# Industrial Automation
## (Automação de Processos Industriais)

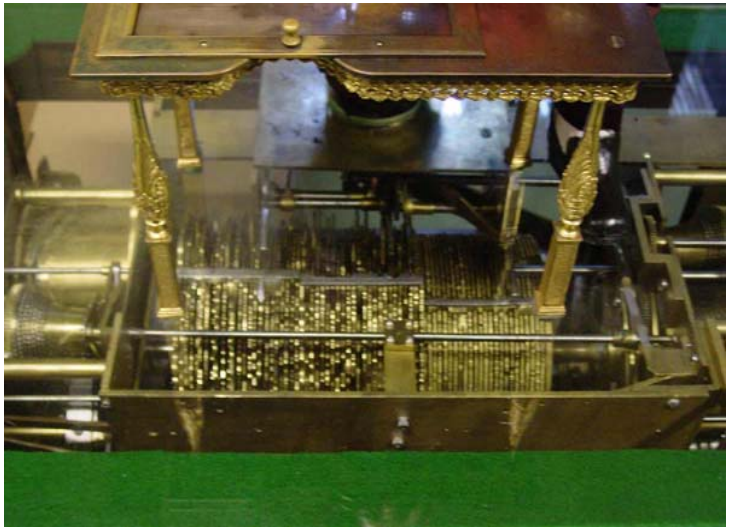
http://users.isr.ist.utl.pt/~jag/courses/api1213/api1213.html

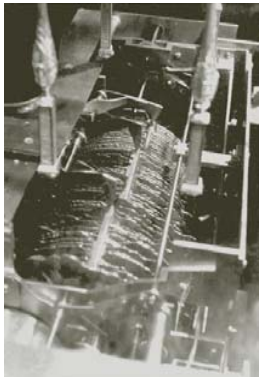
Slides 2010/2011 Prof. Paulo Jorge Oliveira

