

Industrial Automation

(Automação de Processos Industriais)

<http://users.isr.ist.utl.pt/~jag/courses/api1617/api1617.html>

Prof. Paulo Jorge Oliveira, original slides

Prof. José Gaspar, rev. 2016/2017

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)

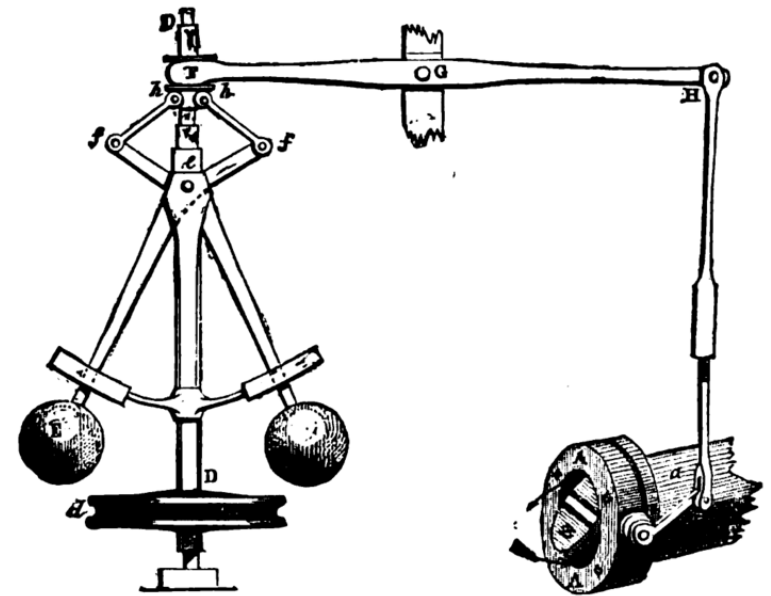
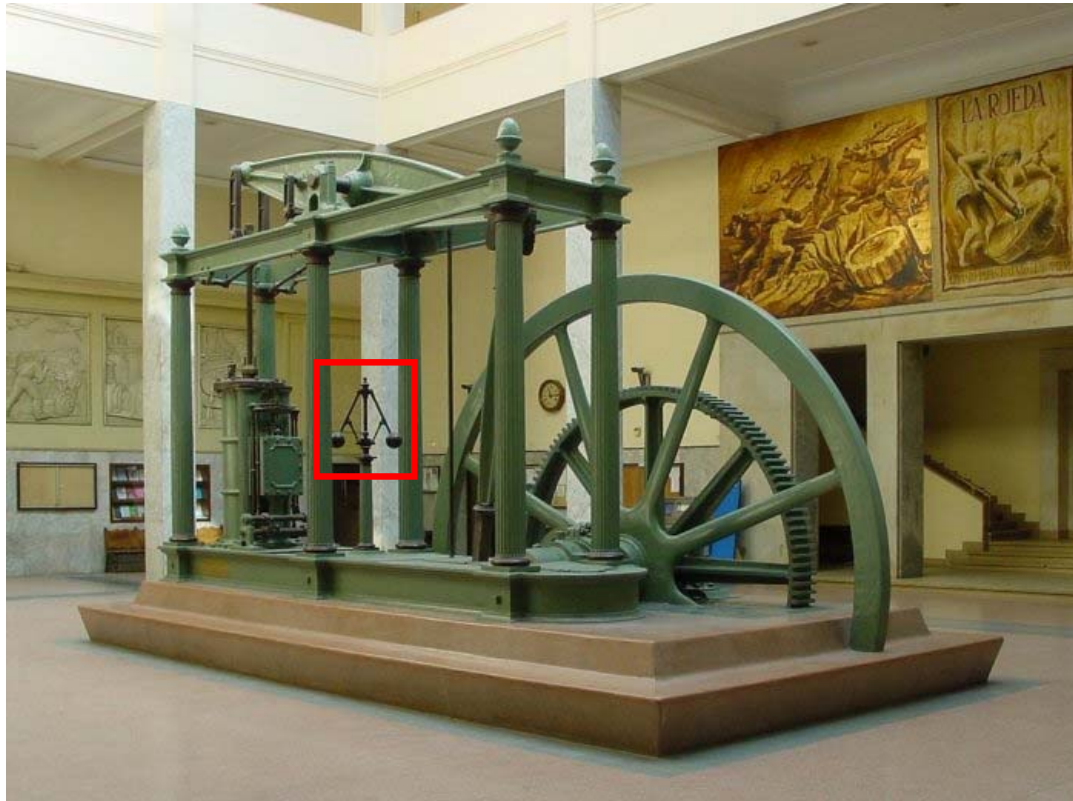
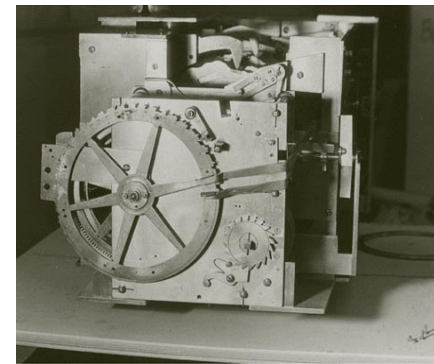
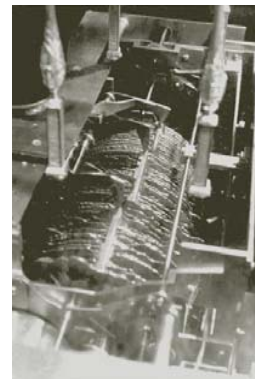
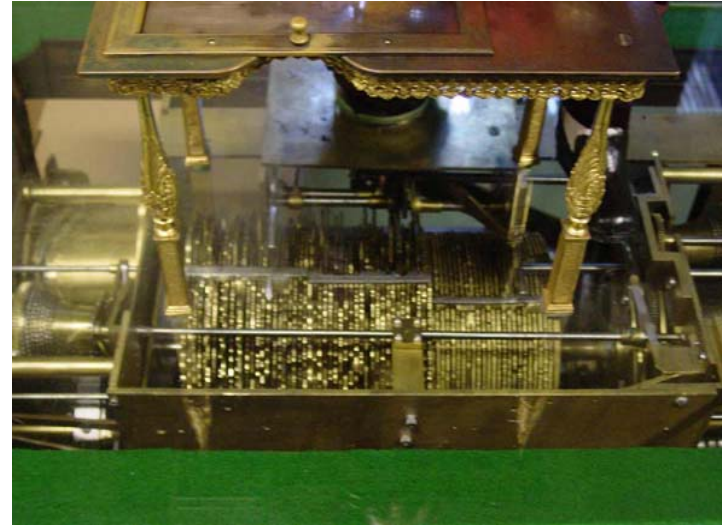


FIG. 4.—Governor and Throttle-Valve.

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

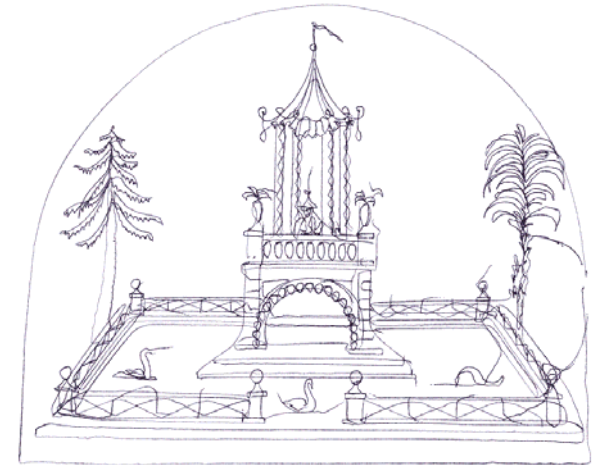
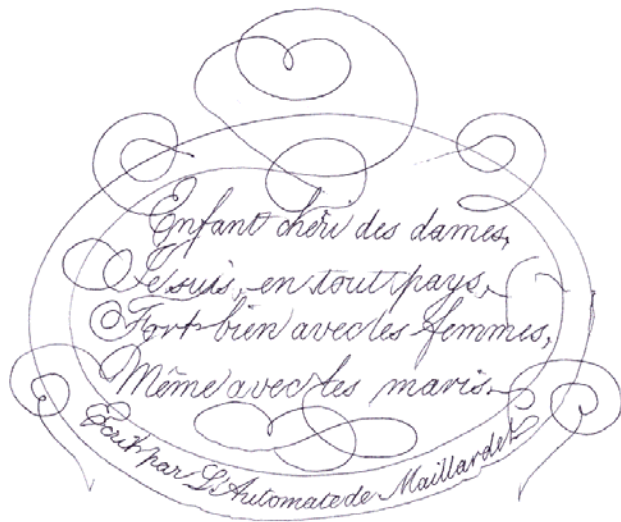
A jewel: Maillardet's Automaton, 18th century, the largest known mechanical memory



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

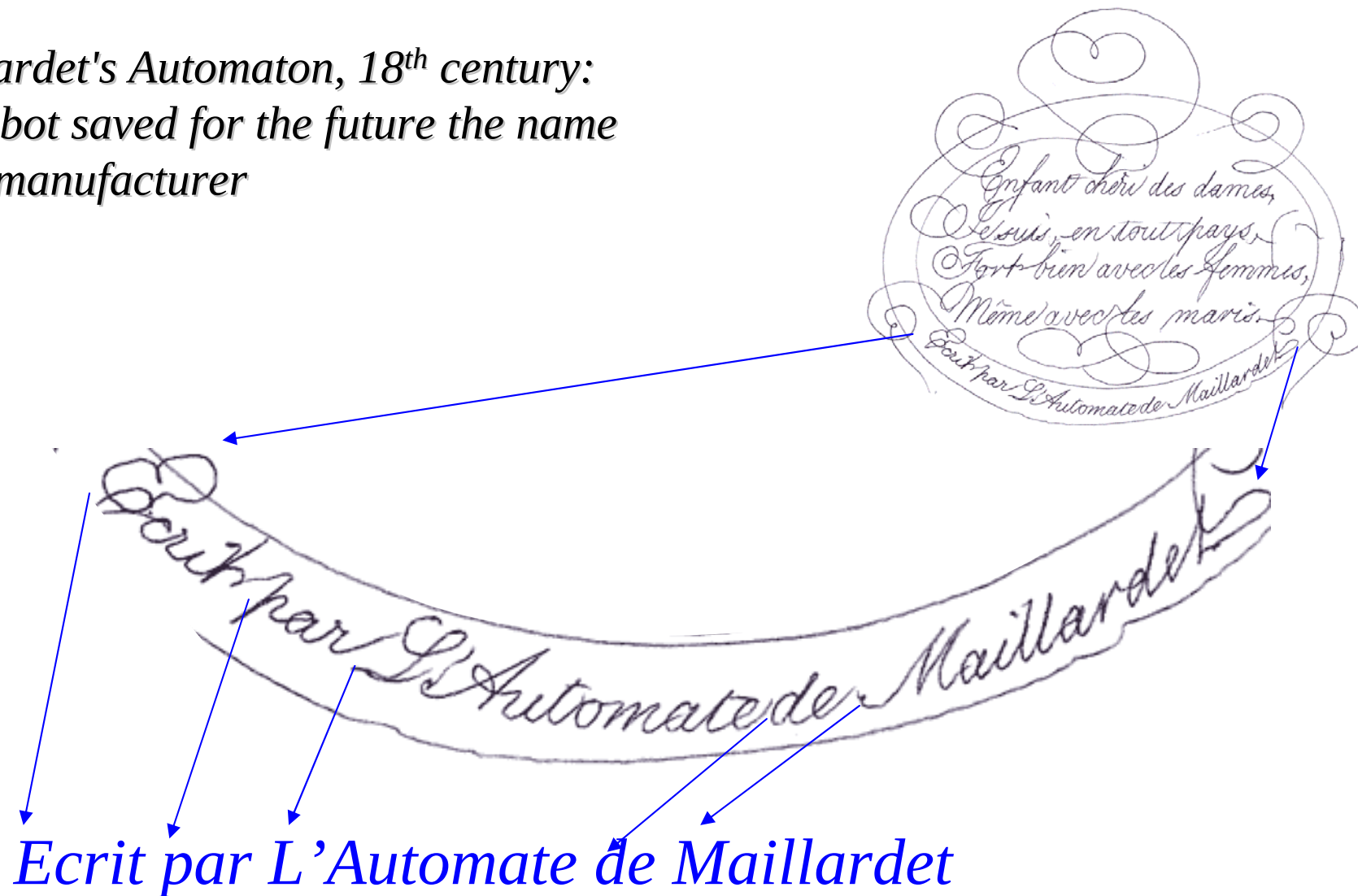
Maillardet's Automaton, 18th century: the largest known mechanical memory

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*

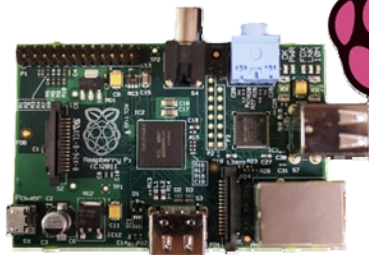


<https://www.fi.edu/history-automaton>

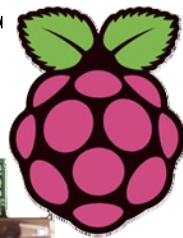
Microcontrollers



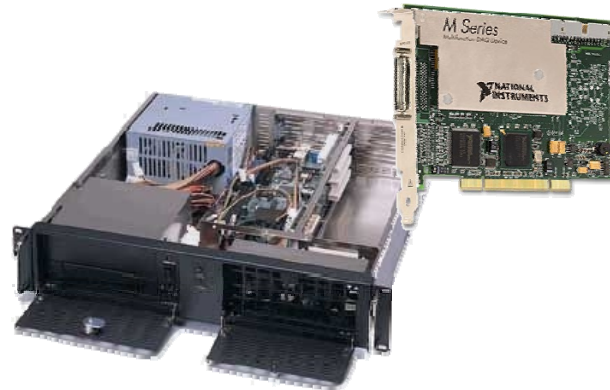
Arduino



Raspberry-pi



Computer + IO



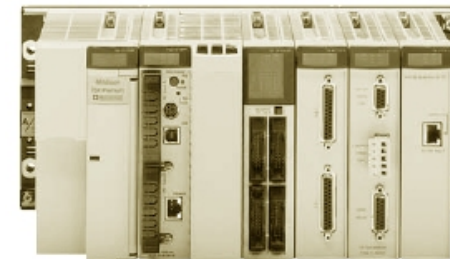
National
Instruments
AD/DA



PLC

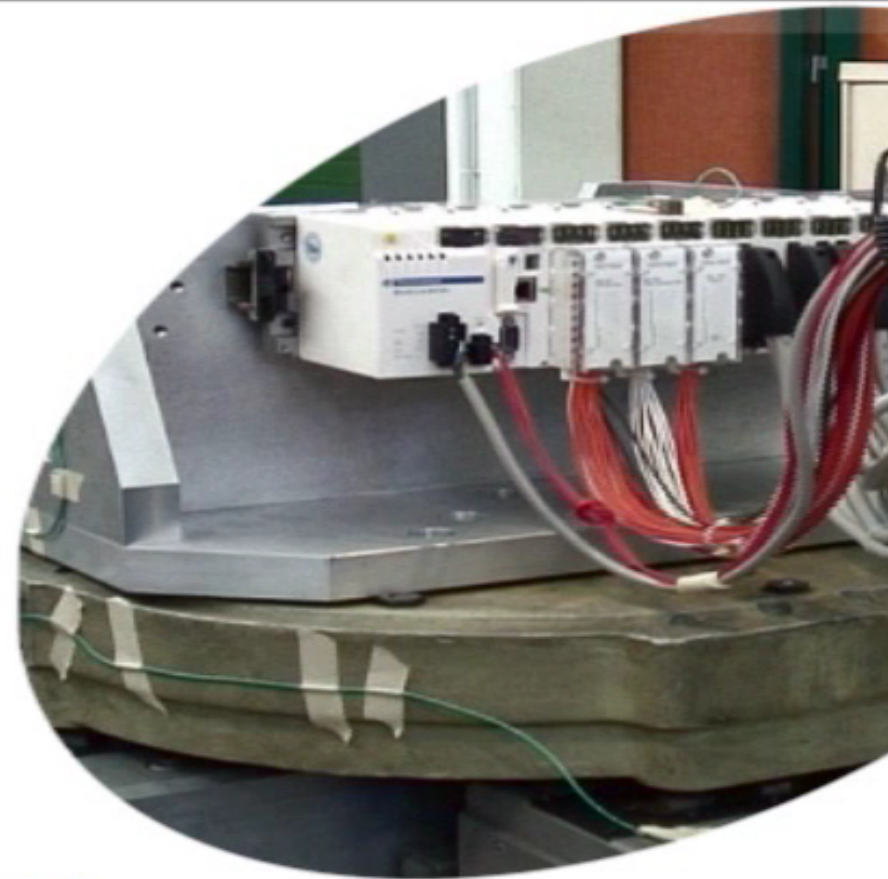


Premium P57



Many options for controlling real world devices! Why PLCs?

