# Industrial Automation

## (Automação de Processos Industriais)

http://users.isr.ist.utl.pt/~jag/courses/api1718/api1718.html

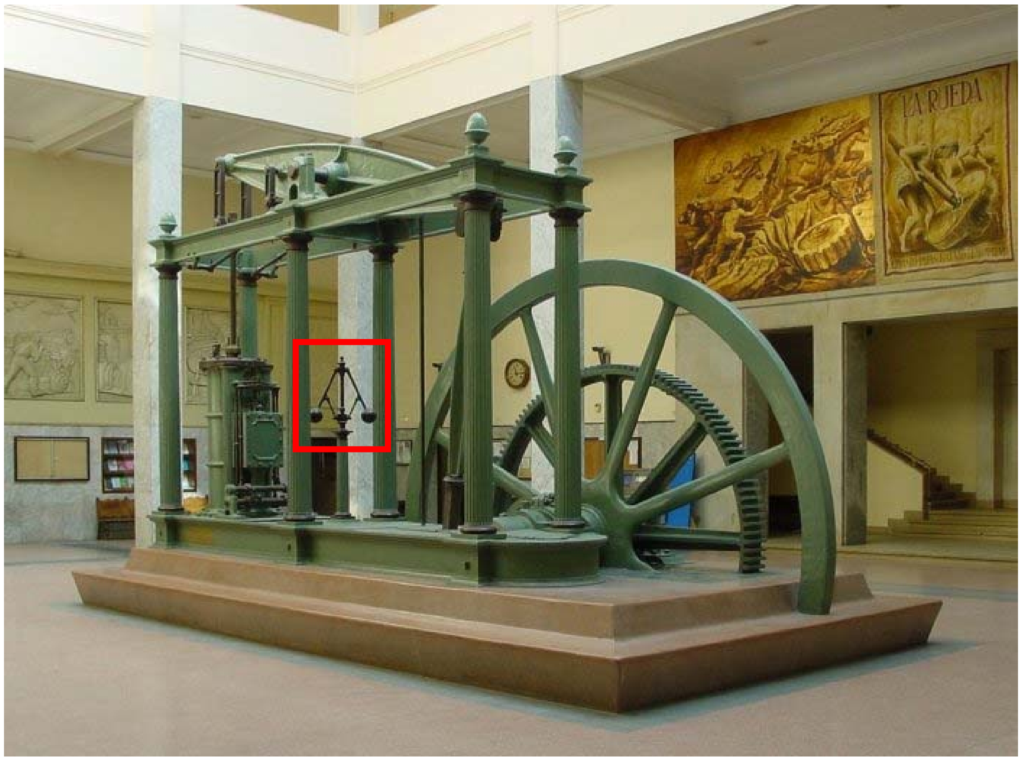
Prof. Paulo Jorge Oliveira, original slides

Prof. José Gaspar, rev. 2017/2018

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

*A steam engine built according to James Watt's patent in 1848 at Freiberg in Germany [wikipedia]*

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



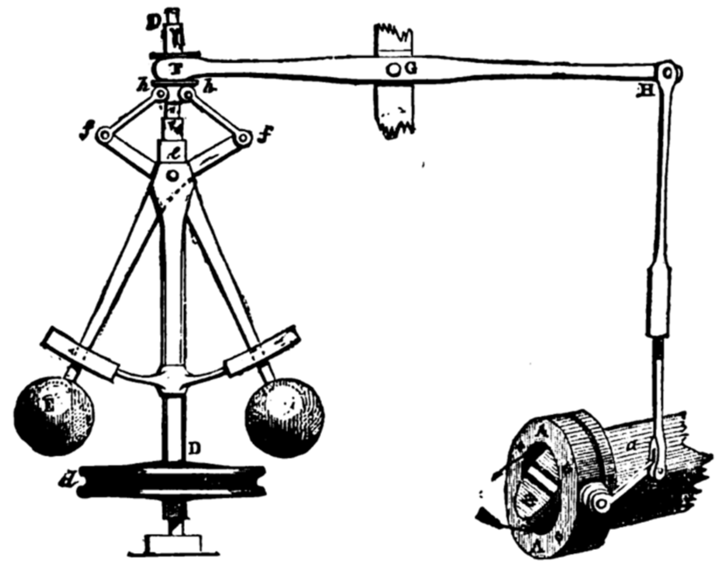
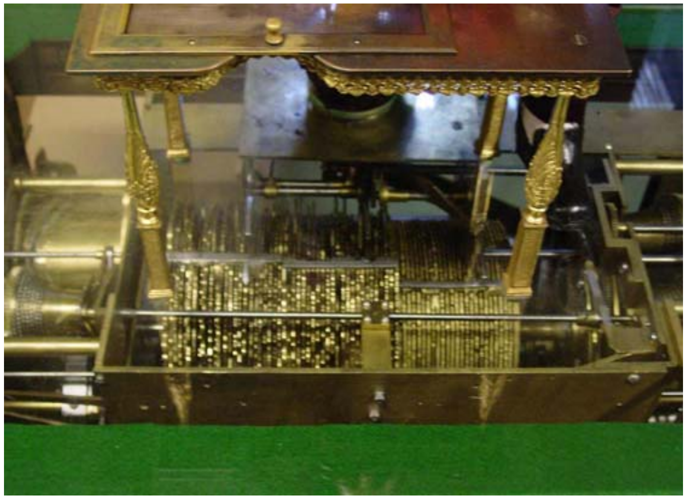
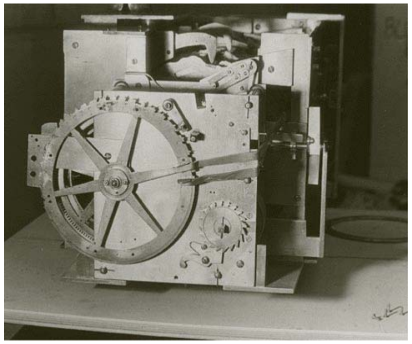



FIG. 4.—*Governor and Throttle-Valve.*

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

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

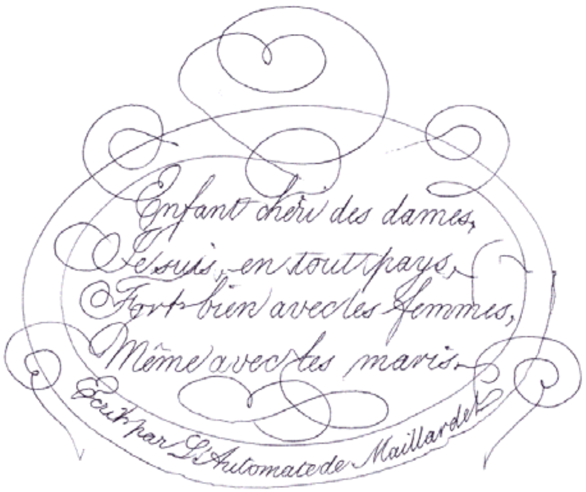


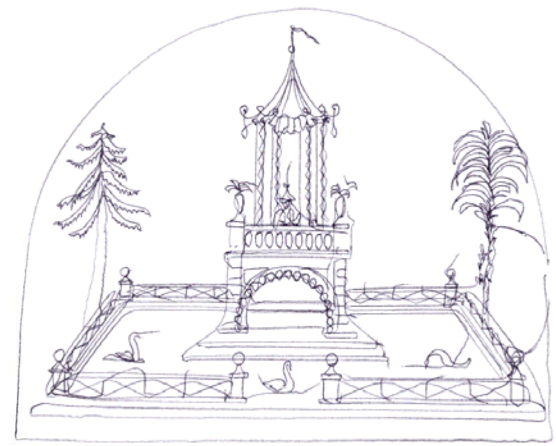


https://www.fi.edu/history-automaton

*Maillardet's Automaton, 18$^{th}$ century: the largest known mechanical memory*

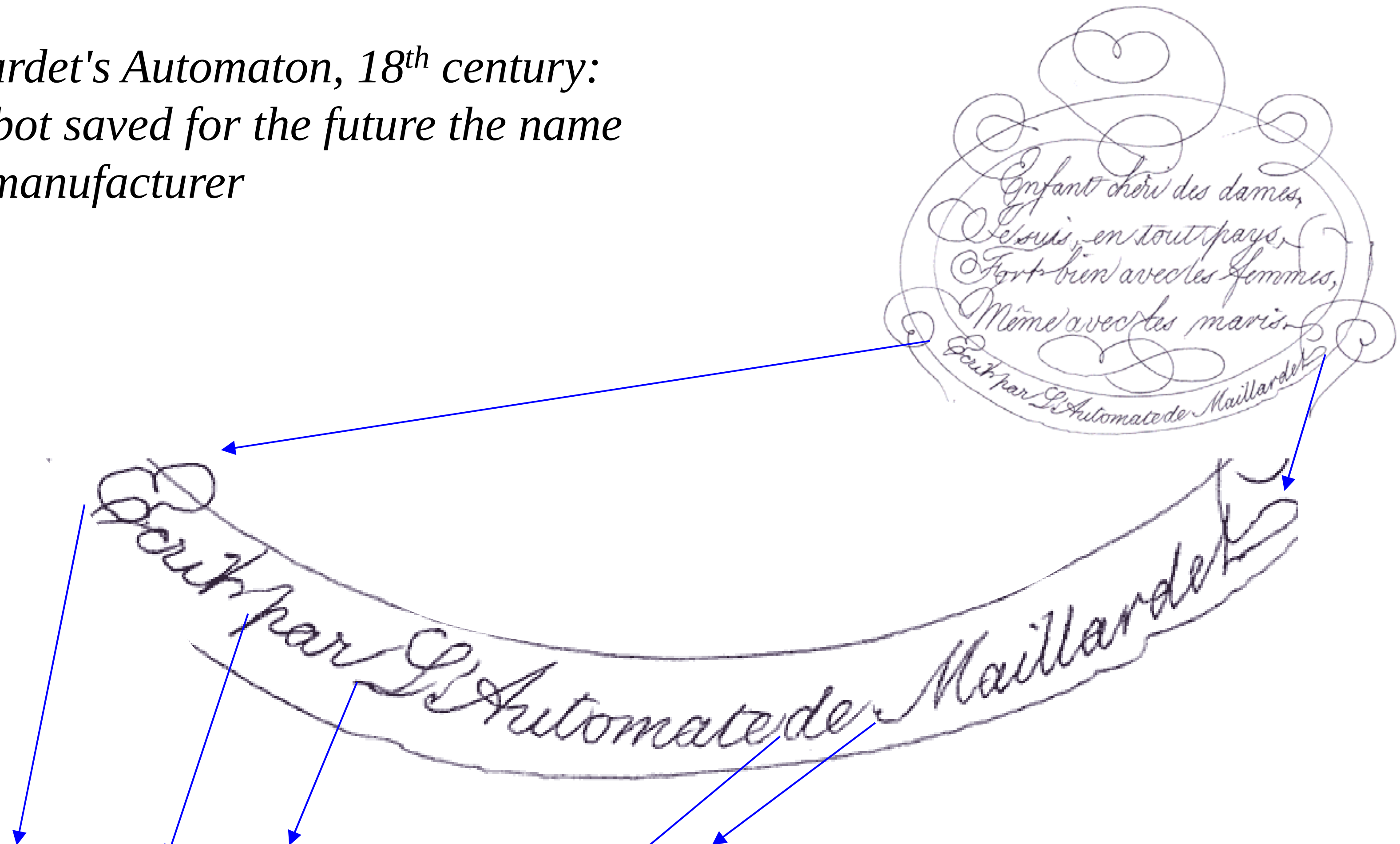
*Four drawings and three poems*



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

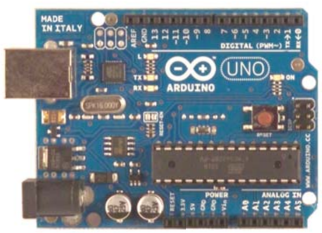
*Maillardet's Automaton, 18th century: the robot saved for the future the name of its manufacturer*