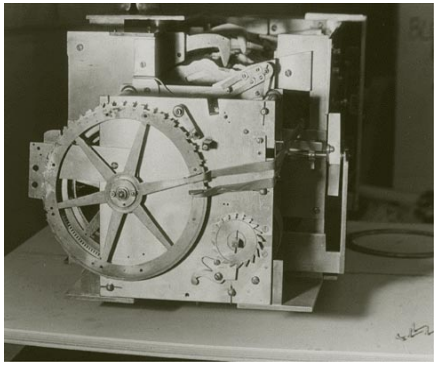
Rev. 2011-2013 Prof. José Gaspar

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

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



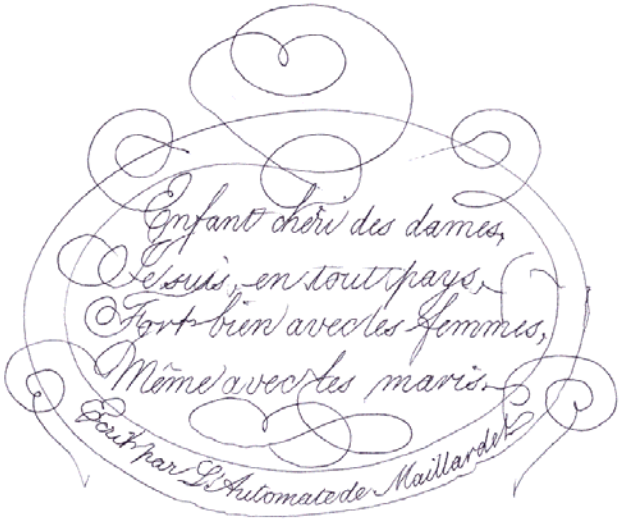


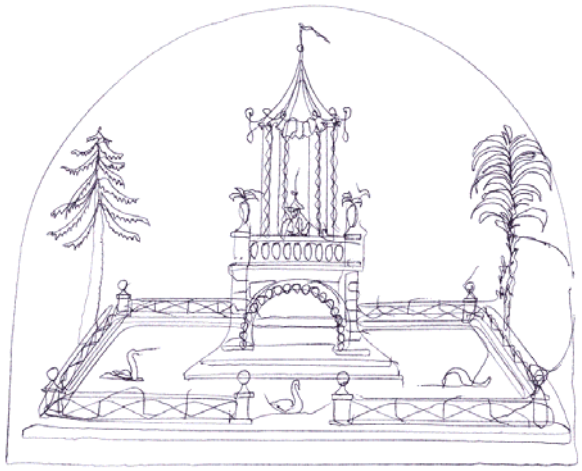


http://www.fi.edu/learn/sci-tech/automaton

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

*Four drawings and three poems*



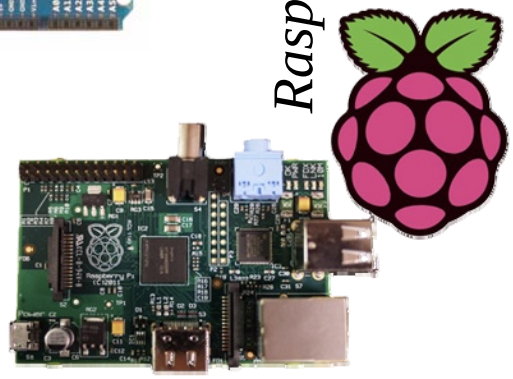


http://www.fi.edu/learn/sci-tech/automaton

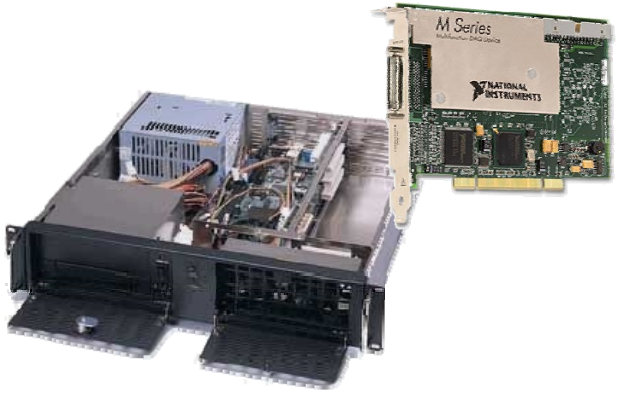
## *Microcontrollers*

*Arduino*

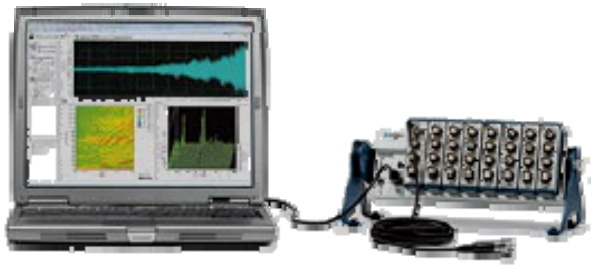
*Raspberry-pi*



## *Computer + IO*




*National Instruments AD/DA*

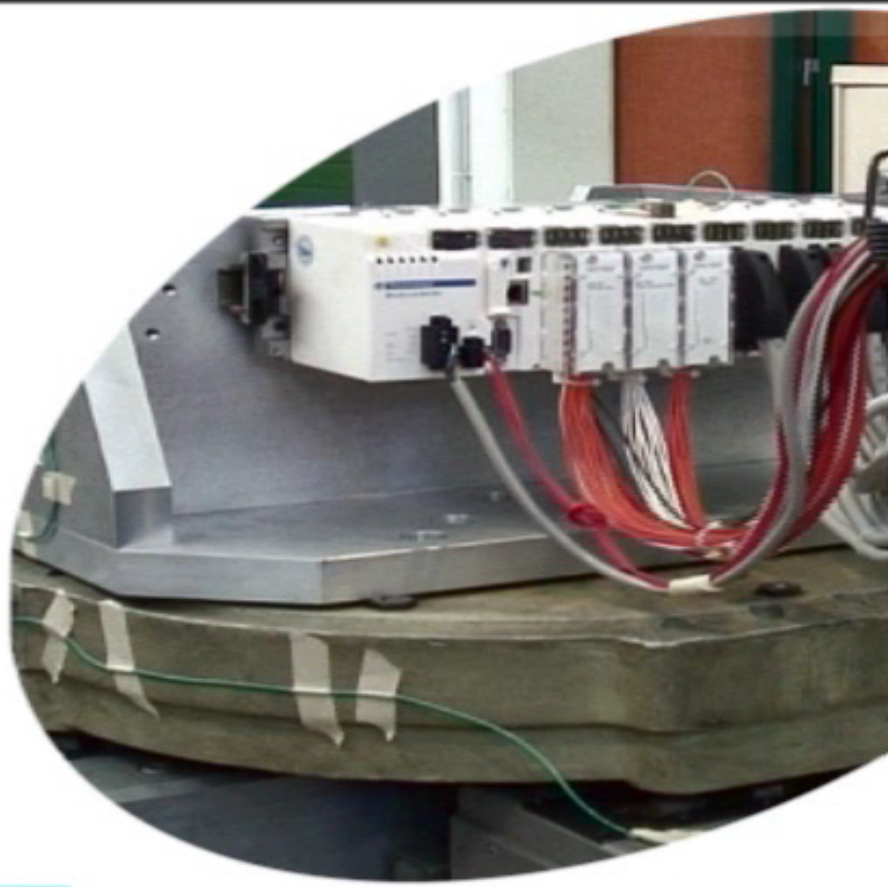


## *PLC*

*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 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.*
- *Exams (40% of the final grade). Two written.*

  *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 50% of recitations.*

# Schedule (laboratories & exam):

| | | |
|---|---|---|
| Lab. registration[1] | First week | 17-22/09/2012 |
| 1st preliminary lab. | 1 week | 01-12/09/2012 |
| 2nd preliminary lab. | 1 week | 15-19/10/2012 |
| 1st lab. assignment | 3 weeks | 22/10-09/11/2012 |
| 2nd lab. assignment | 3 weeks | 19/11-07/12/2012 |
| 3rd lab. assignment | 0.5h seminar | One date >= week 8 |
| Exams | 3h | 9Jan, 30Jan 2012 |

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

# Schedule (according to IST-GOP):

- Recitation classes

| | |
|---|---|
| Monday | 11.00 h – 12.30h Ea5 |
| Friday | 11.00 h – 12.30h 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:

• 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…

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• 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.

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

• Moody, J. e 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/api1213/api1213.html