Robustness is not an Option



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.*

Microsoft Excel - API_14_15_sem1_demo.xls				
File Edit View Insert Format Tools Data Window Help				
Type a question for help				
B3 João silva				
A	B	C	D	E
1	Industrial Automation 2014/5 - Self-taken links to bibliography			
2				
3	Name:	João silva	Number:	12345
4				
5	Bibliography:			
6	[slides13]	API Slides 2013/2014, P. Oliveira, J. Gaspar, IST		
7	[Petruszella96]	"Programmable Logic Controllers", Frank D. Petruzella, McGraw-Hill, 1996.		
8	[Jack08]	"Automating Manufacturing Systems with PLCs", Hugh Jack (online version 2008)		
15	Week	Monday	Tuesday	Notes
16				
17	1	15-Set-14	16-Set-14	Ch1 Introduction, [slides12] C1 pp1-...
18	2	22-Set-14	23-Set-14	Cabled vs programmed logic. Examples of sensors and actuators. [slides12] C1.
19	3	29-Set-14	30-Set-14	
20	4	06-Out-14	07-Out-14	

Schedule (semester view, laboratories & exam):

Lab. registration ¹	First week
1 st preliminary lab.	1 week
2 nd preliminary lab.	1 week
1 st lab. assignment	3 weeks
2 nd lab. assignment	3 weeks
3 rd lab. assignment	0.5h seminar (one date $\geq$ week 8)
Exams	3h, 19Jan or 03Feb 2017

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/api1617/api1617.html>

Prof. Paulo Jorge Oliveira, original slides
Prof. José Gaspar, rev. 2016/2017

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.



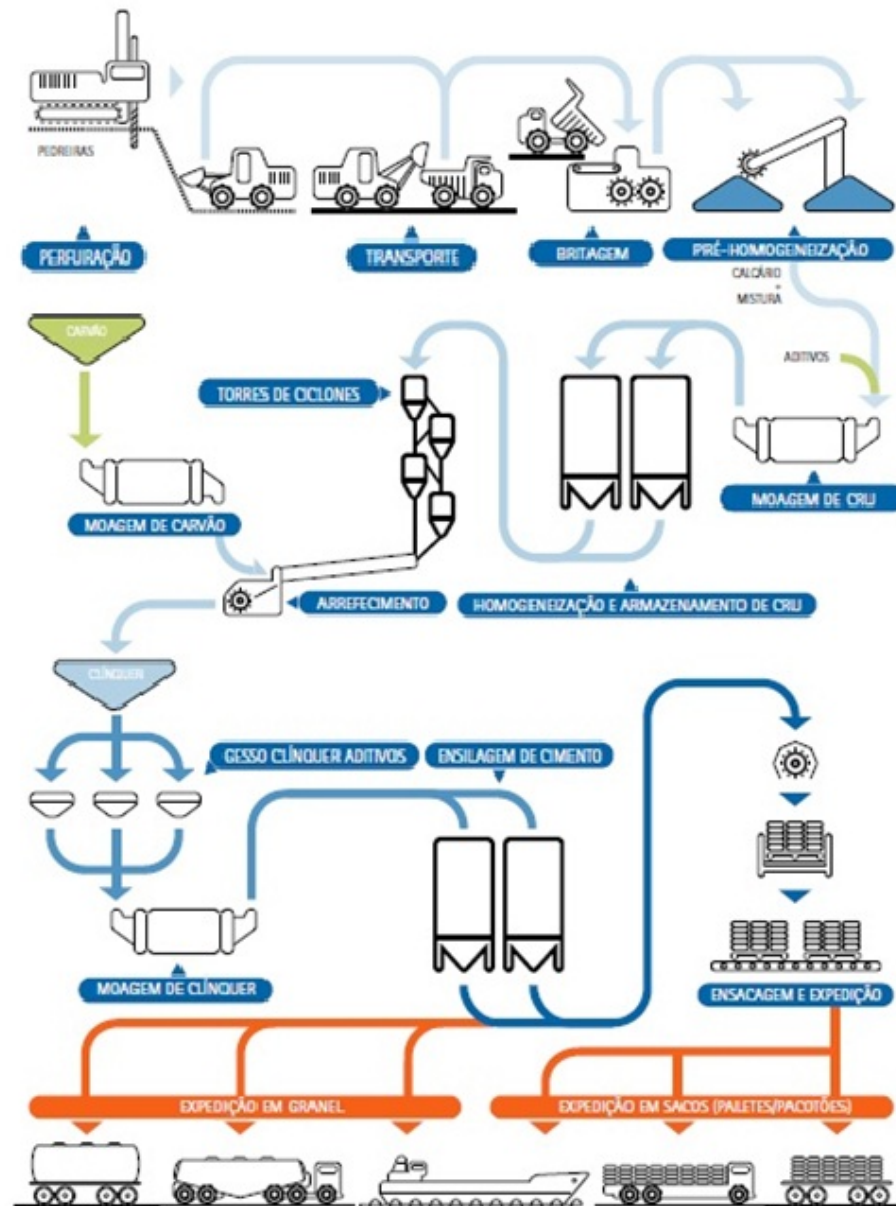
¹ Motivated by the continuous growth of the world population and migration to cities.

Industrial Process:

Making Cement

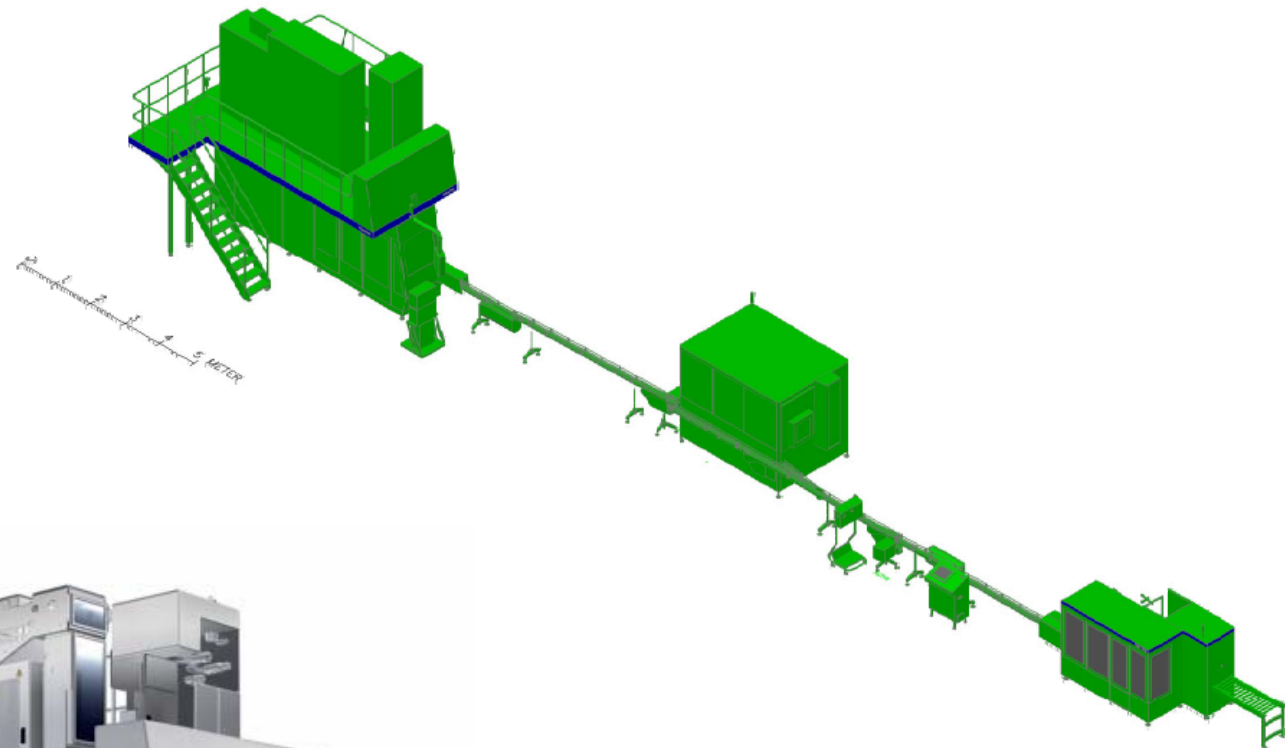
*[Outão / Setúbal /
Portugal]*

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



Industrial Process:

Tetra Pak / Parmalat

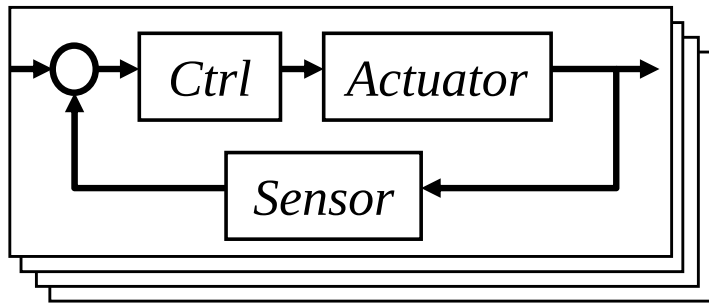


Complexity handled with modularity.

Filling machine, complete line:

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

Robot + Robot + Robot + ...



*Other courses as
e.g. Control*



***= Automated
Industrial
Process***

*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

- the generic workers

Computerized CNC Machines

- the specialized workers

Handling materials

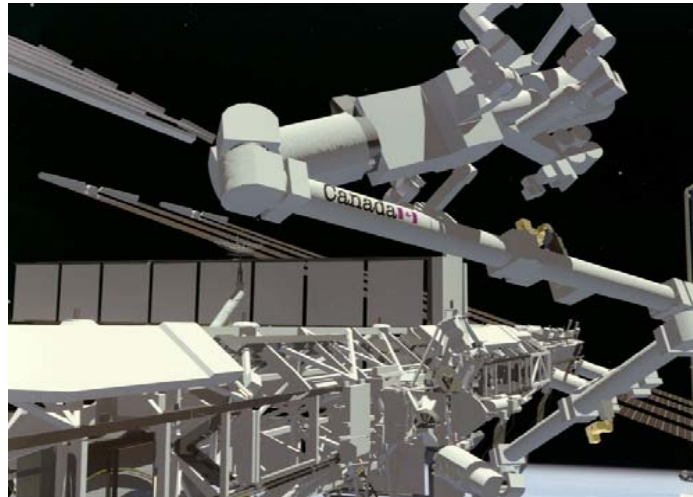
- specialized load and unload

Low level actuation

- motors



Robotic Manipulators



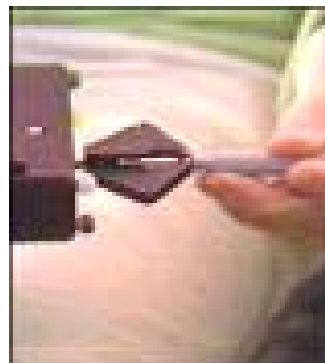
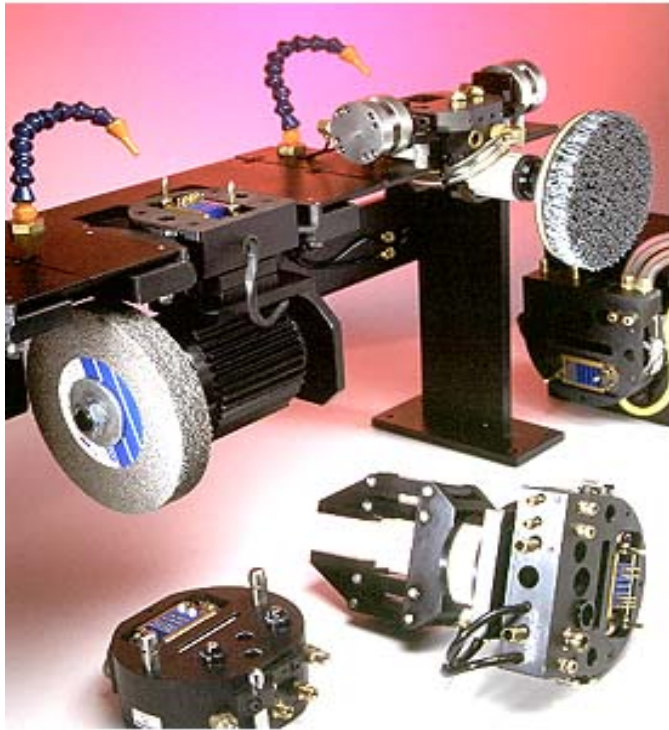
Robotic Manipulators



Riding an ABB IRB 6600 Robot 1 [Youtube]

