# Industrial Automation
## (Automação de Processos Industriais)

http://users.isr.ist.utl.pt/~jag/courses/api1415/api1415.html

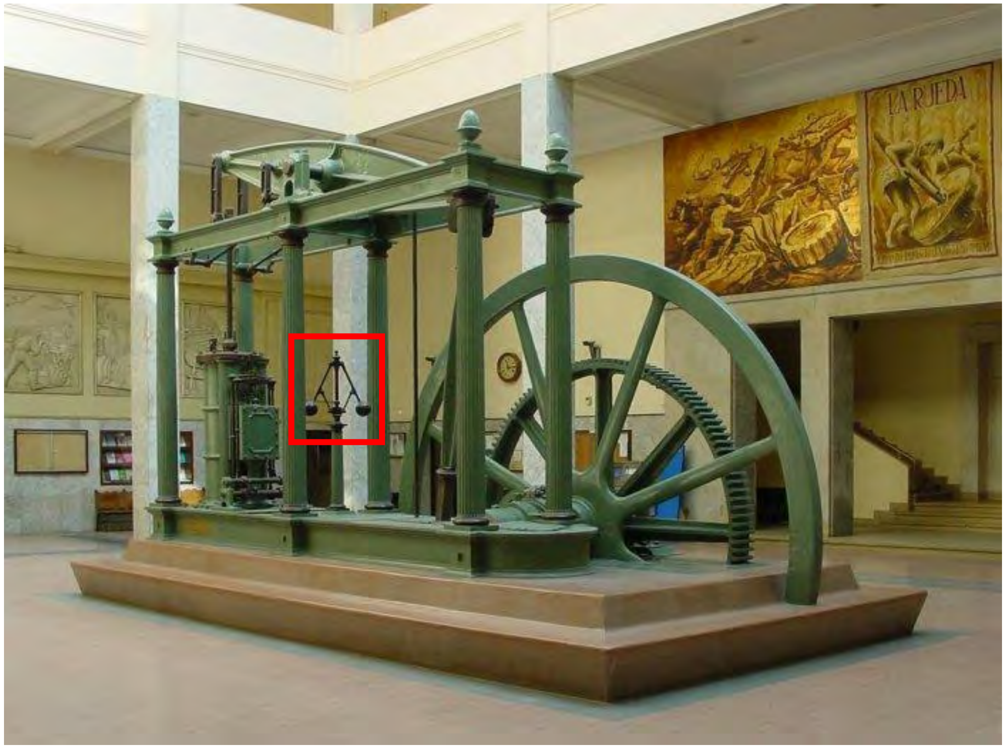
Slides 2010/2011 Prof. Paulo Jorge Oliveira

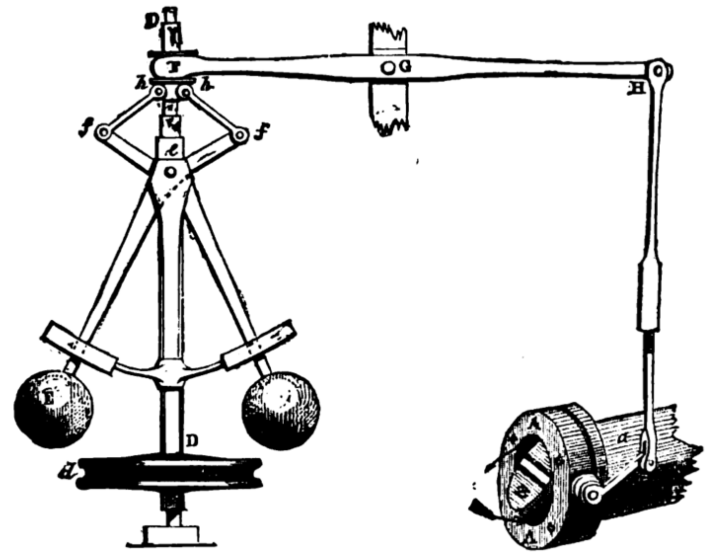
Rev. 2011-2015 Prof. José Gaspar

*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]*

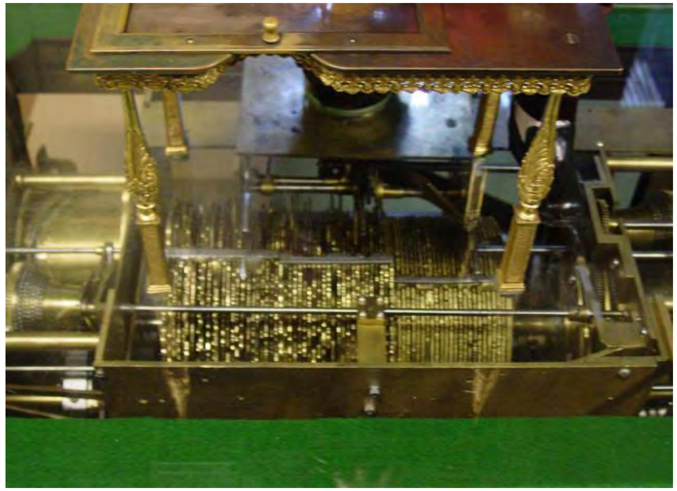
*Industrial Revolution 1760/80 – 1820/40 (historians E. Hobsbawm, T. S. Ashton)*

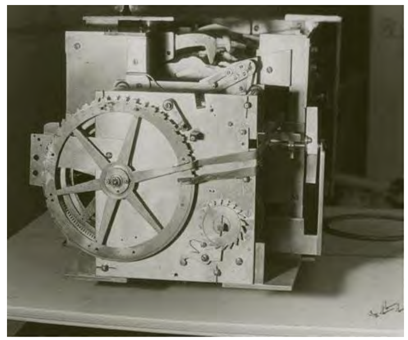



*Steam engine and detail of the governor, James Watt's [wikipedia].*

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

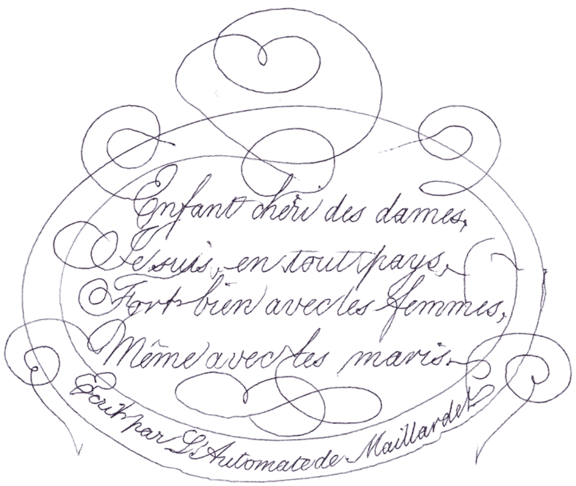


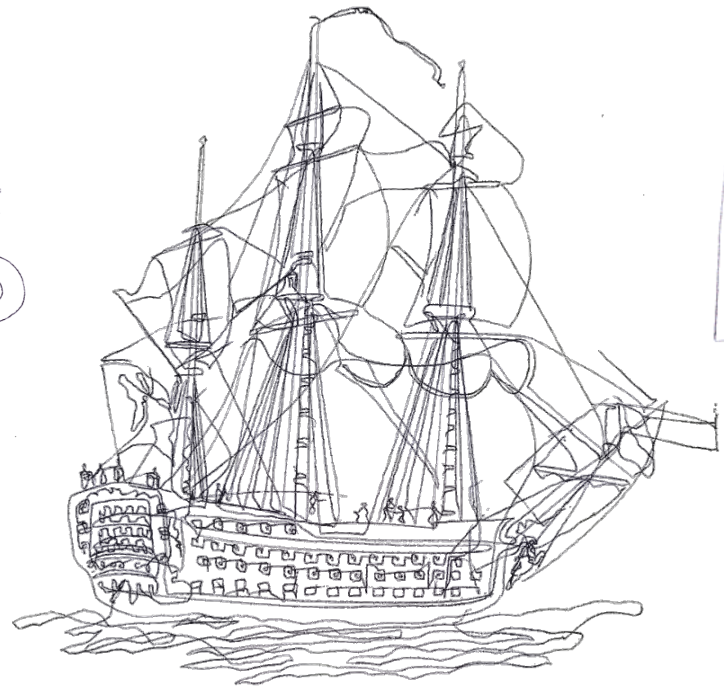


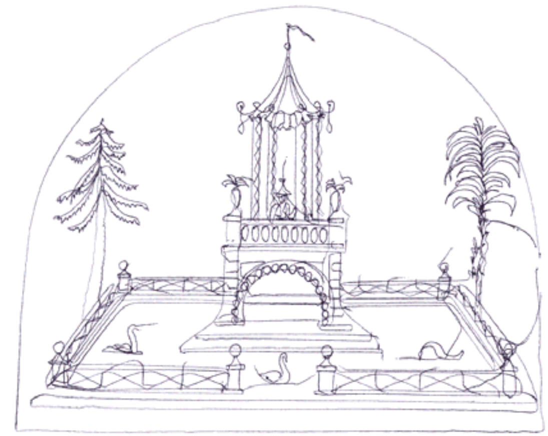
http://www.fi.edu/learn/sci-tech/automaton

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

*Four drawings and three poems*





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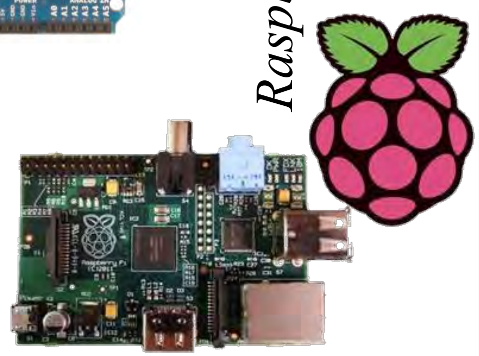
## *Microcontrollers*



*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 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 or 4 students.*
- *1 Seminar (20% of the final grade). Topics to be selected with each group.*
- *1 Exam (40% of the final grade).*

