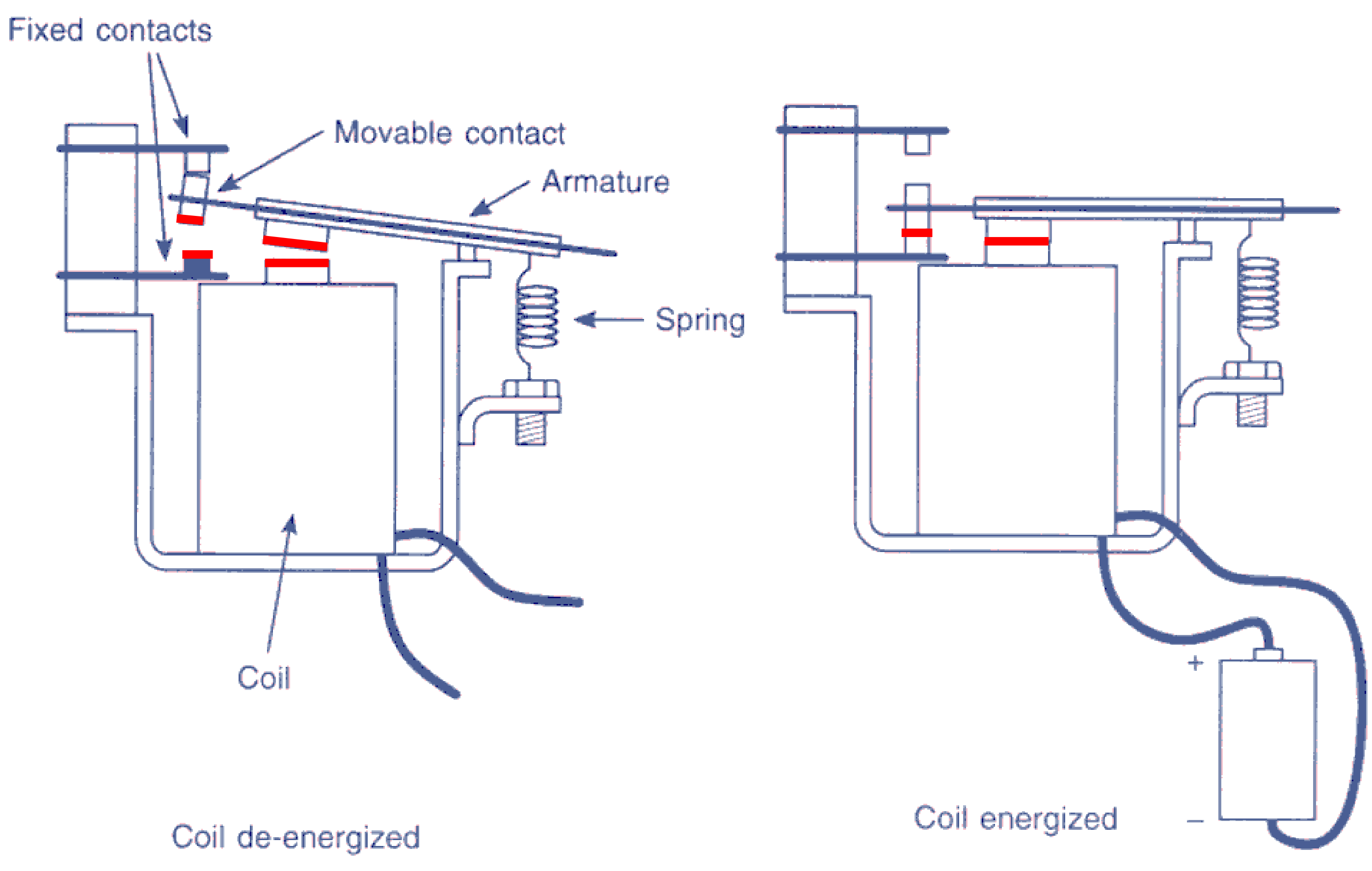
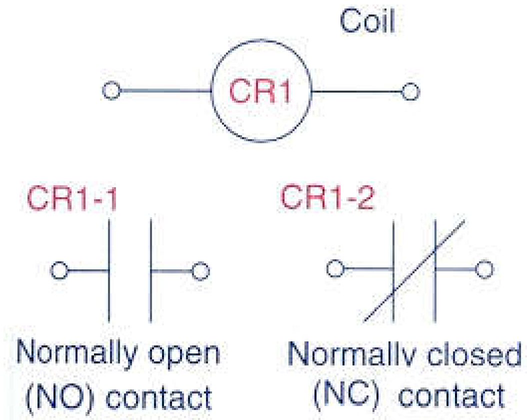
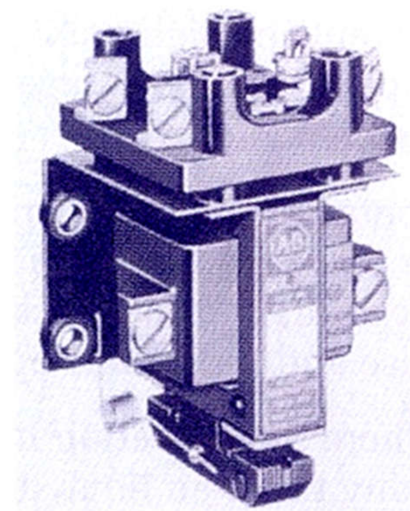


Fig. 6-1
Electromagnetic control relay operation.



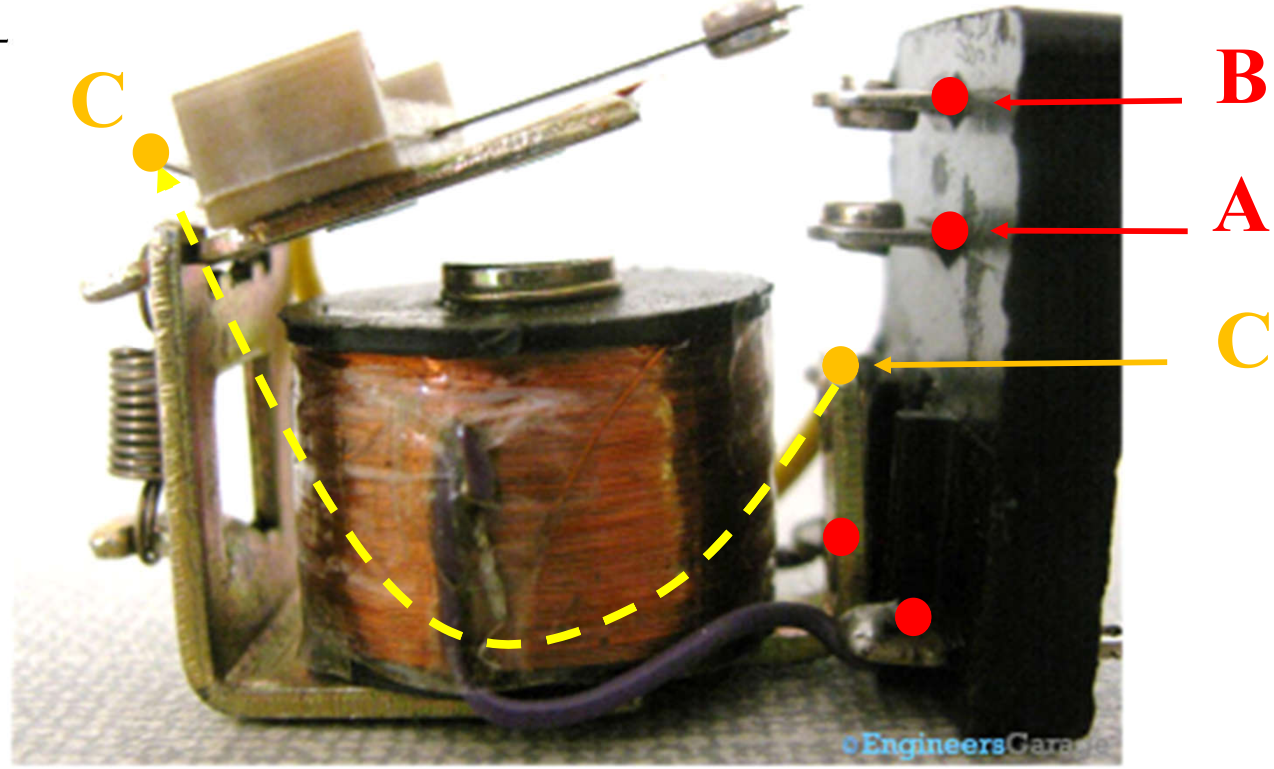
(*a*) Control relay symbol



(*b*) Typical industrial control relay. *(Courtesy of Allen-Bradley Company, Inc.)*