*Ecrit par L'Automate de Maillardet*

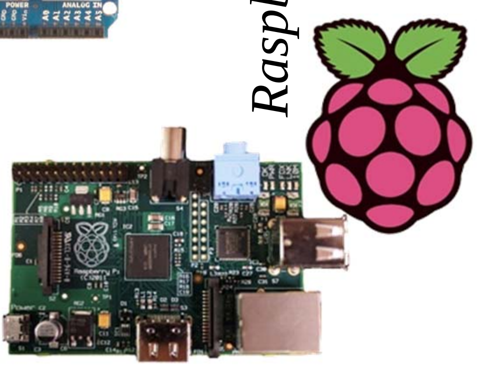
https://www.fi.edu/history-automaton

## *Microcontrollers*

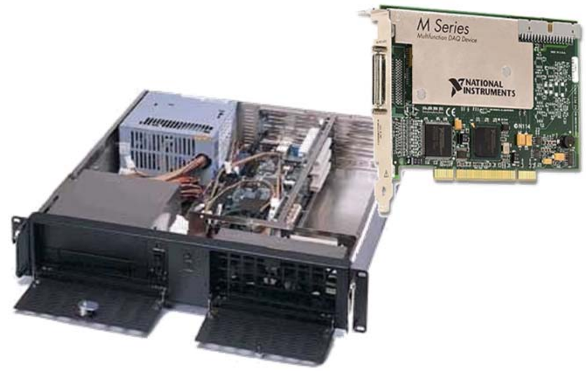




*Arduino*

*Raspberry-pi*



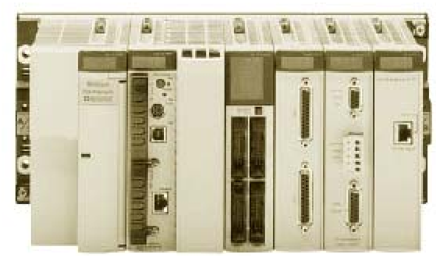
## *Computer + IO*




*National Instruments AD/DA*

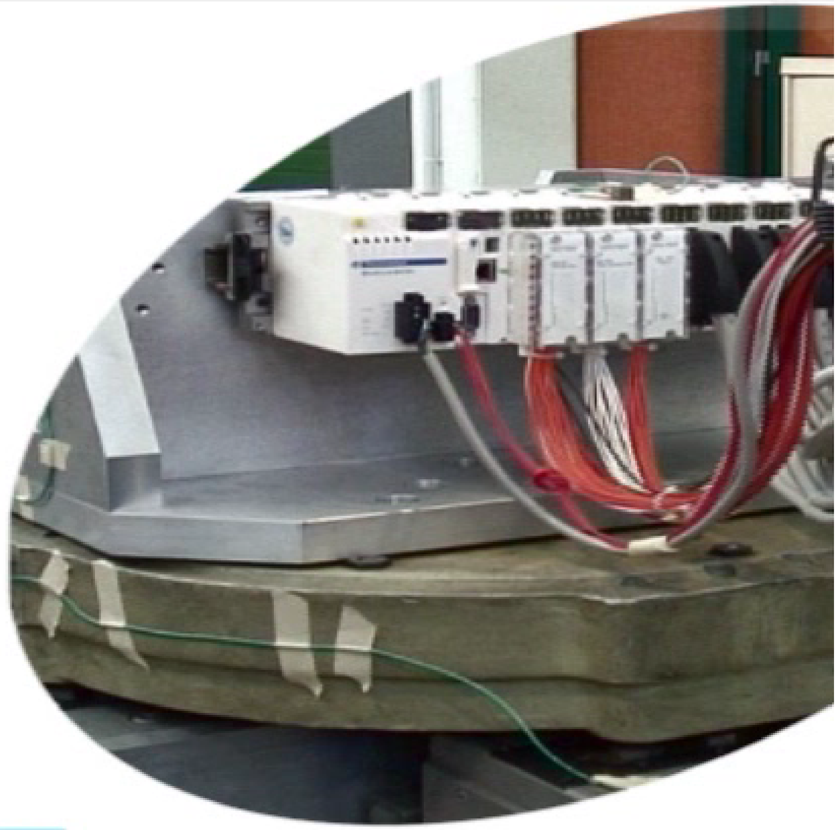
## *PLC*

*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).*

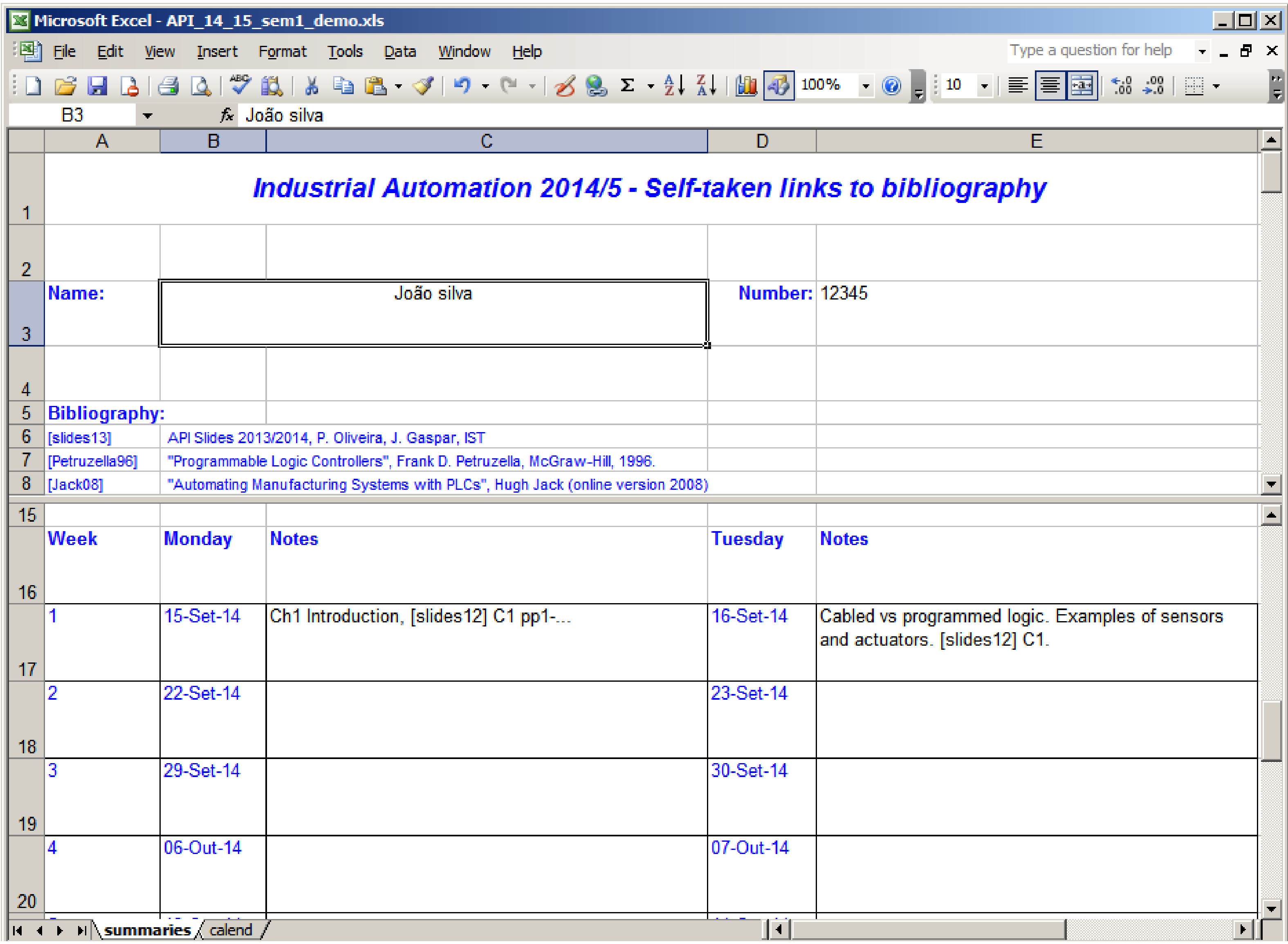
*Upon student choice, the second exam can be oral.*

- *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)<br>*20min presentation + 10min discussion* |
| Exams (do at least one) | 3h, **18Jan** or **02Feb** 2018 |

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

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

- Recitation classes

| | | |
|---|---|---|
| Monday | 11.00 h – 12.30h | Ea5 |
| Tuesday | 08.00 h – 09.30h | Ea4 |

- Lab. Classes (once per week)

| | | |
|---|---|---|
| Monday | 09.30h – 11.00h L1 | LSDC4 (room 5.21) |
| Friday | 09.30h – 11.00h L2 | 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.

• **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/api1718/api1718.html

Prof. Paulo Jorge Oliveira, original slides
Prof. José Gaspar, rev. 2017/2018

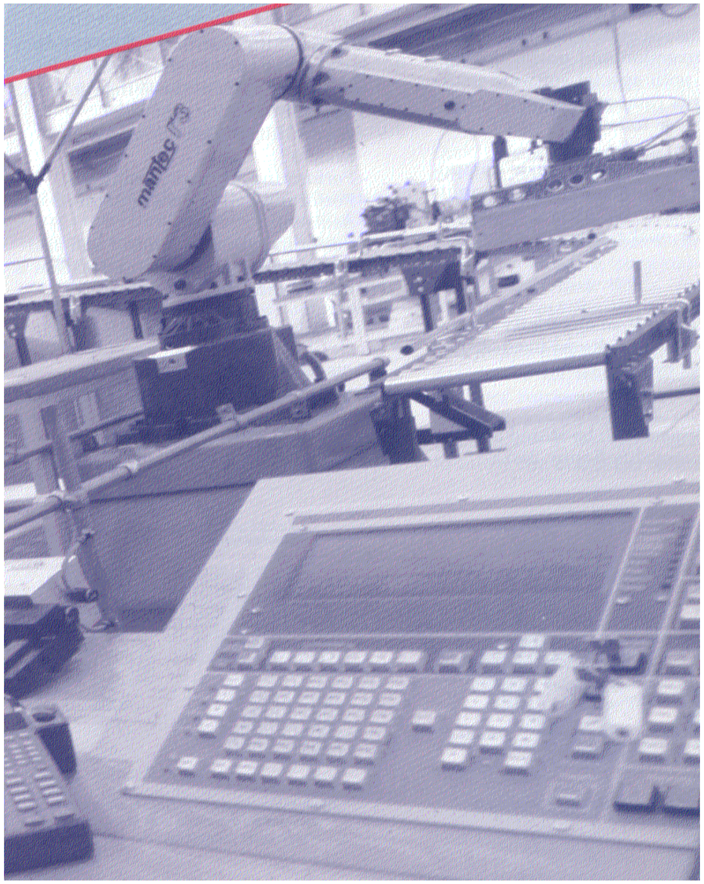
# Industrial Automation is Necessary and is Happening

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.

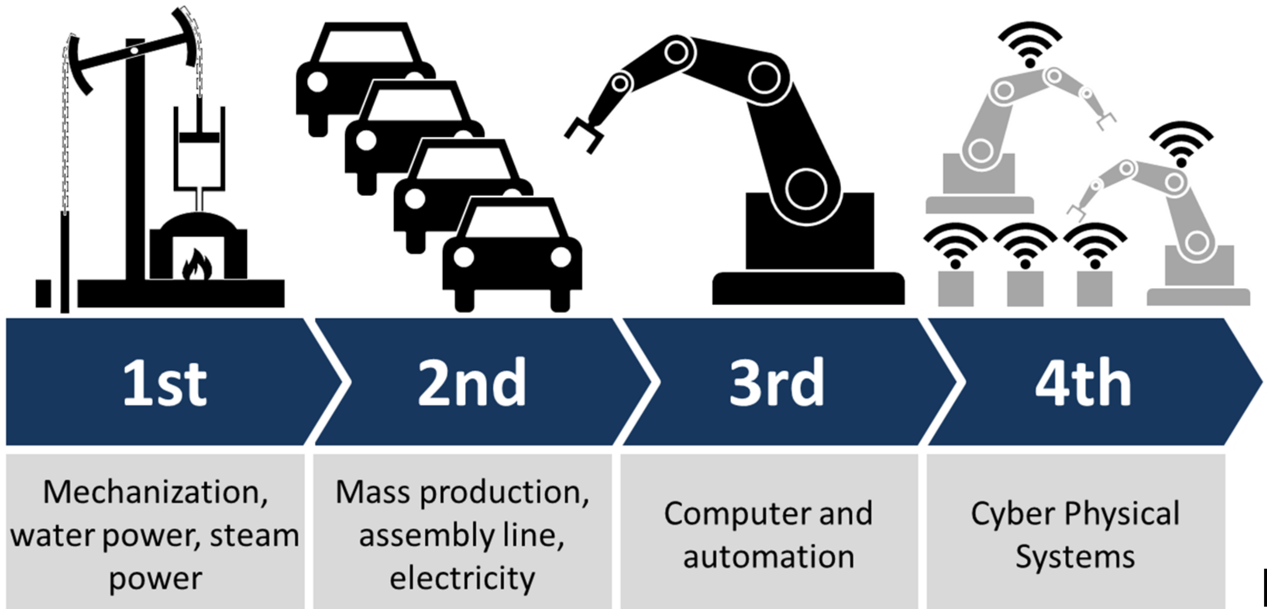
Need to use **automatic tools and systems**.

**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** Industrie 4.0 term revived at the Hannover Fair |

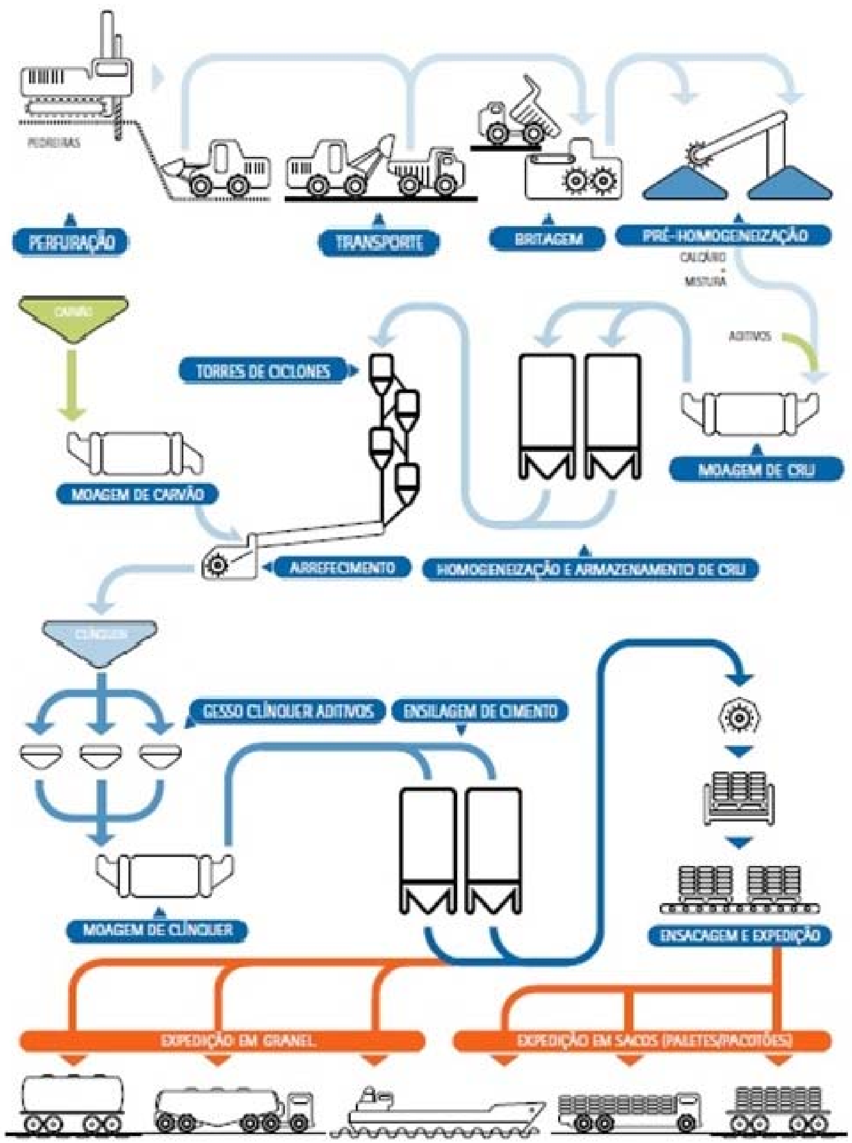
***1807-1811*** *French invasions, 1821 Independence of* ***Brasil***
***1974-1975*** *Independence of Guiné-Bissau, Moçambique, Cabo Verde, São Tomé e Príncipe,* ***Angola***

*Industrial Process:*

***Making Cement***

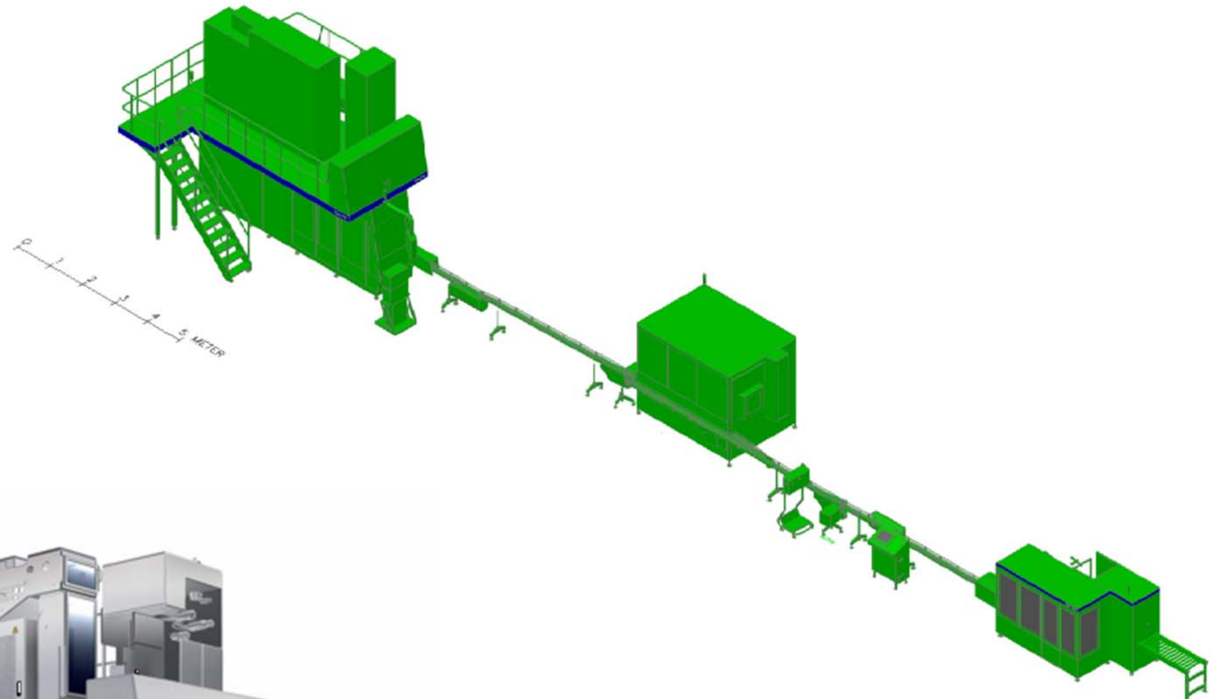
*[Outão / Setúbal / Portugal]*

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



*Industrial Process:*

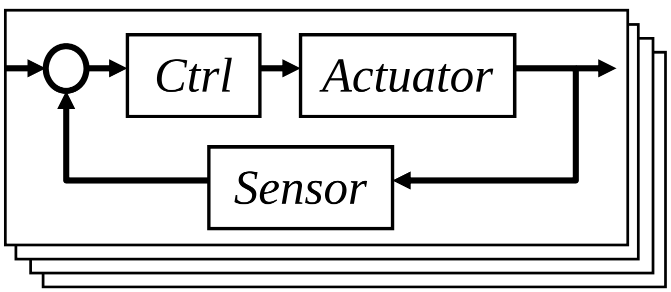
***Tetra Pak / Parmalat***




*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

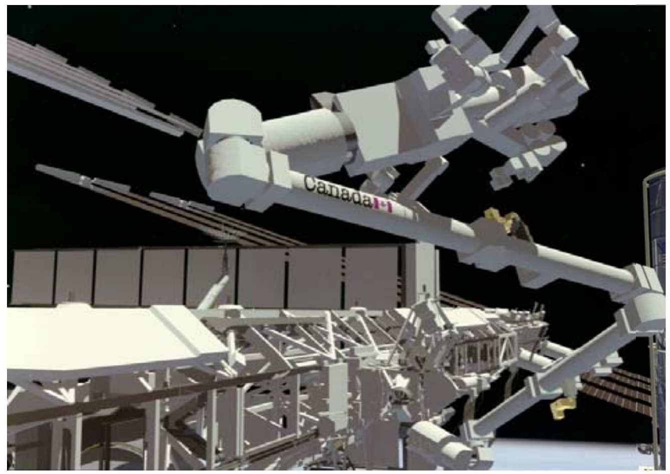
Robotic Manipulators
– generic load, unload, handle, work