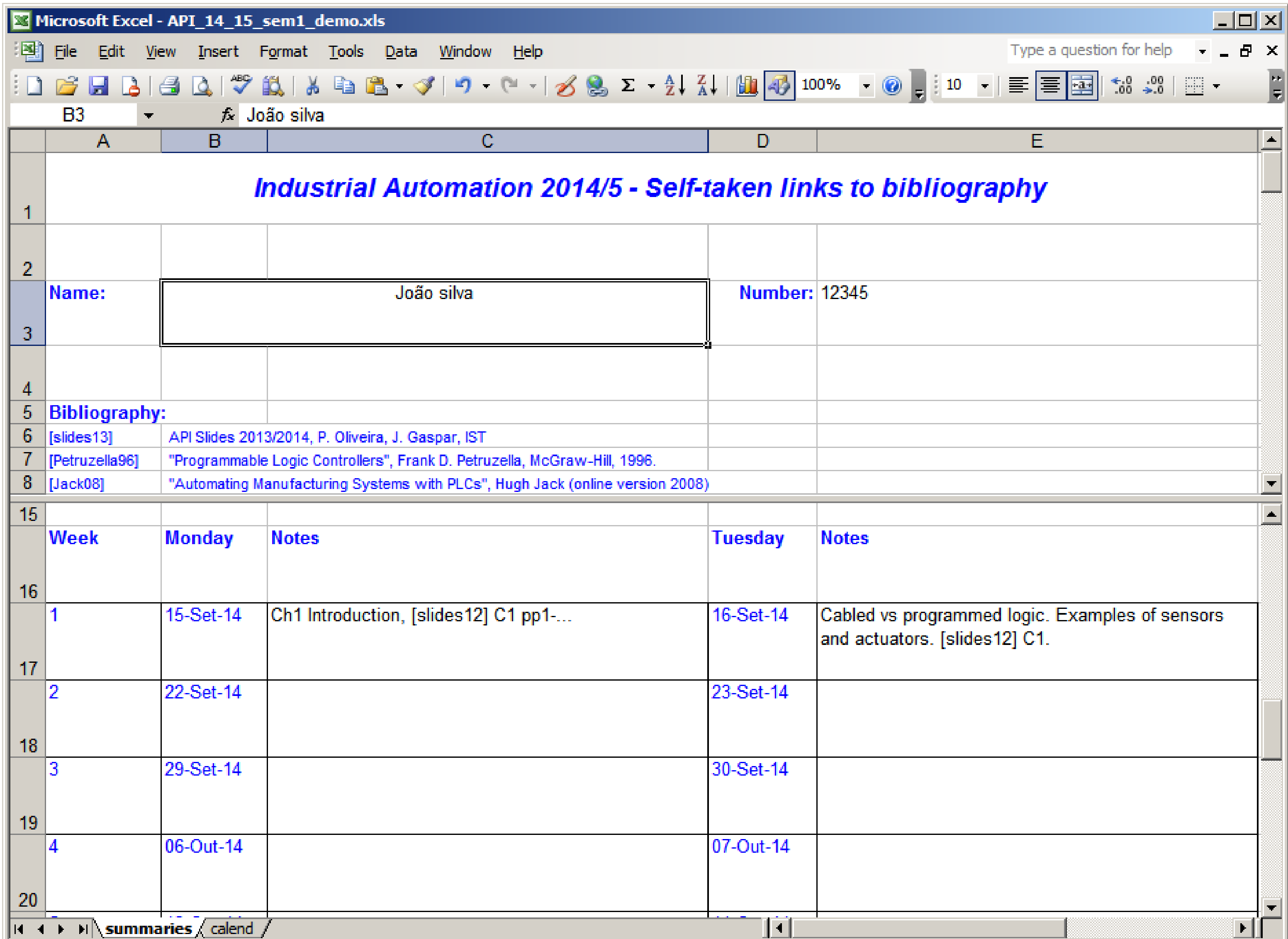
*Upon student choice, the second exam can be oral.*

- *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) |
| Exams | 3h, 15Jan or 31Jan 2015 |

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

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

- Recitation classes

| | | |
|---|---|---|
| Monday | 11.00 h – 12.30h | Ea5 |
| Tuesday | 09.30 h – 11.00h | Ea3 |

- 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:

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

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

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

--- secondary---

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

• Petri Nets and GRAFCET: Tools for Modeling Discrete Event Systems, R. DAVID, H. ALLA, New York : PRENTICE HALL Editions, 1992.

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

• Christos Cassandras, "Discrete Event Systems - Modeling and Performance Analysis", Aksen Associates, 1993.

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

# Industrial Automation

## (Automação de Processos Industriais)

## Introduction to Automation

http://www.isr.ist.utl.pt/~jag/aulas/api1415/api1415.html

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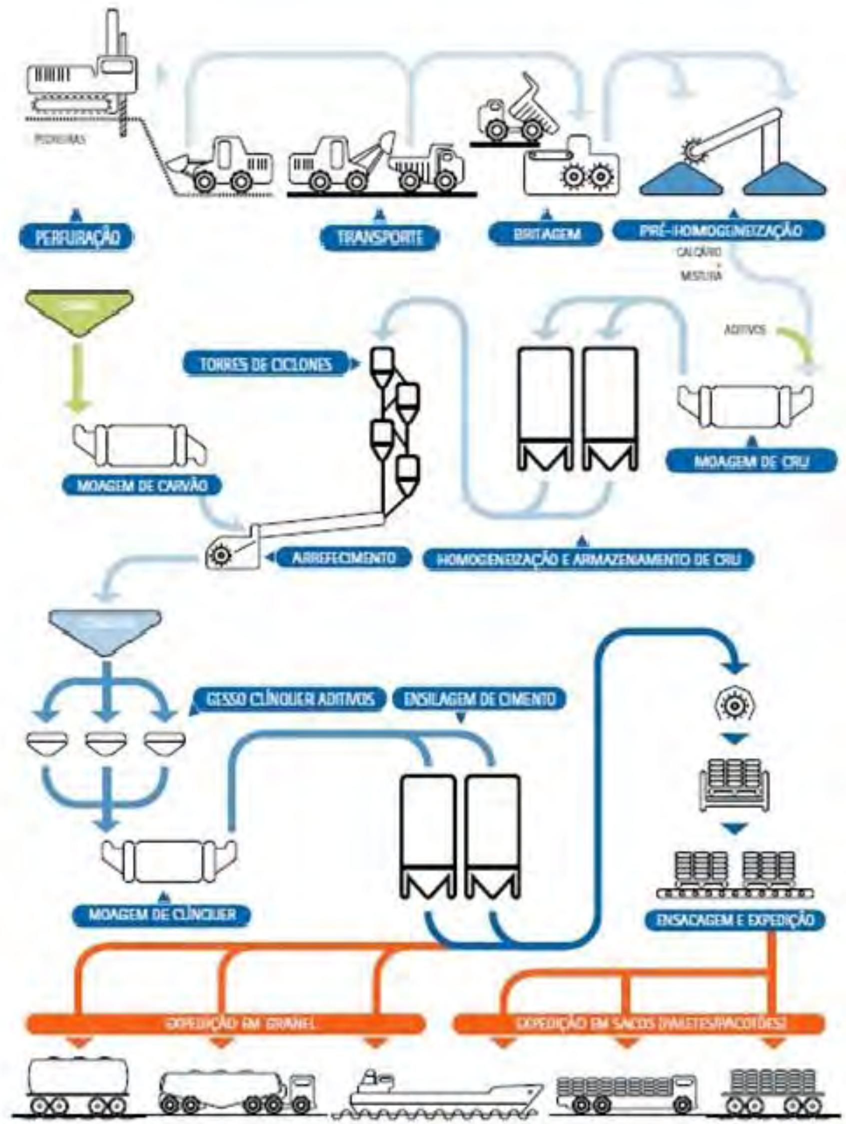
*Industrial Process:*

***Making Cement***

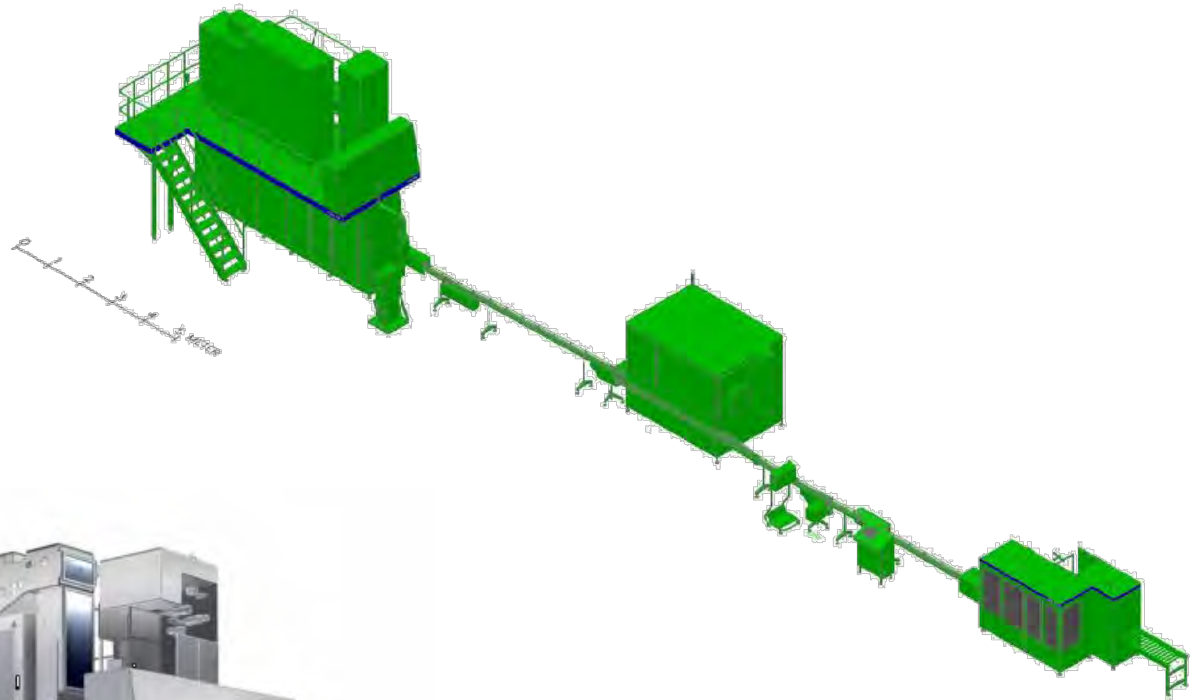
*[Outão / Setúbal / Portugal]*

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



*Industrial Process:*

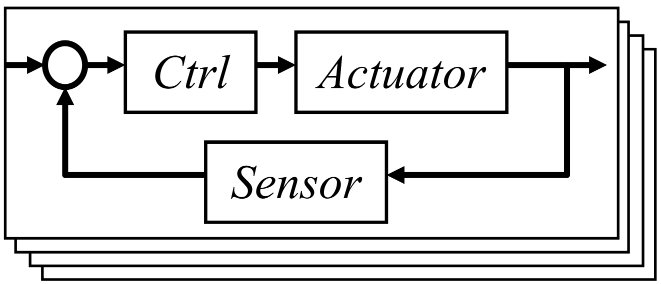
***Tetra Pak / Parmalat***




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

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

***Robot* +*Robot* +*Robot* + ... + *Global Controller* = *Automated Industrial Process***




*Other courses as e.g. Control*

*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


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

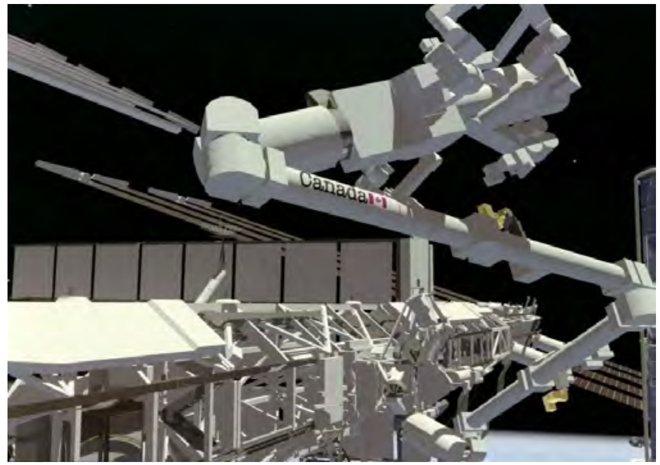
The production of **increasing amounts** of goods requires the storage and handling of large quantities of resources.