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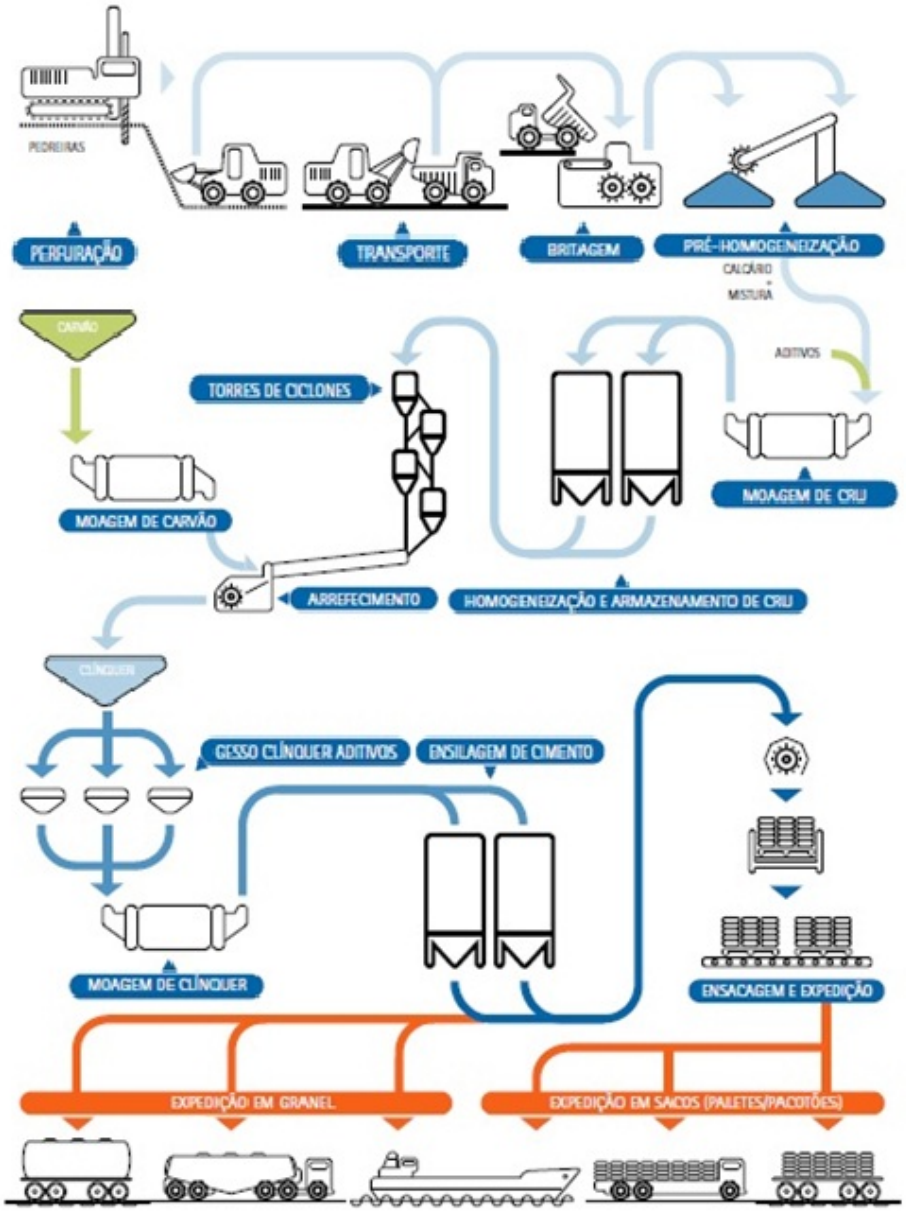
*Industrial Process:*

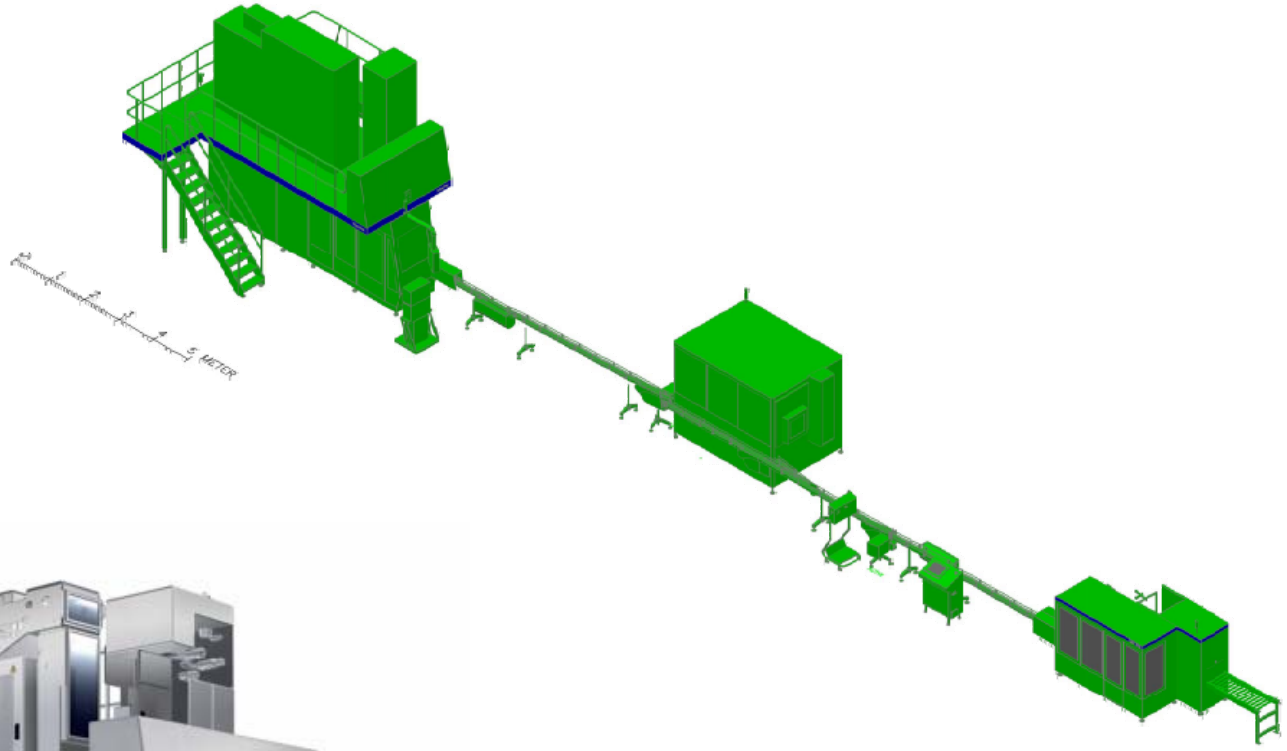
***Making Cement***

*[Outão / Setúbal / Portugal]*



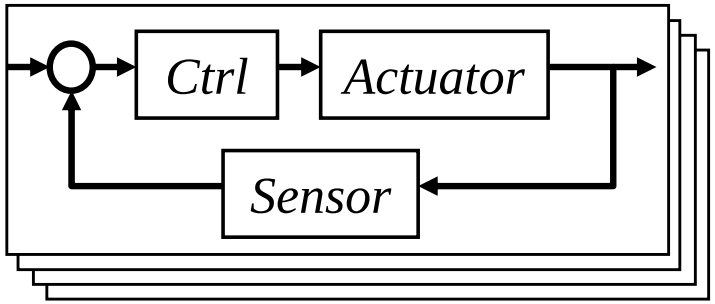
*Industrial Process:*

***Tetra Pak / Parmalat***



*Complexity handled with modularity*

***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]

Introduction to components in industrial automation.