Computerized CNC Machines
– specialized workers

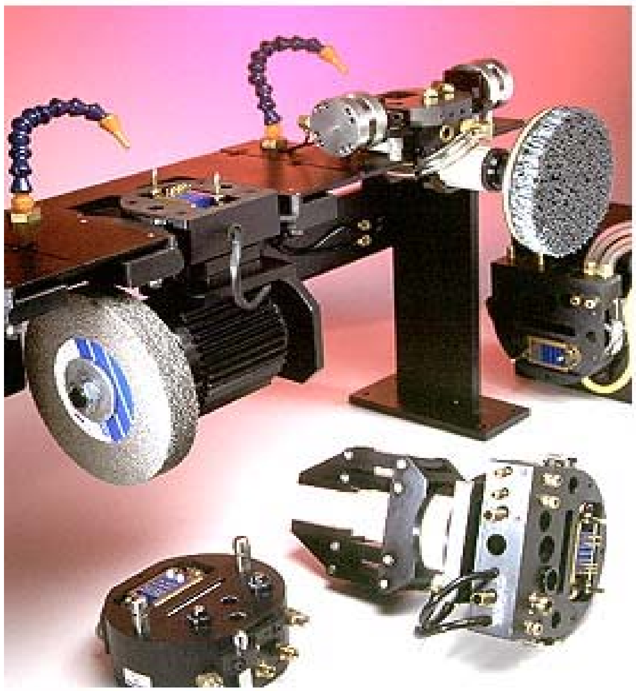
Handling materials
– specialized load and unload

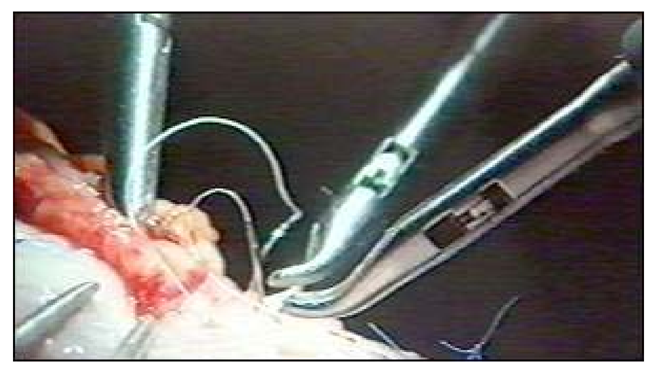
*How it is done:*
*– Low level actuation and sensing*
*– Motors, sensors, local and global integration*

# Robotic Manipulators


# Robotic Manipulators - End Effectors





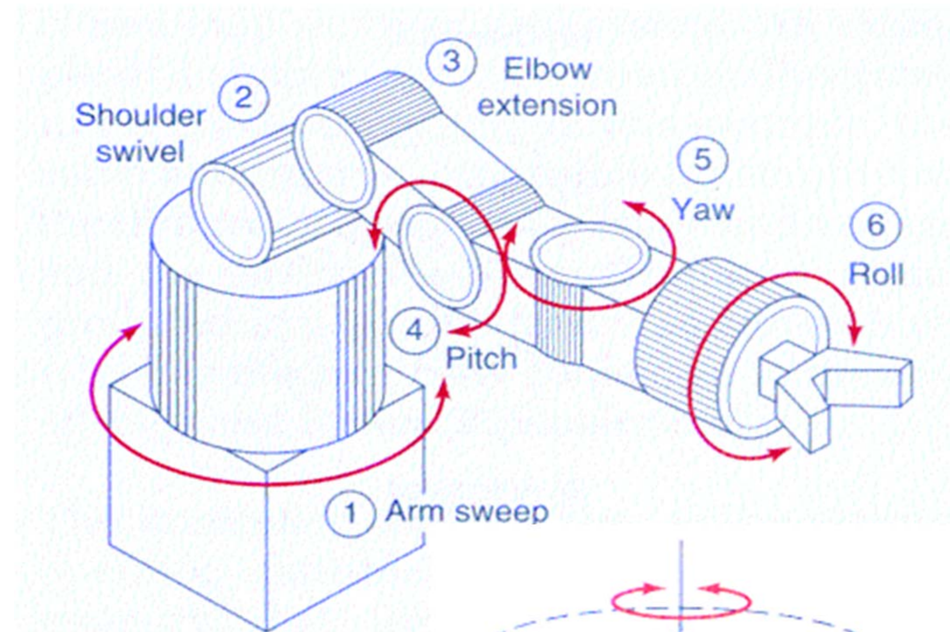
# Robotic Manipulators

## 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
- …



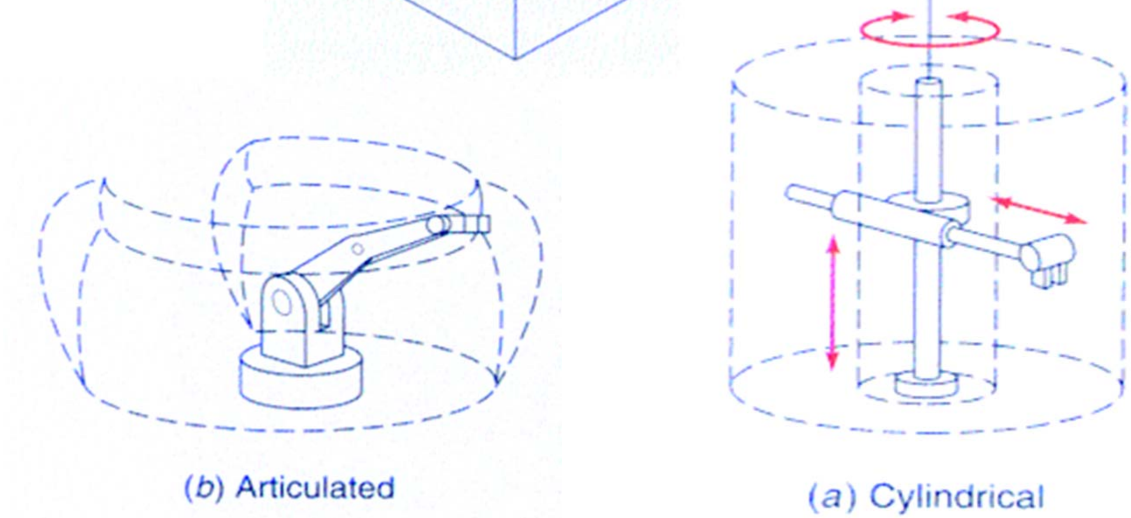
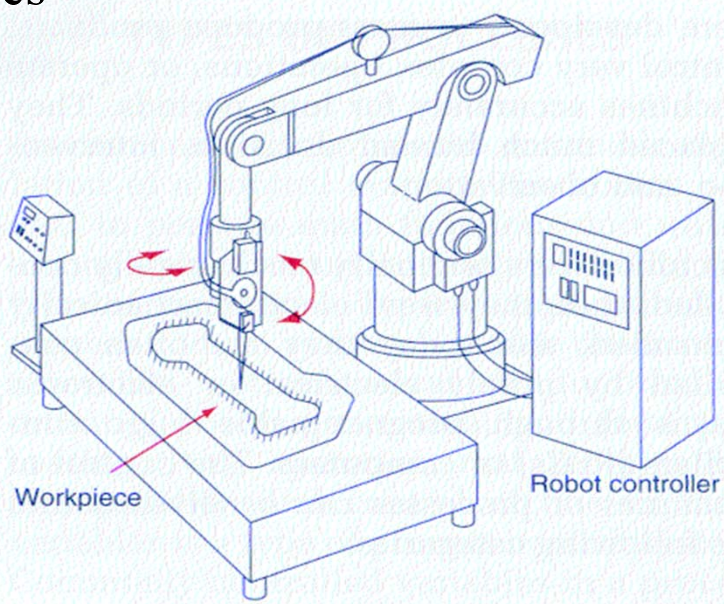




Fig. 15-23
Robot work envelope.

## 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.

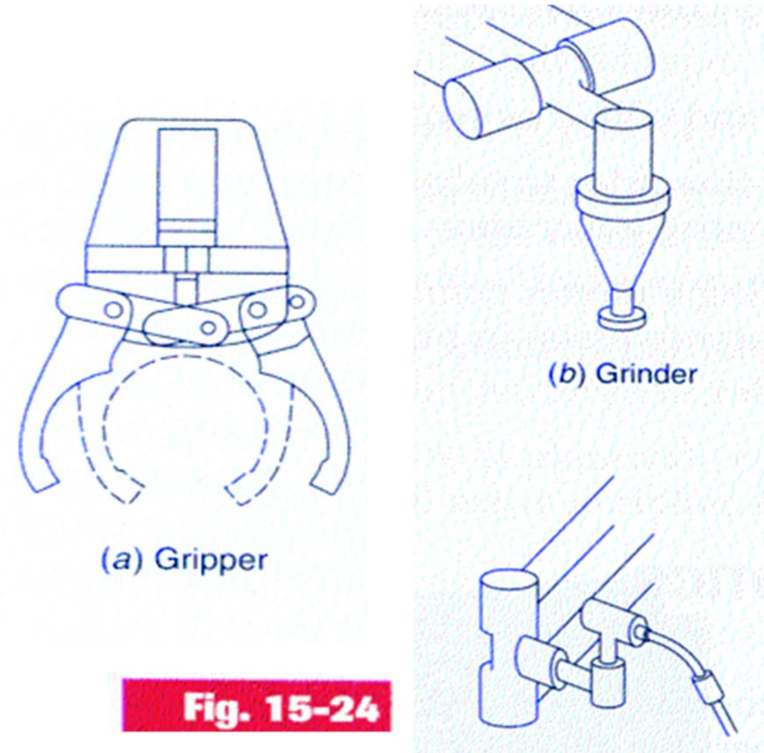



**Fig. 15-24**

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

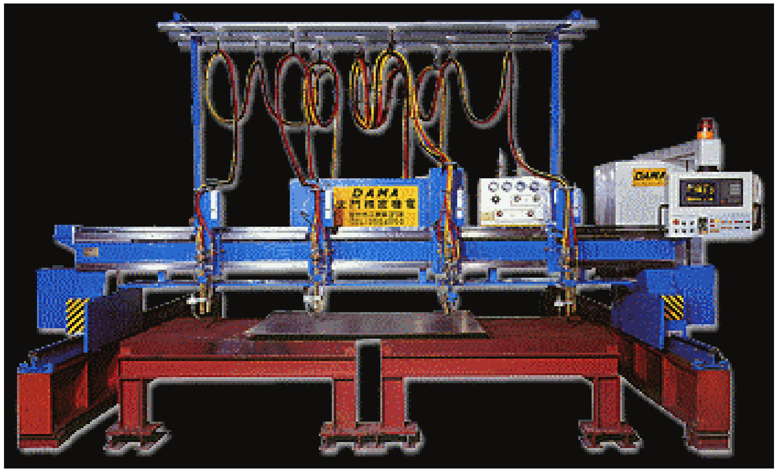
**Major characteristics:**

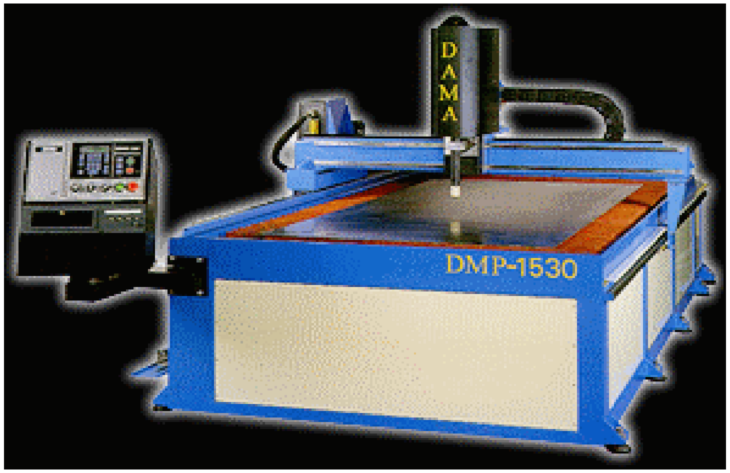
- Number of degrees of freedom
- Interpolation methods
- Load/unload automation, and also in tool change
- Programming (high level languages, teach pendent, ...)
- Workspace
- Accuracy, reliability
- Payload and robustness
- Interface
- Synchronization with exterior