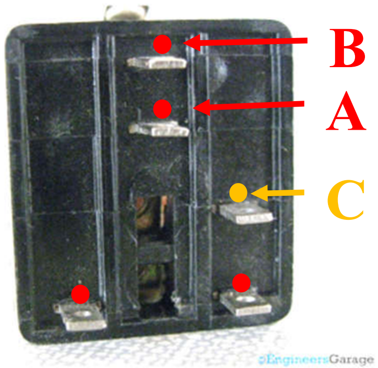
Fig. 6-2
Control relay.

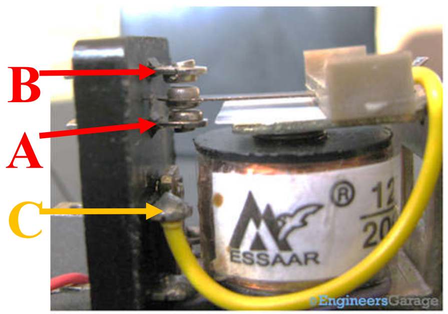
Command Relay



A *= NO = Normally Open*

B *= NC = Normally Closed*



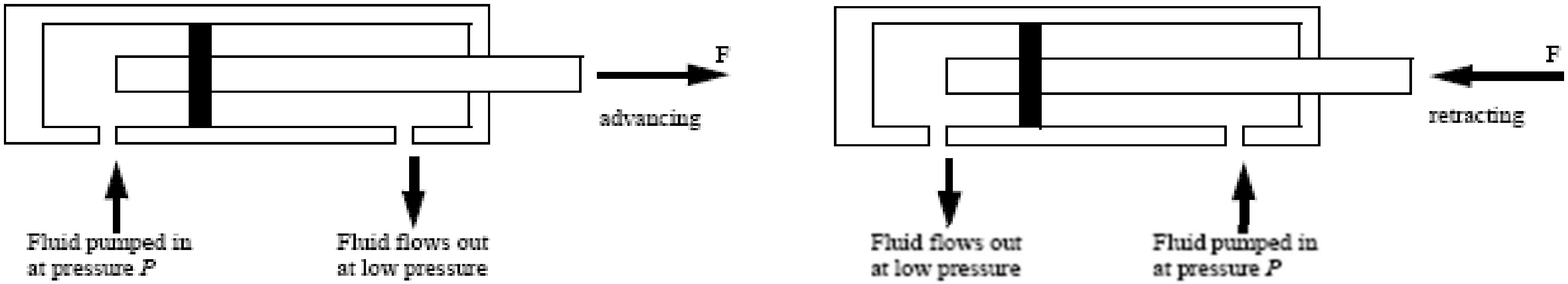



DC off


DC on

from: http://www.engineersgarage.com/insight/how-relay-switch-works

Cylinders (Pneumatics)



Force:

$$P = \frac{F}{A} \qquad F = PA$$

where

P = the pressure of the hydraulic fluid

A = the area of the piston

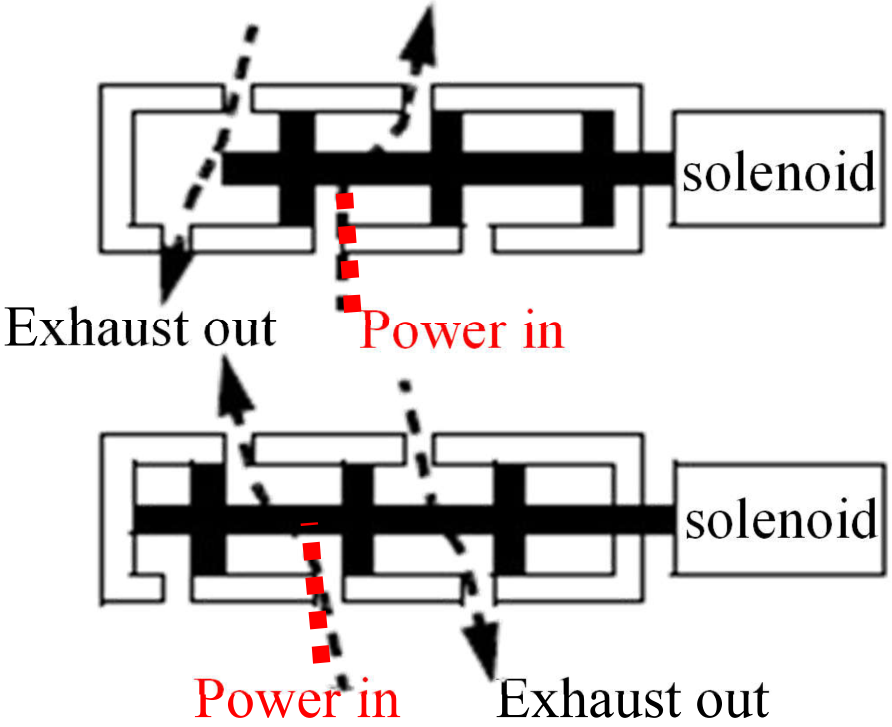
F = the force available from the piston rod

Air flow in or out

https://www.smctraining.com/en/webpage/indexpage/1108

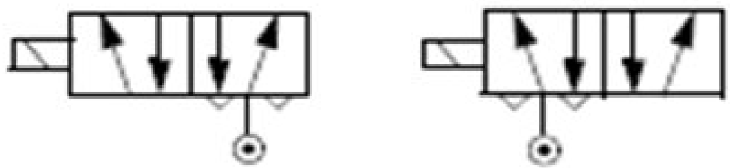
Solenoid Valves (Electrovalves, Electro-pneumatics)

The solenoid has 2 positions. Each position implies one direction of fluid flowing:

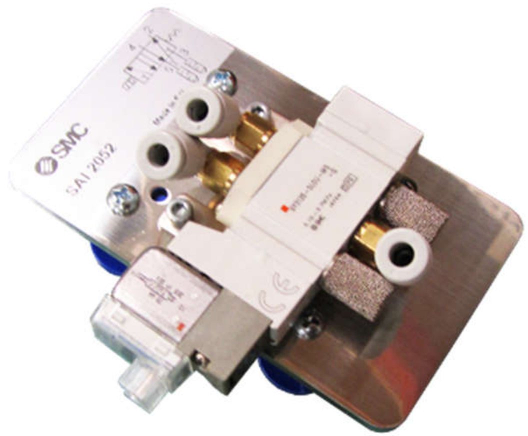


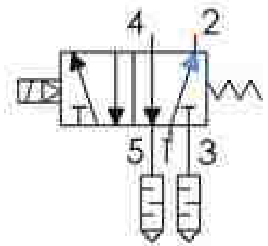
Two types: ON/OFF valves, Proportional Valves

Symbols commonly used to represent the two cases:



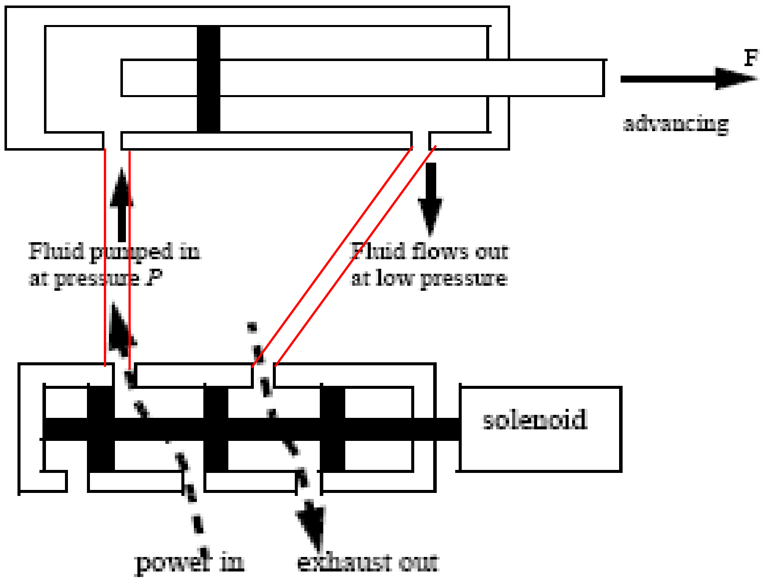
Example of a commercial valve:

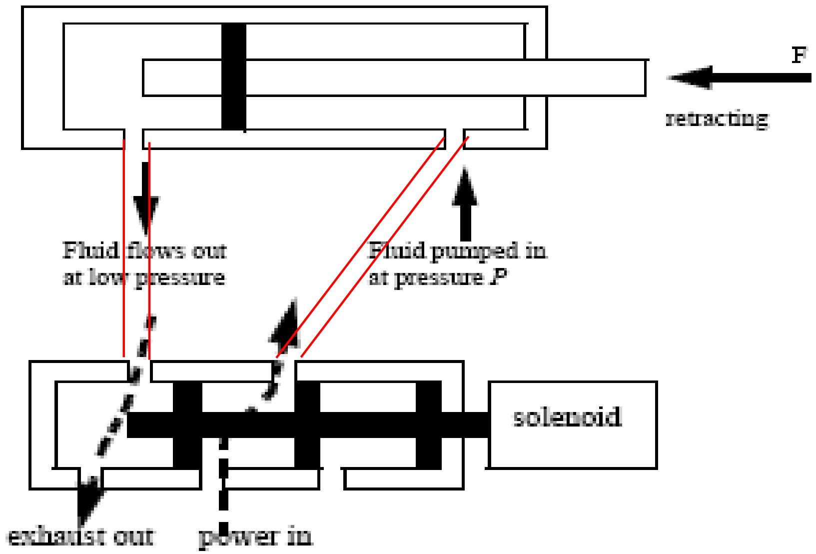


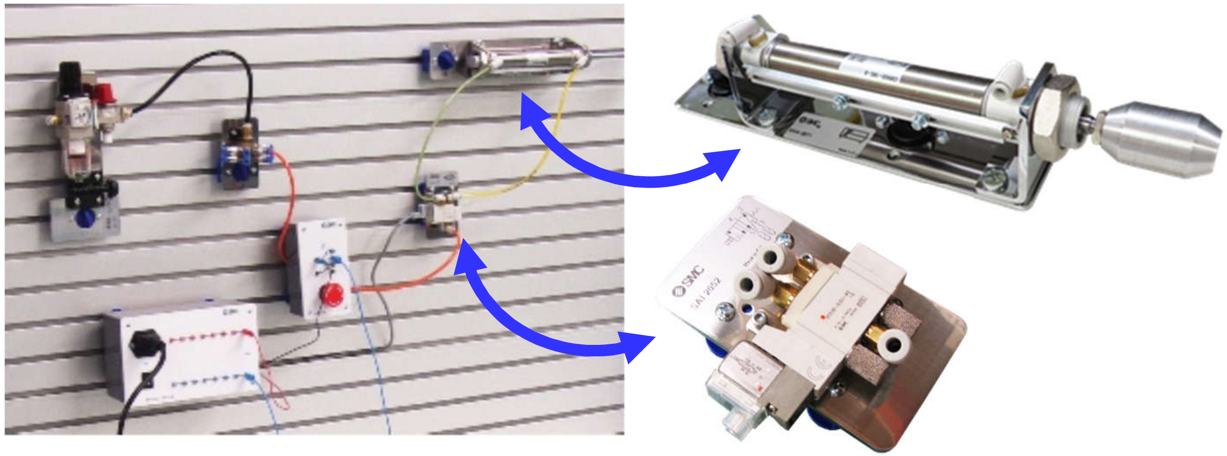


https://www.smctraining.com/en/webpage/indexpage/354

Solenoid Valves and Cylinders





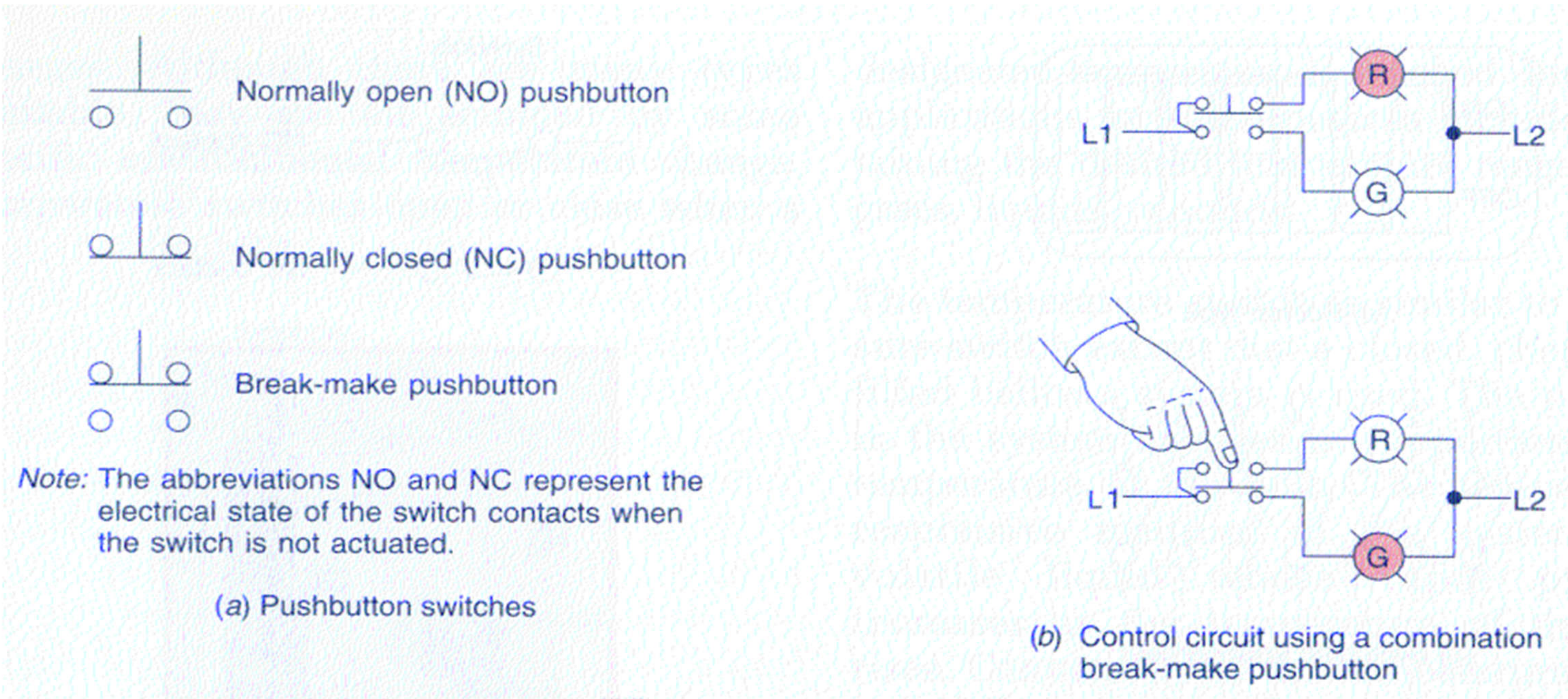


https://www.smctraining.com/webpage/indexpage/341/

Note about the most flexible systems:
- Proportional pneumatics (proportional valve),
- Servo-pneumatics (e.g. feedback of the position of the piston).