Cabled logic versus programmed logic versus networked logic.

Introduction to methodologies for problem modeling.
Methodologies of work.

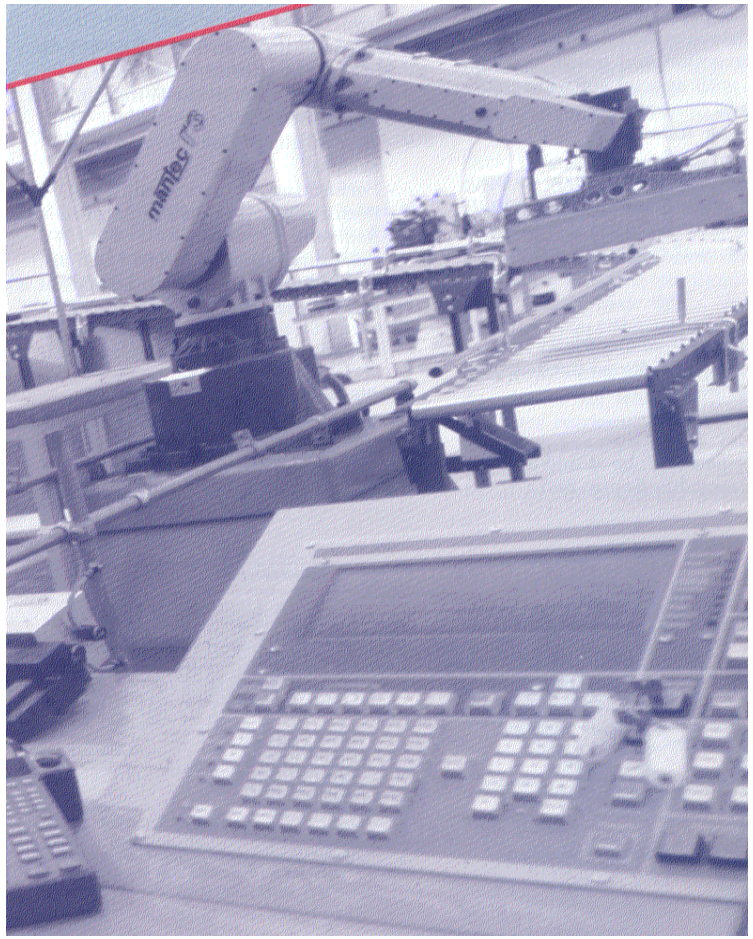
# Components used in industrial automation

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

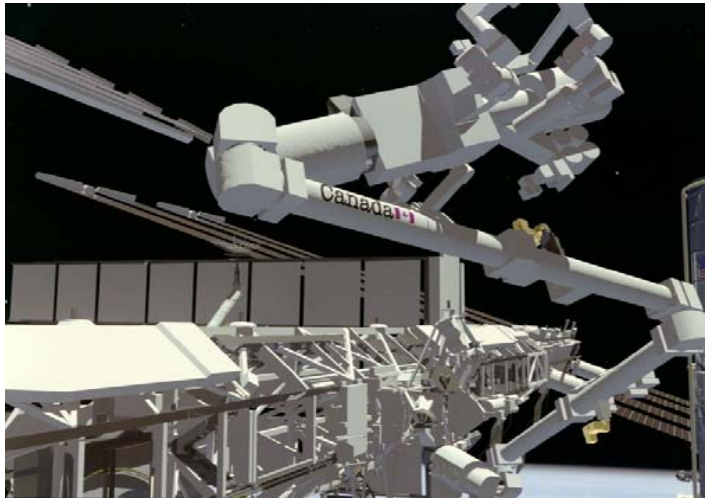
The use of **specialized, automatic tools are mandatory**.

Consistent trend in the last three centuries (since the Industrial Revolution).