**Examples:**
Milling, Lathes, ...

MITSUI SEIKI Machining Center

# Computerized Numerical Controlled (CNC) Machines

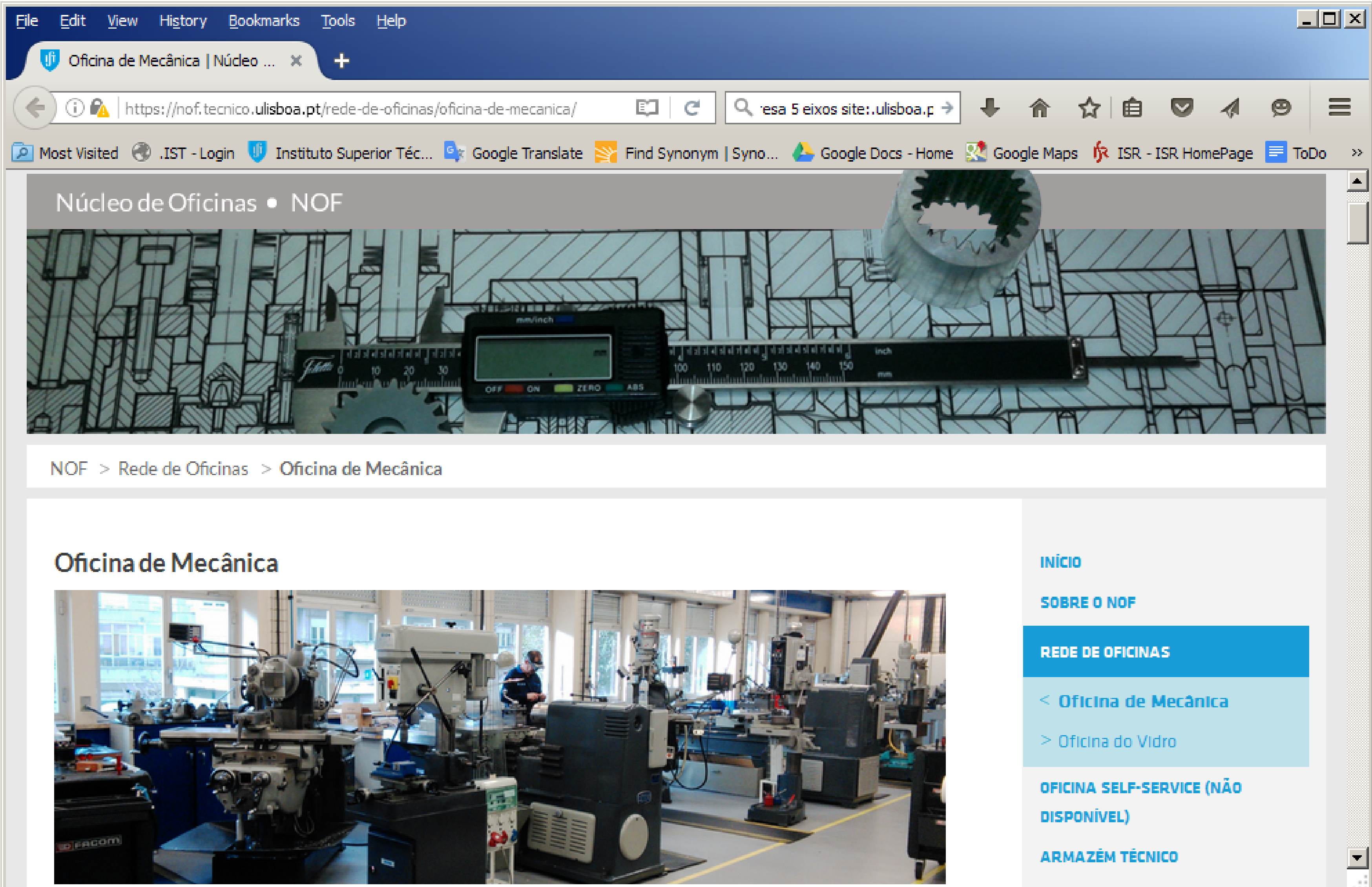




Compact CNC plasma cutting machine
Effective cutting :1.5 m X 3 m
Plasma torch cutting capacity up to 5cm (mild steel), Gas torch option allows up to 10cm.

# 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*

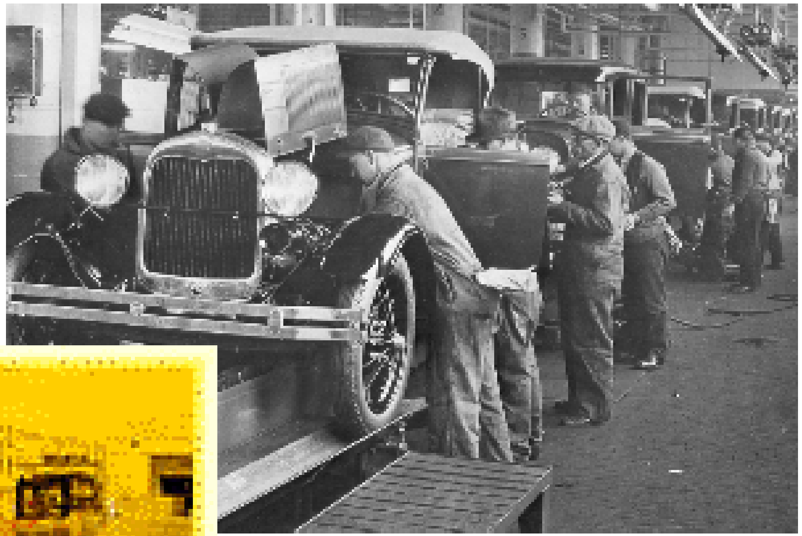
# Automatic Guided Vehicles (AGVs)

**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]

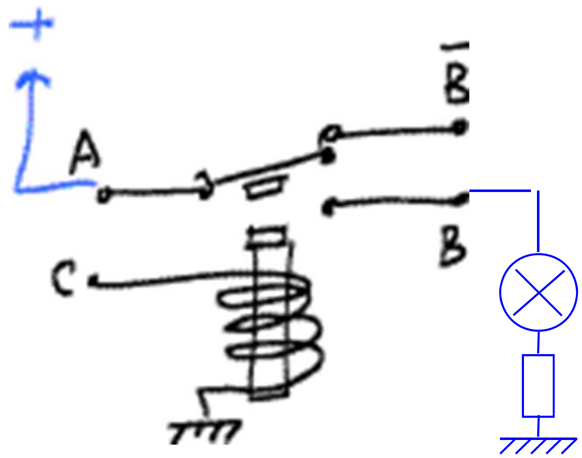
1.1 Introduction to **components** in industrial automation.

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

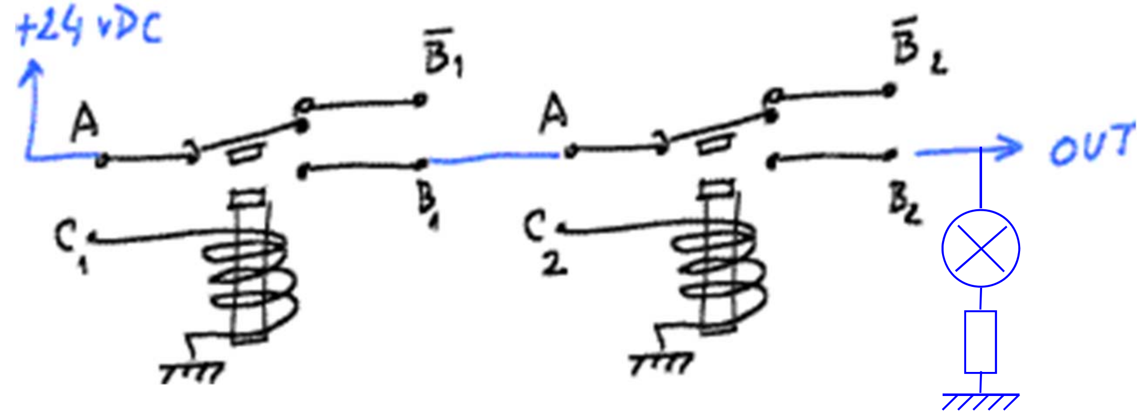
*One Relay*




$$B = C$$

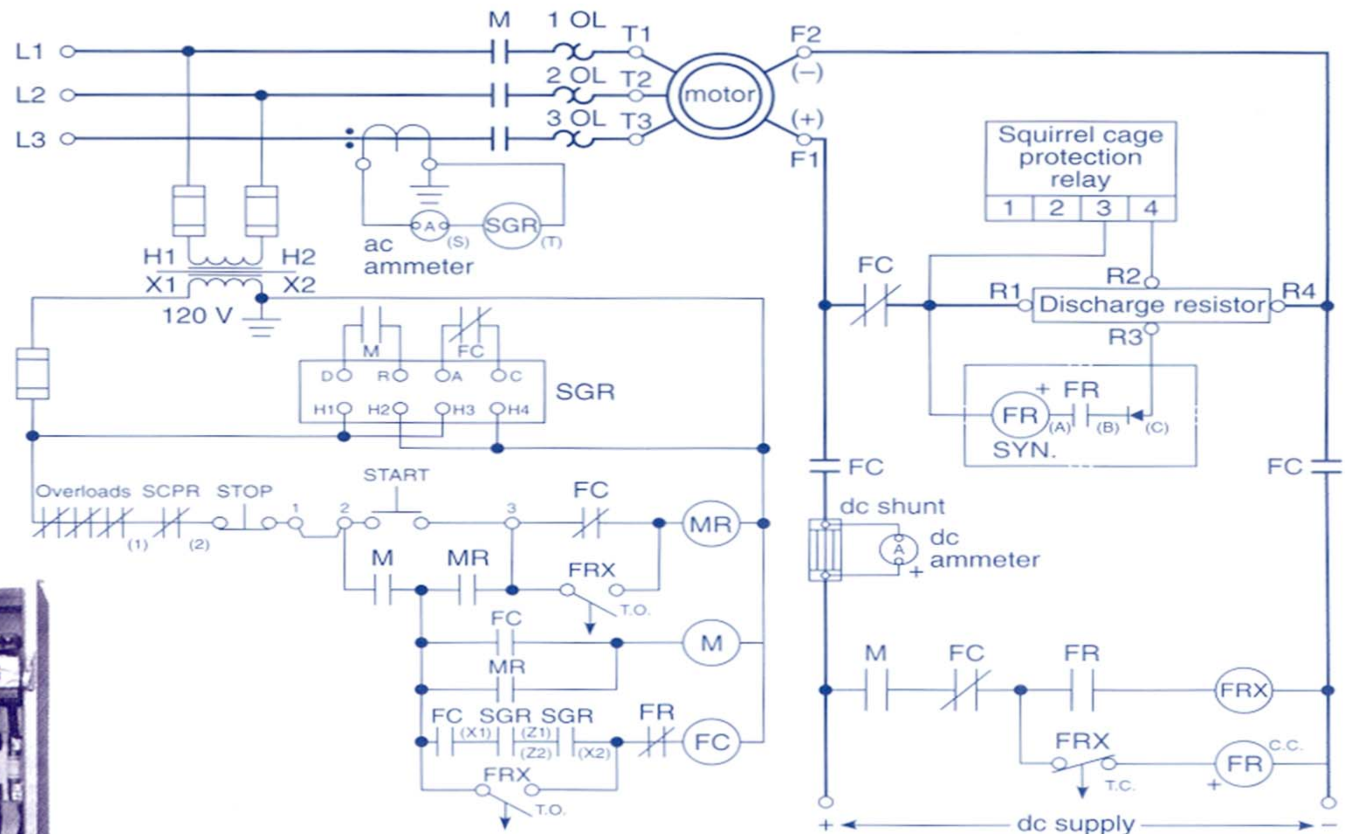
$$\overline{B} = \overline{C}$$

*Two Relays making one AND gate*

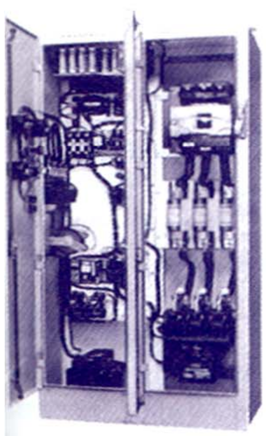



$$B_2 = C_1 \wedge C_2$$

# 1.2 Cabled Logic versus ...




(b)



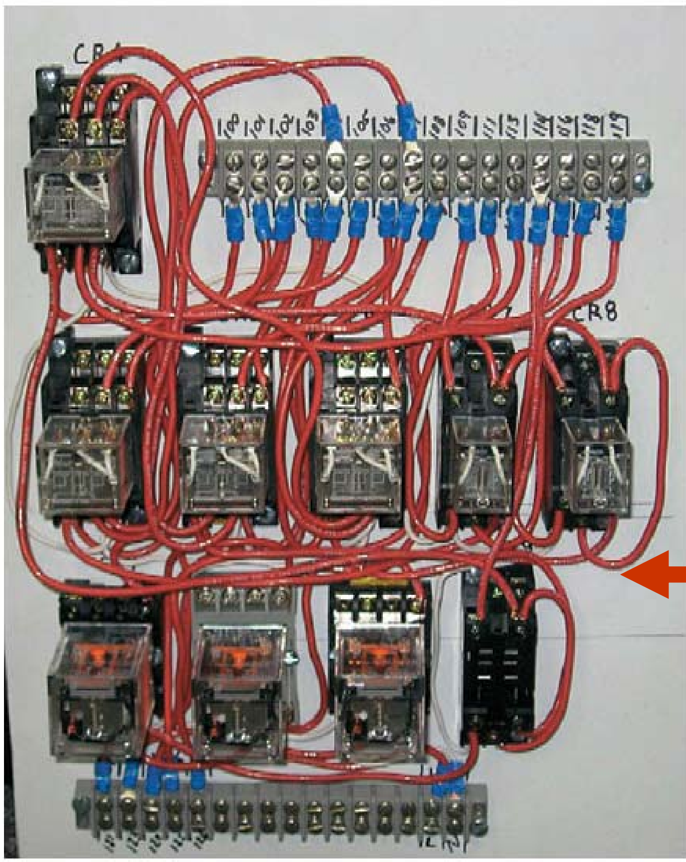
(a)

**Fig. 1-2**

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

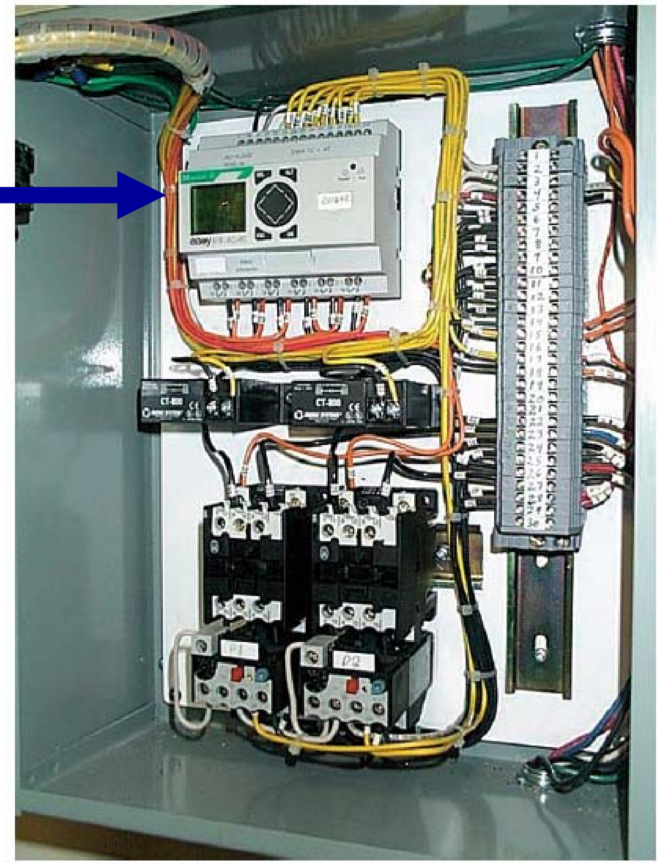
# Cabled Logic versus ...