Sensors

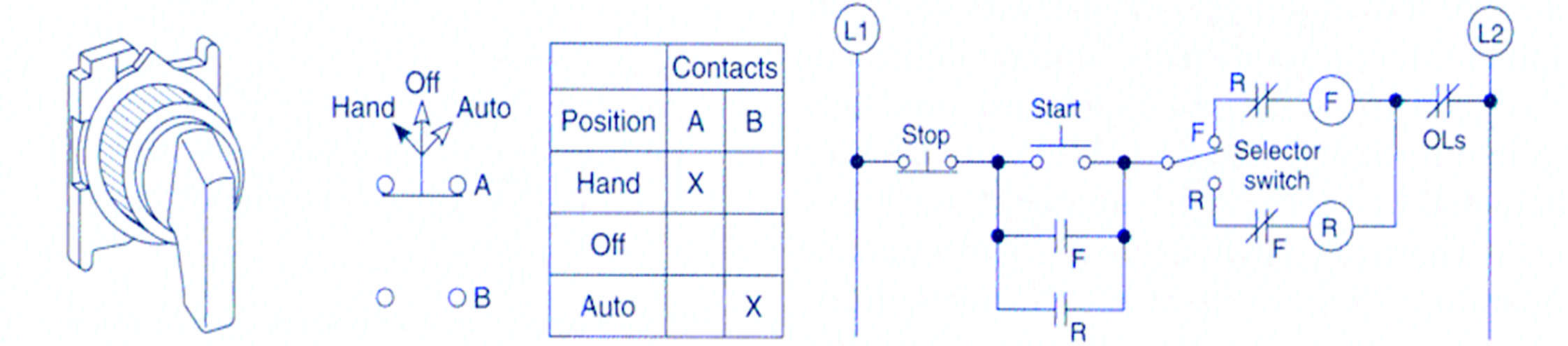
Push buttons



(a) Pushbutton switches

(b) Control circuit using a combination break-make pushbutton

Selector with three positions



	Contacts	
Position	A	B
Hand	X	
Off		
Auto		X

(*a*) Selector switch operator

(*b*) Three-position selector switch and truth table

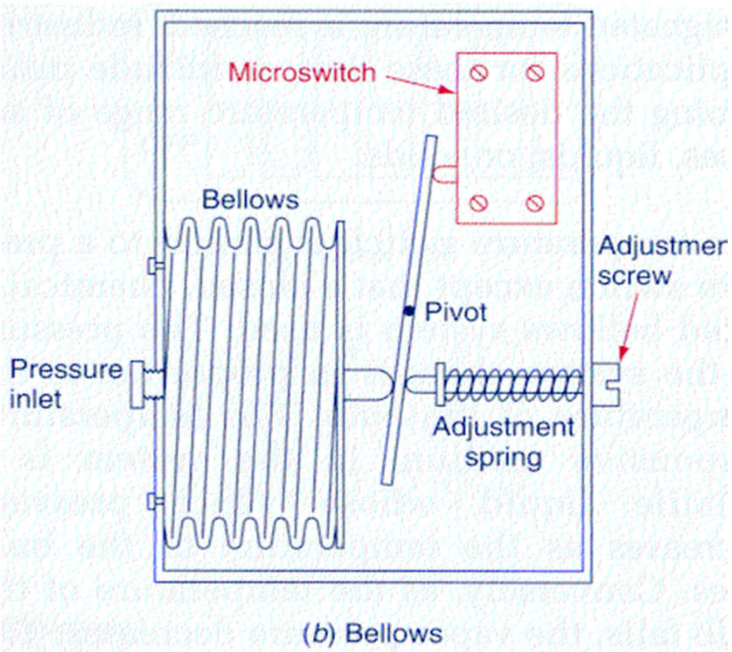
(*c*) Selector switch used in conjunction with a reversing motor starter to select forward or reverse operation of the motor

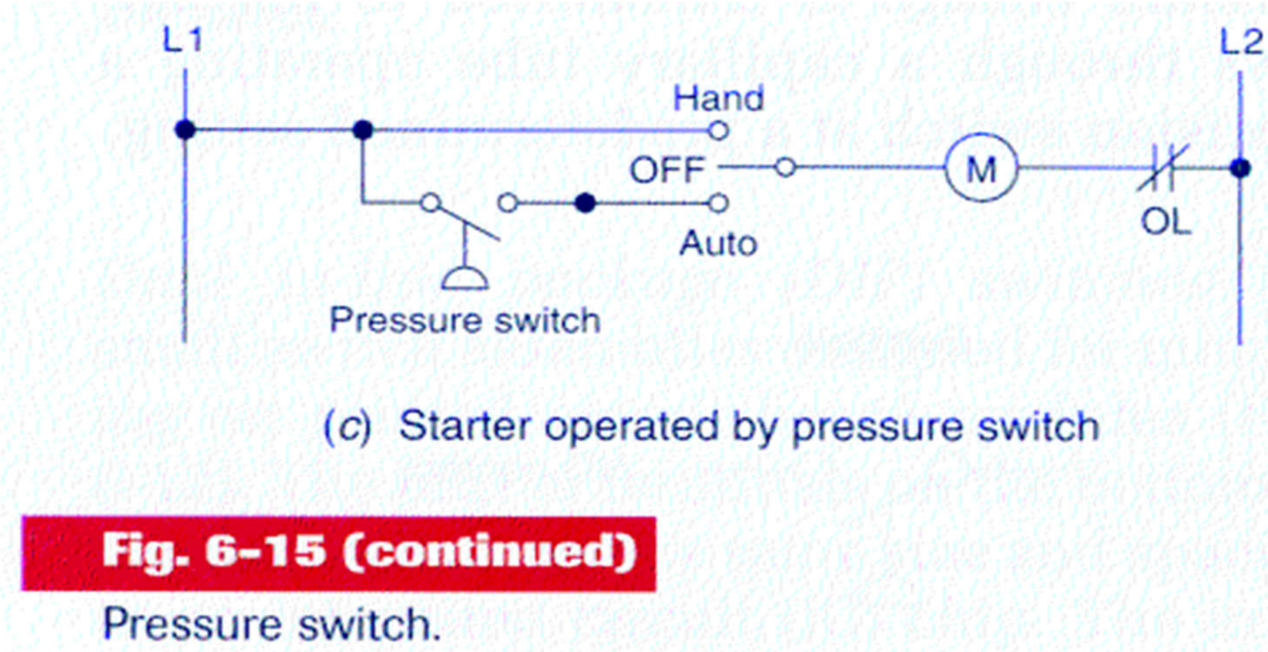
Fig. 6-11

Selector switch.