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

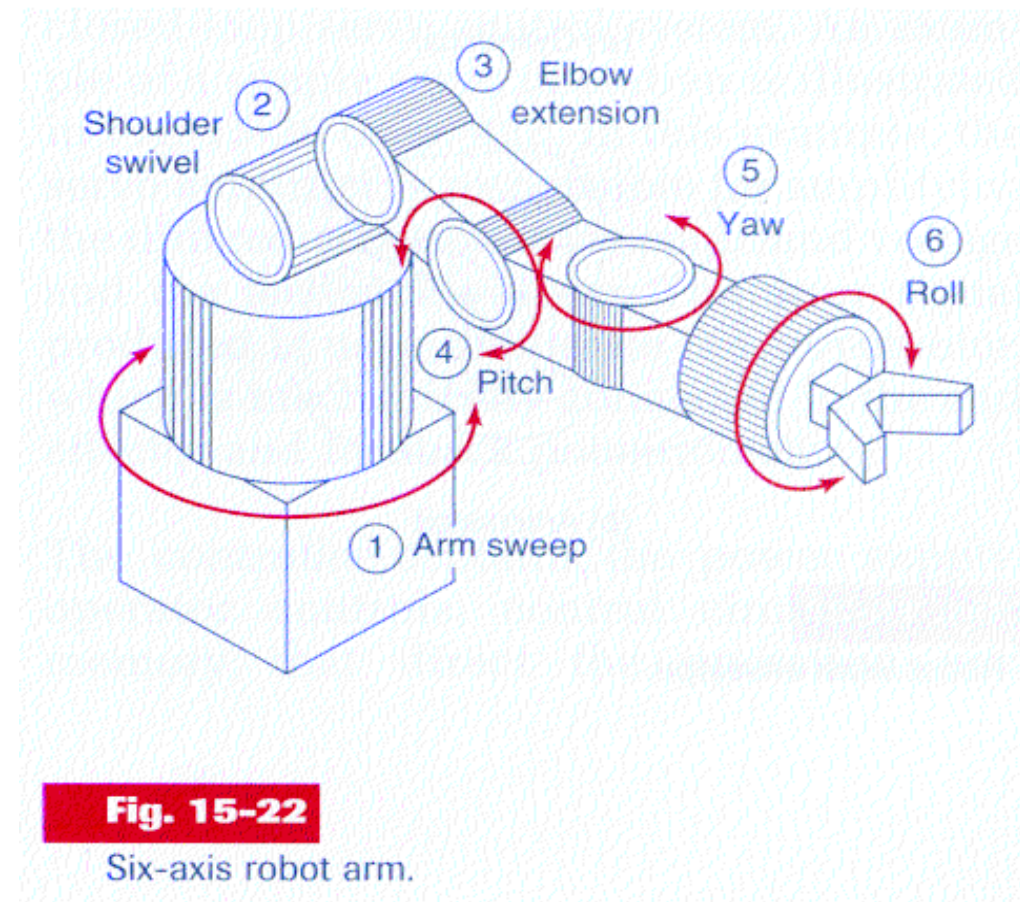
Robotic Manipulators - End Effectors



Robotic Manipulators

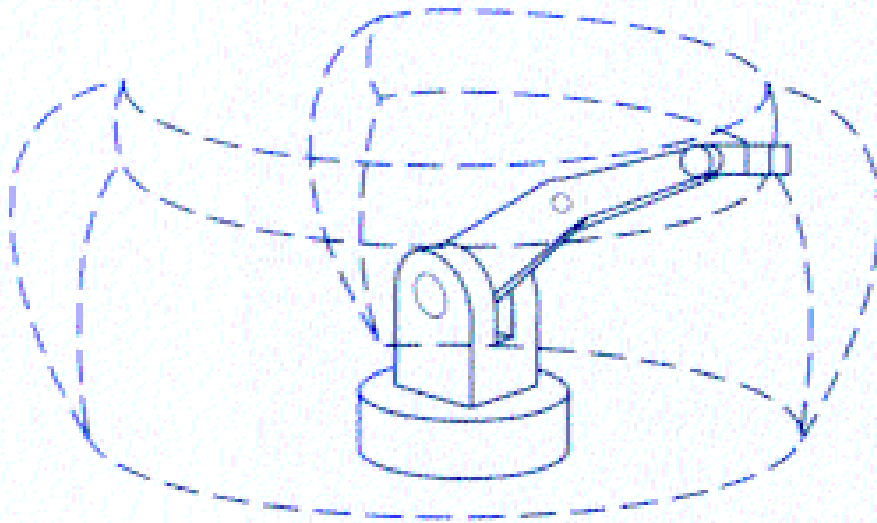
Major characteristics:

- 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

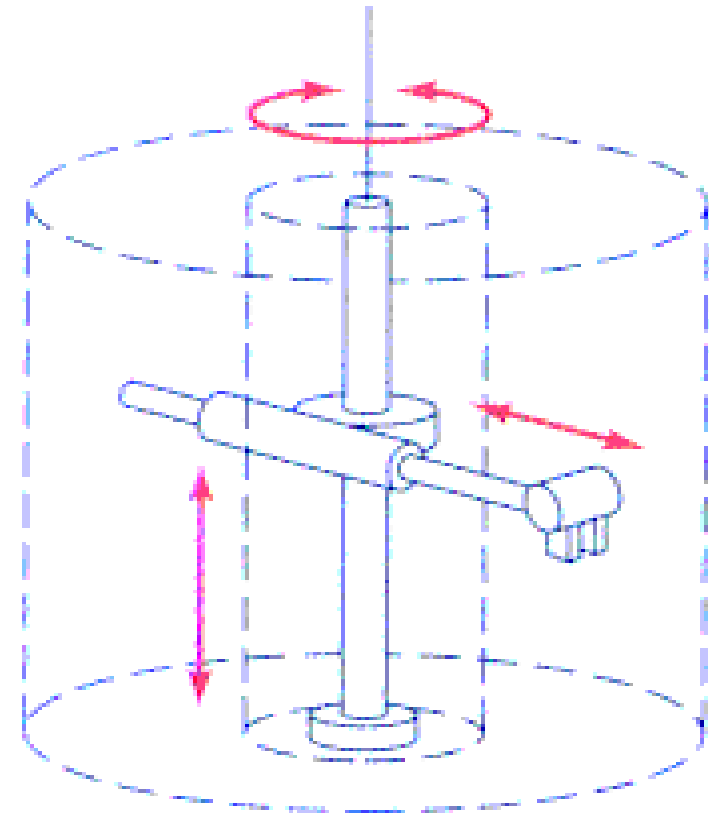


Robotic Manipulators

Workspace, examples:



(b) Articulated



(a) 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

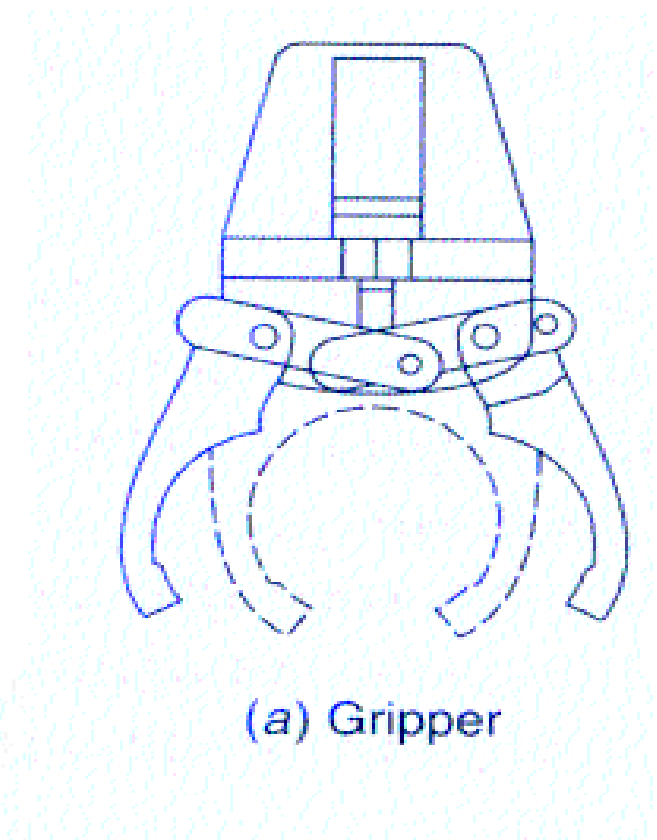
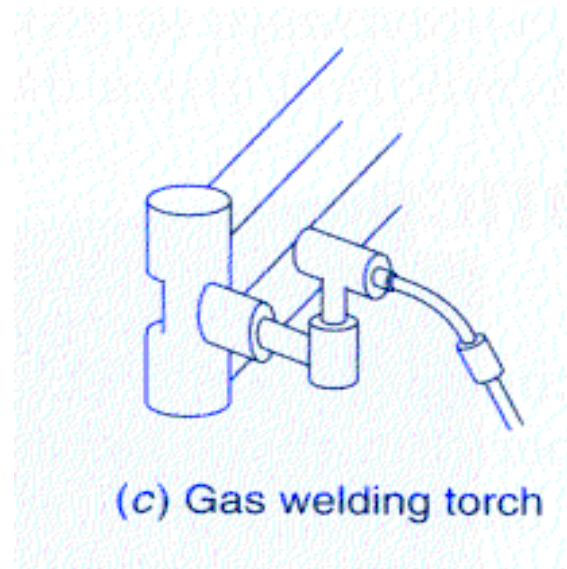
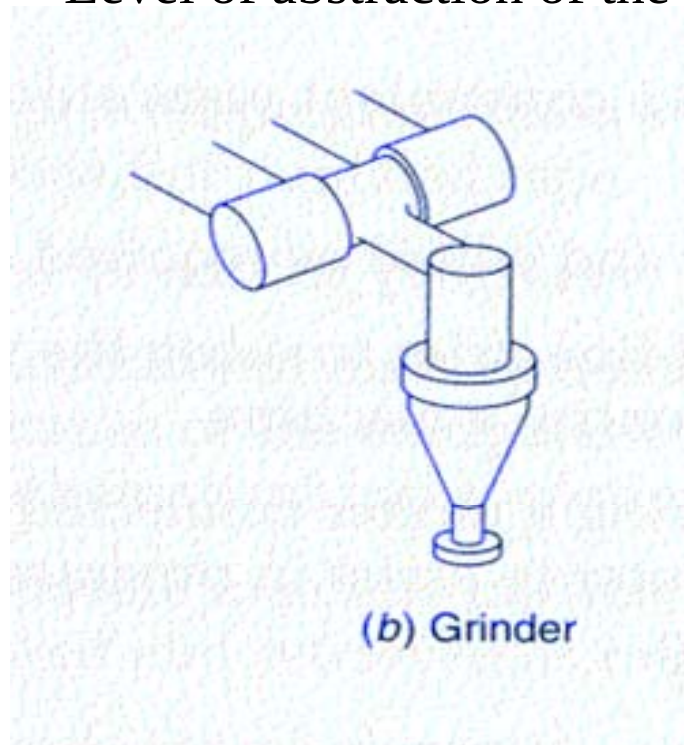


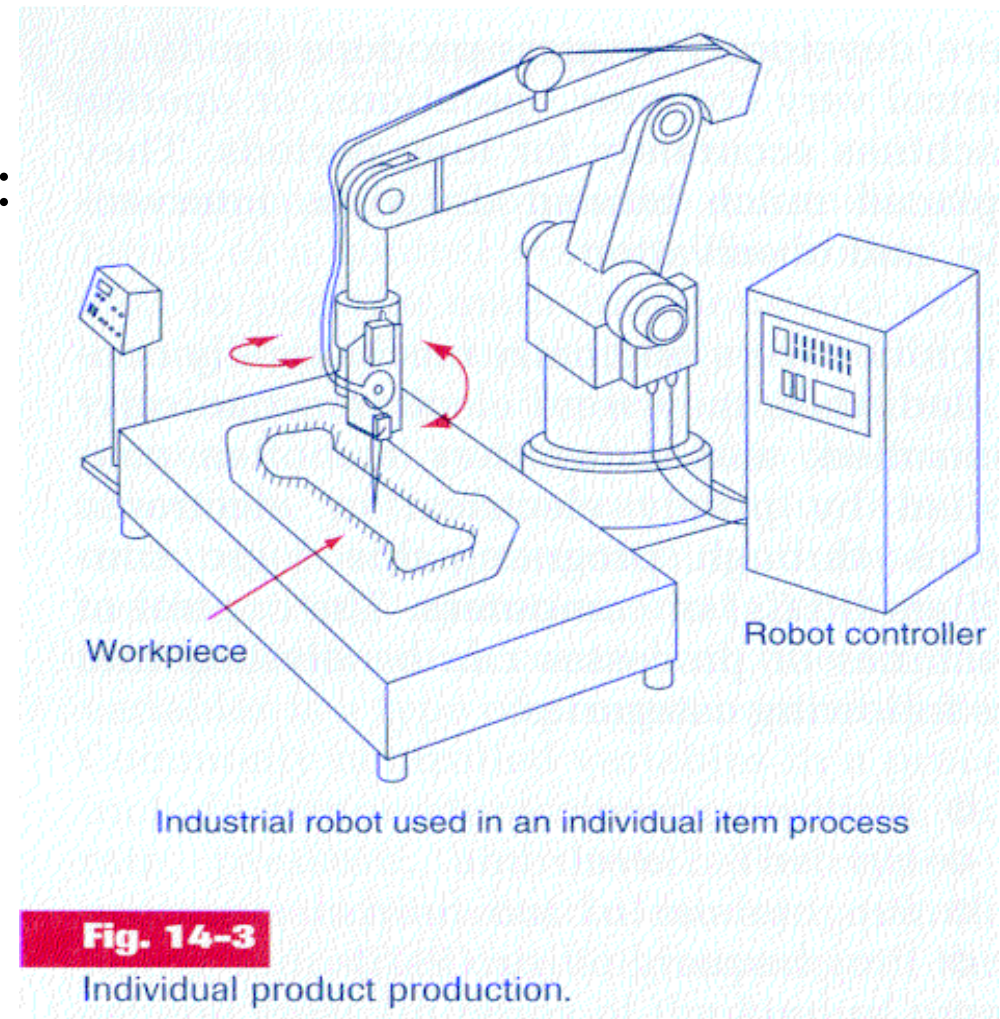
Fig. 15-24

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.