Automation was also fostered by the invention of computers,



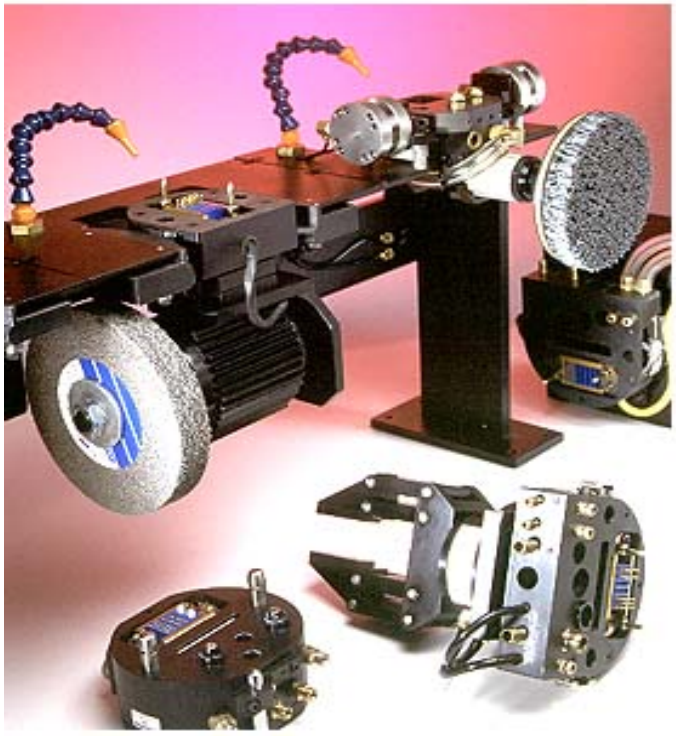
# Robotic Manipulators

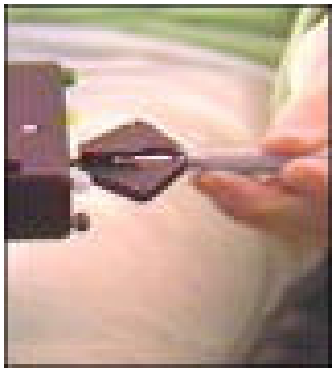


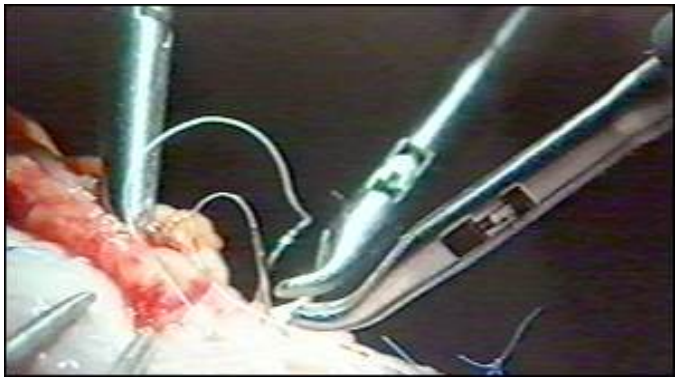
*Riding an ABB IRB 6600 Robot 1 [Youtube]*