Sensors

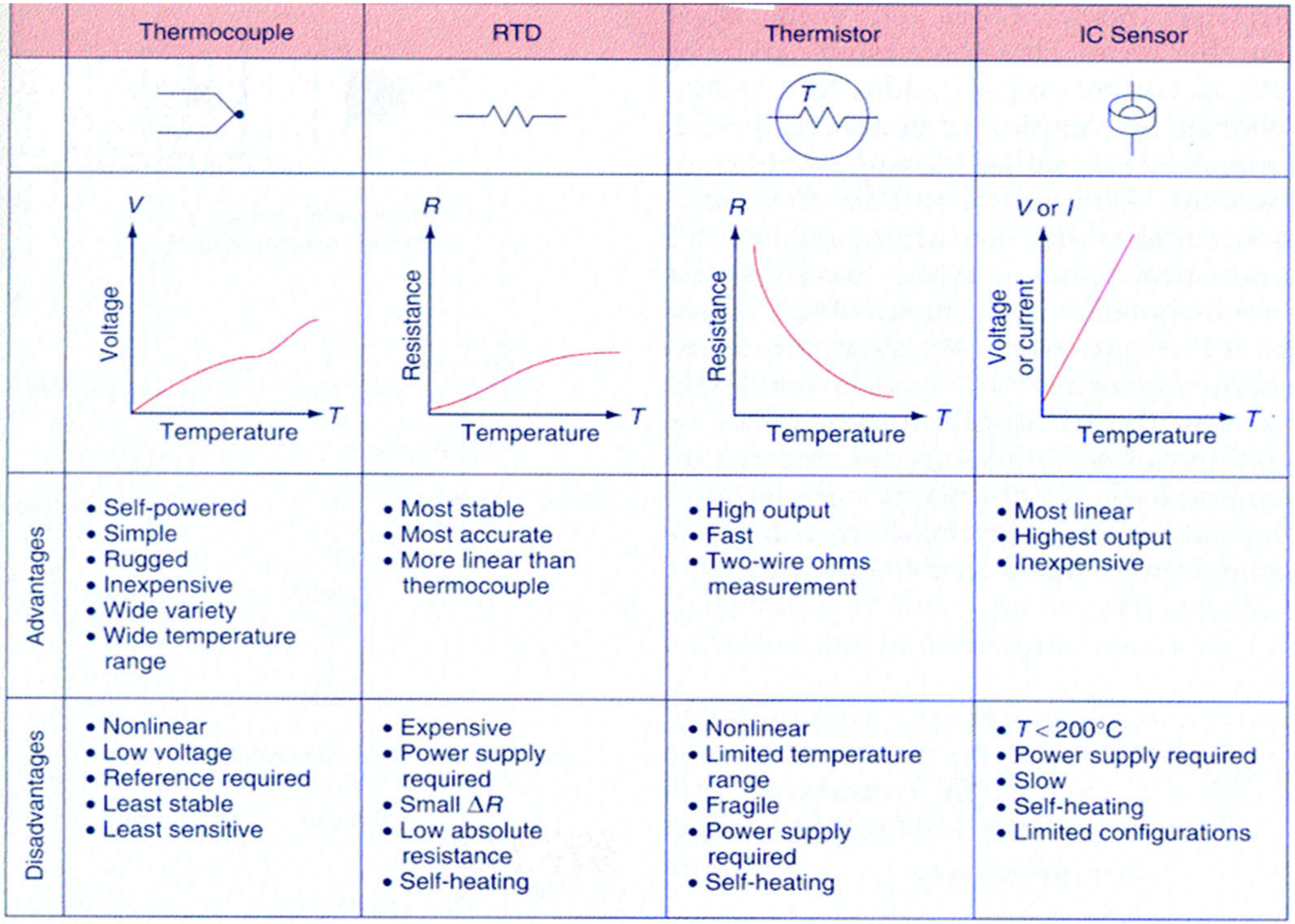
Pressure Switch





Temperature

Sensors



	Thermocouple	RTD	Thermistor	IC Sensor
	V, Voltage, T, Temperature	R, Resistance, T, Temperature	R, Resistance, T, Temperature	V or I, Voltage or current, T, Temperature
Advantages	• Self-powered • Simple • Rugged • Inexpensive • Wide variety • Wide temperature range	• Most stable • Most accurate • More linear than thermocouple	• High output • Fast • Two-wire ohms measurement	• Most linear • Highest output • Inexpensive
Disadvantages	• Nonlinear • Low voltage • Reference required • Least stable • Least sensitive	• Expensive • Power supply required • Small ΔR • Low absolute resistance • Self-heating	• Nonlinear • Limited temperature range • Fragile • Power supply required • Self-heating	• $T < 200°C$ • Power supply required • Slow • Self-heating • Limited configurations

Fig. 6-38 Common temperature sensors.

RTD = Resistance Temperature Detector
IC = Integrated Circuit

Thermocouple

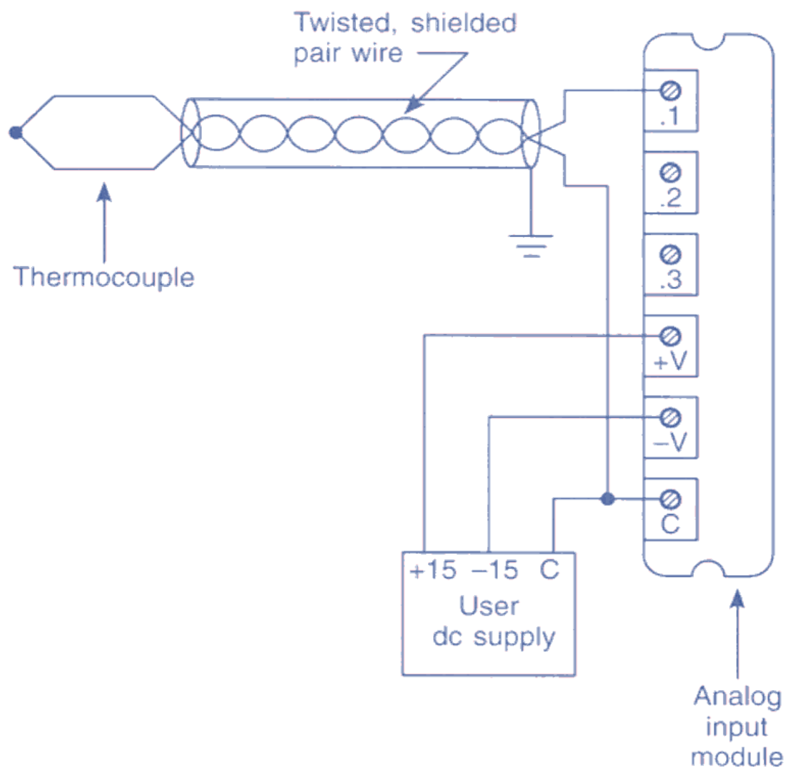


Fig. 2-12
Typical thermocouple connection to an analog input module.

Proximity detector

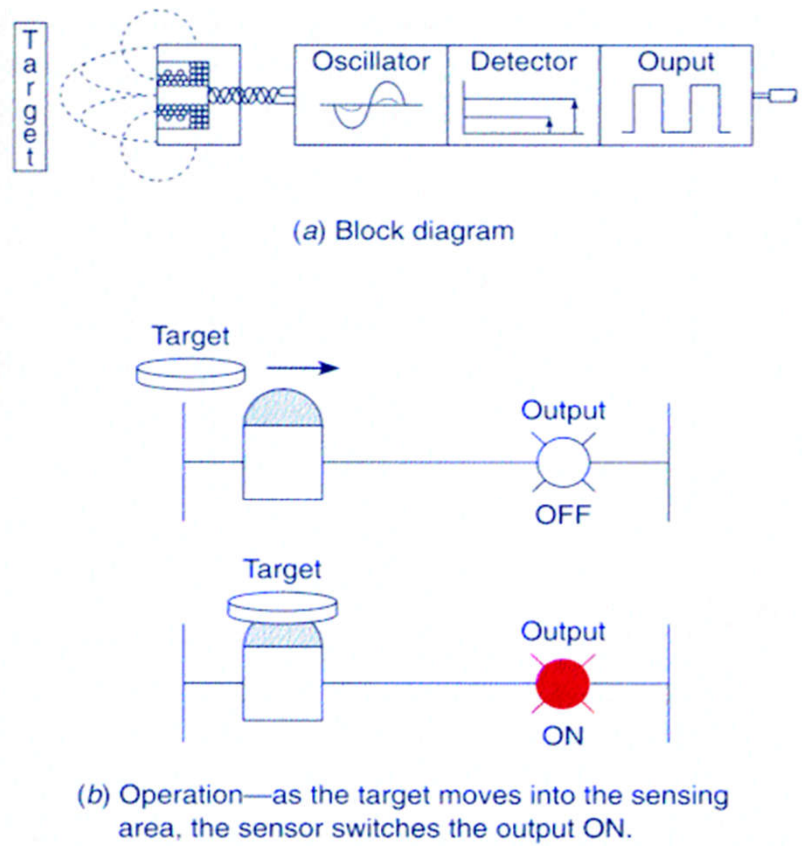


Fig. 6-20
Inductive proximity sensor.