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

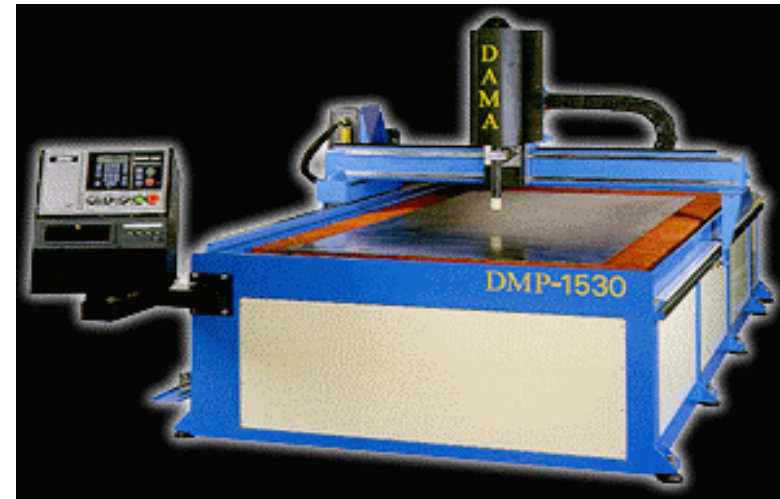
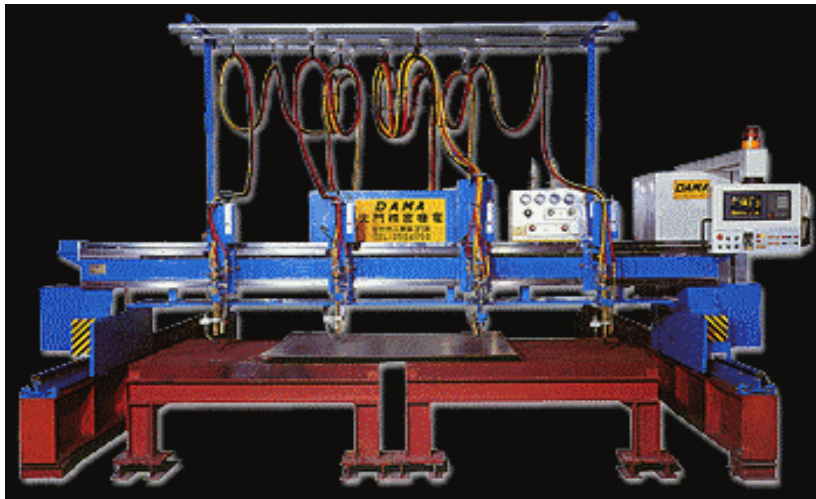
Examples:

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

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INÍCIO

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> Oficina do Vidro

OFICINA SELF-SERVICE (NÃO DISPONÍVEL)

ARMAZÉM TÉCNICO

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)

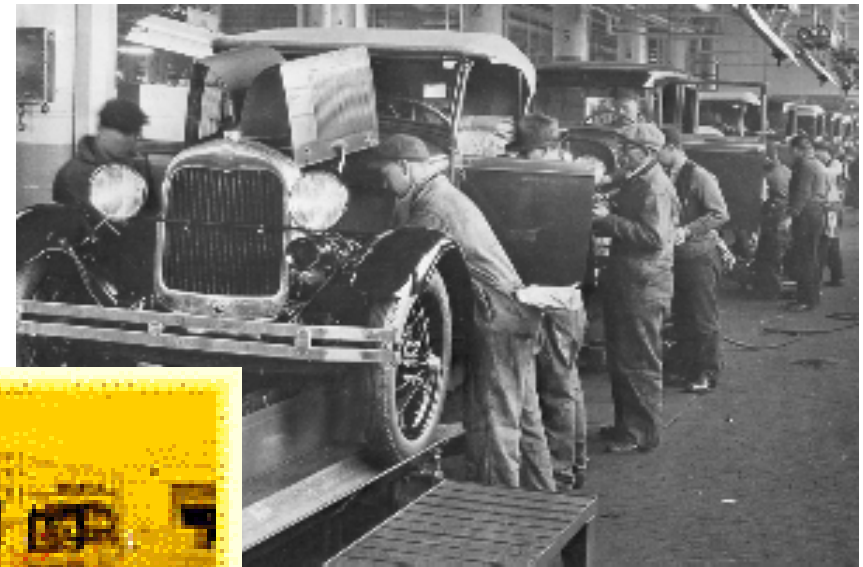
Major characteristics:

- 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]

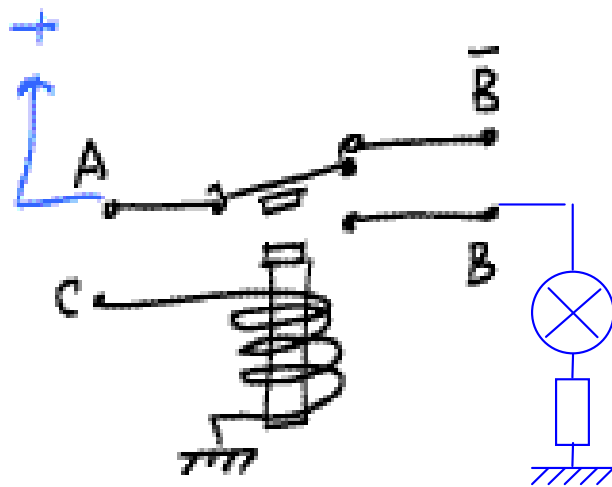
1.1 Introduction to **components** in industrial automation.

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

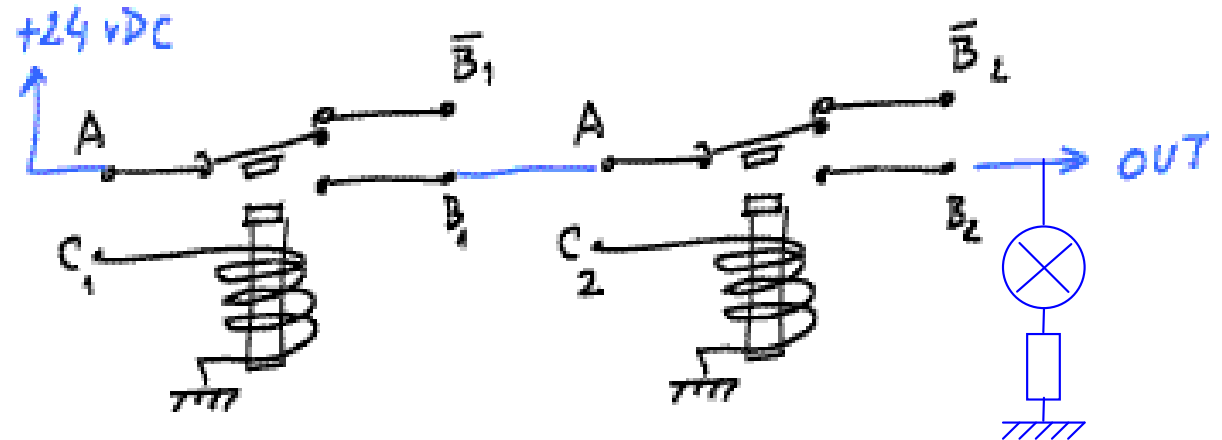
One Relay



$$B = C$$

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

Two Relays making one AND gate



$$B_2 = C_1 \wedge C_2$$

1.2 Cabled Logic versus ...

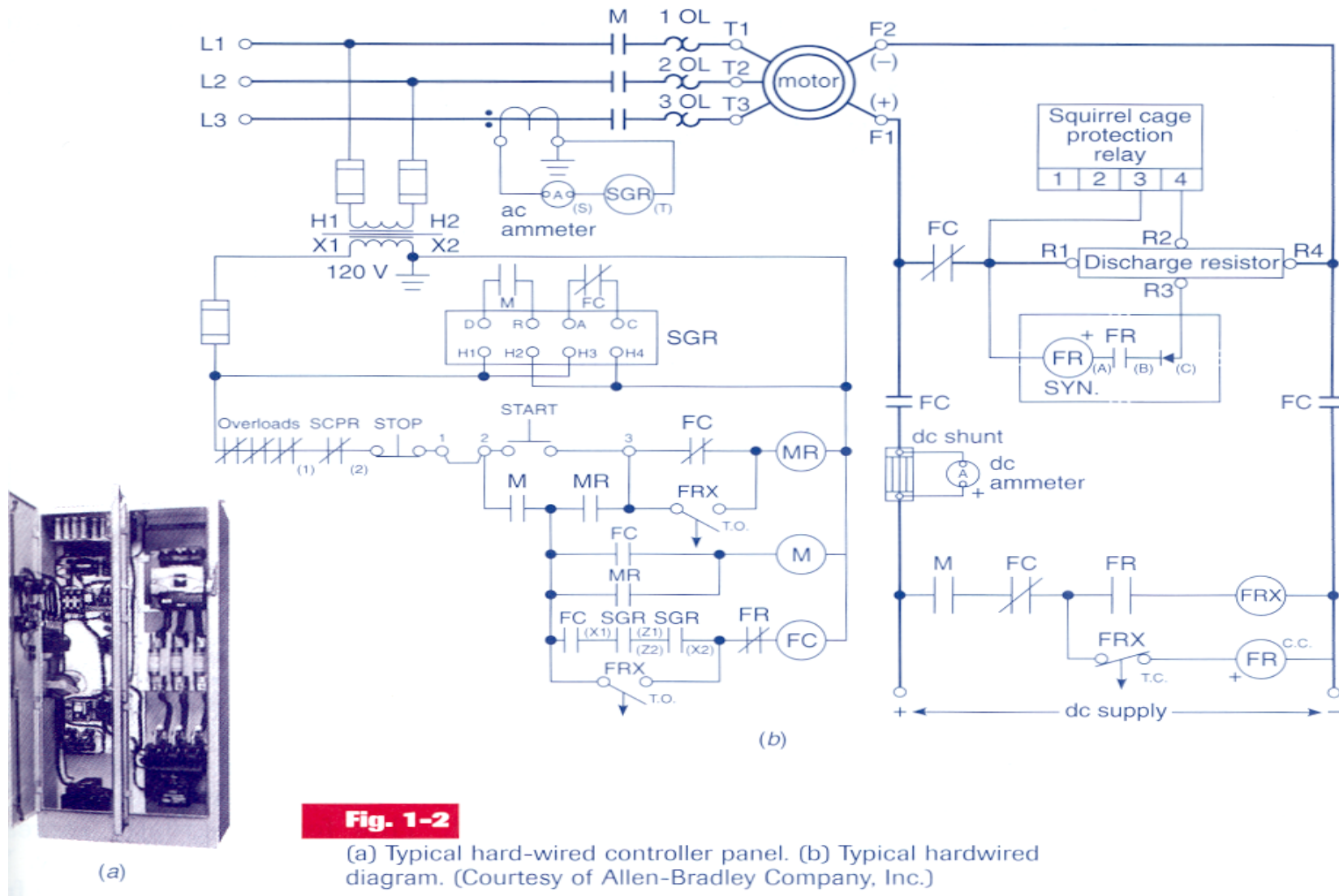
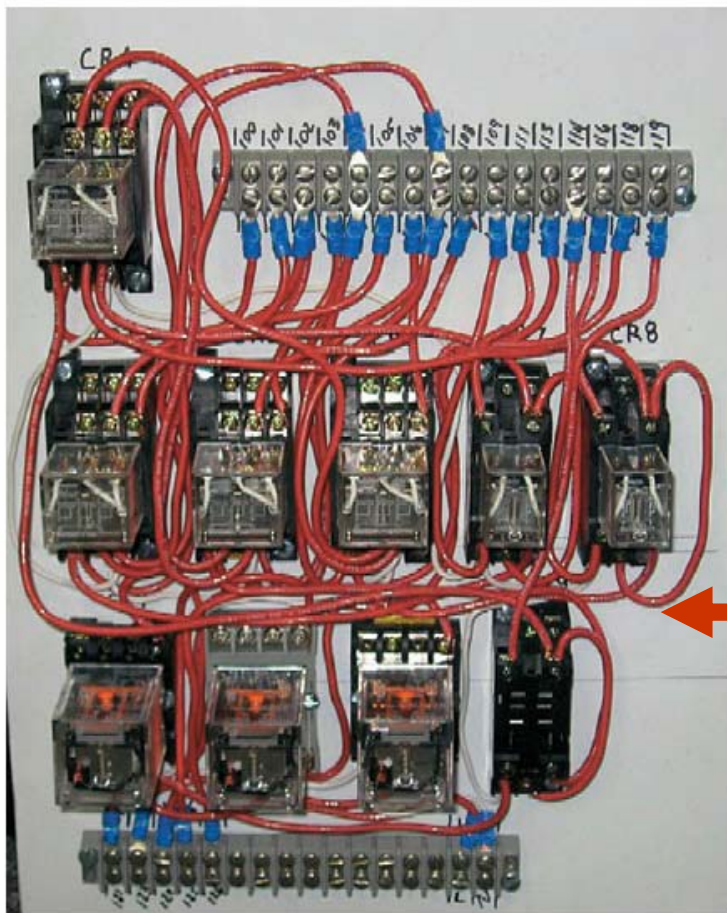


Fig. 1-2

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

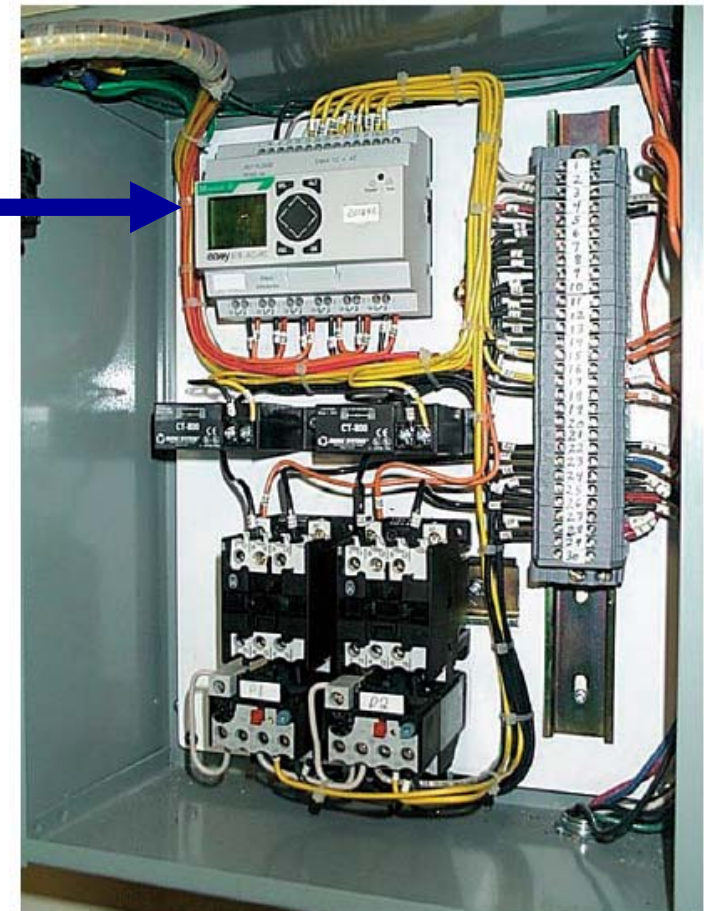
Cabled Logic versus ...

... versus Programmed Logic ...