## ... versus Programmed Logic …

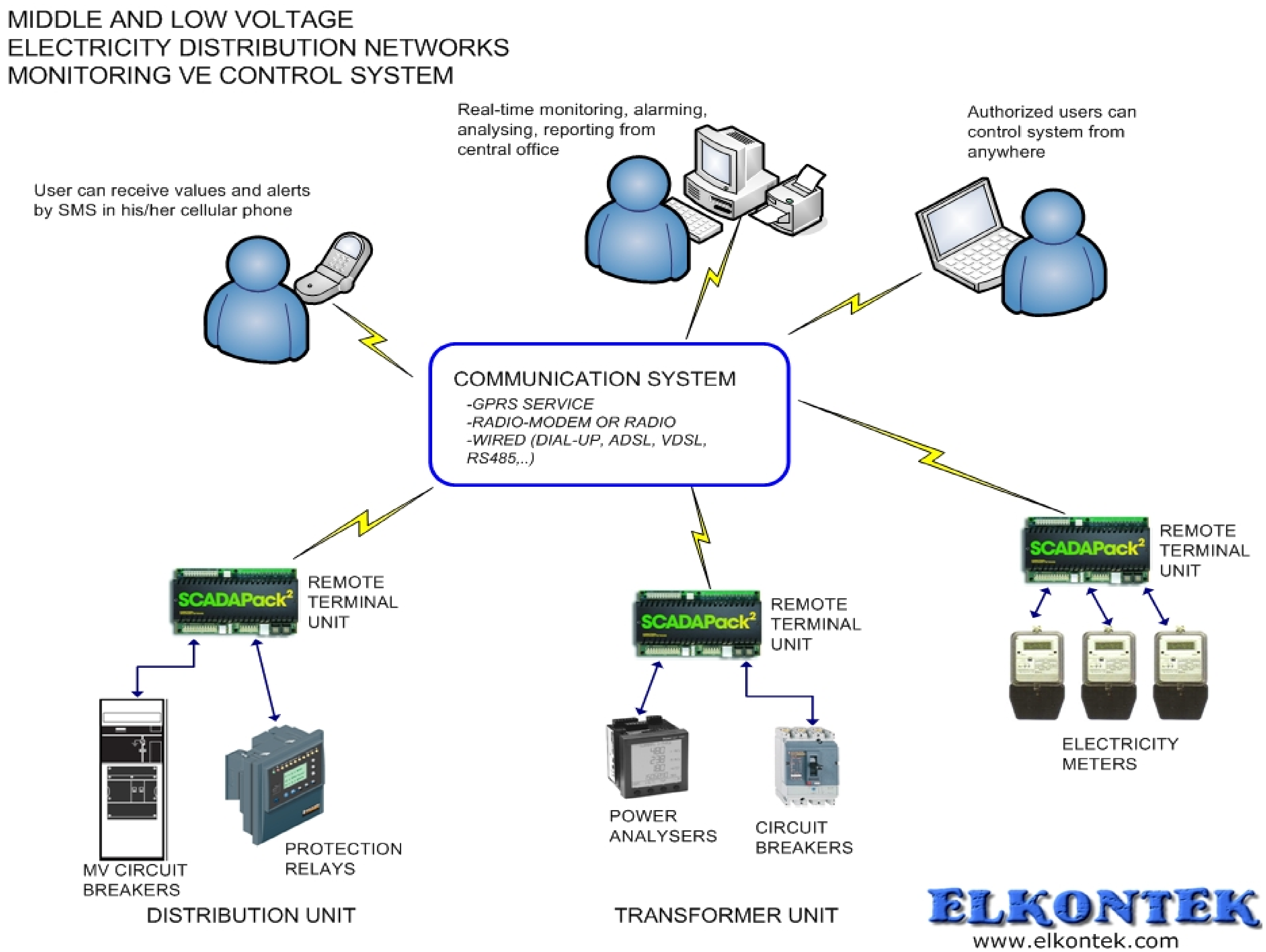


Relay control panel

PLC control panel



# ... versus Networked Logic



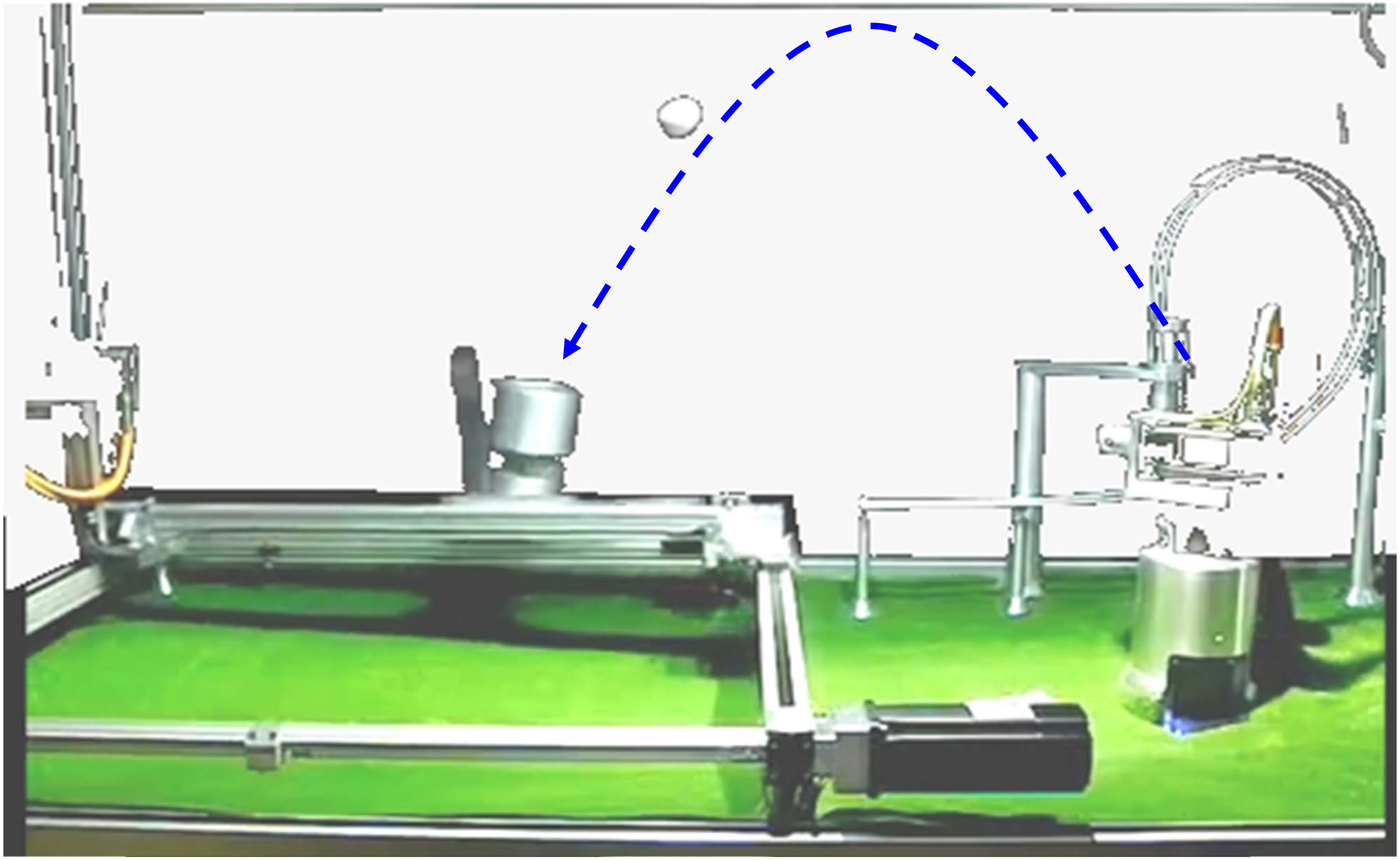
## Ch. 1 – Introduction to Automation [1 week]

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.

*Demonstration of precise actuation – Schneider Electric*



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**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.*

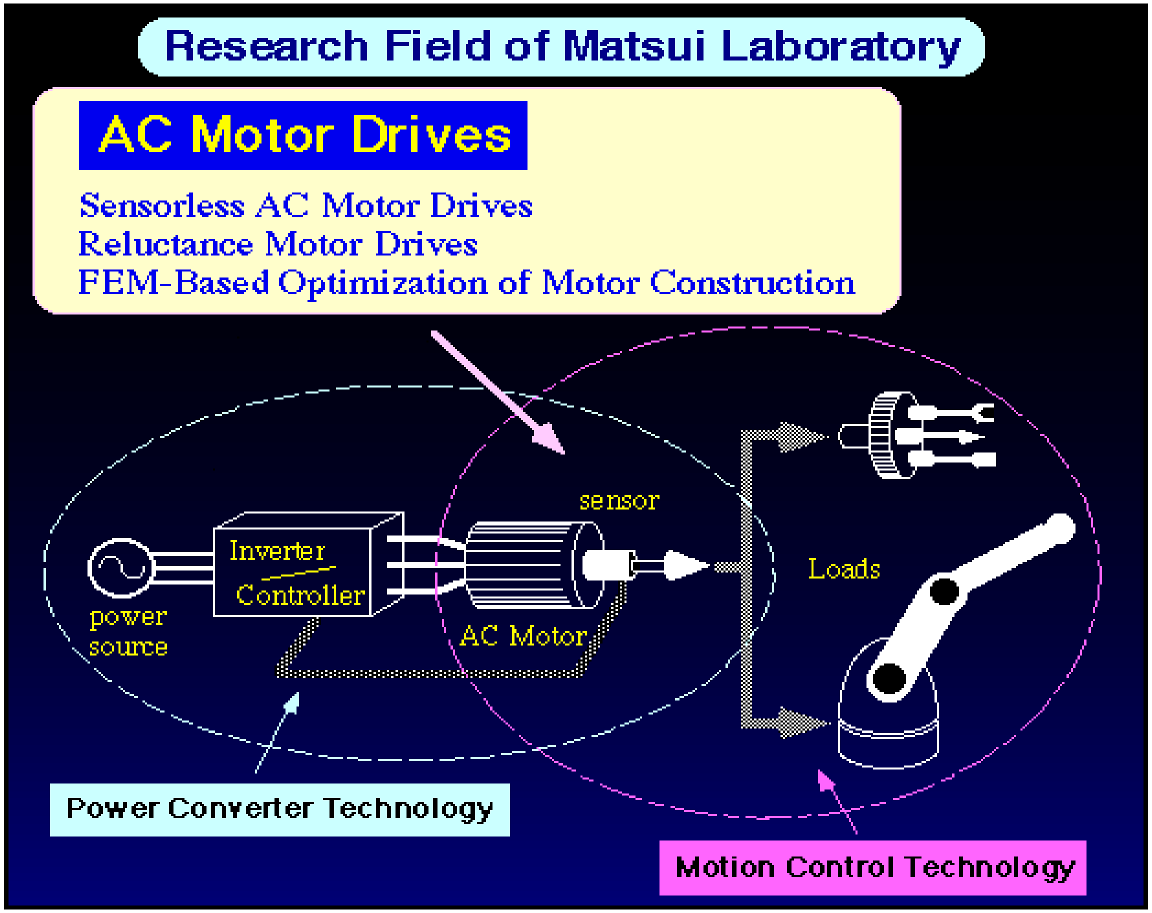
# Actuation

## Motors

### Major characteristics:

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

# Example of AC motor, with driver



# Solenoid Valve

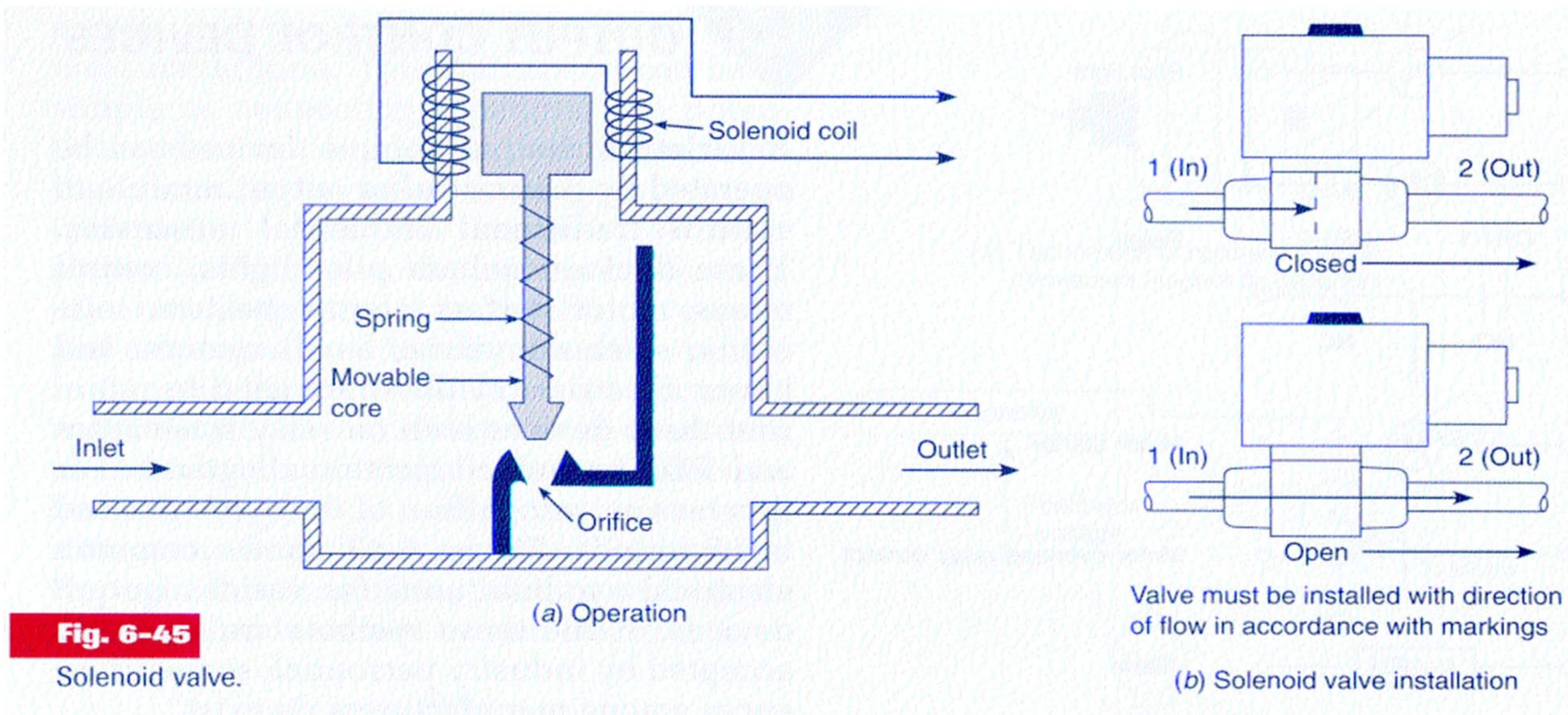



Fig. 6-45 Solenoid valve.