Magnetic detector

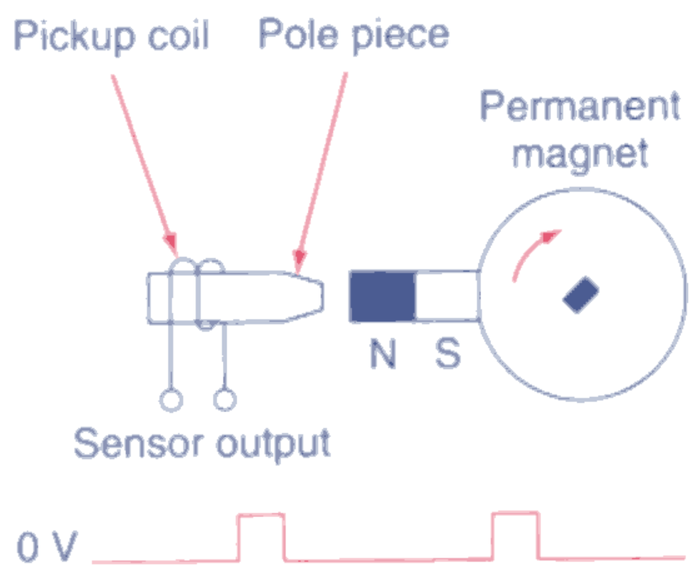


Fig. 6-42
Magnetic pickup sensor.

Magnetic switch

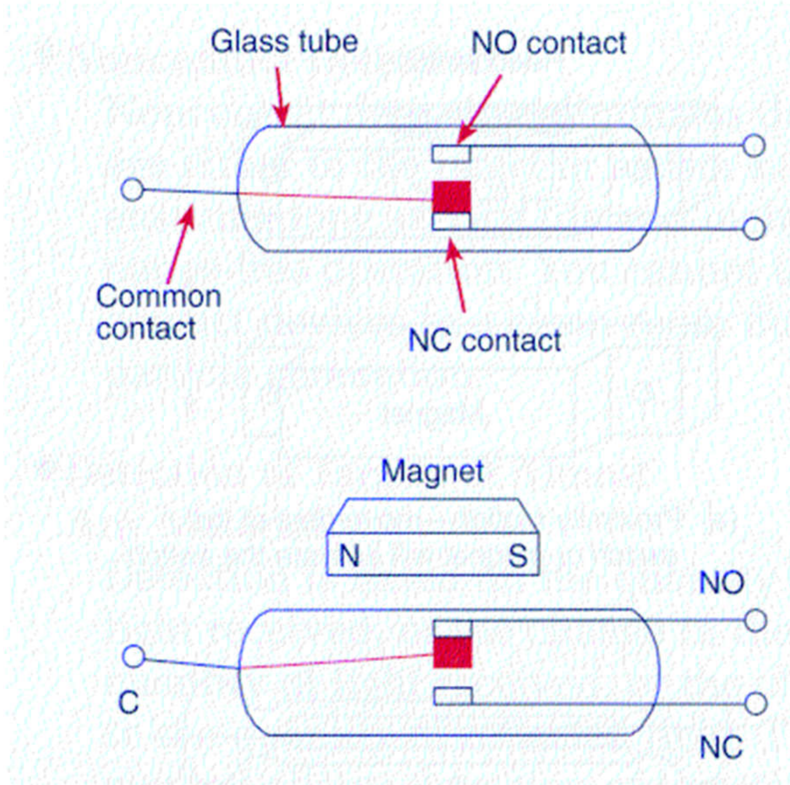


Fig. 6-25
Magnetic switch (reed switch).

Symbols associated to all components

Standards - Joint International Committee (JIC) Wiring Symbols

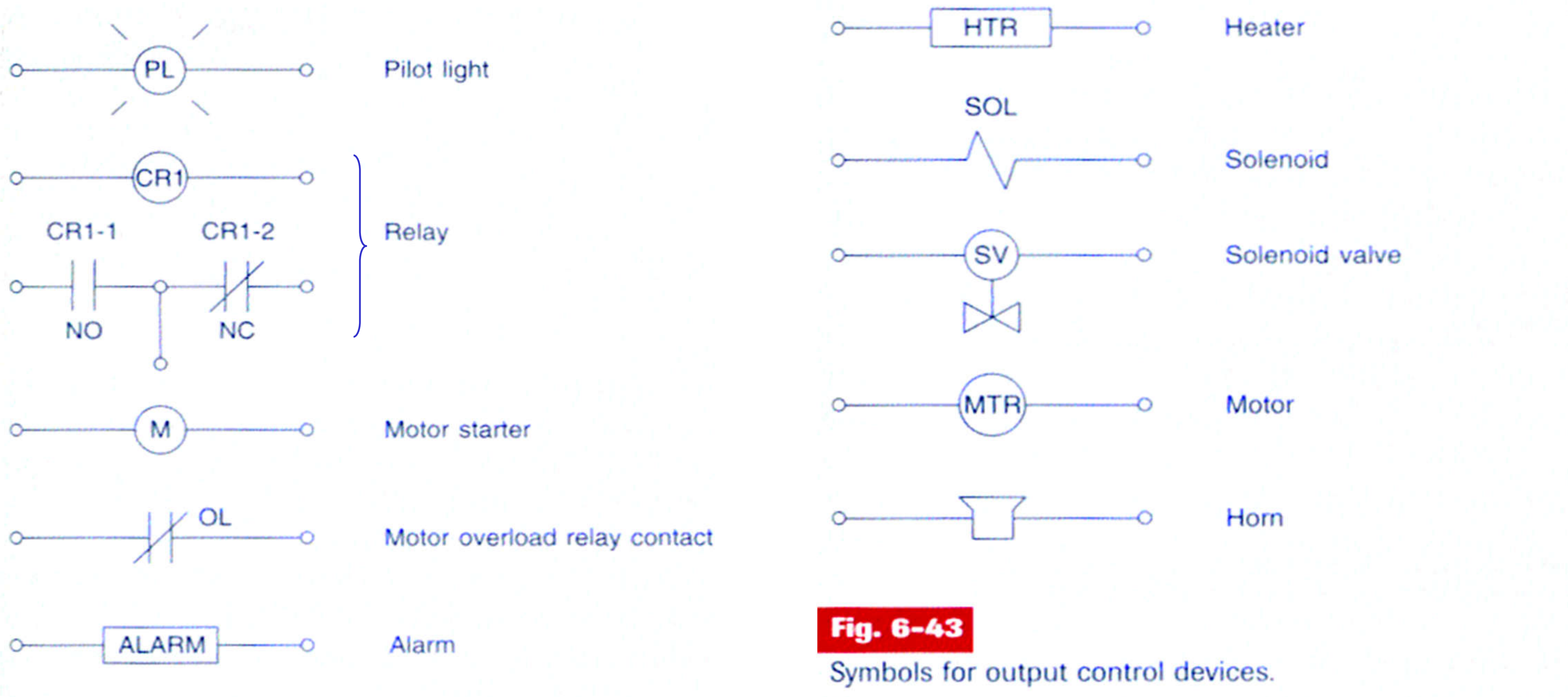
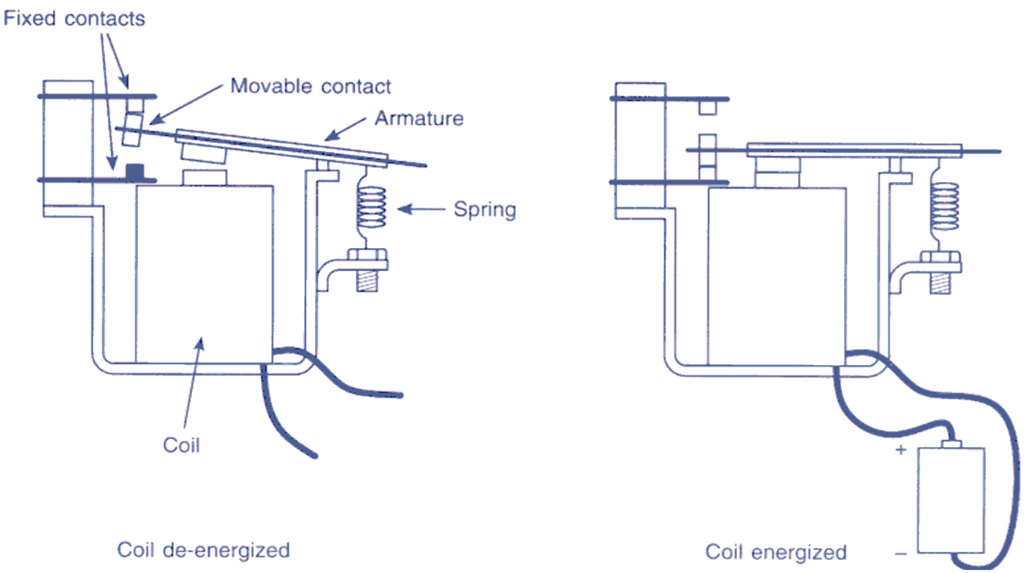