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.

# Robotic Manipulators


# 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!*

# 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

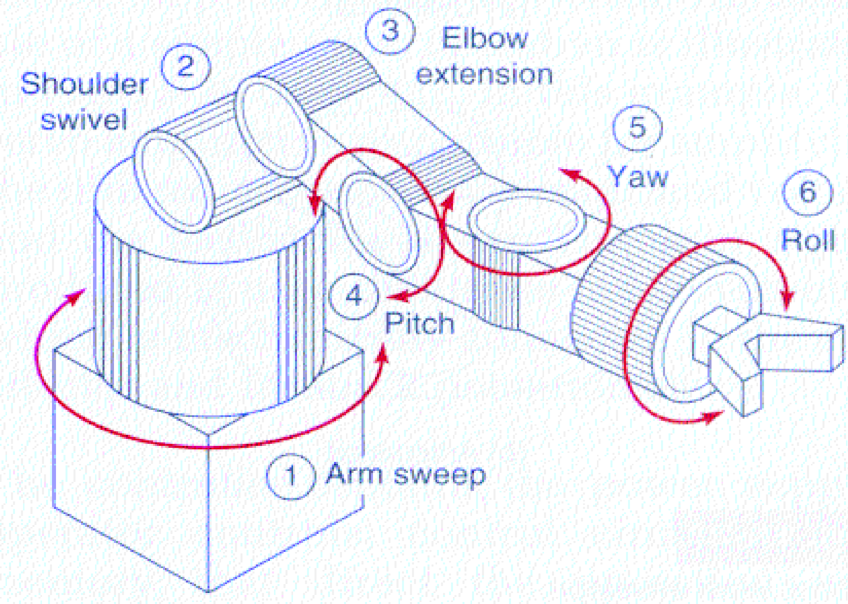


Fig. 15-22
Six-axis robot arm.

# Robotic Manipulators

## Workspace:

### Examples

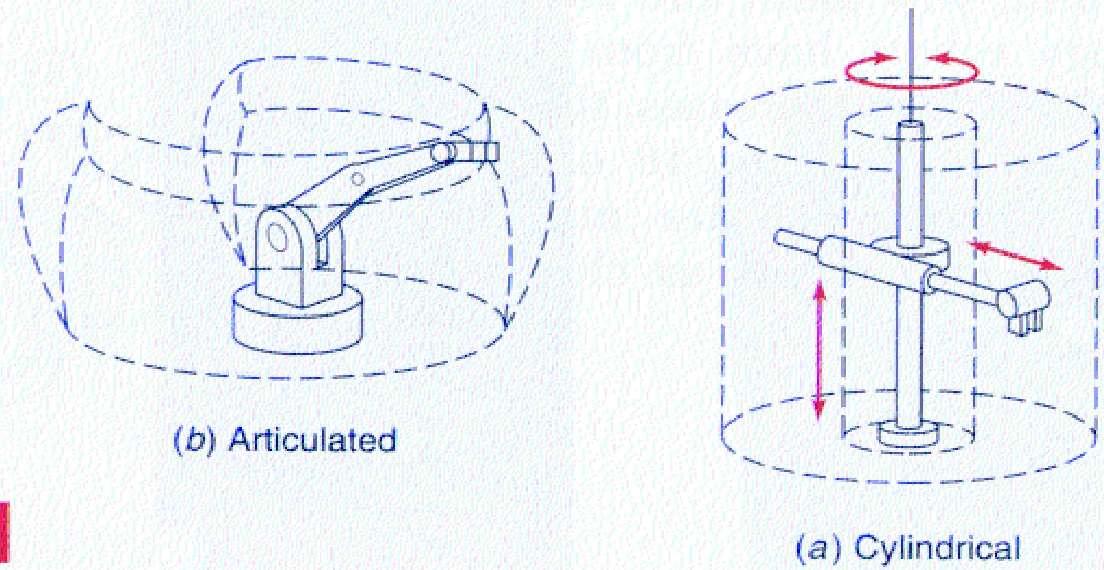
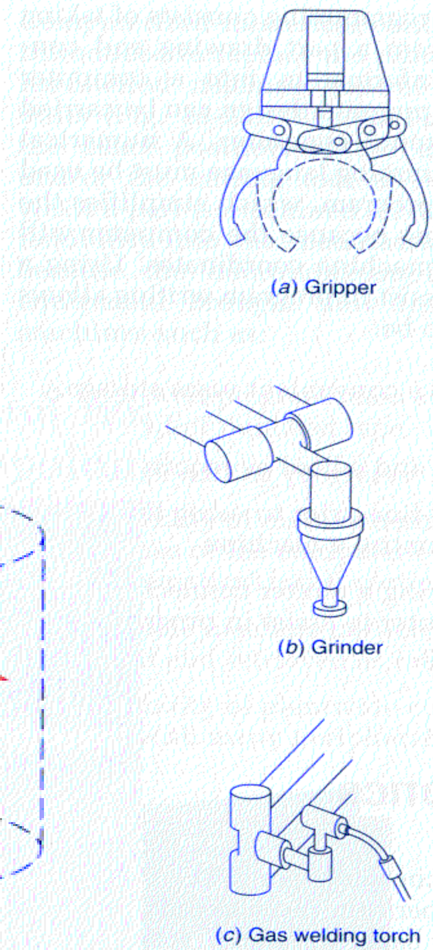



Fig. 15-23
Robot work envelope.




-24
End-of-arm tooling devices.

# Robotic Manipulators

**Central problems to address and solve:**

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

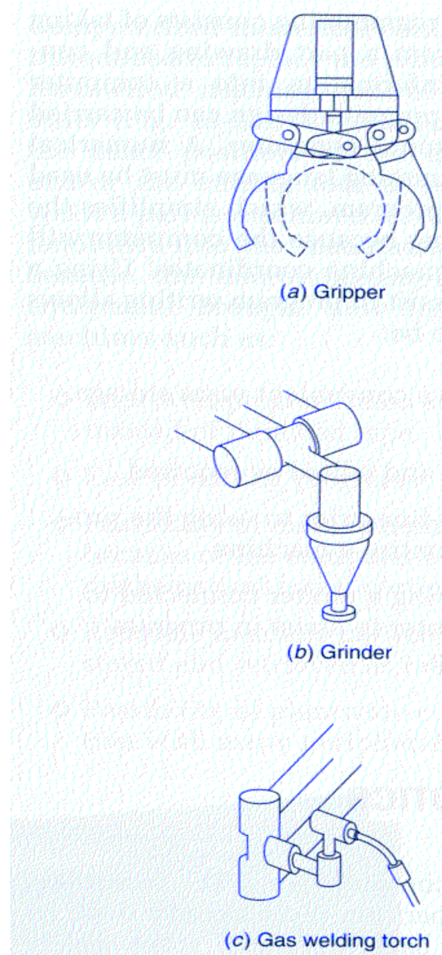



Fig. 15-24
End-of-arm tooling devices.

# Robotic Manipulators

Use in Flexible Cells of Fabrication:

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

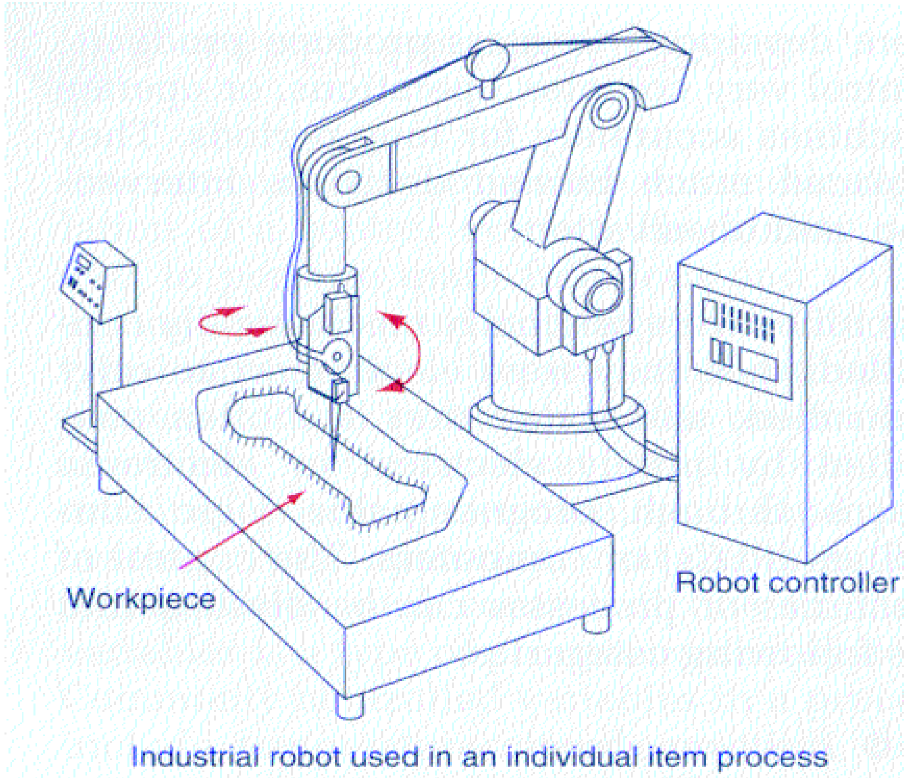



Fig. 14-3
Individual product production.