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

# 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

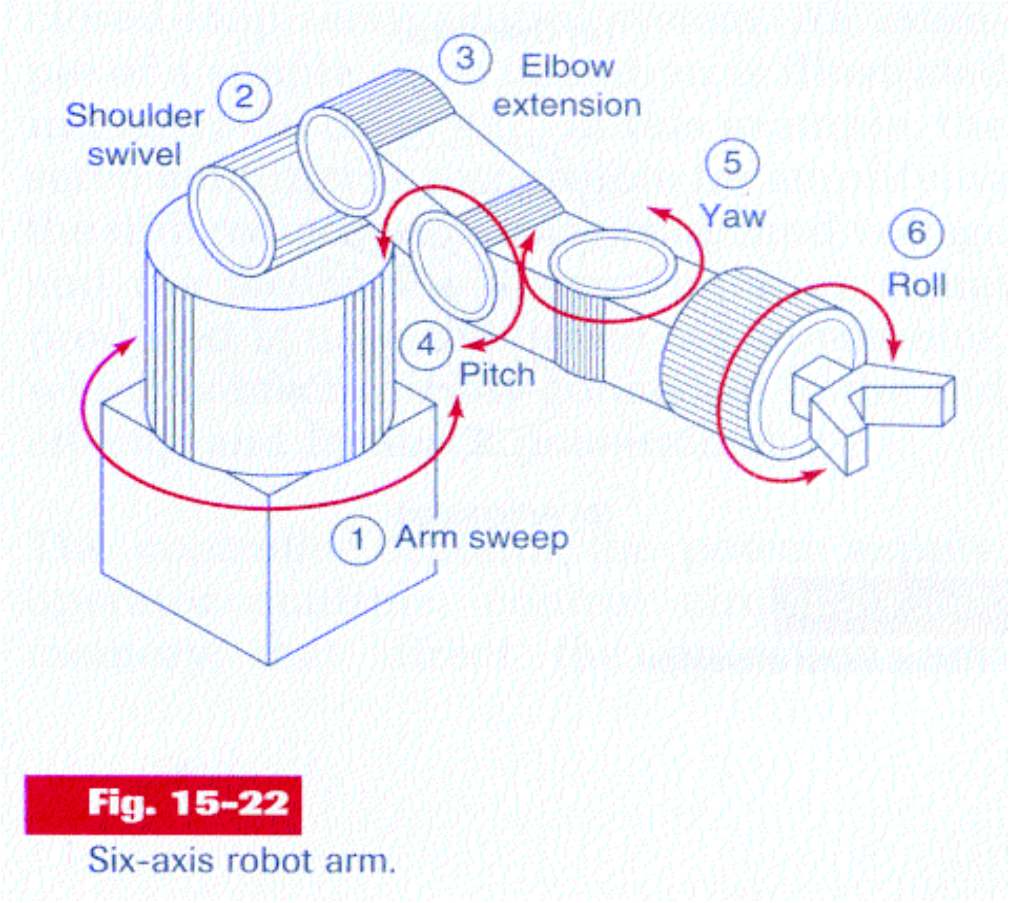



**Fig. 15–22**
Six-axis robot arm.

# Robotic Manipulators

## Workspace:

## Examples

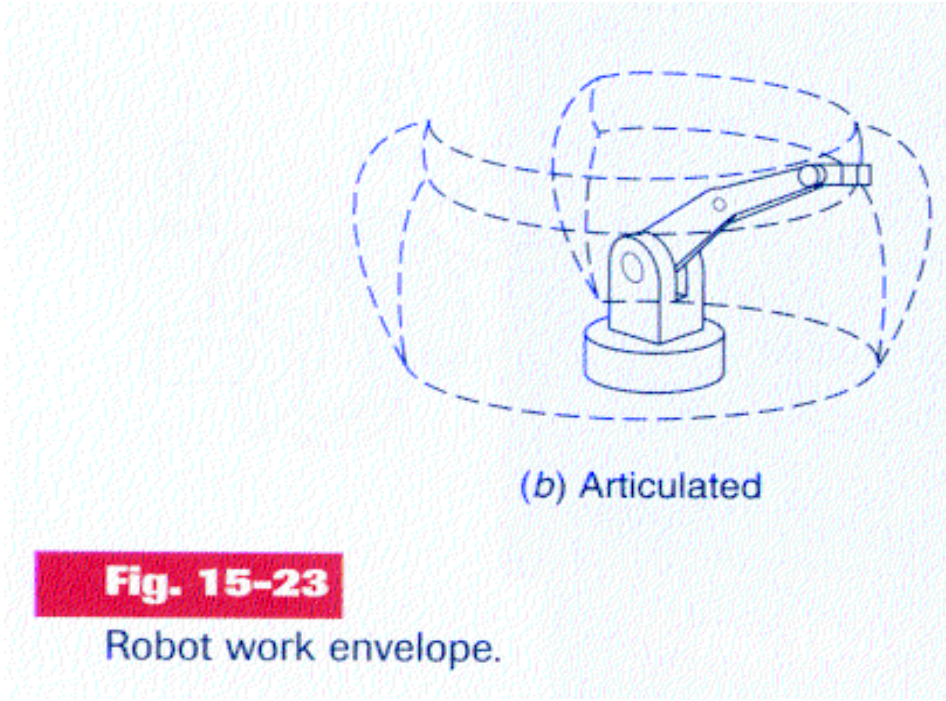
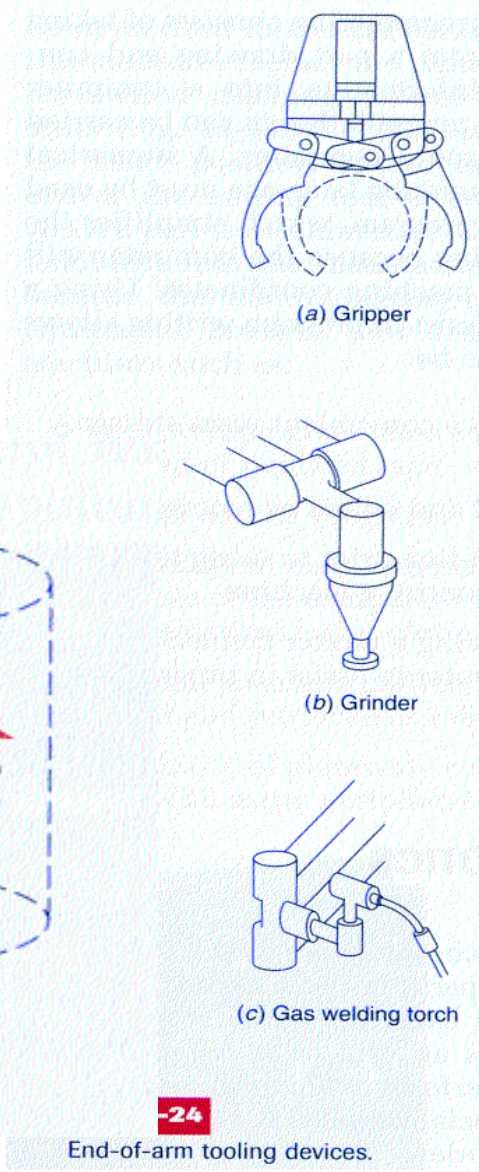



Fig. 15-23
Robot work envelope.