Fig. 6-43
Symbols for output control devices.

Methodologies for the implementation of solutions in industrial automation

Device: Relay



Contact Diagram or *Ladder Diagram*

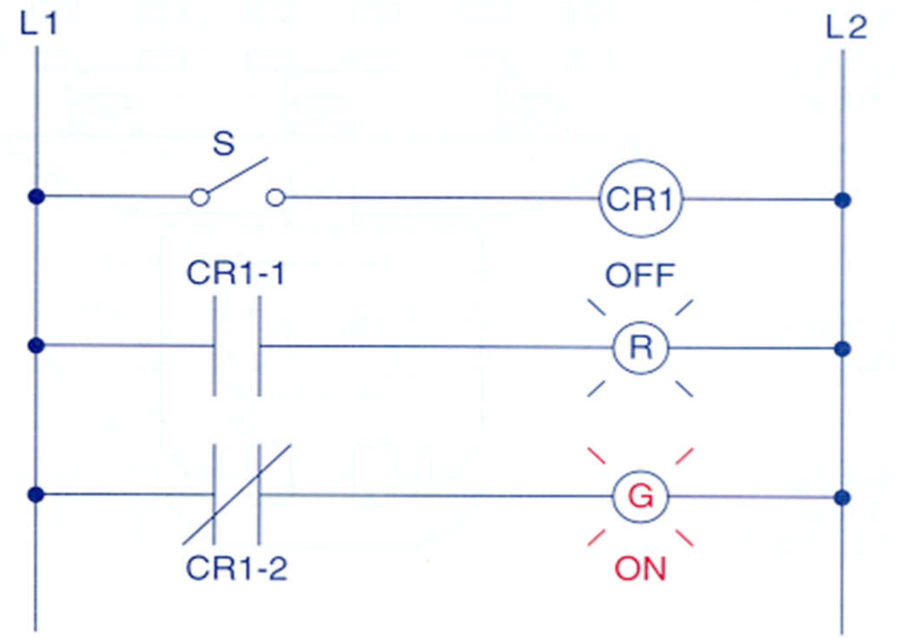


Fig. 6-3
Relay circuit—switch open.

Example of relay and ladder diagrams:

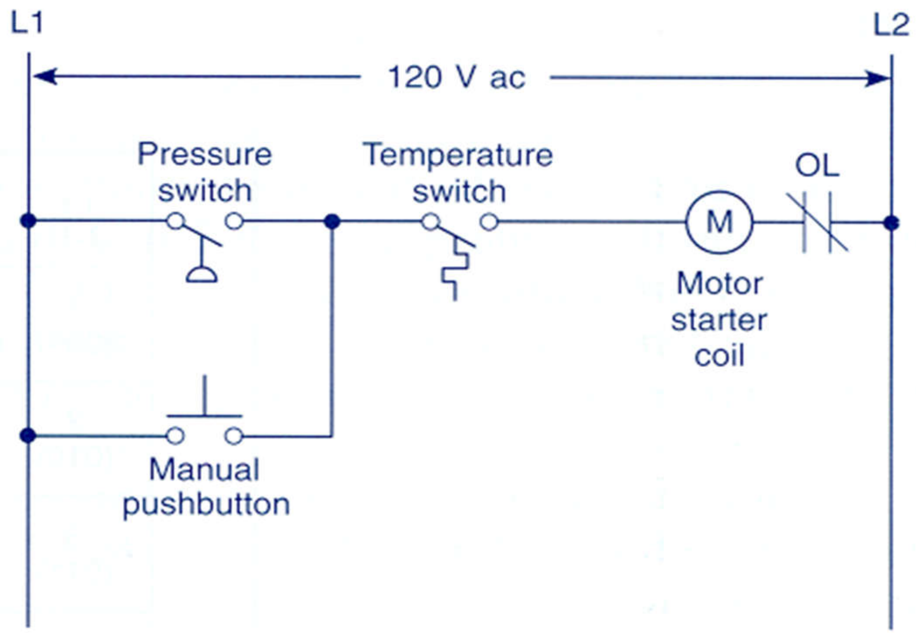


Fig. 1-13
Relay ladder diagram for modified process.

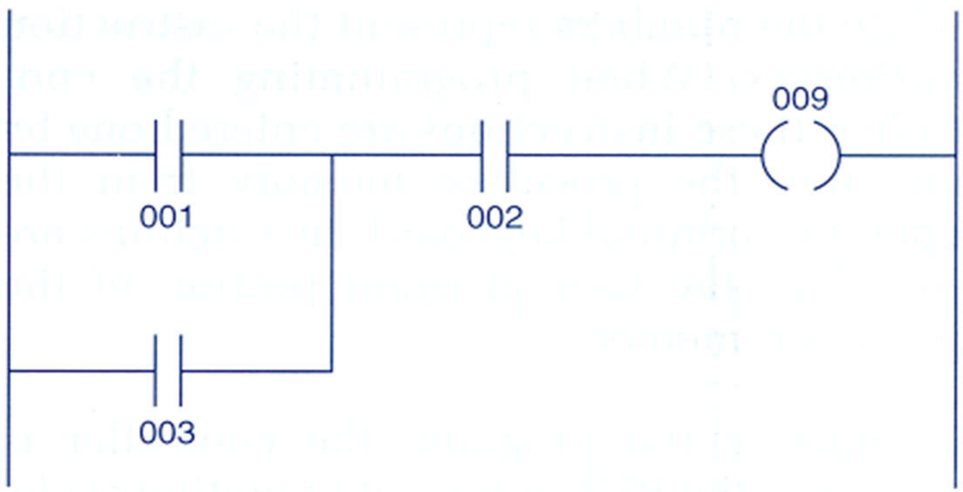
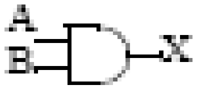


Fig. 1-14
PLC ladder logic diagram for modified process.