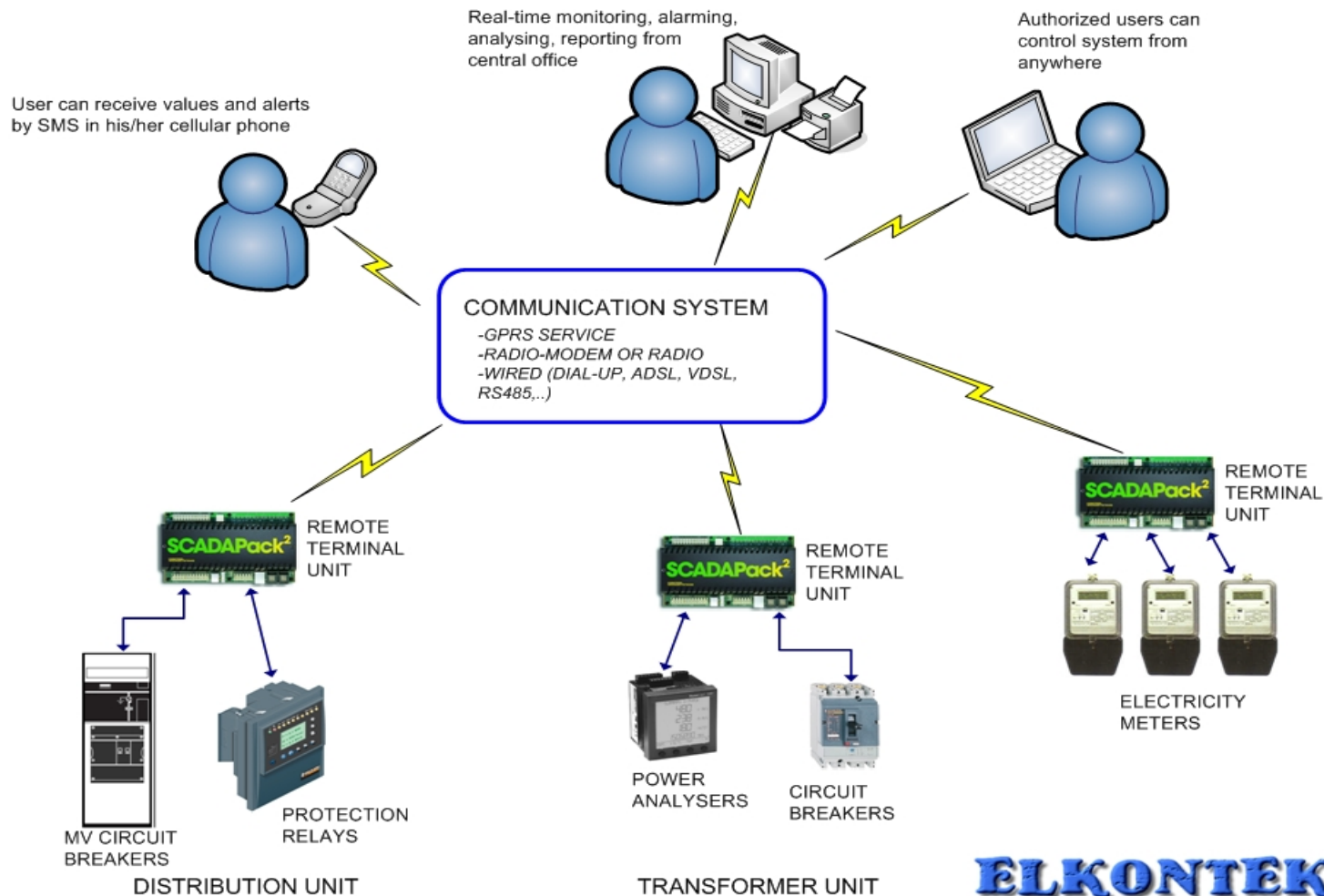
PLC
control
panel

Relay
control
panel



... versus Networked Logic

MIDDLE AND LOW VOLTAGE
ELECTRICITY DISTRIBUTION NETWORKS
MONITORING AND CONTROL SYSTEM



Ch. 1 – Introduction to Automation [1 week]

- 1.1 Introduction to **components** in industrial automation.
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Methodologies of work.

Relay diagram / Ladder diagram, design methodology:

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

Actuators

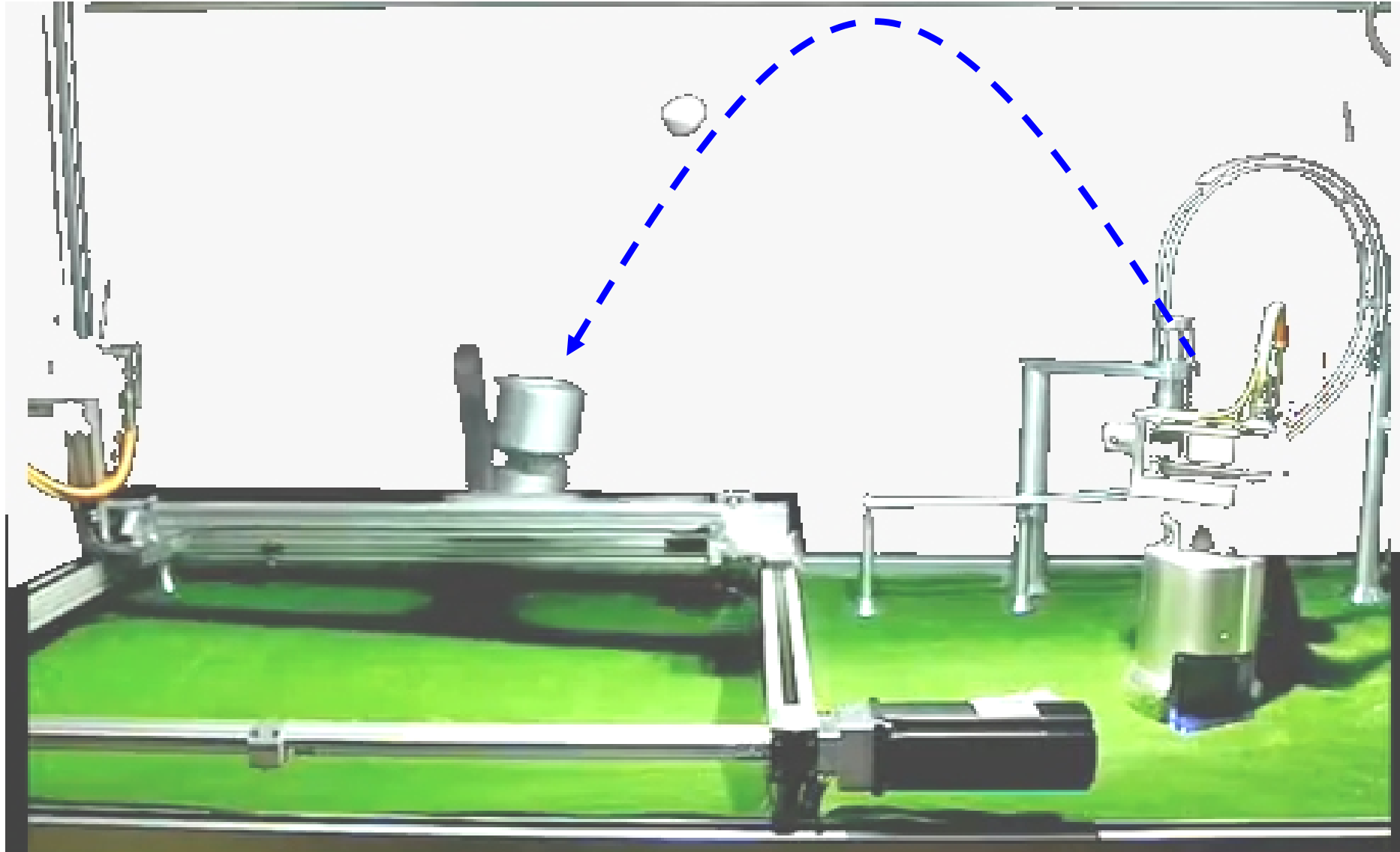
Motors
Solenoid valve
Command relay
Pneumatic cylinder
Electro pneumatic

Sensors

Pressure switch
Temperature sensors
Proximity sensors

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

Demonstration of precise actuation – Schneider Electric



Actuation

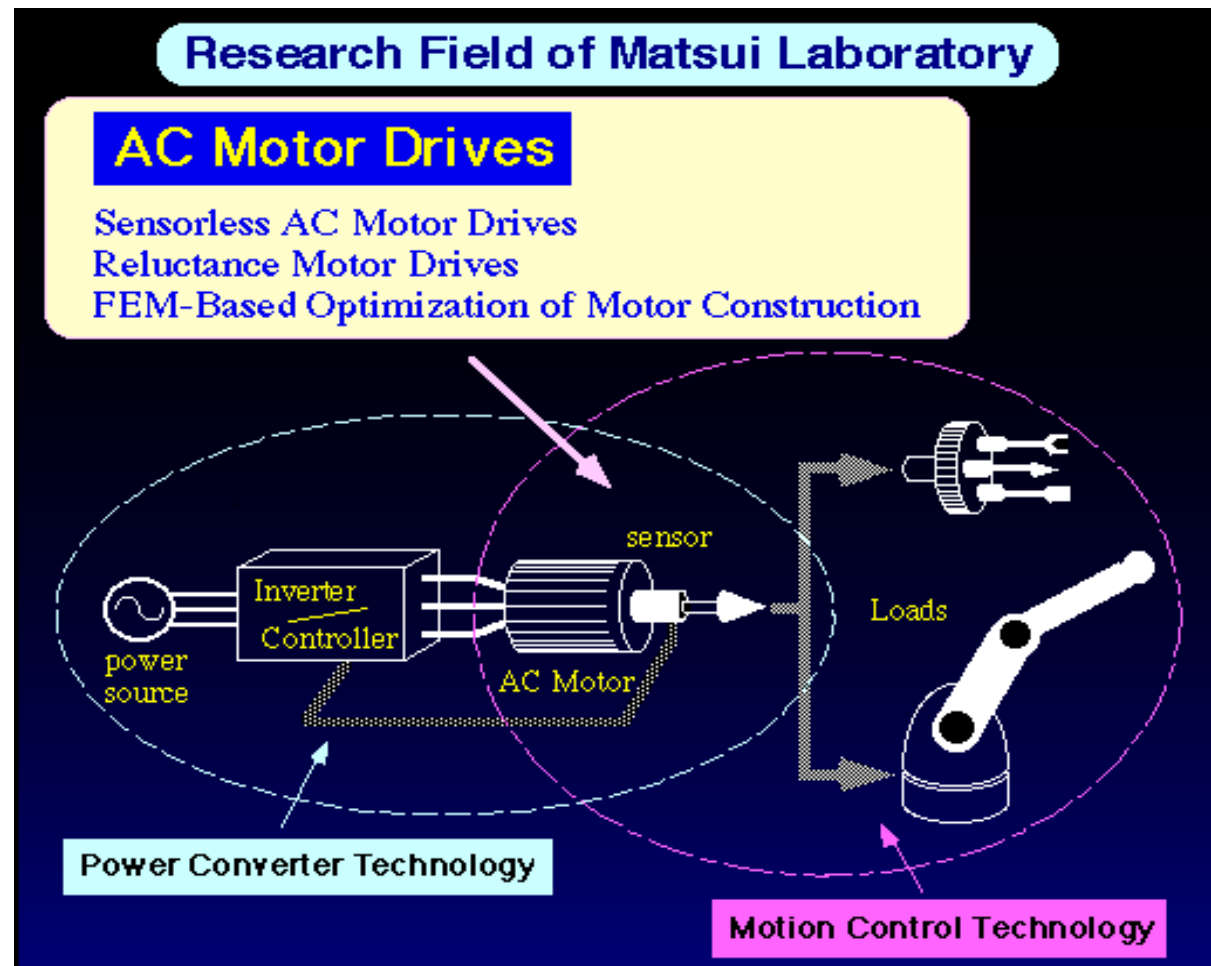
Motors

Major characteristics:

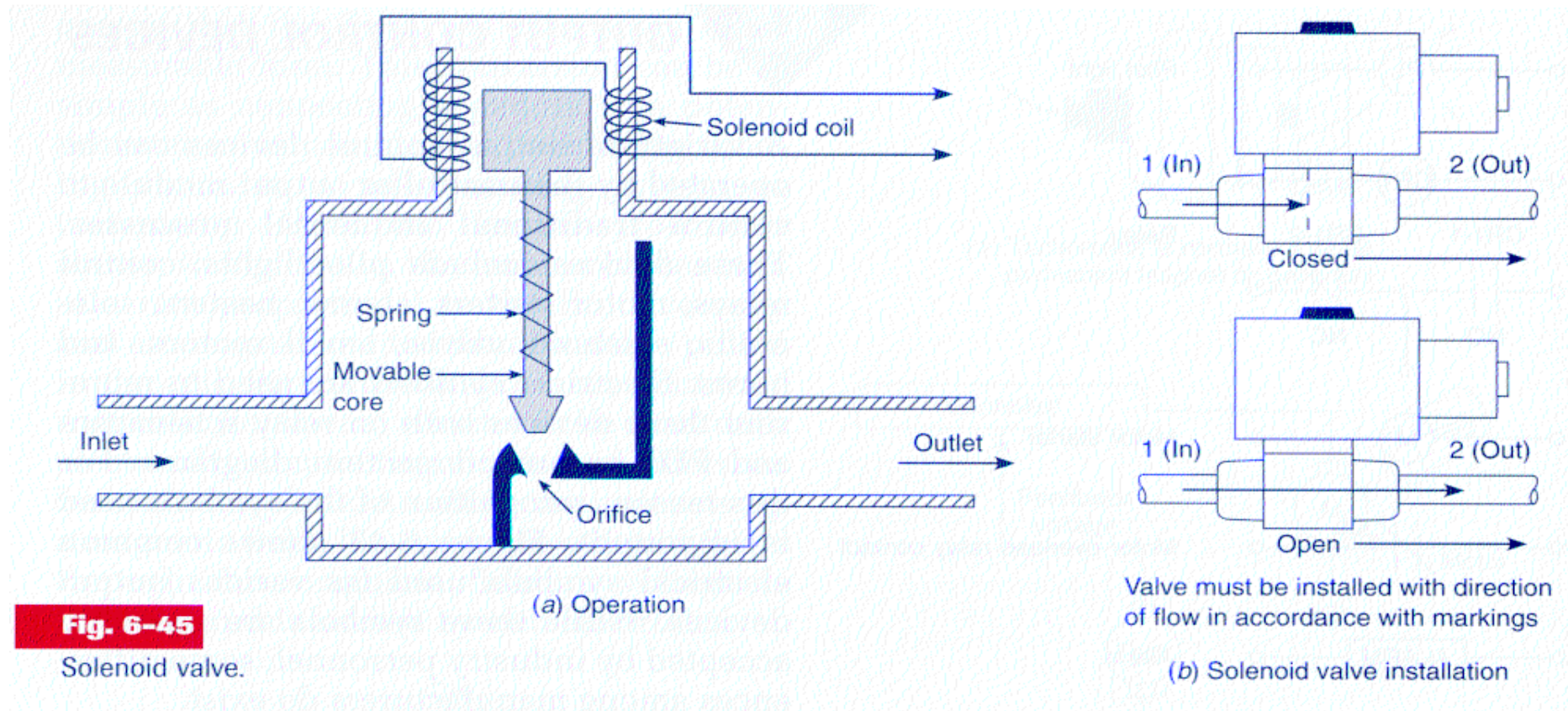
- Type of start
- Type of control
- Accuracy, reliability
- Payload and robustness
- Interface with exterior
- Synchronization