-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

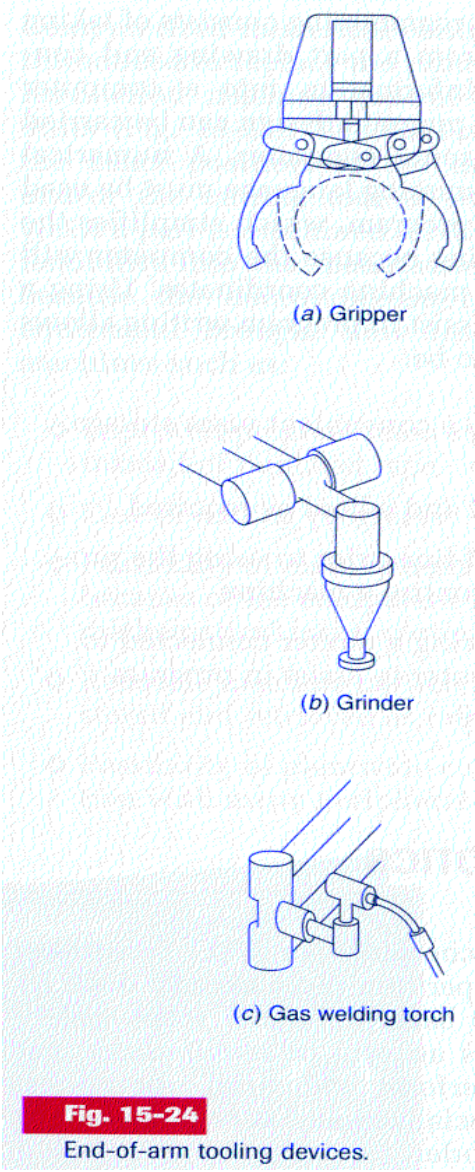


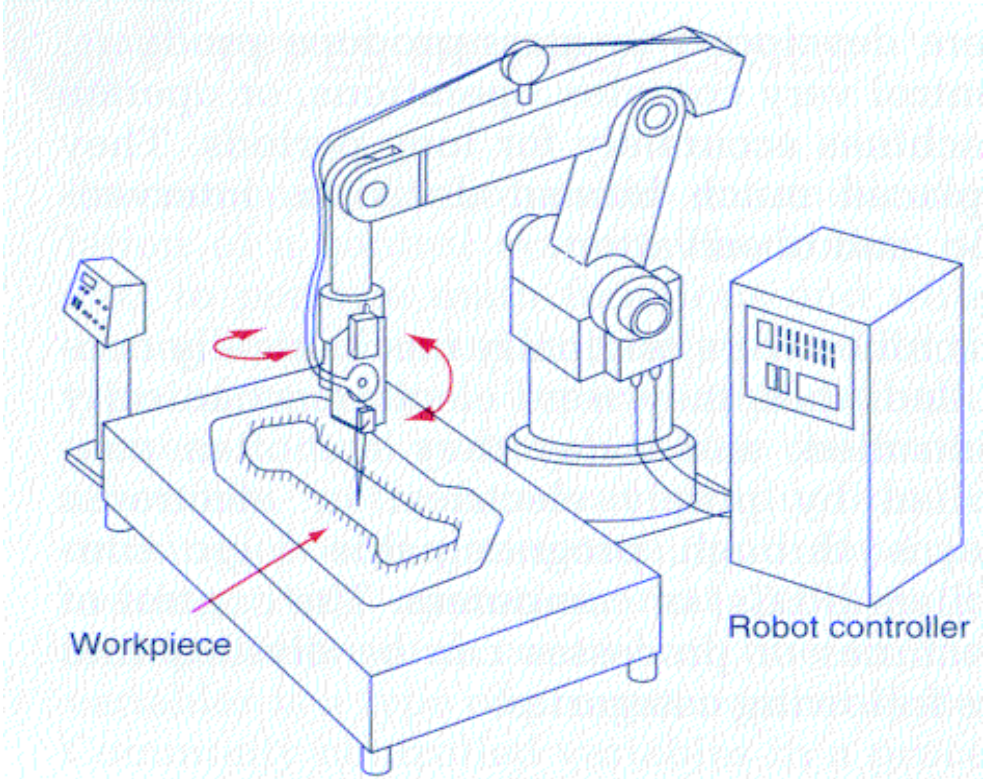

Fig. 15-24
End-of-arm tooling devices.

# 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.




Industrial robot used in an individual item process

**Fig. 14–3**
Individual product production.

# Computerized Numerical Controlled Machines

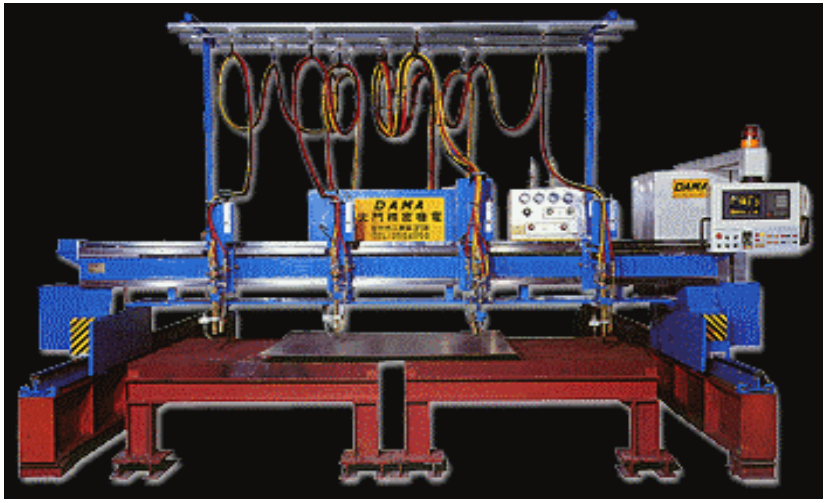
**Major characteristics:**

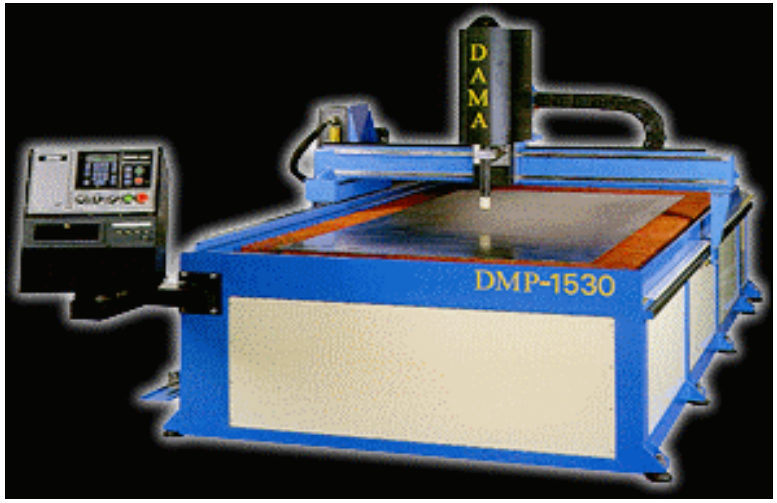
- Number of degrees of freedom
- Interpolation methods
- Load/unload automation, and also in tool change
- Programming (high level languages, teach pendent, ...)
- Workspace
- Accuracy, reliability
- Payload and robustness
- Interface
- Synchronization with exterior