# Computerized Numerical Controlled (CNC) Machines

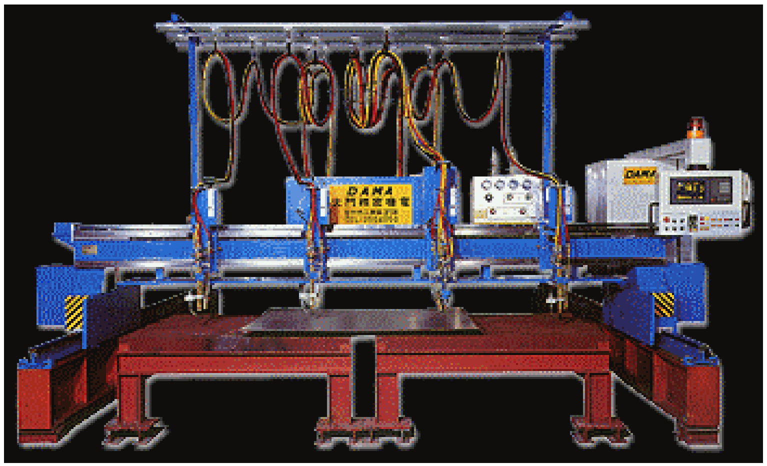
**Major characteristics:**

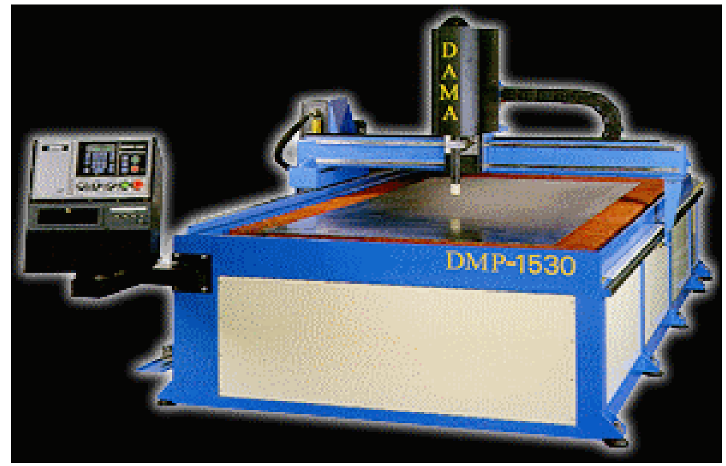
• Number of degrees of freedom
• Interpolation methods
• Load/unload automation, and also in tool change
• Programming (high level languages, teach pendent, ...)
• Workspace
• Accuracy, reliability
• Payload and robustness
• Interface
• Synchronization with exterior

**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.

# Solutions for Handling materials

## For transport...

### Major characteristics:

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

# AGVs (Automatic Guided Vehicles)

**Major characteristics:**

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

# AGVs (Automatic  Guided Vehicles)

**Example of fleet operating in industry**

# AGVs (Automatic Guided Vehicles)

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.

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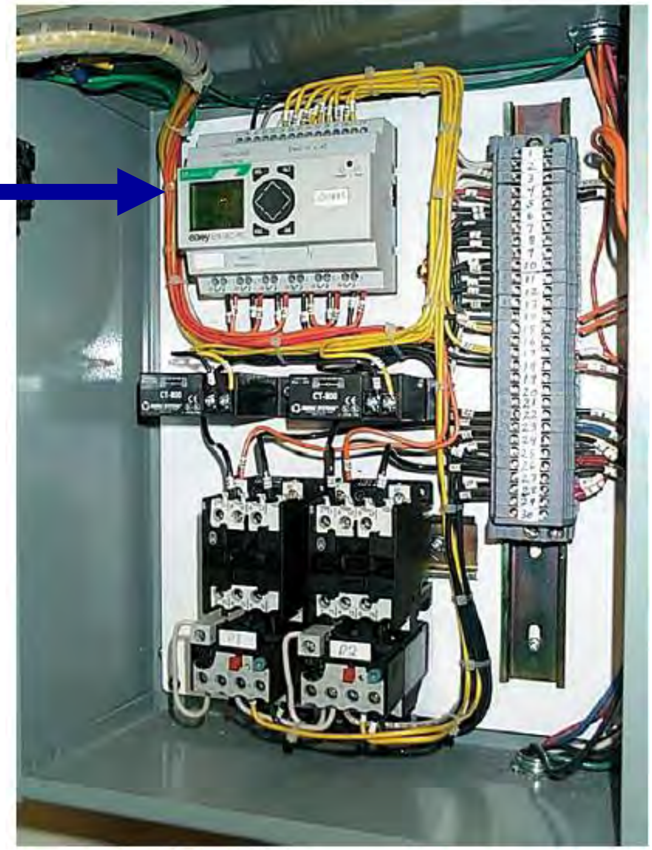
# Cabled Logic versus ...

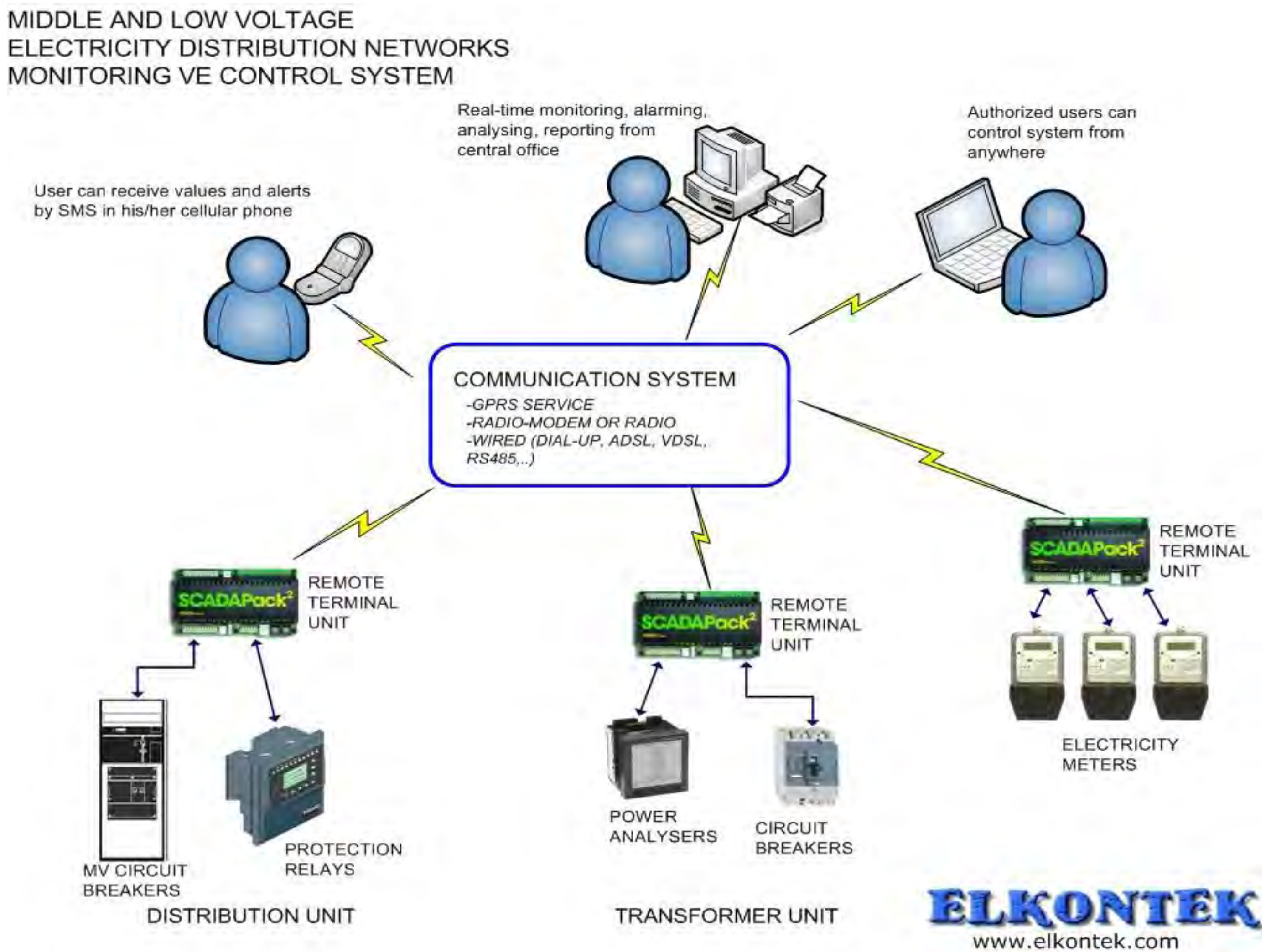
# ... versus Programmed Logic ...

Relay control panel

PLC control panel



# ... versus Networked Logic



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

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**Relay** diagram / Ladder diagram:

hardware (sensors, actuators) integration
break system into sub-systems, select hardware
integrate hardware (logic and sequencing)

**Actuators**

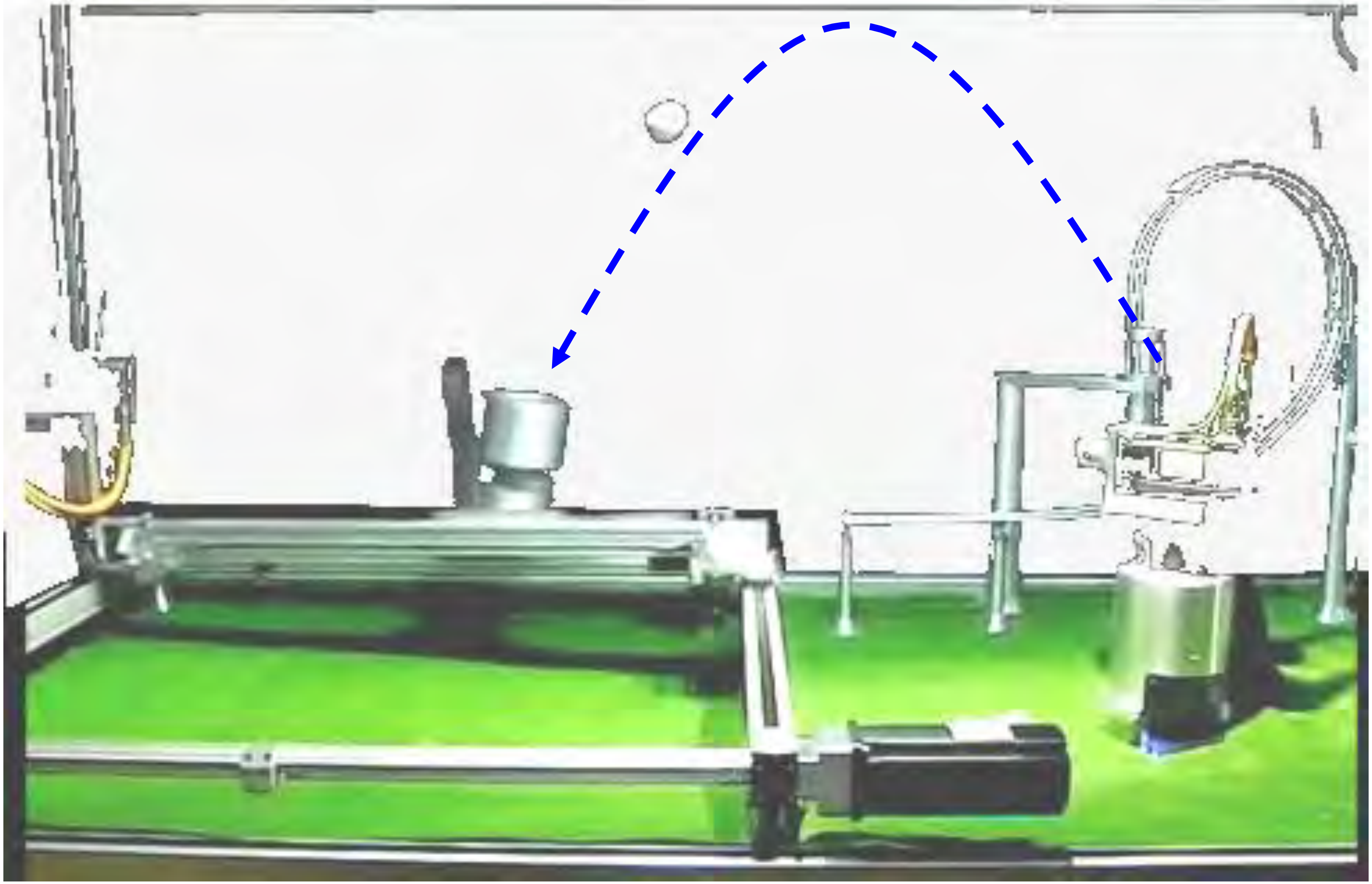
Motors
Solenoide valve
Command relay
Pneumatic cylinder
Electro pneumatic