# Command Relay

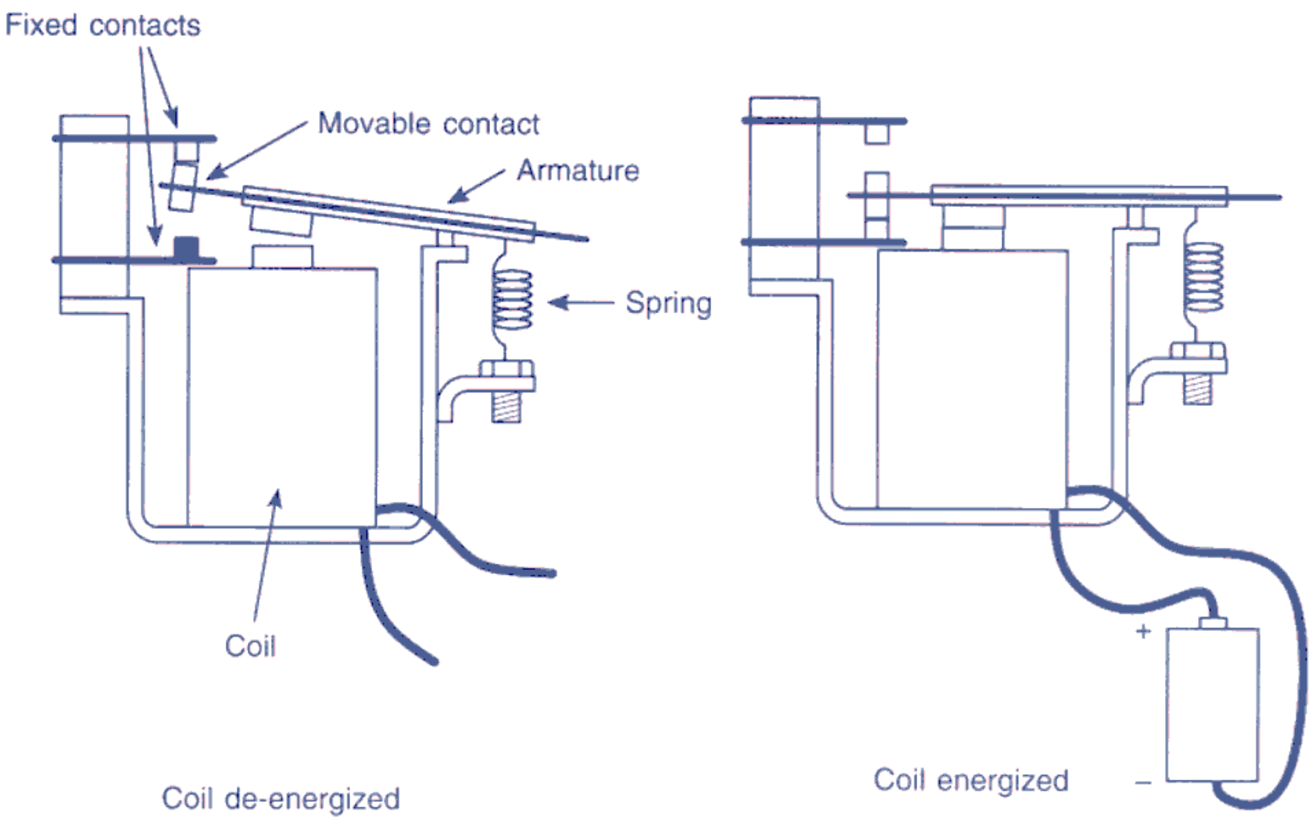
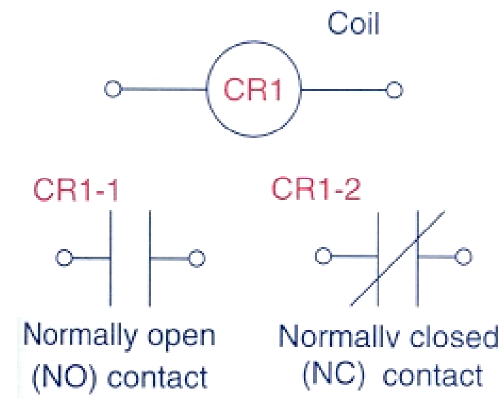
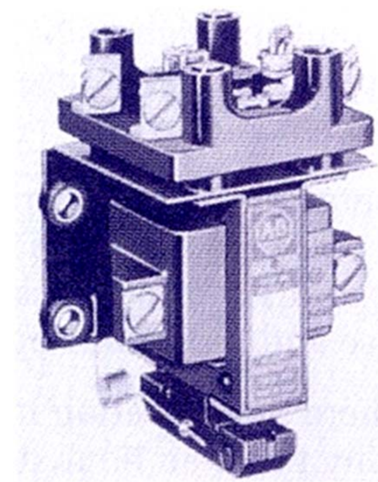



**Fig. 6-1**
Electromagnetic control relay operation.




(*a*) Control relay symbol



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

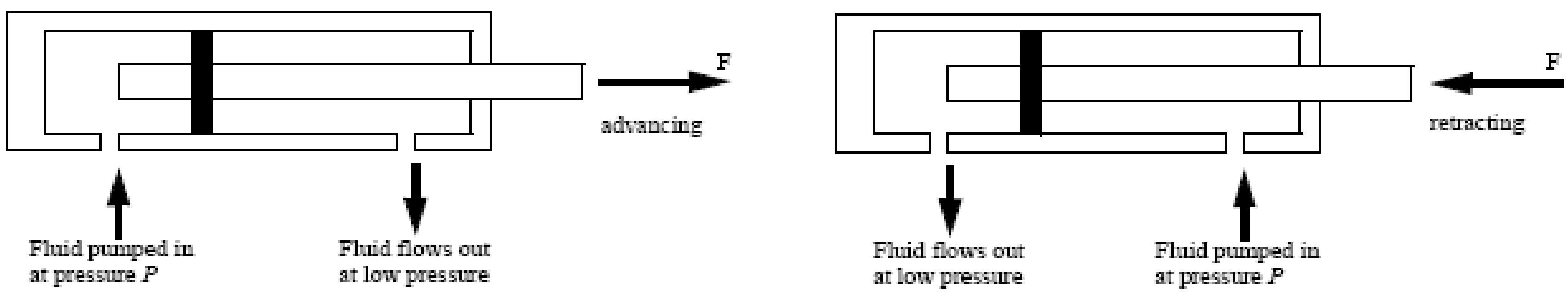
**Fig. 6-2**
Control relay.

# Command Relay




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

# Cylinders (Pneumatics)



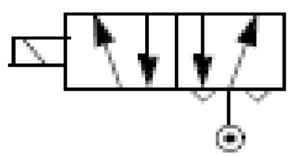

Force:

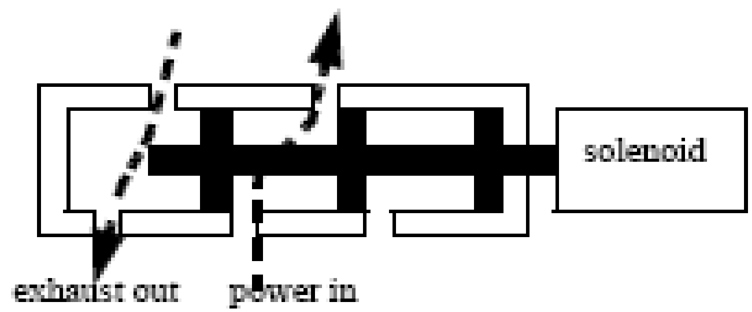
$$P = \frac{F}{A} \qquad\qquad F = PA$$

where

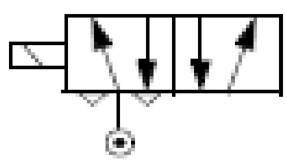
$P$ = the pressure of the hydraulic fluid
$A$ = the area of the piston
$F$ = the force available from the piston rod

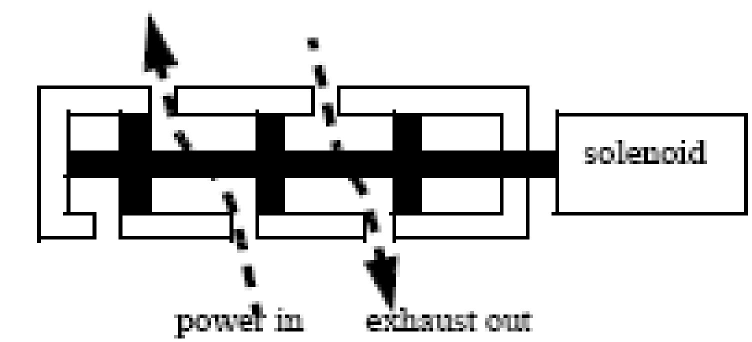
# Solenoid Valves (Electrovalves, Electro-pneumatics)





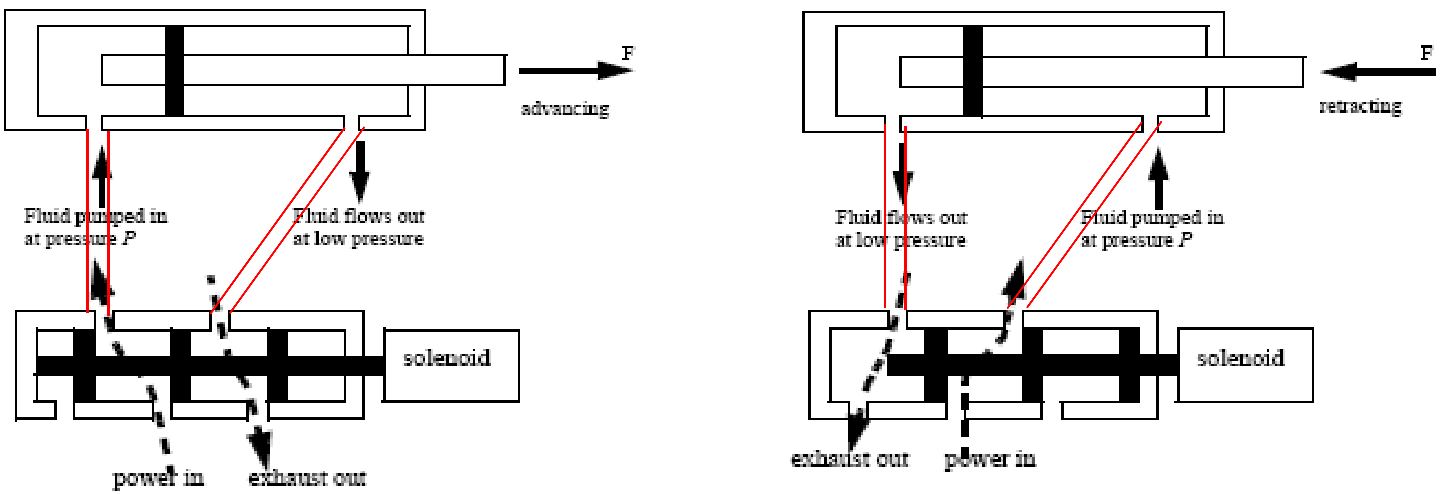

The solenoid has two positions and when actuated will change the direction that fluid flows to the device. The symbols shown here are commonly used to represent this type of valve.






Two types: ON/OFF valves, Proportional Valves

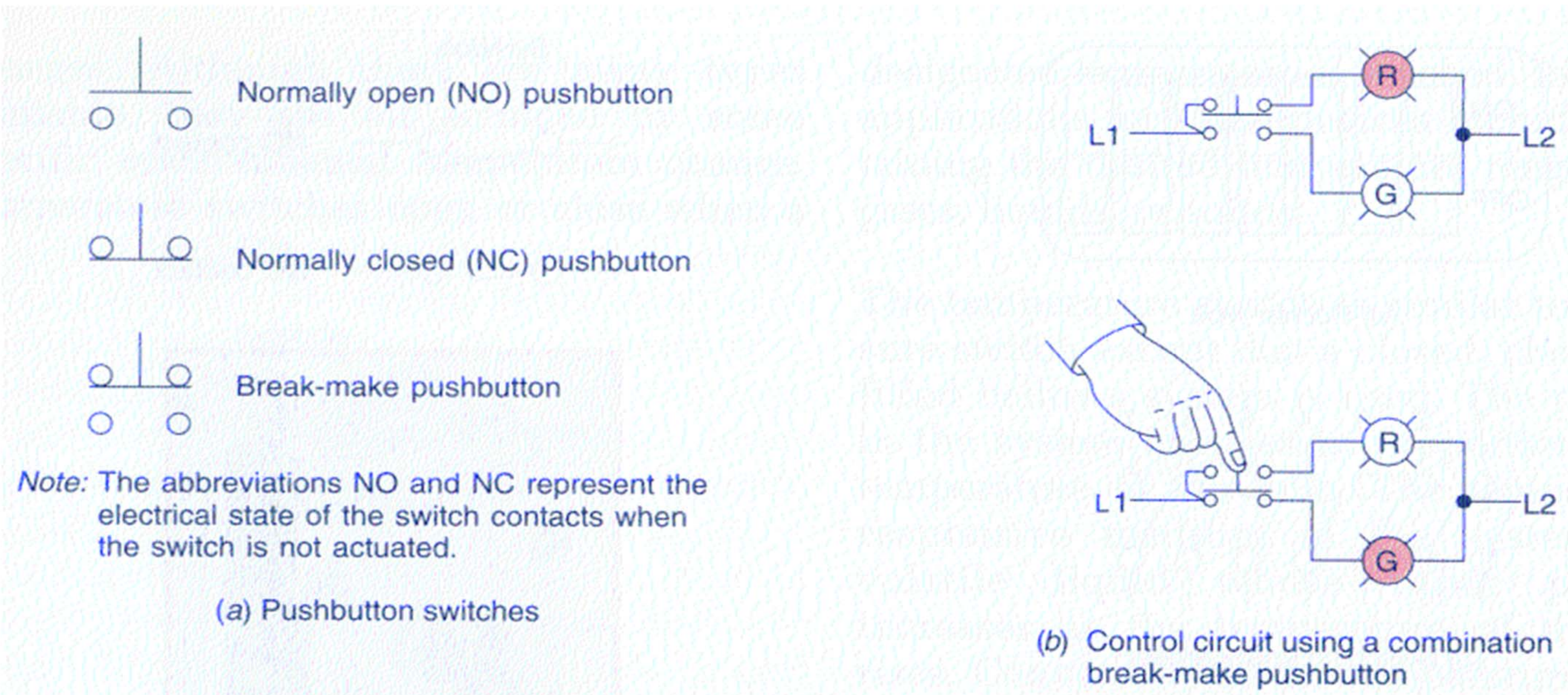
# Solenoid Valves and Cylinders




Proportional pneumatics (proportional valve),
Servo-pneumatics (e.g. feedback of the position of the piston).