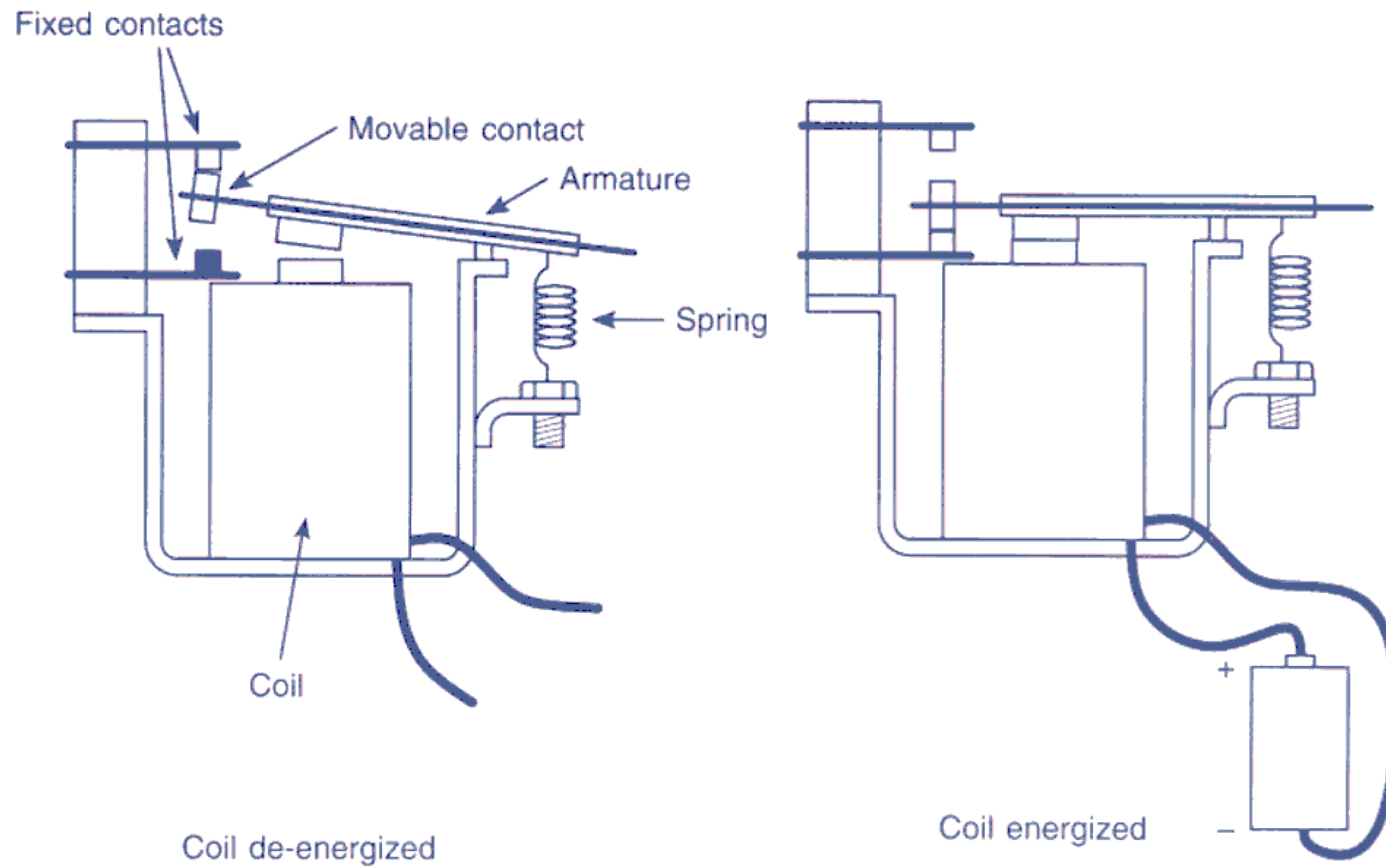
Example of AC motor, with driver



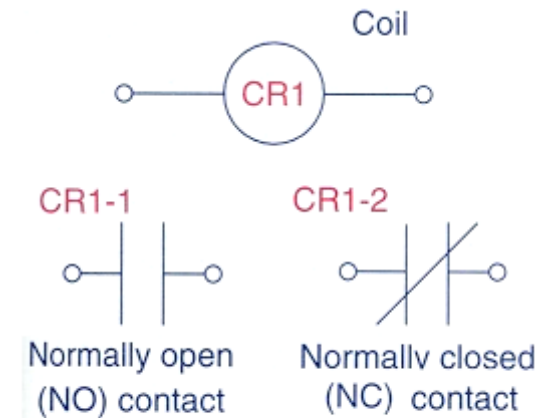
Solenoid Valve



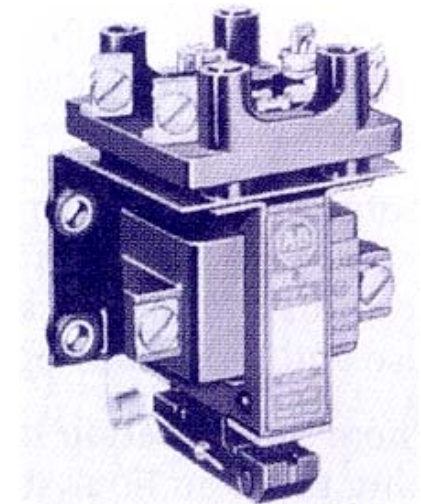
Command Relay


Fig. 6-1

Electromagnetic control relay operation.



(a) Control relay symbol



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

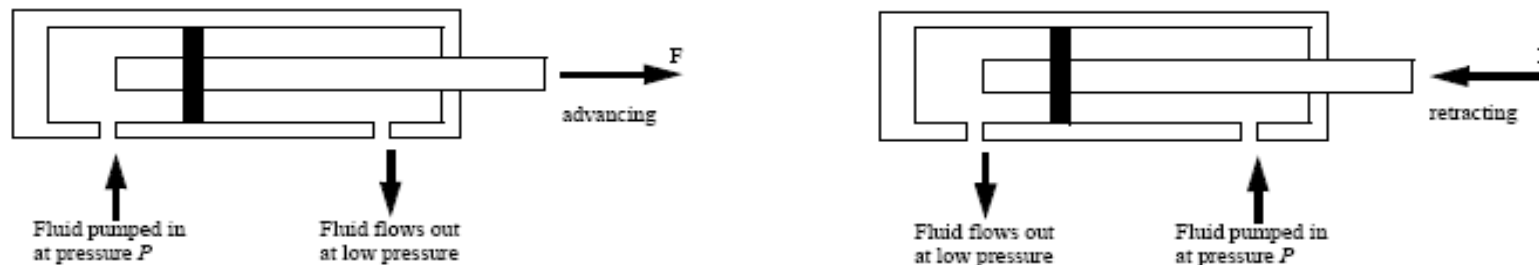
Fig. 6-2

Control relay.

Command Relay



Cylinders (Pneumatics)



For Force:

$$P = \frac{F}{A} \quad F = P \cdot A$$

where,

P = the pressure of the hydraulic fluid

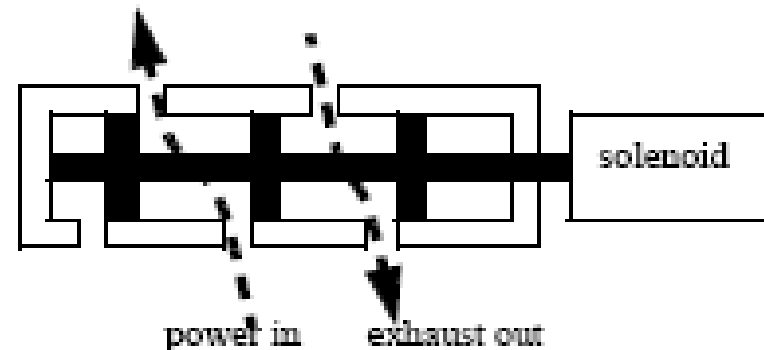
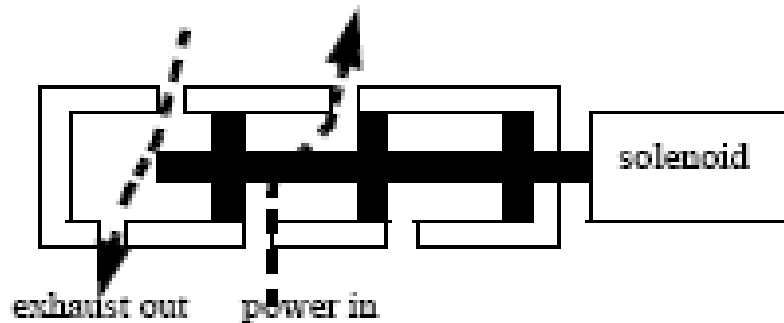
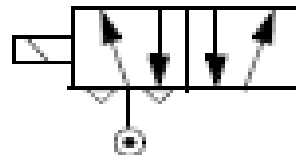
A = the area of the piston

F = the force available from the piston rod

Solenoid Valves (Electrovalves, Electro-pneumatics)

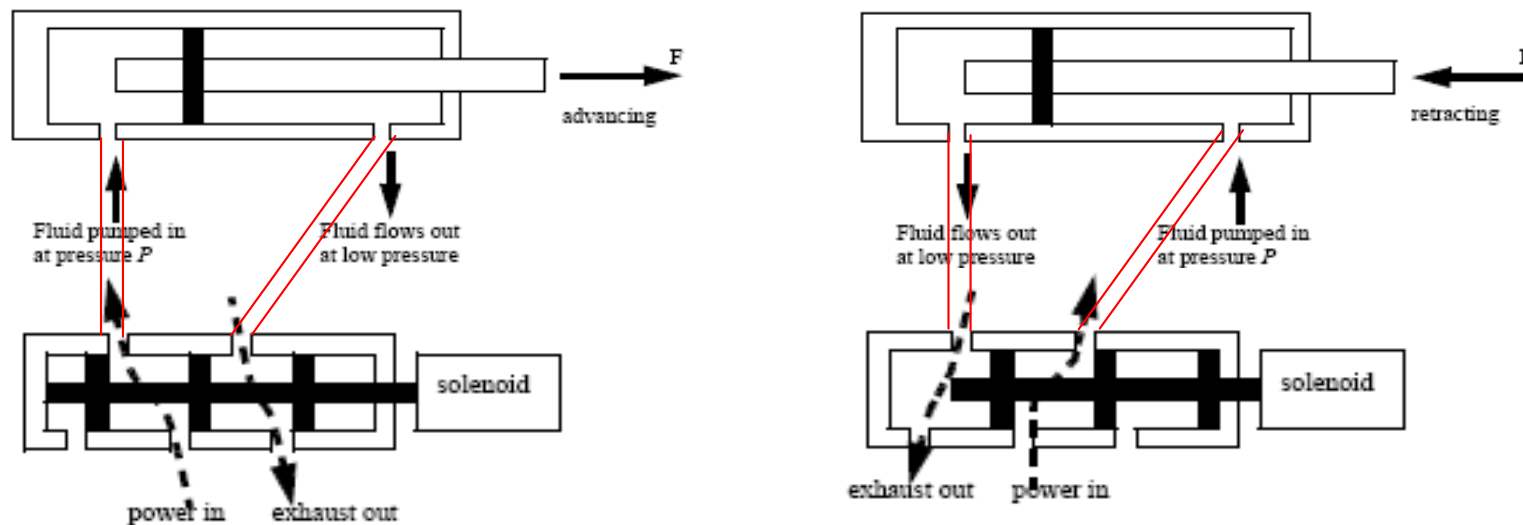


The solenoid has two positions and when actuated will change the direction that fluid flows to the device. The symbols shown here are commonly used to represent this type of valve.



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

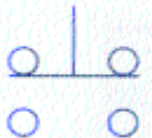
Push buttons



Normally open (NO) pushbutton



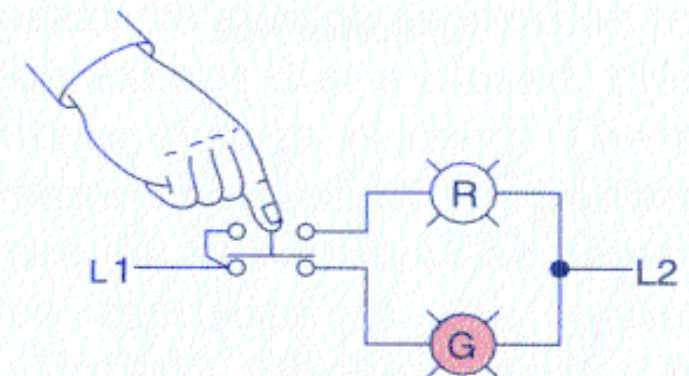
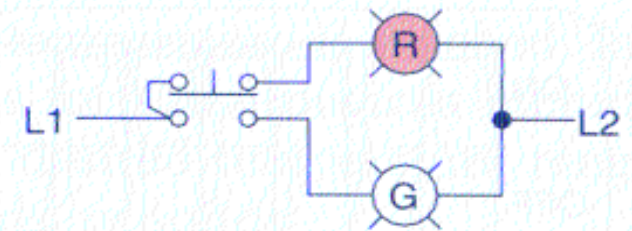
Normally closed (NC) pushbutton



Break-make pushbutton

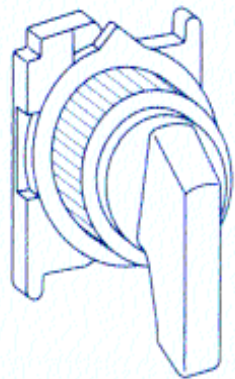
Note: The abbreviations NO and NC represent the electrical state of the switch contacts when the switch is not actuated.