**Sensors**

Pressure switch
Temperature sensors
Proximity sensors

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

## *Demonstration of precise actuation – Schneider Electric*



# Actuation

## Motors

### Major characteristics:

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

# Solenoid Valve

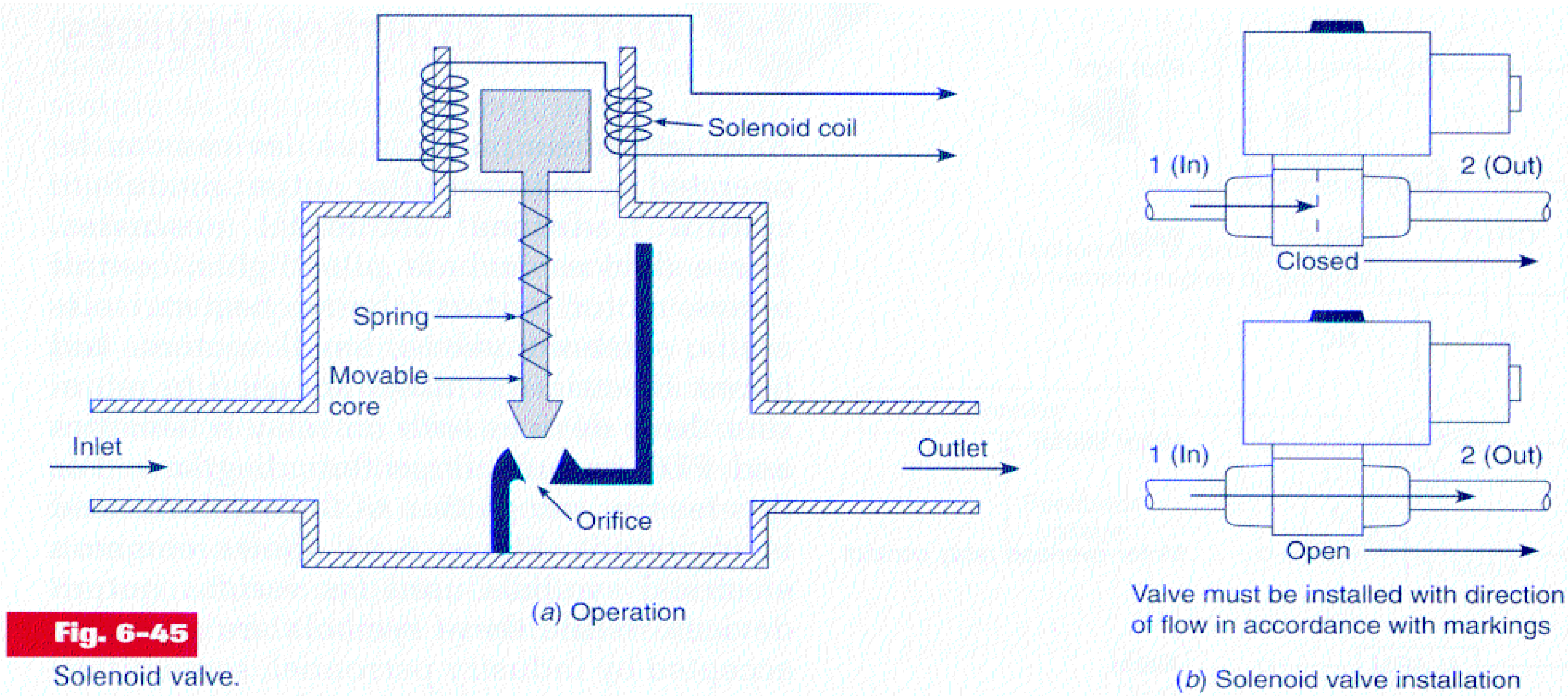



Fig. 6-45
Solenoid valve.

# Command Relay

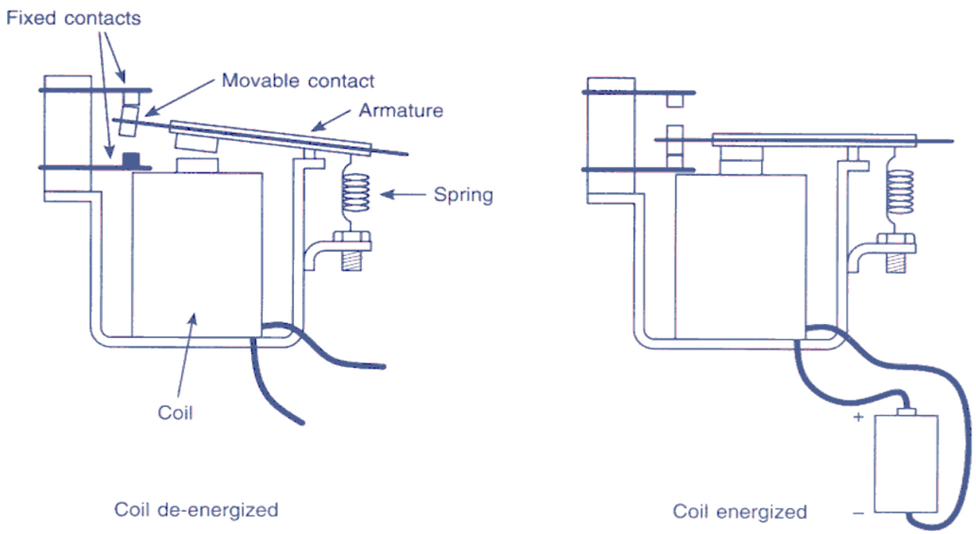
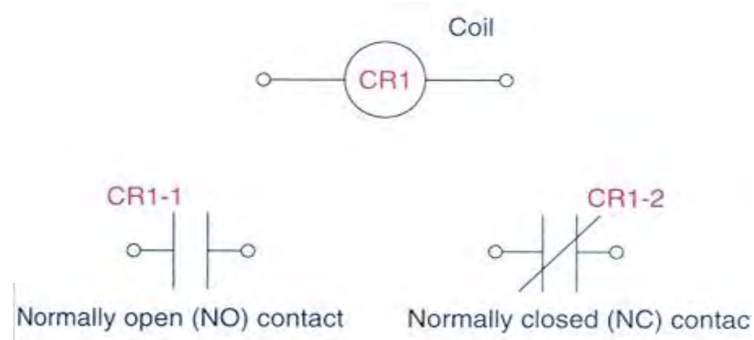
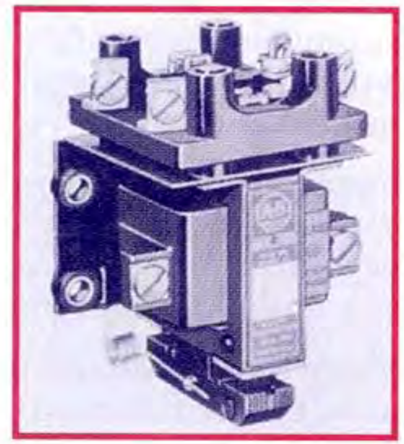



Fig. 6-1
Electromagnetic control relay operation.



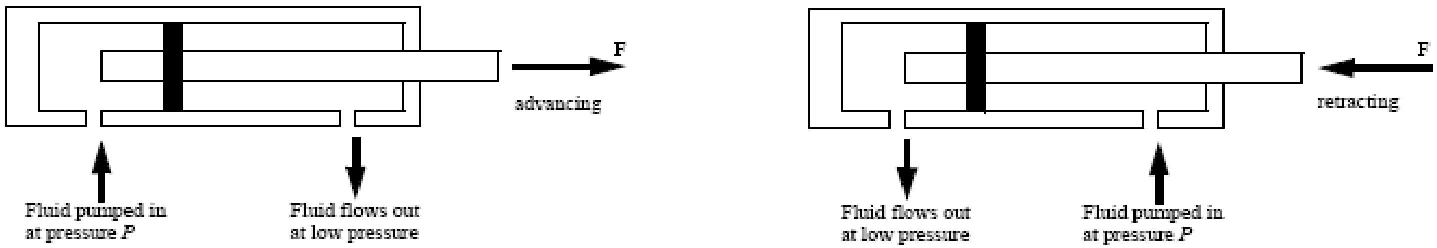

(a) Control relay symbol



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

Fig. 6-2
Control relay.

# Cylinders (Pneumatics)



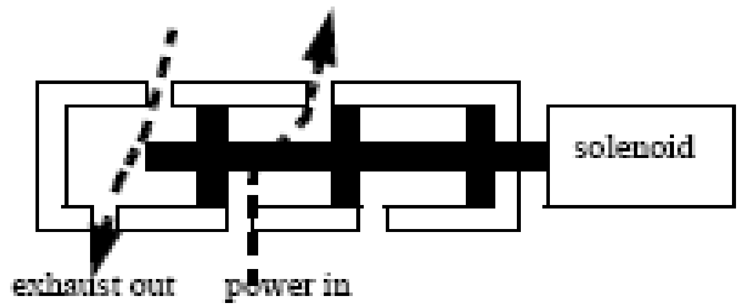

For Force:

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

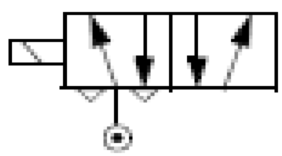
where,

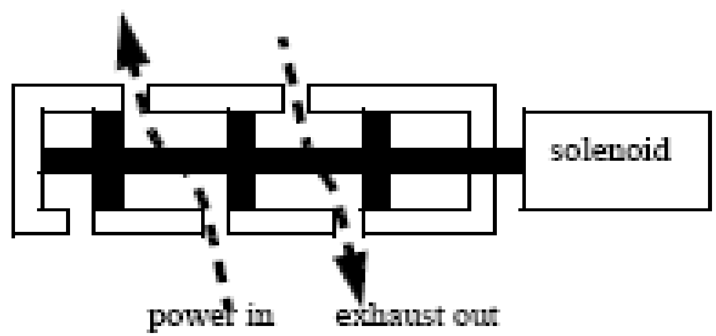
P = the pressure of the hydraulic fluid
A = the area of the piston
F = the force available from the piston rod