# Sensors

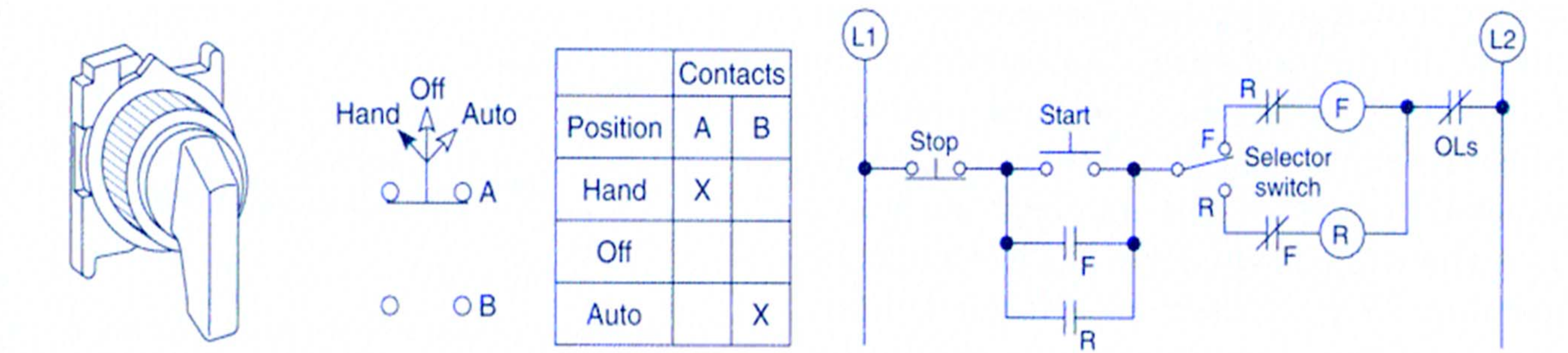
## Push buttons




(a) Pushbutton switches

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

# Selector with three positions




(*a*) Selector switch operator

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

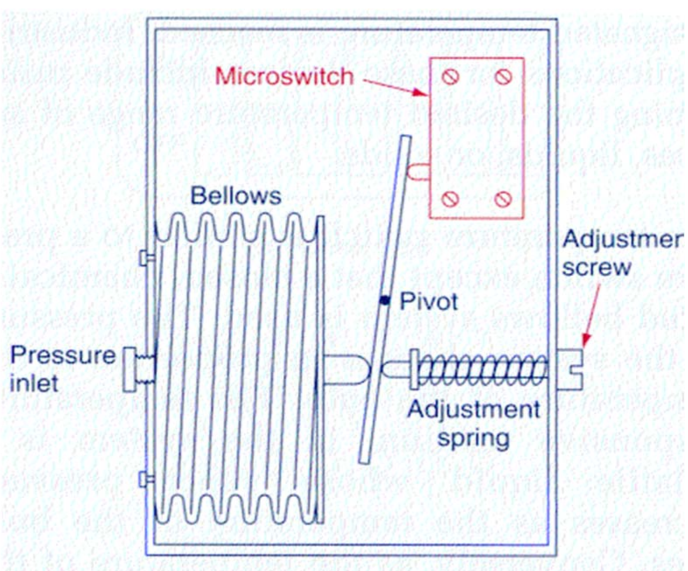
(*c*) Selector switch used in conjunction with a reversing motor starter to select forward or reverse operation of the motor

**Fig. 6-11**

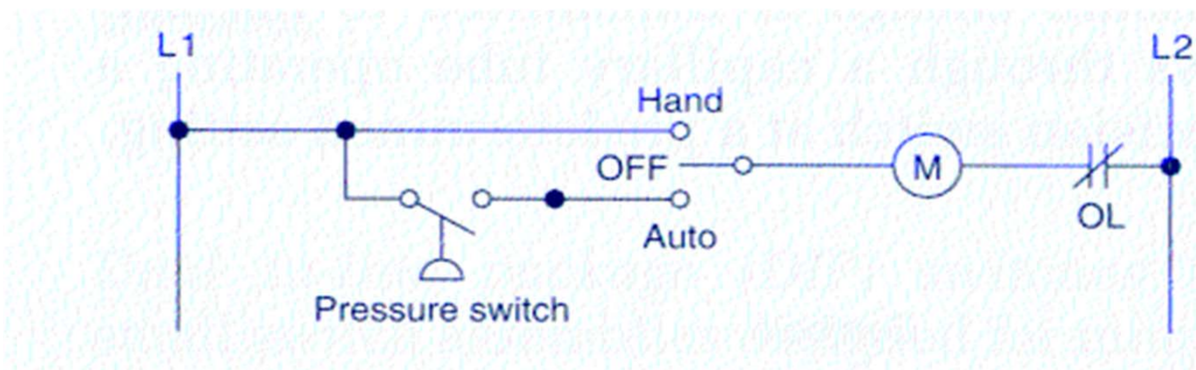
Selector switch.

# Sensors

## Pressure Switch




(*b*) Bellows



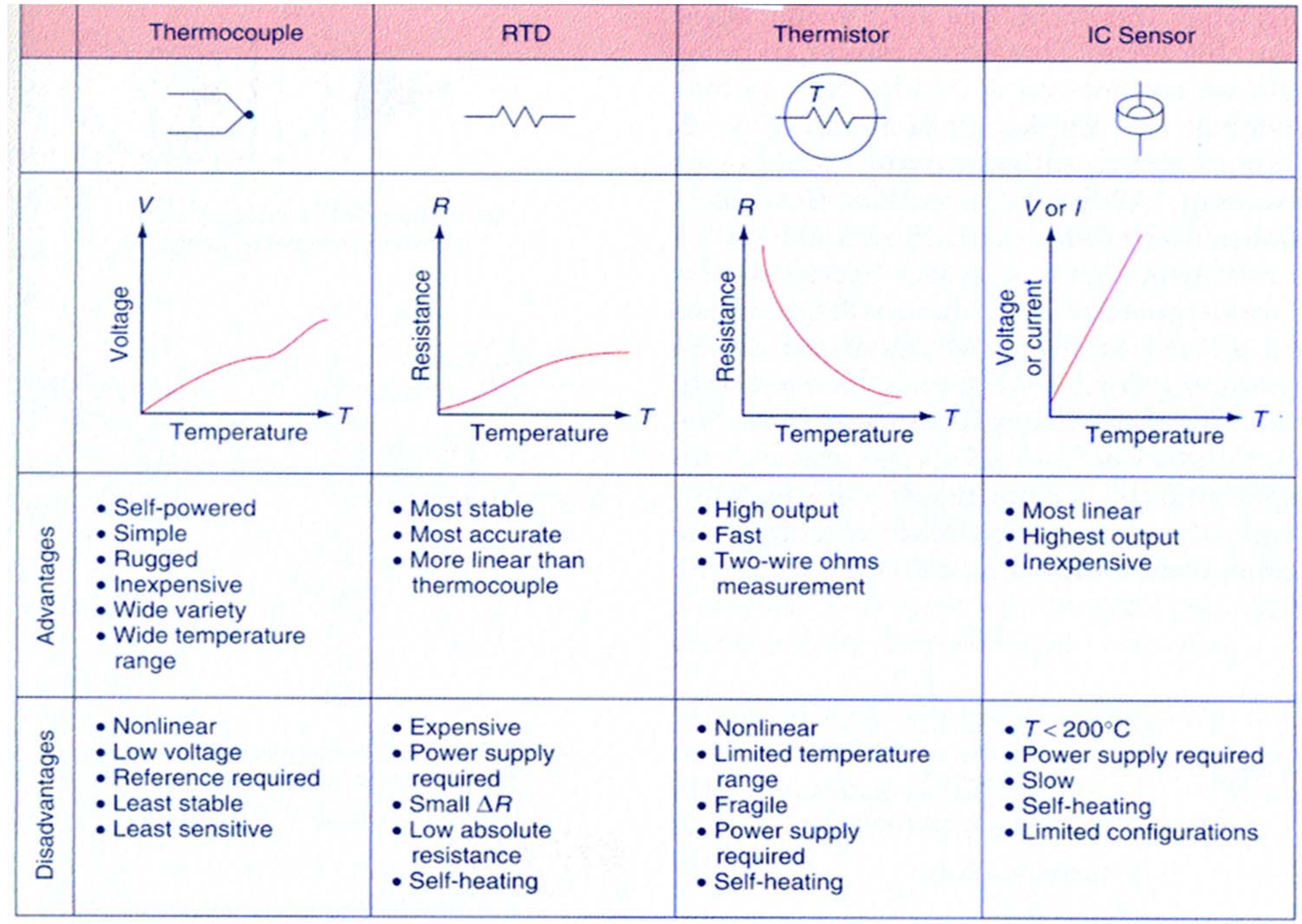

(*c*) Starter operated by pressure switch

**Fig. 6-15 (continued)**

Pressure switch.

# Temperature

# Sensors



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

**Fig. 6-38**
Common temperature sensors.

RTD = Resistance Temperature Detector
IC = Integrated Circuit

# Thermocouple

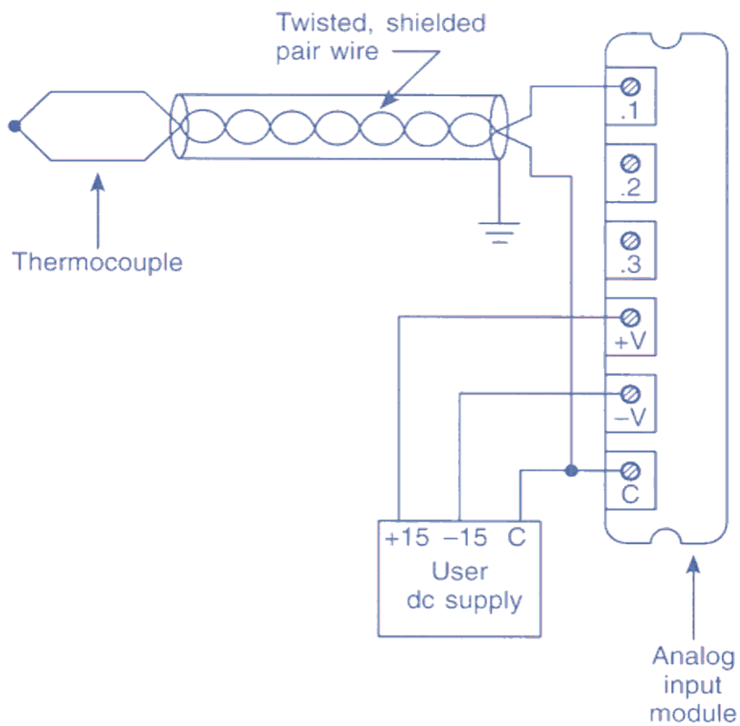



**Fig. 2-12**
Typical thermocouple connection to an analog input module.

# Proximity detector

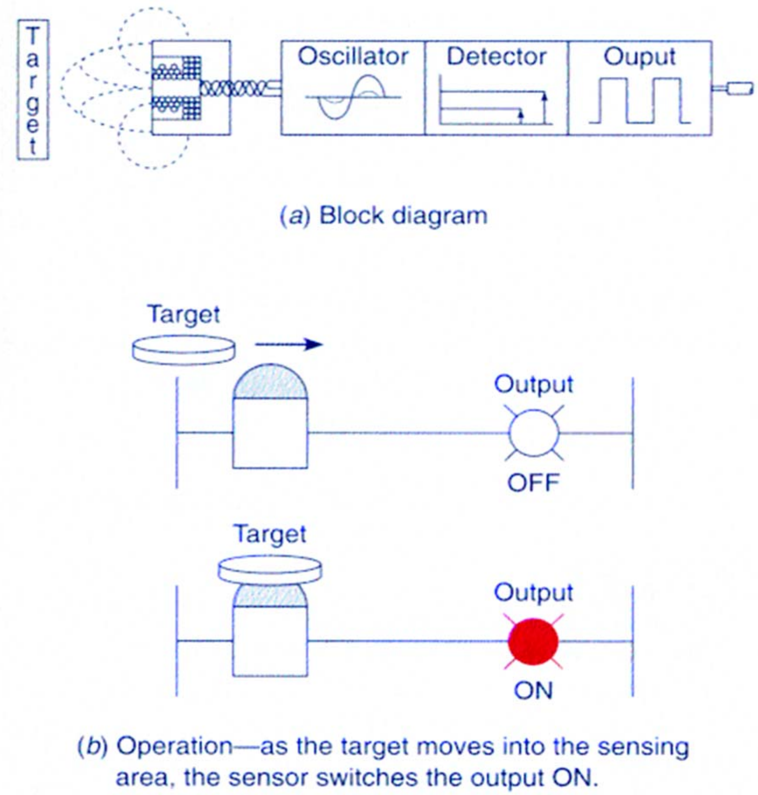



**Fig. 6-20**
Inductive proximity sensor.

## Magnetic detector

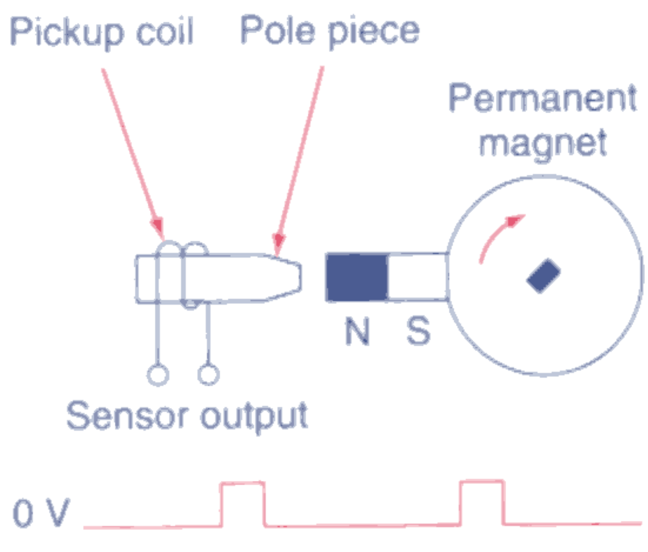



Fig. 6-42
Magnetic pickup sensor.

## Magnetic switch

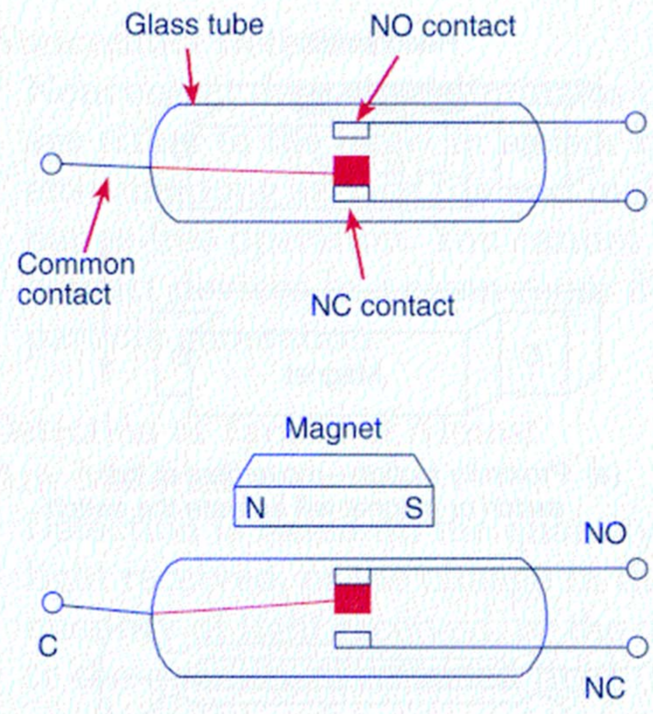



Fig. 6-25
Magnetic switch (reed switch).