Logic Functions

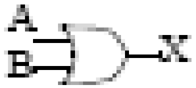
AND



$X = A \cdot B$

A	B	X
0	0	0
0	1	0
1	0	0
1	1	1

OR



$X = A + B$

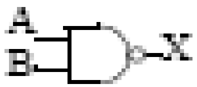
A	B	X
0	0	0
0	1	1
1	0	1
1	1	1

NOT

$X = \bar{A}$

A	X
0	1
1	0

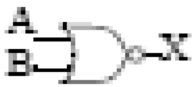
NAND



$X = \overline{A \cdot B}$

A	B	X
0	0	1
0	1	1
1	0	1
1	1	0

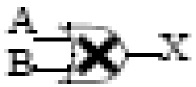
NOR



$X = \overline{A + B}$

A	B	X
0	0	1
0	1	0
1	0	0
1	1	0

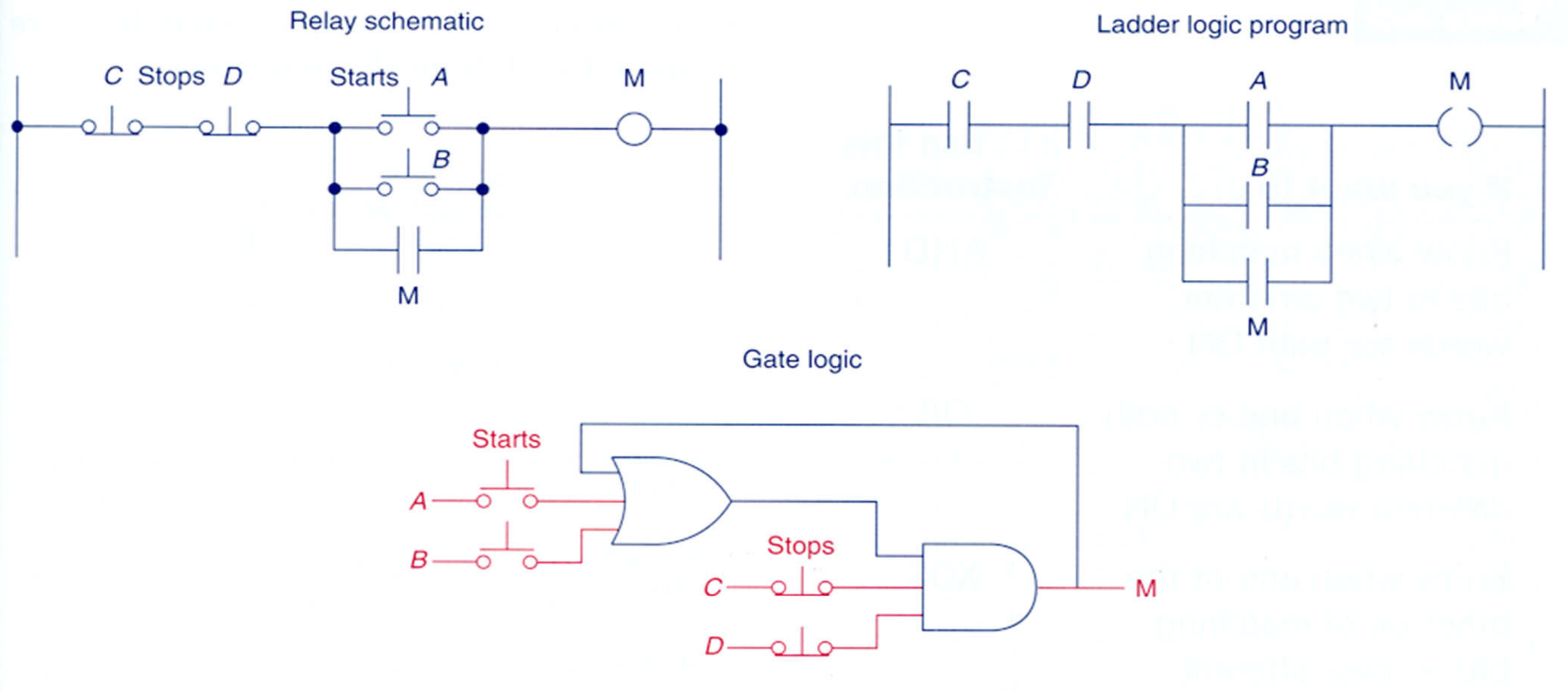
EOR



$X = A \oplus B$

A	B	X
0	0	0
0	1	1
1	0	1
1	1	0

Example of relay and ladder diagrams, and gate logic:

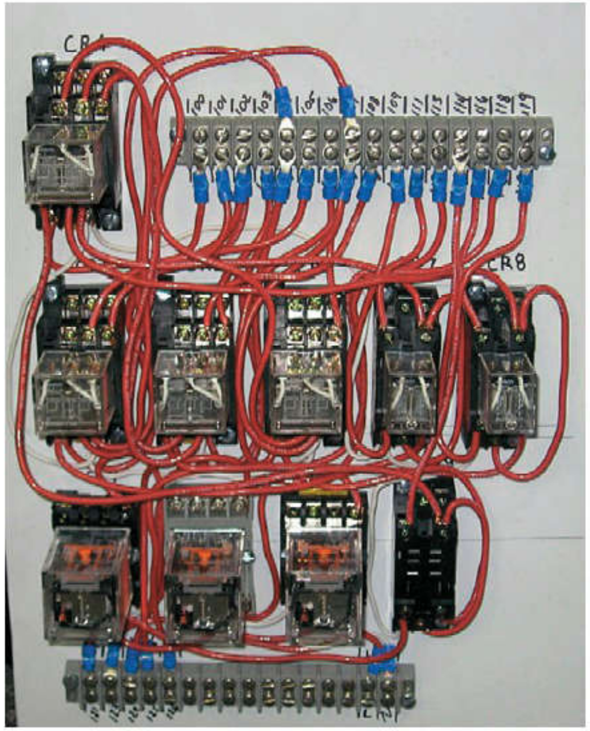


Example 4-9

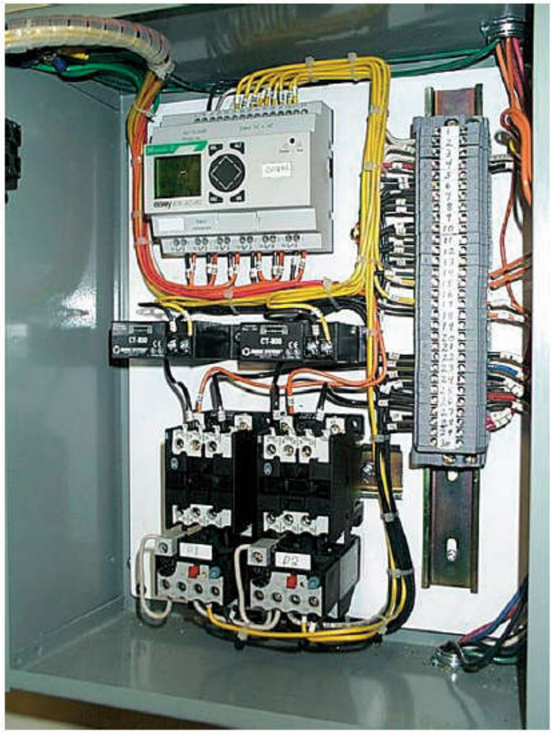
A motor control circuit with two stop buttons. When the start button is depressed, the motor runs. By sealing, it continues to run when the start button is released. The stop buttons stop the motor when they are depressed.

The world is always moving forward: Exploit the advantages of Programmed Logic!

Relay control panel



PLC control panel



Rule of thumb: if using more than 6 relays then a PLC is already lesser expensive