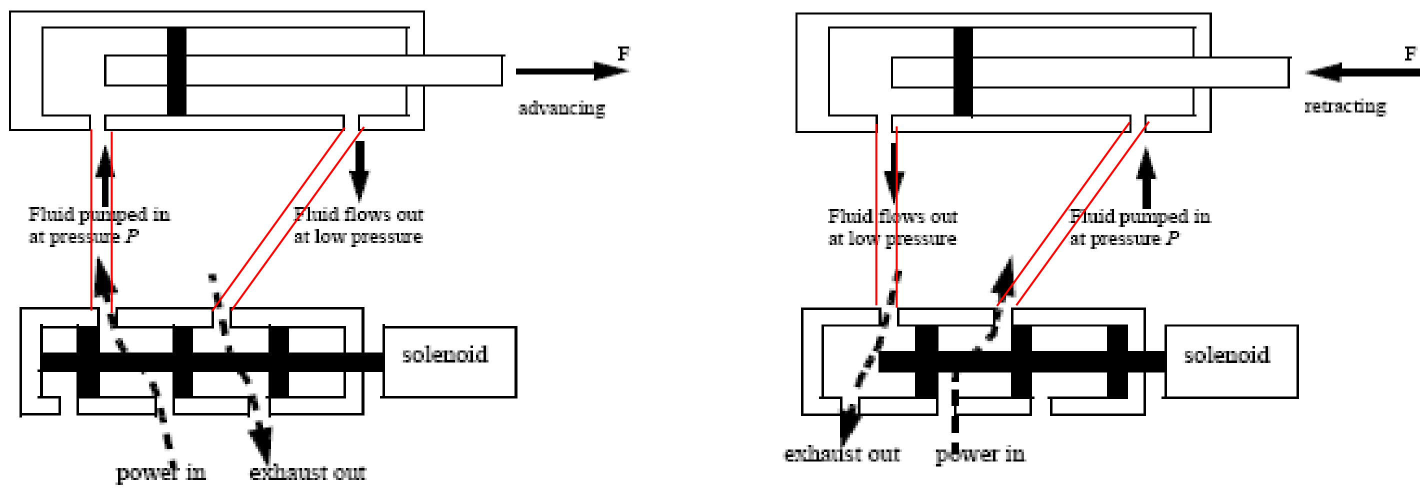
# Valves (Electro-pneumatics)




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.

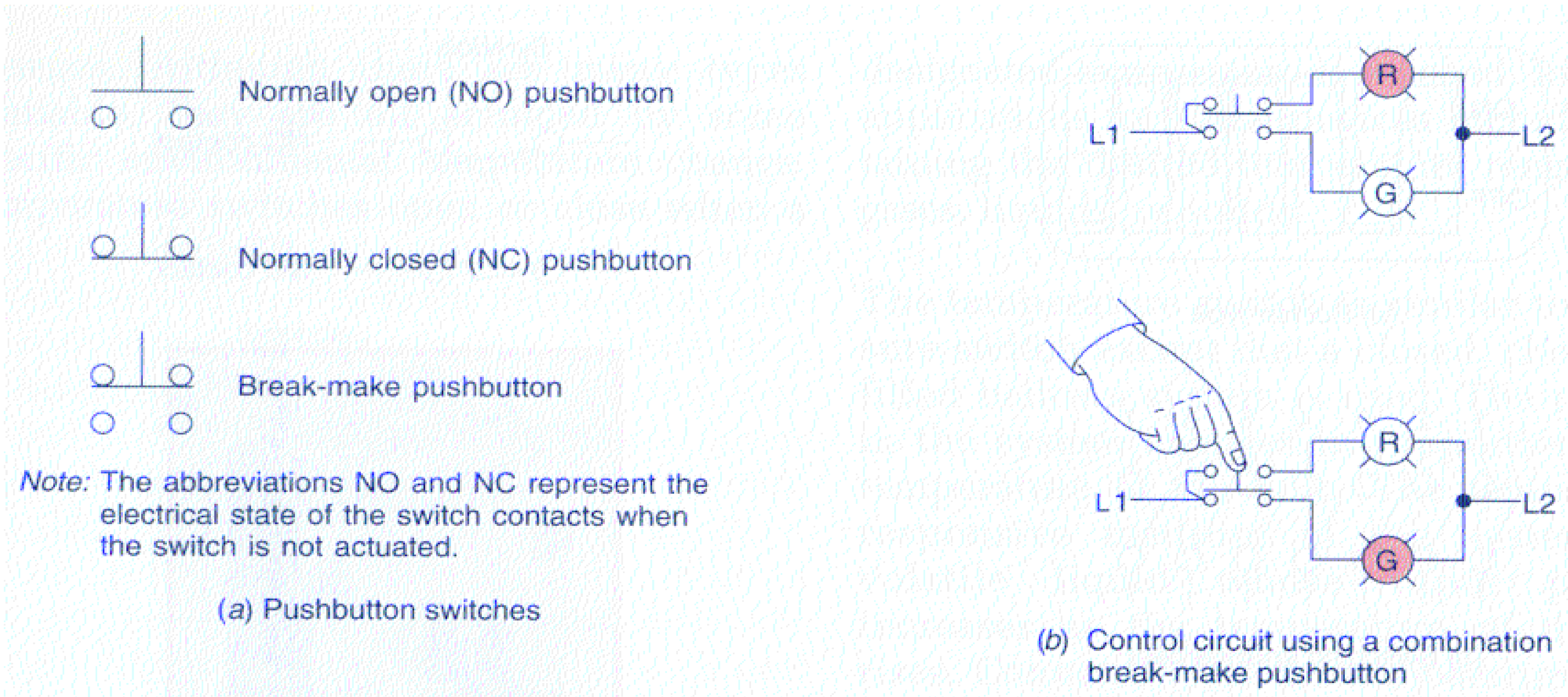





F
advancing
Fluid pumped in
at pressure P
Fluid flows out
at low pressure
solenoid
power in
exhaust out
F
retracting
Fluid flows out
at low pressure
Fluid pumped in
at pressure P
solenoid
exhaust out
power in

# Sensors

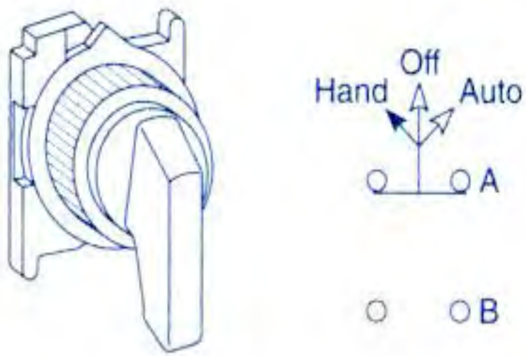
## Push buttons



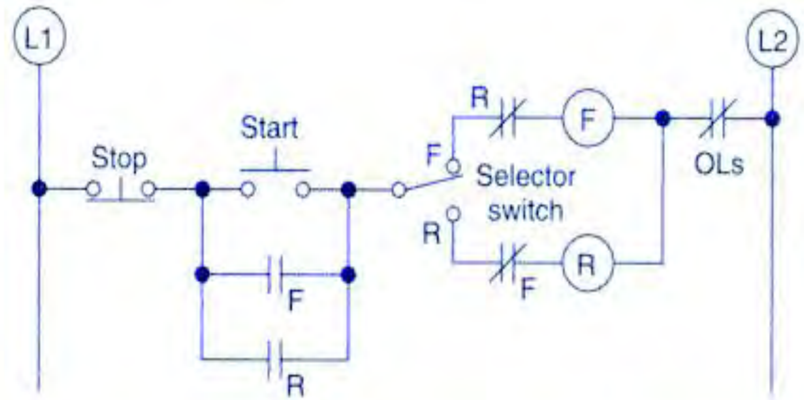

(a) Pushbutton switches

(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

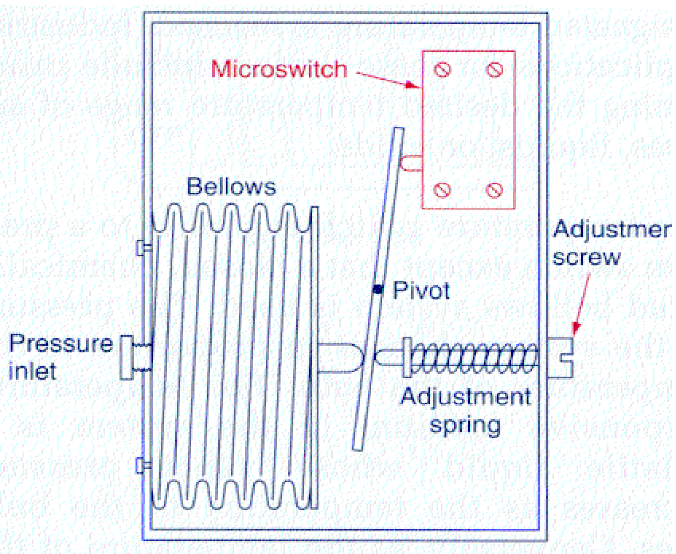
(c) Selector switch used in conjunction with a reversing motor starter to select forward or reverse operation of the motor

**Fig. 6-11**

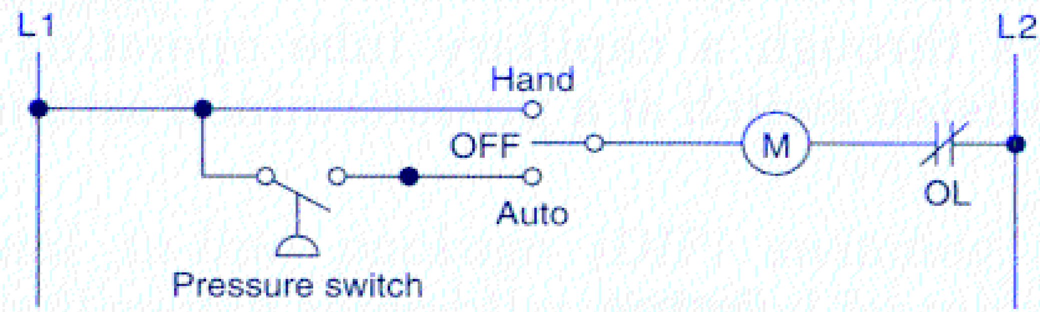
Selector switch.

# Sensors

## Pressure Switch




(b) Bellows




(c) Starter operated by pressure switch

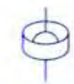
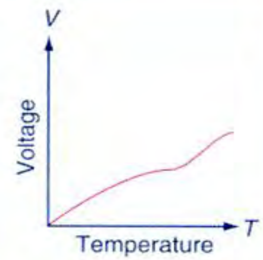
**Fig. 6-15 (continued)**

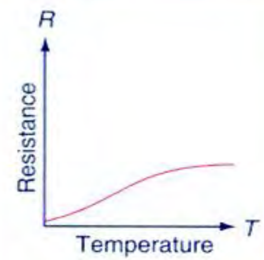
Pressure switch.