## *Symbols associated to all components*

## Standards - Joint International Committee (JIC) Wiring Symbols

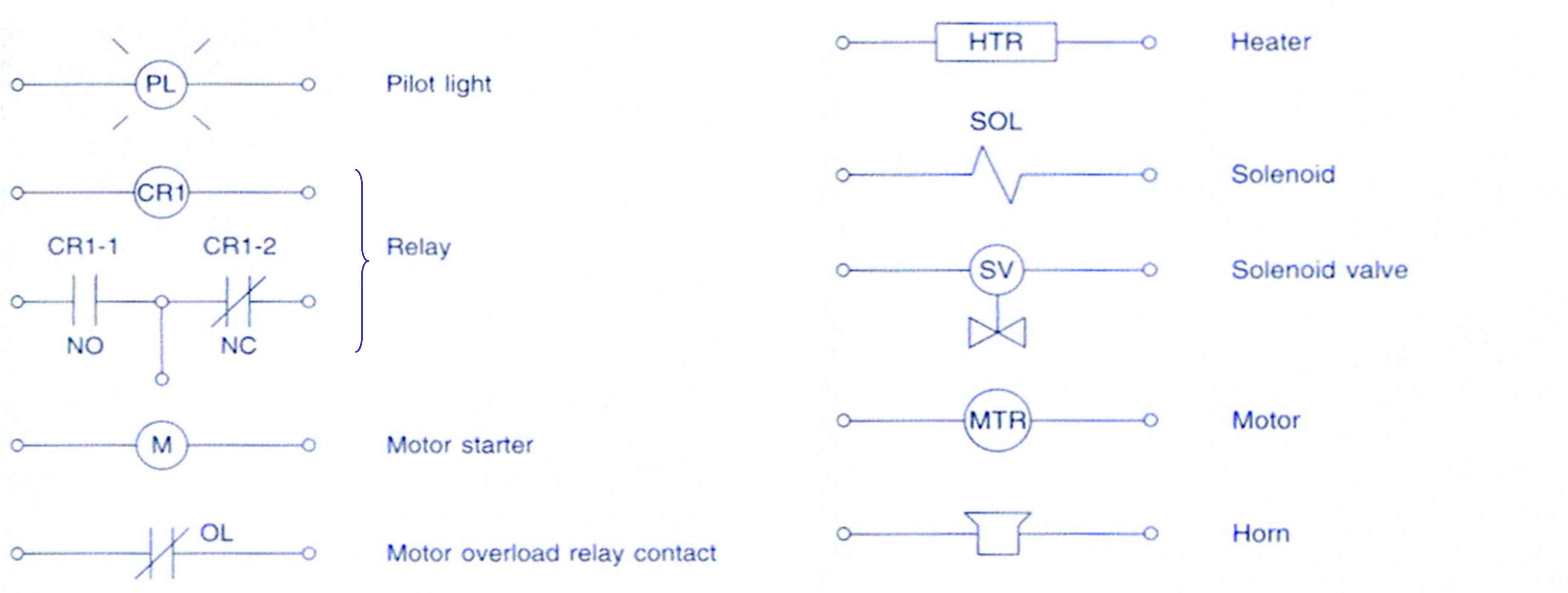
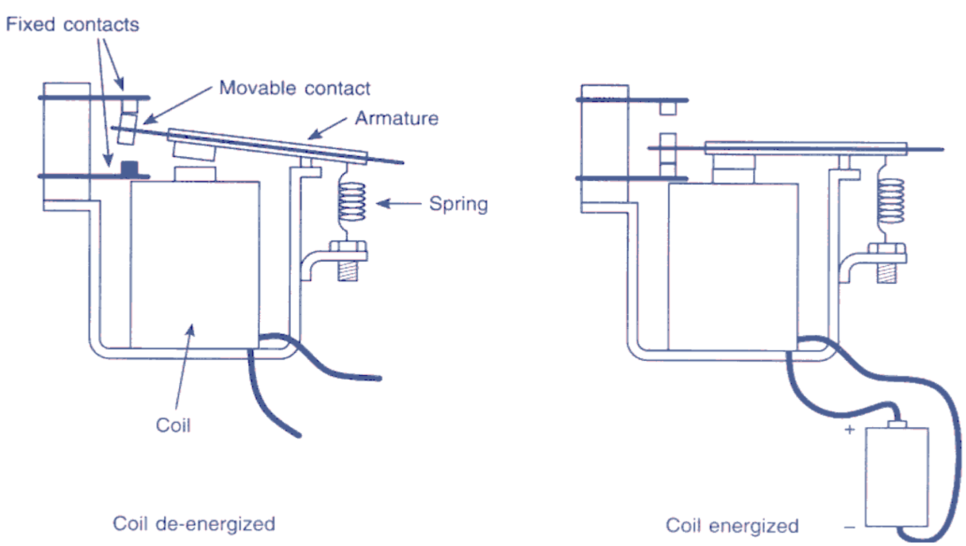



**Fig. 6-43**
Symbols for output control devices.

# *Methodologies for the implementation of solutions in industrial automation*

## *Device: Relay*




## *Contact Diagram* or *Ladder Diagram*

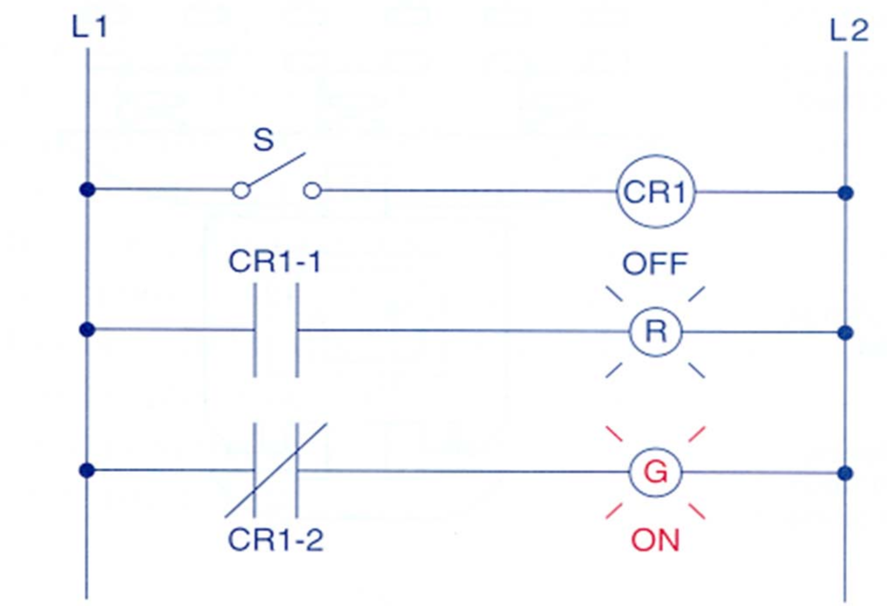



**Fig. 6-3**
Relay circuit—switch open.

# Example of relay and ladder diagrams:

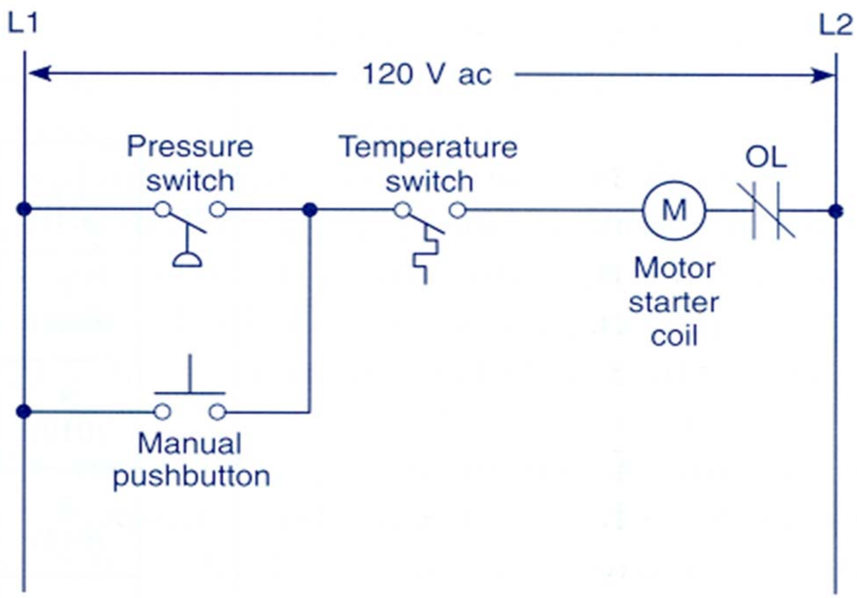



**Fig. 1-13**
Relay ladder diagram for modified process.

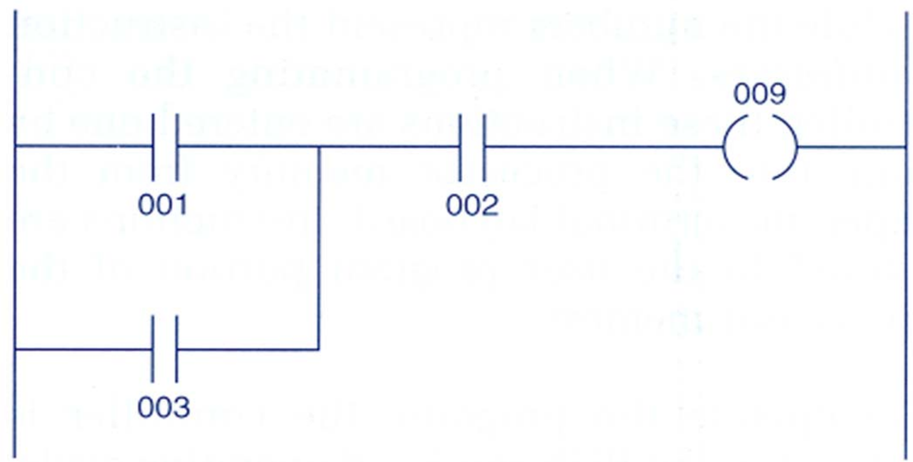
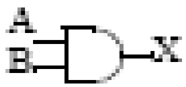



**Fig. 1-14**
PLC ladder logic diagram for modified process.

# Logic Functions

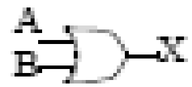
AND




$X = A \cdot B$

| A | B | X |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 0 |
| 1 | 0 | 0 |
| 1 | 1 | 1 |

OR




$X = A + B$

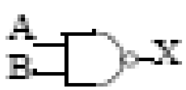
| A | B | X |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 1 |

NOT


$X = \overline{A}$

| A | X |
|---|---|
| 0 | 1 |
| 1 | 0 |

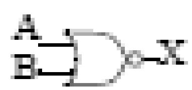
NAND




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

| A | B | X |
|---|---|---|
| 0 | 0 | 1 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 0 |

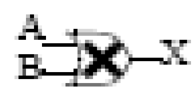
NOR




$X = \overline{A + B}$

| A | B | X |
|---|---|---|
| 0 | 0 | 1 |
| 0 | 1 | 0 |
| 1 | 0 | 0 |
| 1 | 1 | 0 |

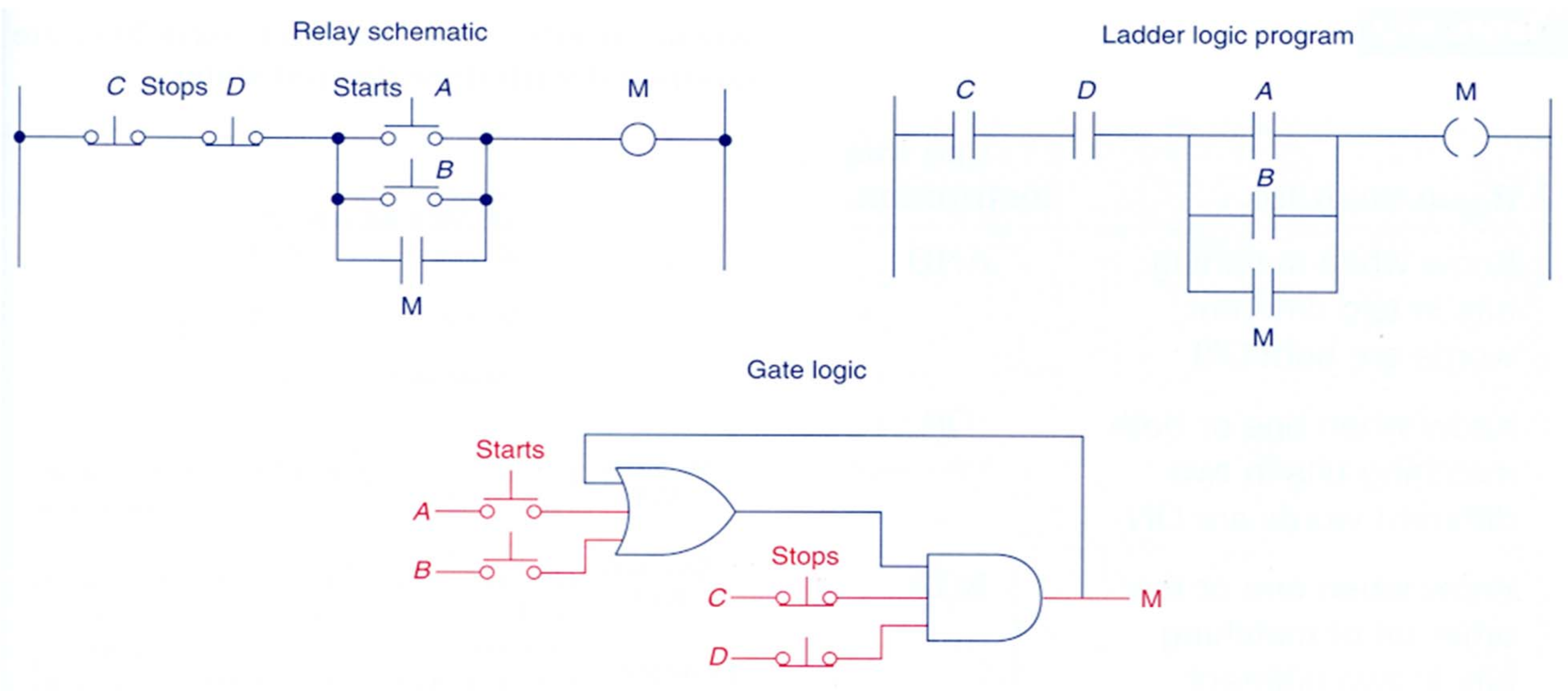
EOR




$X = A \oplus B$

| A | B | X |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 0 |

# Example of relay and ladder diagrams, and gate logic:

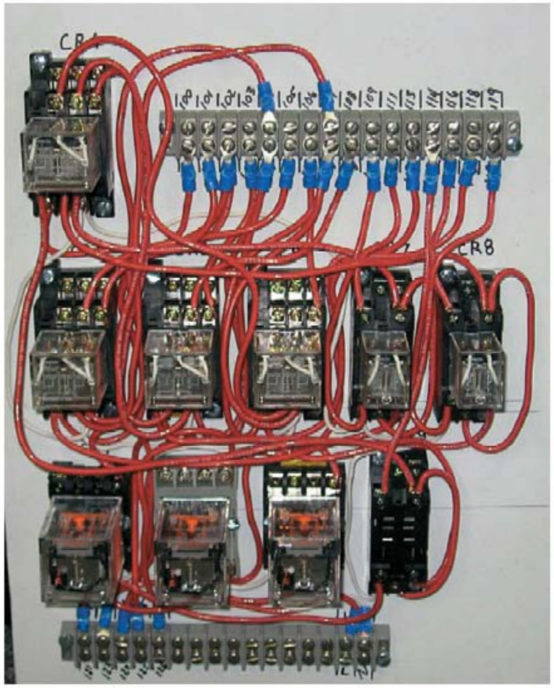



**Example 4-9**

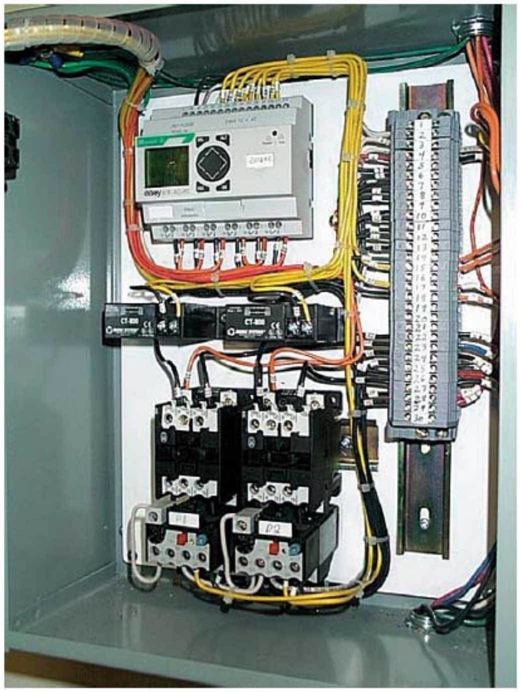
A motor control circuit with two stop buttons. When the start button is depressed, the motor runs. By sealing, it continues to run when the start button is released. The stop buttons stop the motor when they are depressed.

# *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***