(a) Pushbutton switches

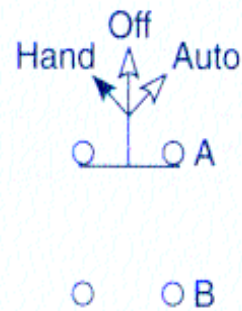


(b) Control circuit using a combination break-make pushbutton

Selector with three positions

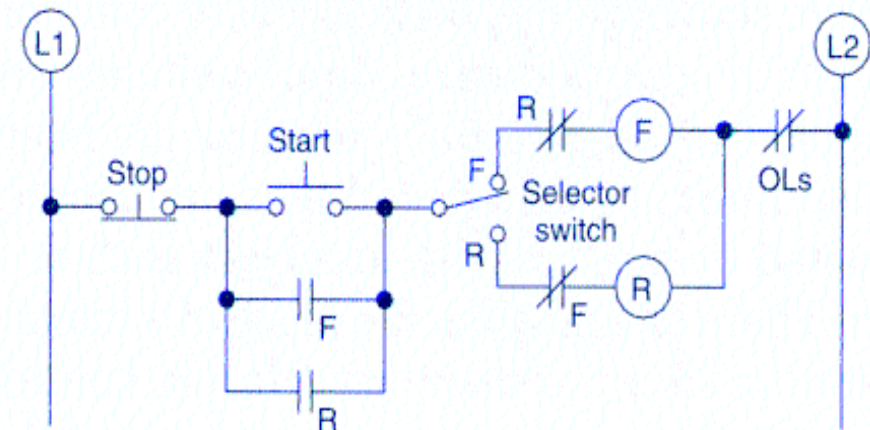


(a) Selector switch operator



(b) Three-position selector switch and truth table

Position	Contacts	
	A	B
Hand	X	
Off		
Auto		X



(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

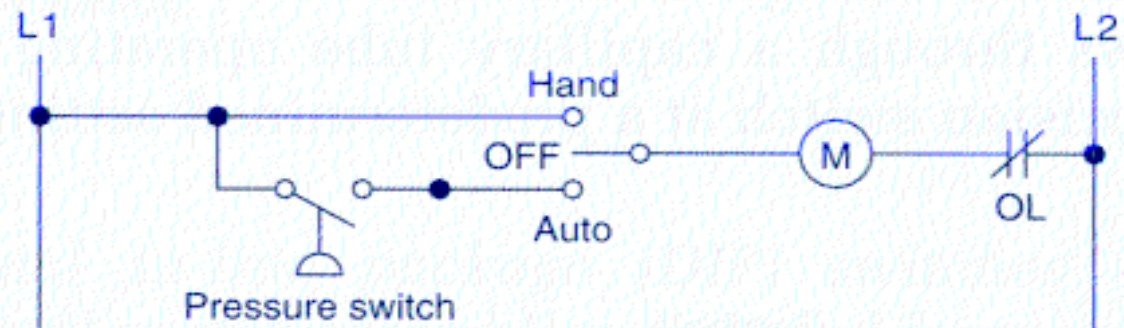
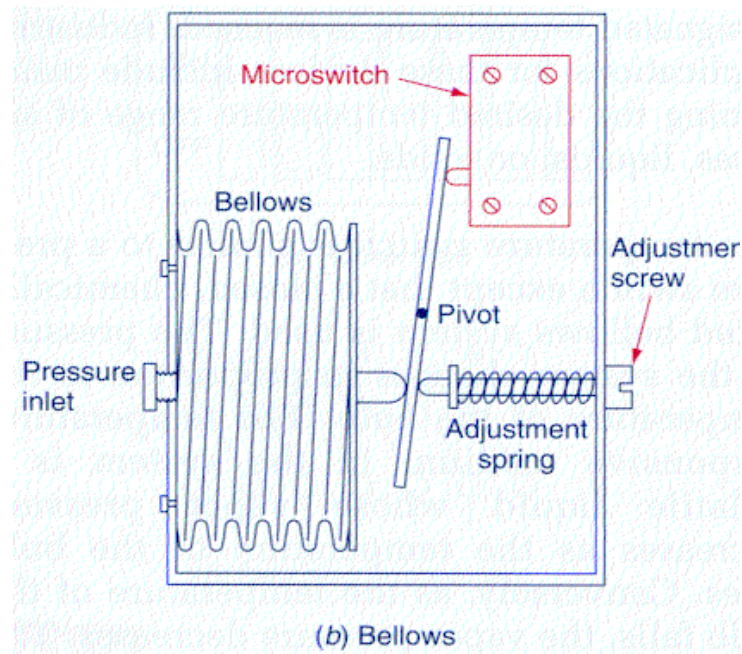


Fig. 6-15 (continued)

Pressure switch.

Temperature Sensors

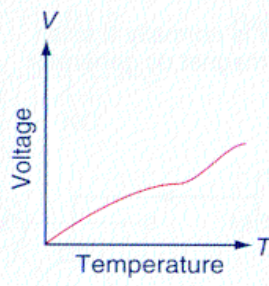
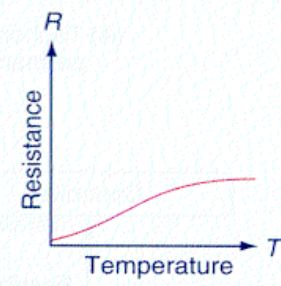
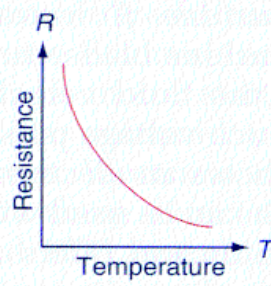
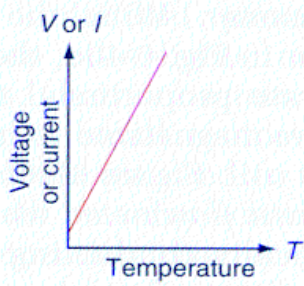
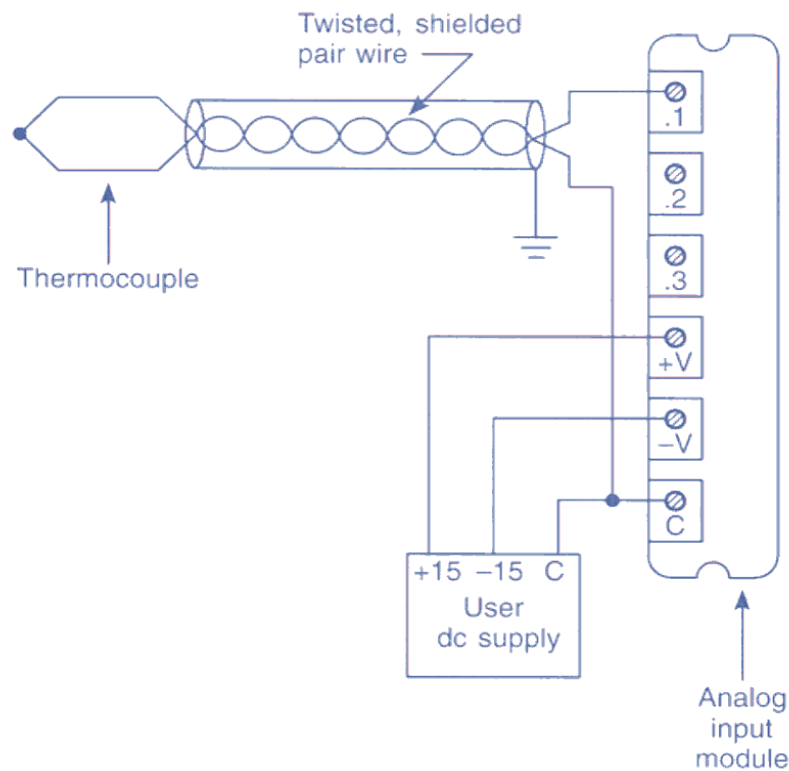
	Thermocouple	RTD	Thermistor	IC Sensor
				
				
Advantages	• Self-powered • Simple • Rugged • Inexpensive • Wide variety • Wide temperature range	• Most stable • Most accurate • More linear than thermocouple	• High output • Fast • Two-wire ohms measurement	• Most linear • Highest output • Inexpensive
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	• $T < 200^\circ\text{C}$ • Power supply required • Slow • Self-heating • Limited configurations

Fig. 6-38

Common temperature sensors.

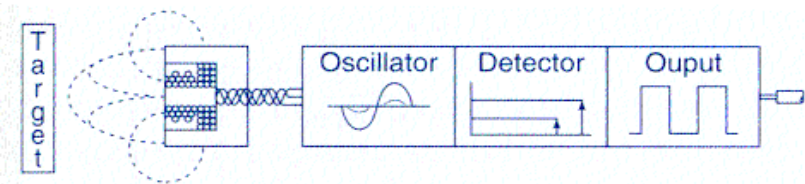
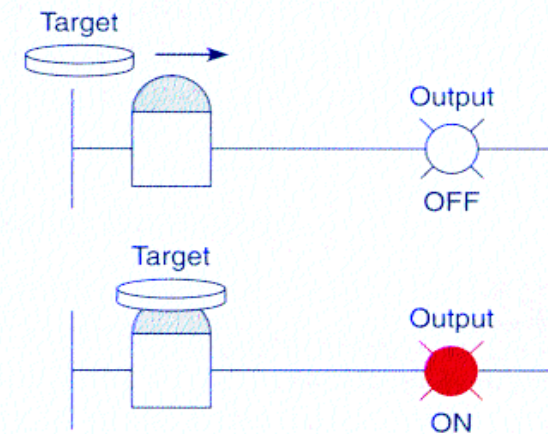
RTD = Resistance Temperature Detector
 IC = Integrated Circuit

Thermocouple

**Fig. 2-12**

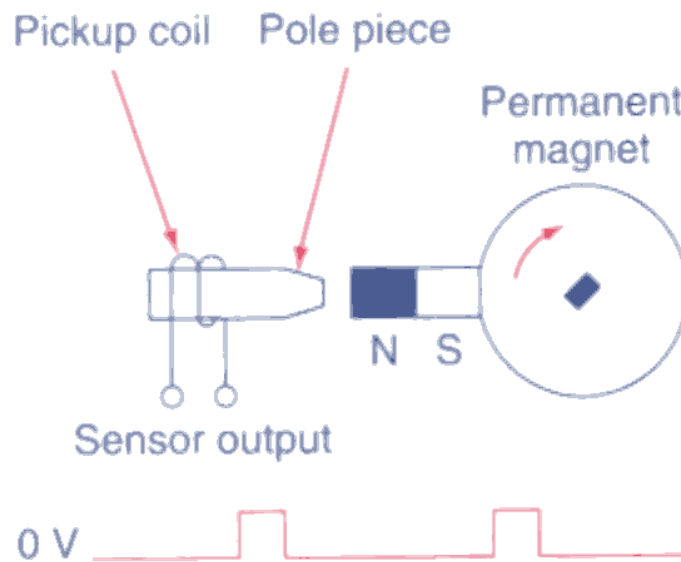
Typical thermocouple connection to an analog input module.

Proximity detector

**(a) Block diagram****(b) Operation**—as the target moves into the sensing area, the sensor switches the output ON.**Fig. 6-20**

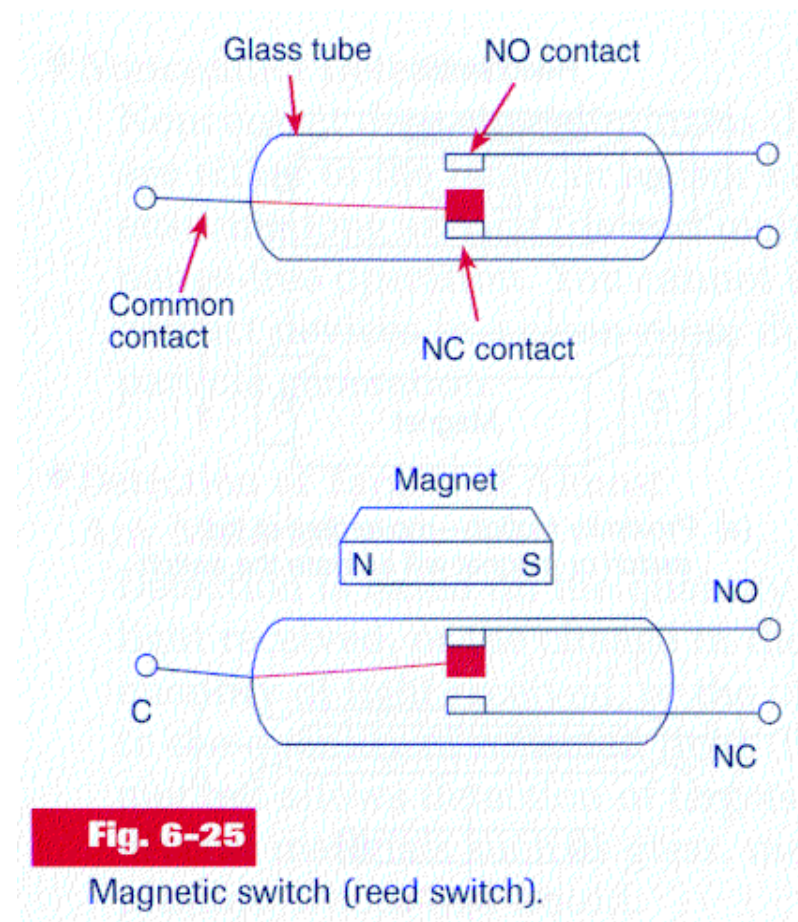
Inductive proximity sensor.

Magnetic detector

**Fig. 6-42**

Magnetic pickup sensor.

Magnetic switch

**Fig. 6-25**

Magnetic switch (reed switch).