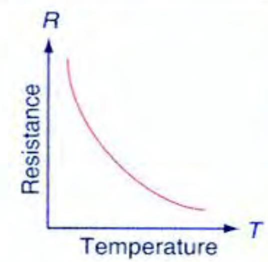
# Temperature

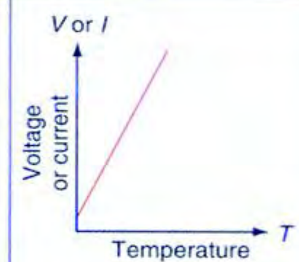
# Sensors










| | Thermocouple | RTD | Thermistor | IC Sensor |
|---|---|---|---|---|
| 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

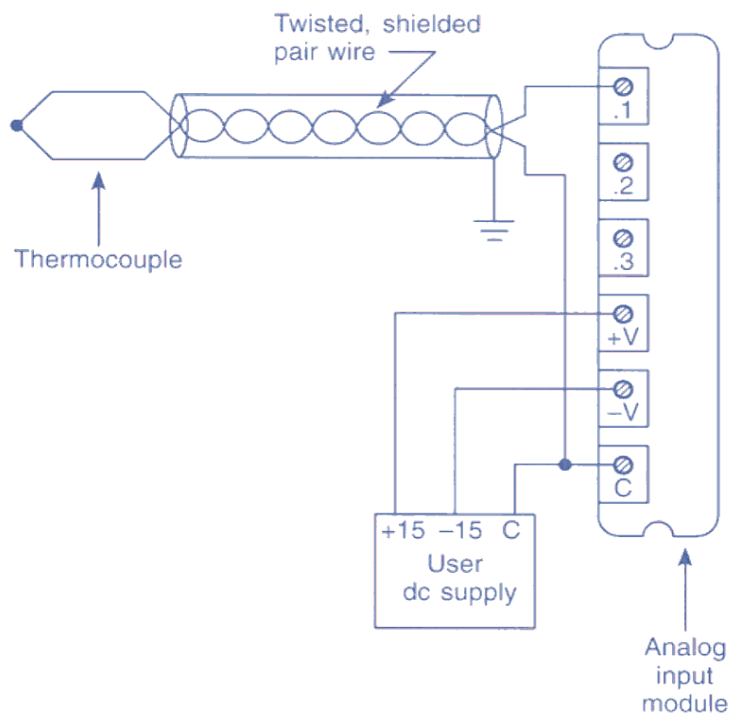



**Fig. 2-12**

Typical thermocouple connection to an analog input module.

# Proximity detector

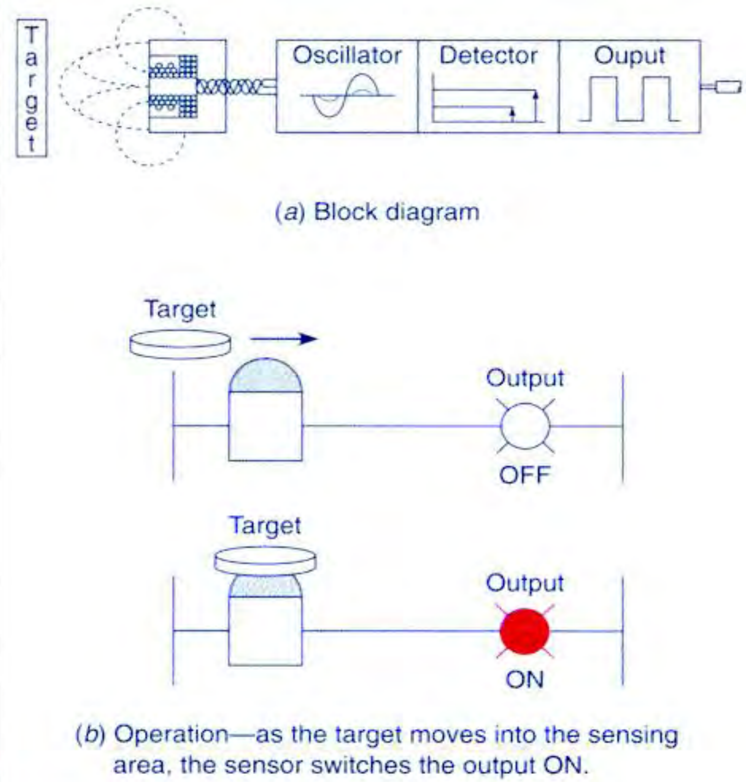



**Fig. 6-20**

Inductive proximity sensor.

# Magnetic detector

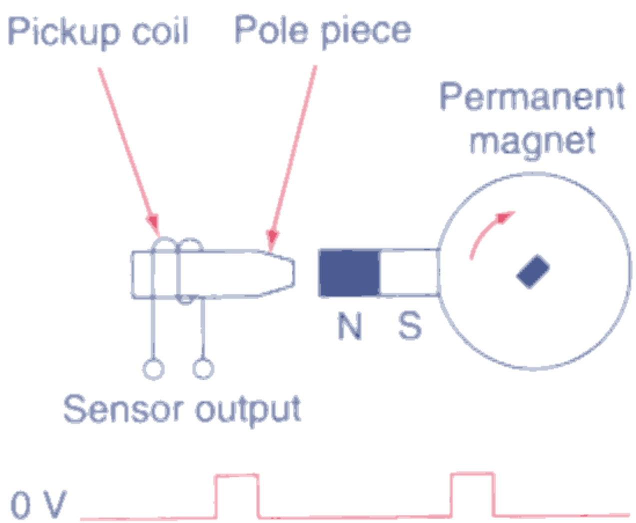



Fig. 6-42
Magnetic pickup sensor.

# Magnetic switch

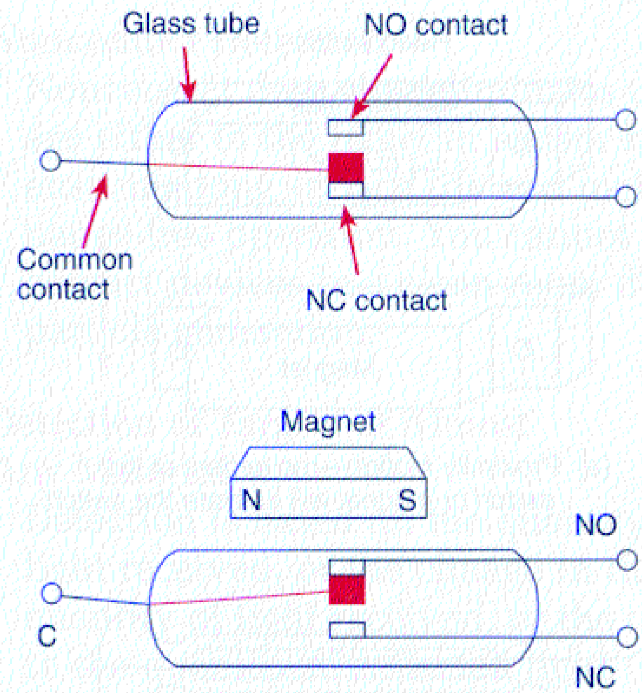



Fig. 6-25
Magnetic switch (reed switch).

# *Symbols associated to all components*

## Standards

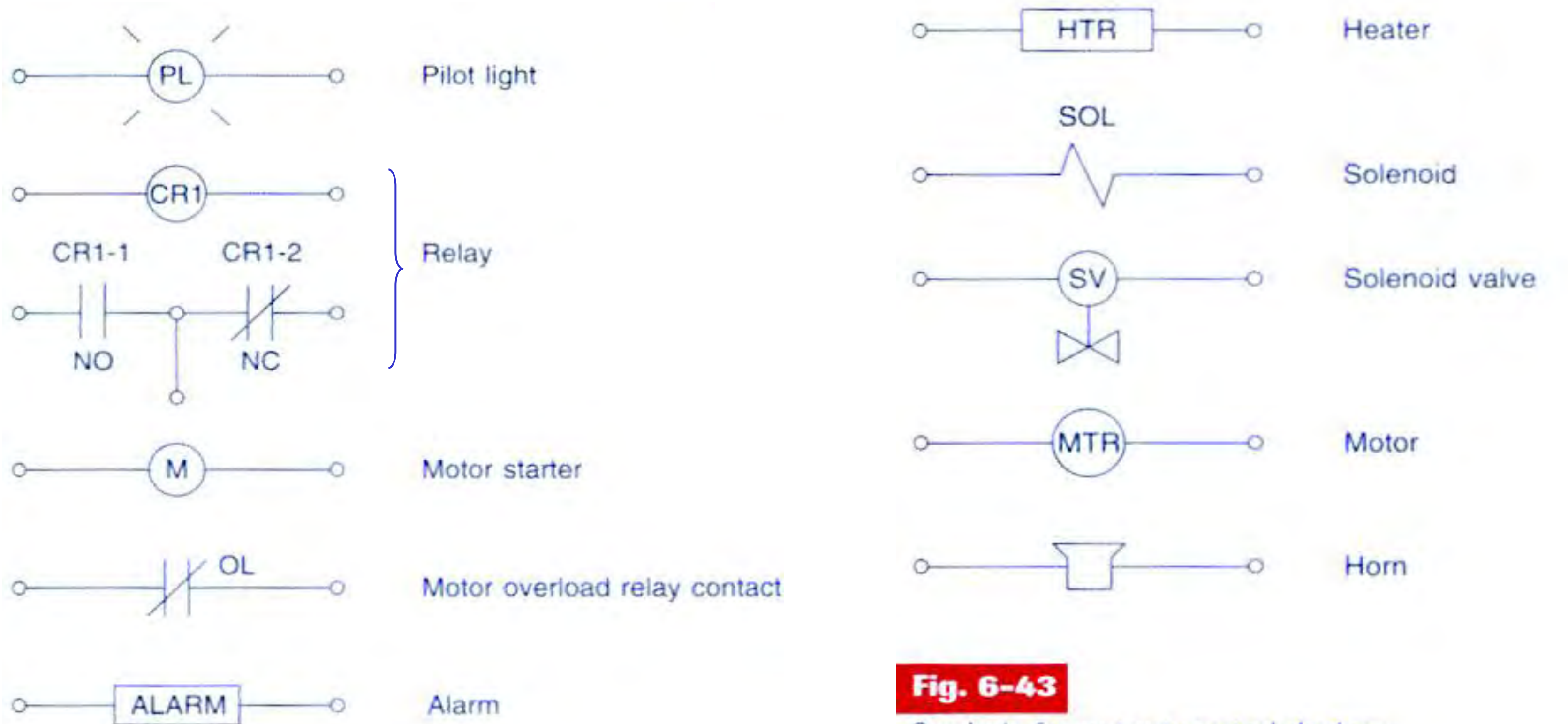
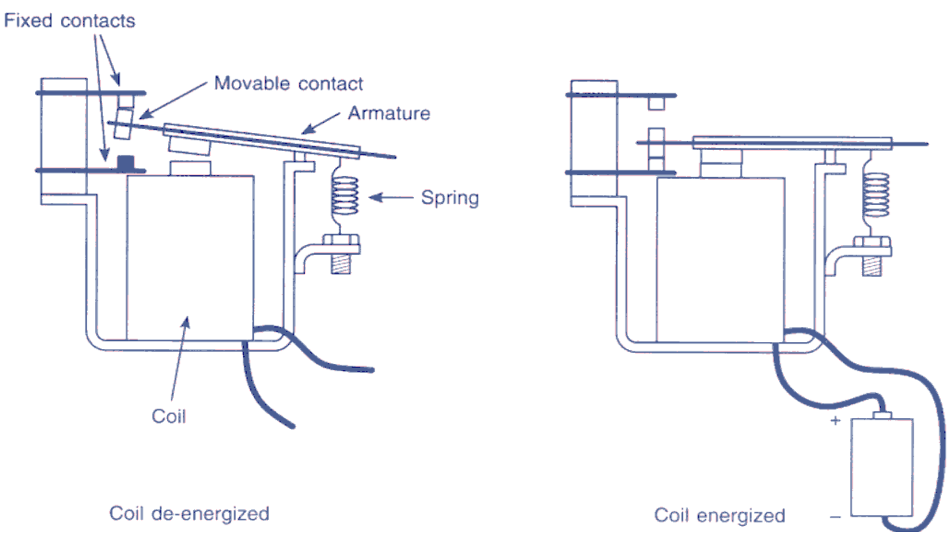



**Fig. 6-43**
Symbols for output control devices.

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

## ***Device: Relay***




## ***Contact Diagram*** or ***Ladder Diagram***

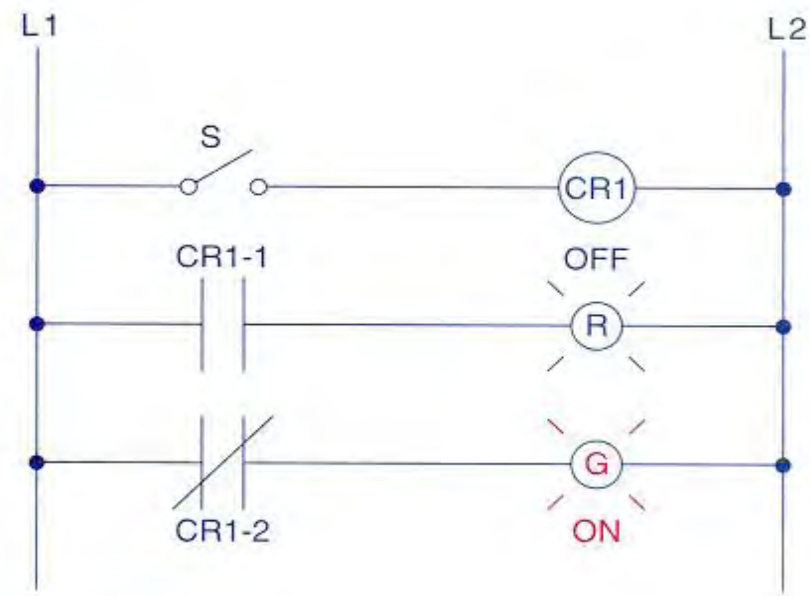



**Fig. 6-3**
Relay circuit–switch open.

# Example:

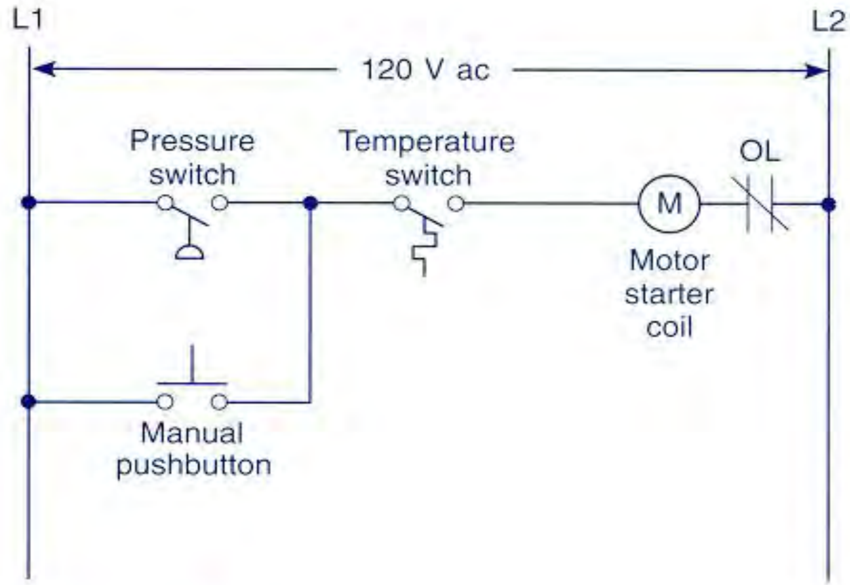



**Fig. 1-13**
Relay ladder diagram for modified process.

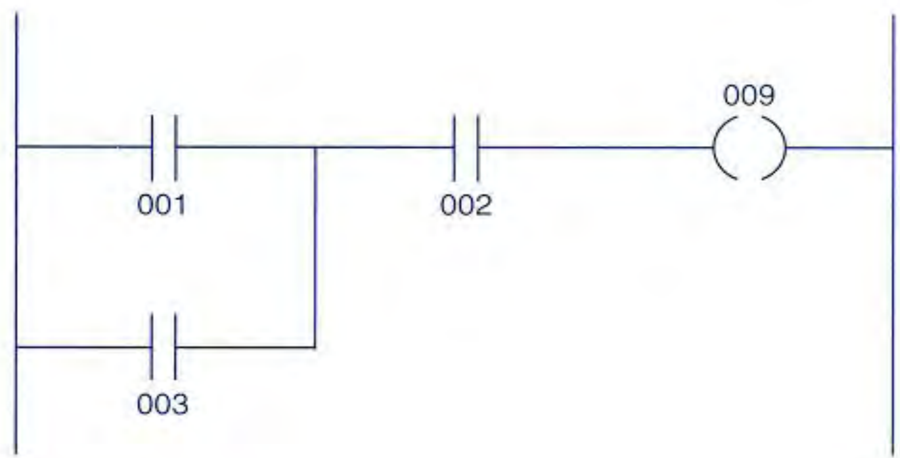
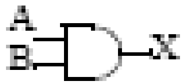



**Fig. 1-14**
PLC ladder logic diagram for modified process.

# Logic Functions

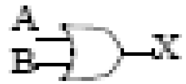
### AND




$X = A \cdot B$

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

### OR




$X = A + B$

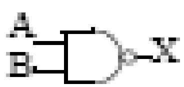
| A | B | X |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 1 |

### NOT


$X = \bar{A}$

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

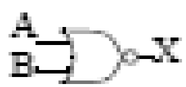
### NAND




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

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

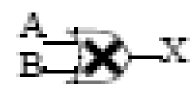
### NOR




$X = \overline{A + B}$

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

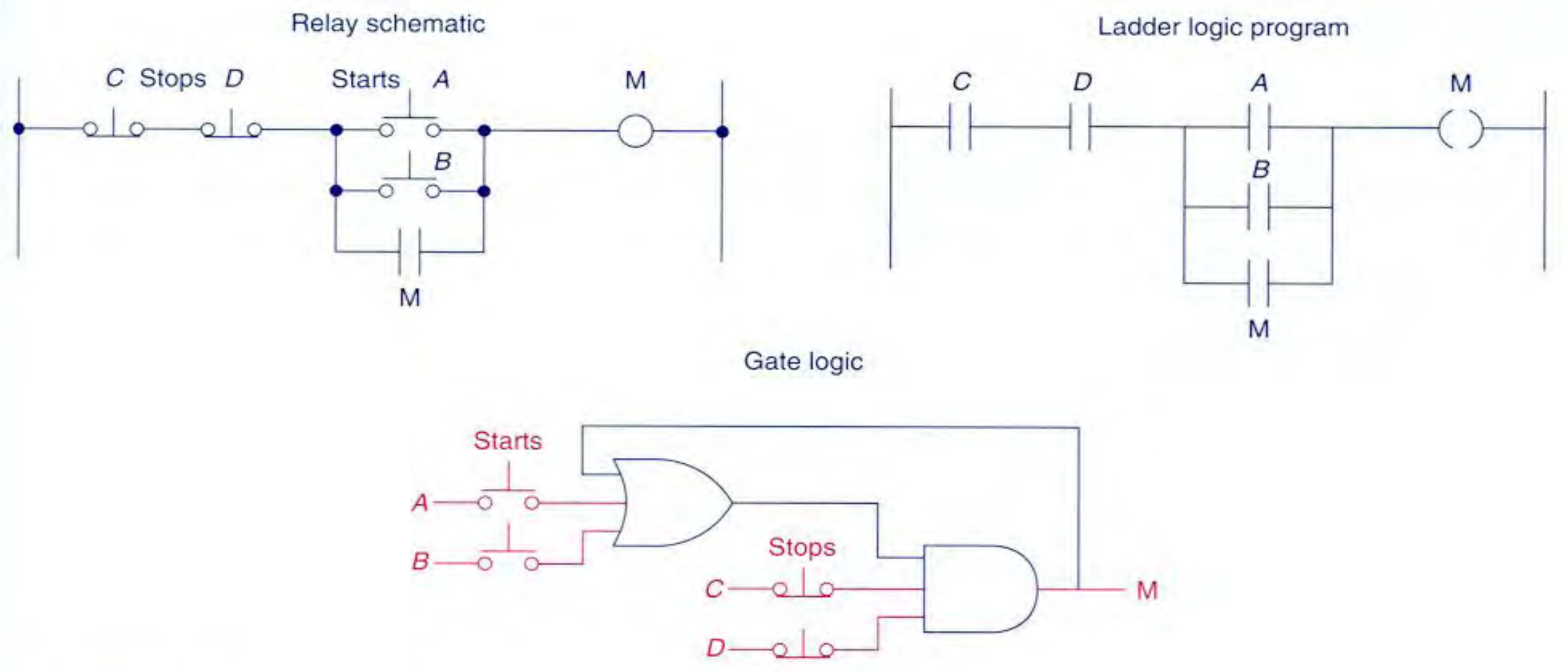
### EOR




$X = A \oplus B$

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

# Example:



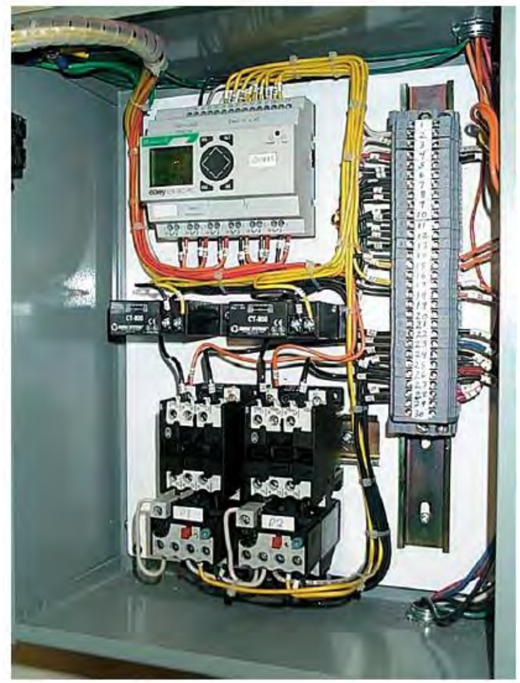

**Example 4-9**

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*