Symbols associated to all components

Standards

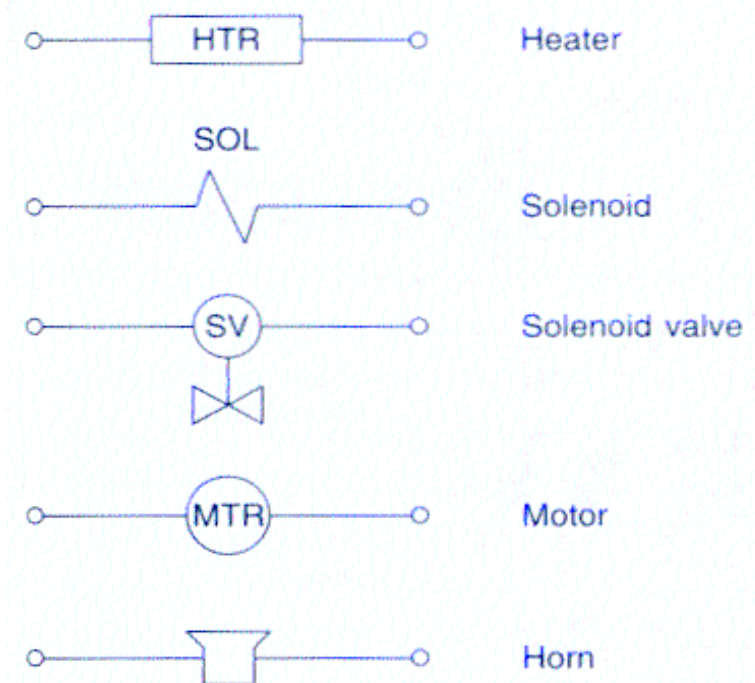
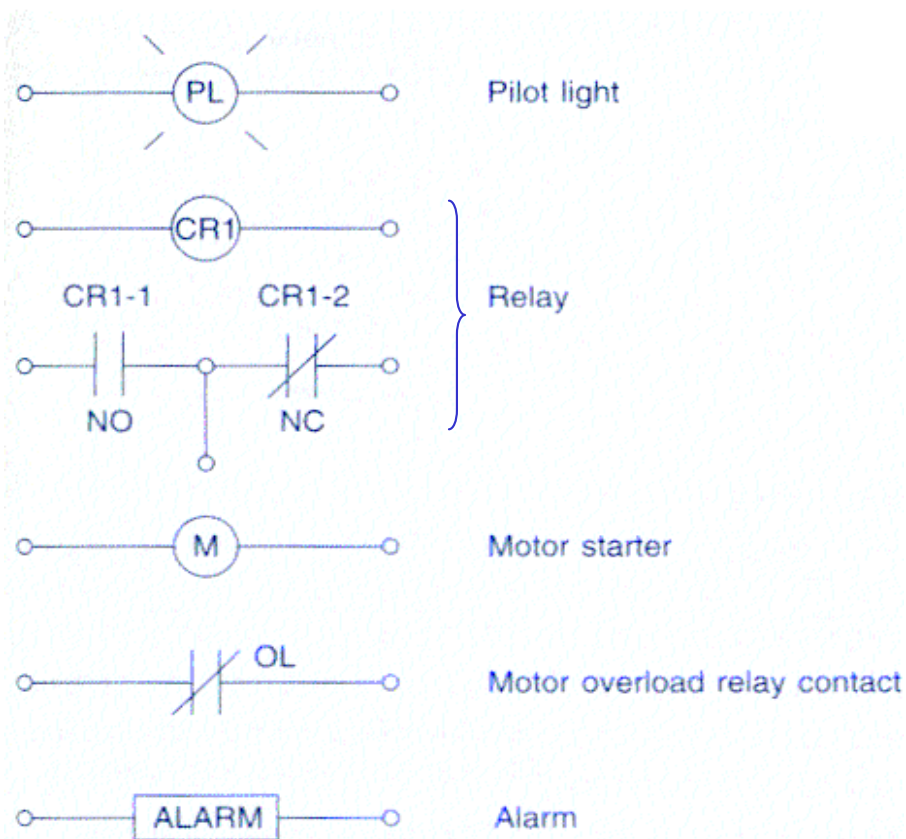
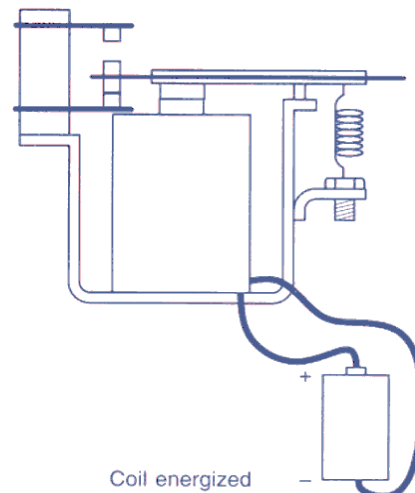
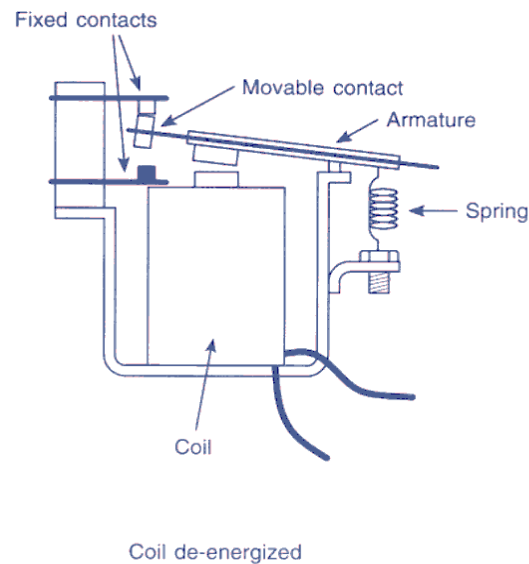


Fig. 6-43

Symbols for output control devices.

Methodologies for the implementation of solutions in industrial automation

Device: Relay



Contact Diagram or Ladder Diagram

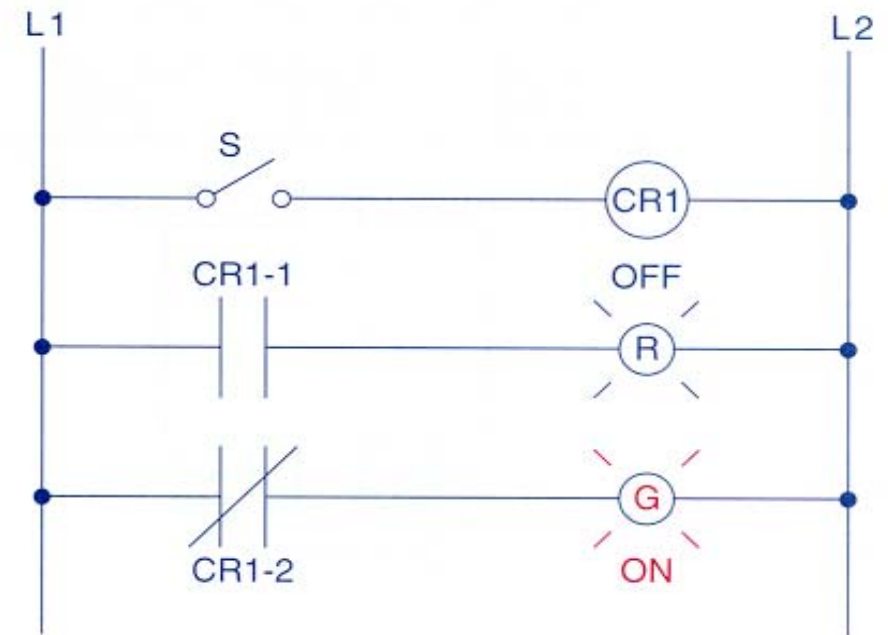
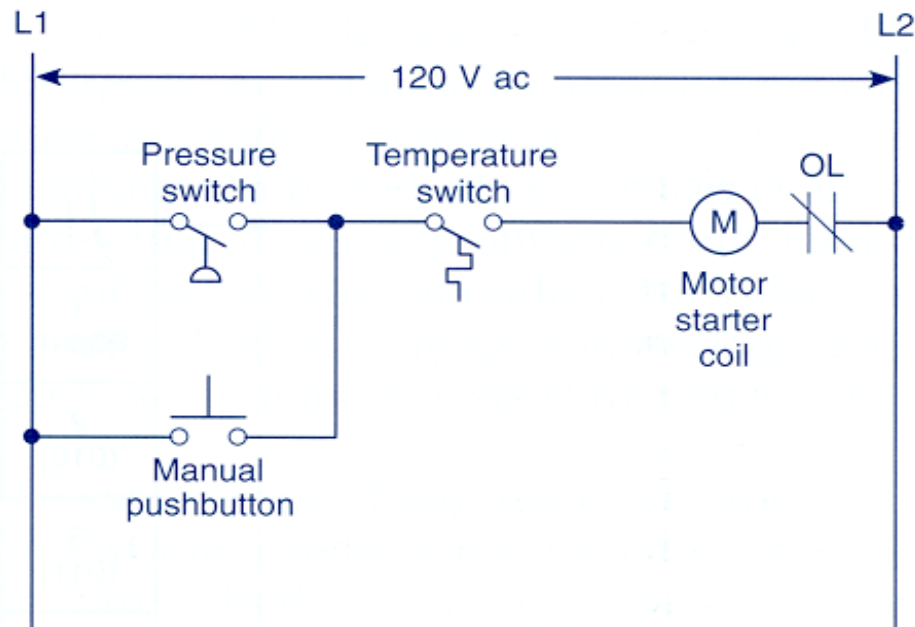


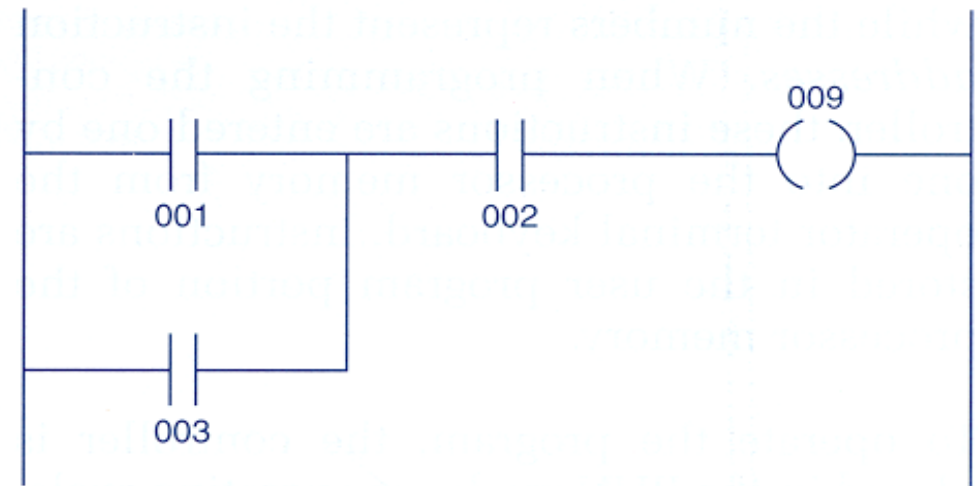
Fig. 6-3

Relay circuit—switch open.

Example:

**Fig. 1-13**

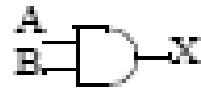
Relay ladder diagram for modified process.

**Fig. 1-14**

PLC ladder logic diagram for modified process.

Logic Functions

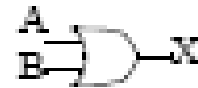
AND



$$X = A \cdot B$$

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

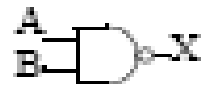
NOT



$$X = \bar{A}$$

A	X
0	1
1	0

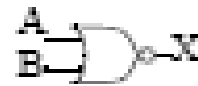
NAND



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

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

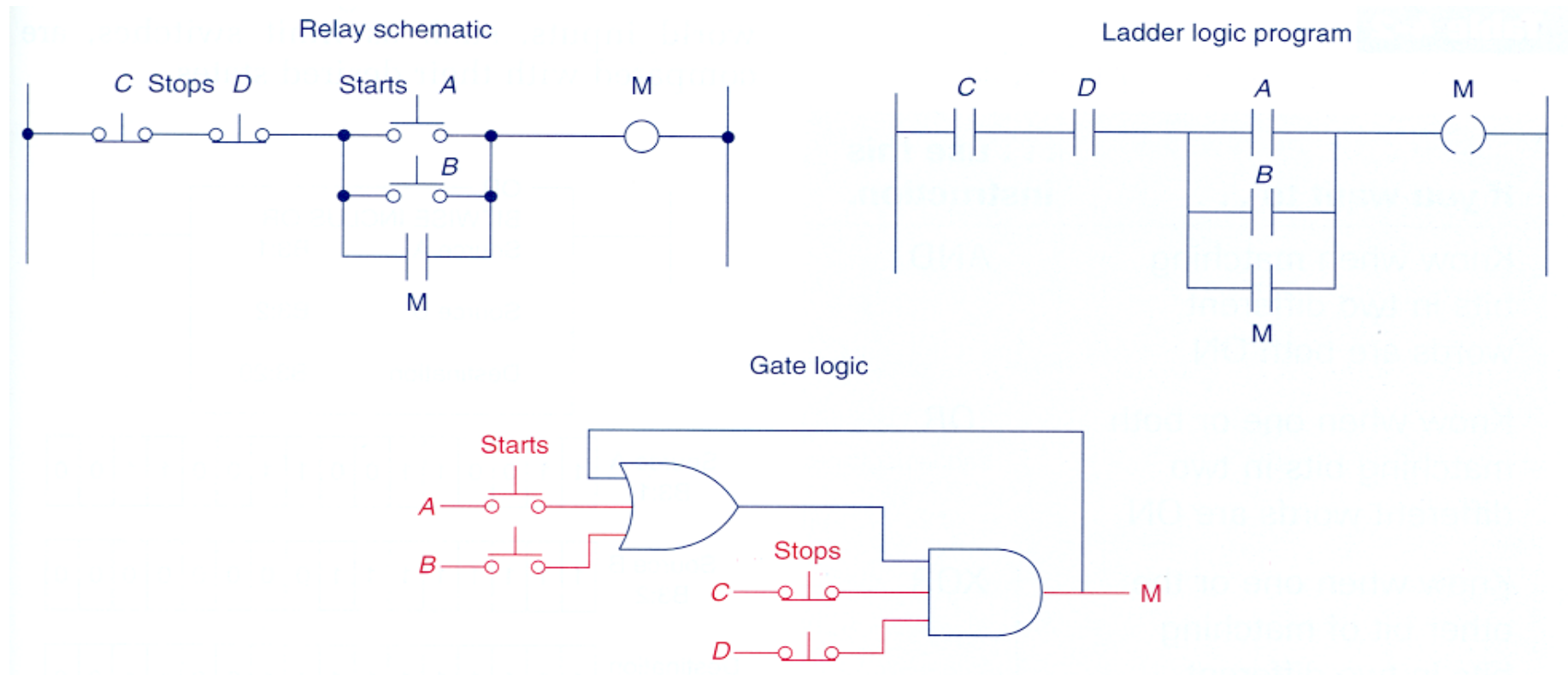
EOR



$$X = A \oplus B$$

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

Example:

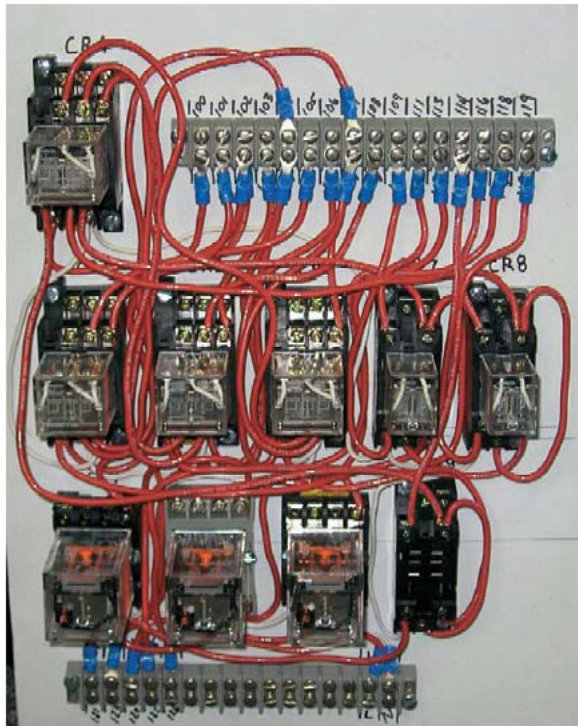


Example 4-9

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