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

MITSUI SEIKI Machining Center

# Computerized Numerical Controlled 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

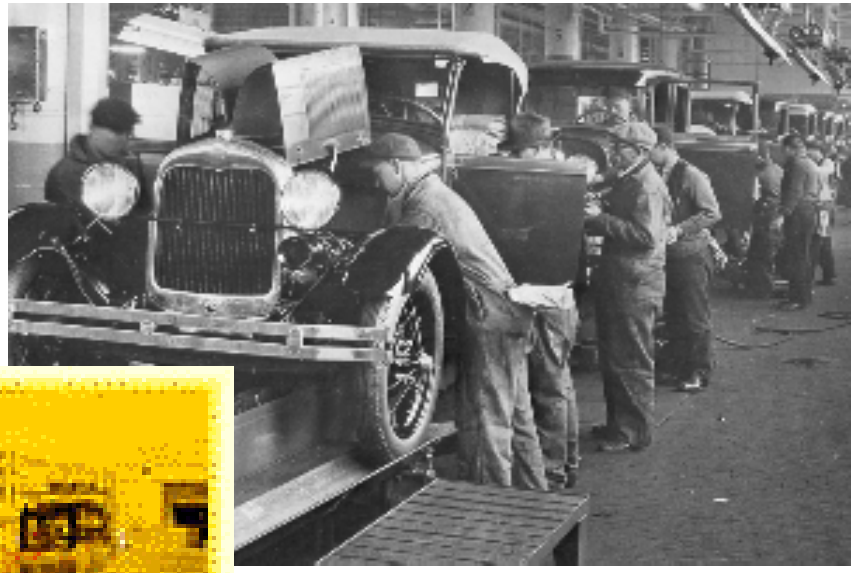
# AGVs (Automatic Guided Vehicles)

**Major characteristics:**

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

# AGVs (Automatic Guided Vehicles)

**Example of fleet operating in industry**



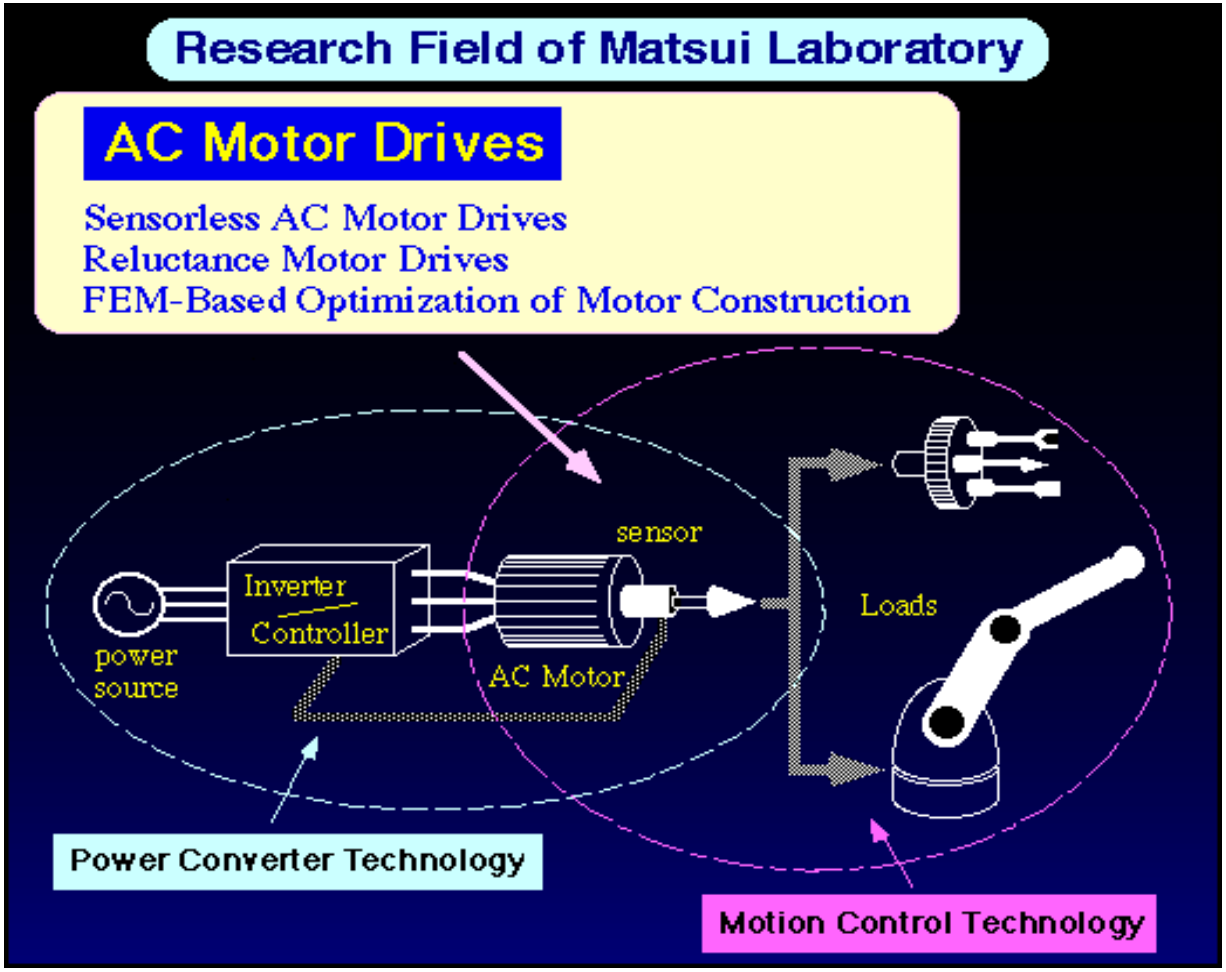
# Actuation

## Motors

### Major characteristics:

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

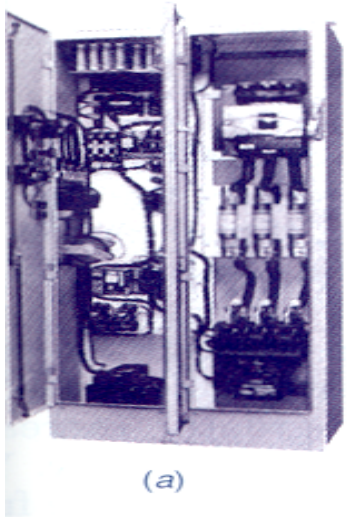
# Exemple of AC motor, with driver



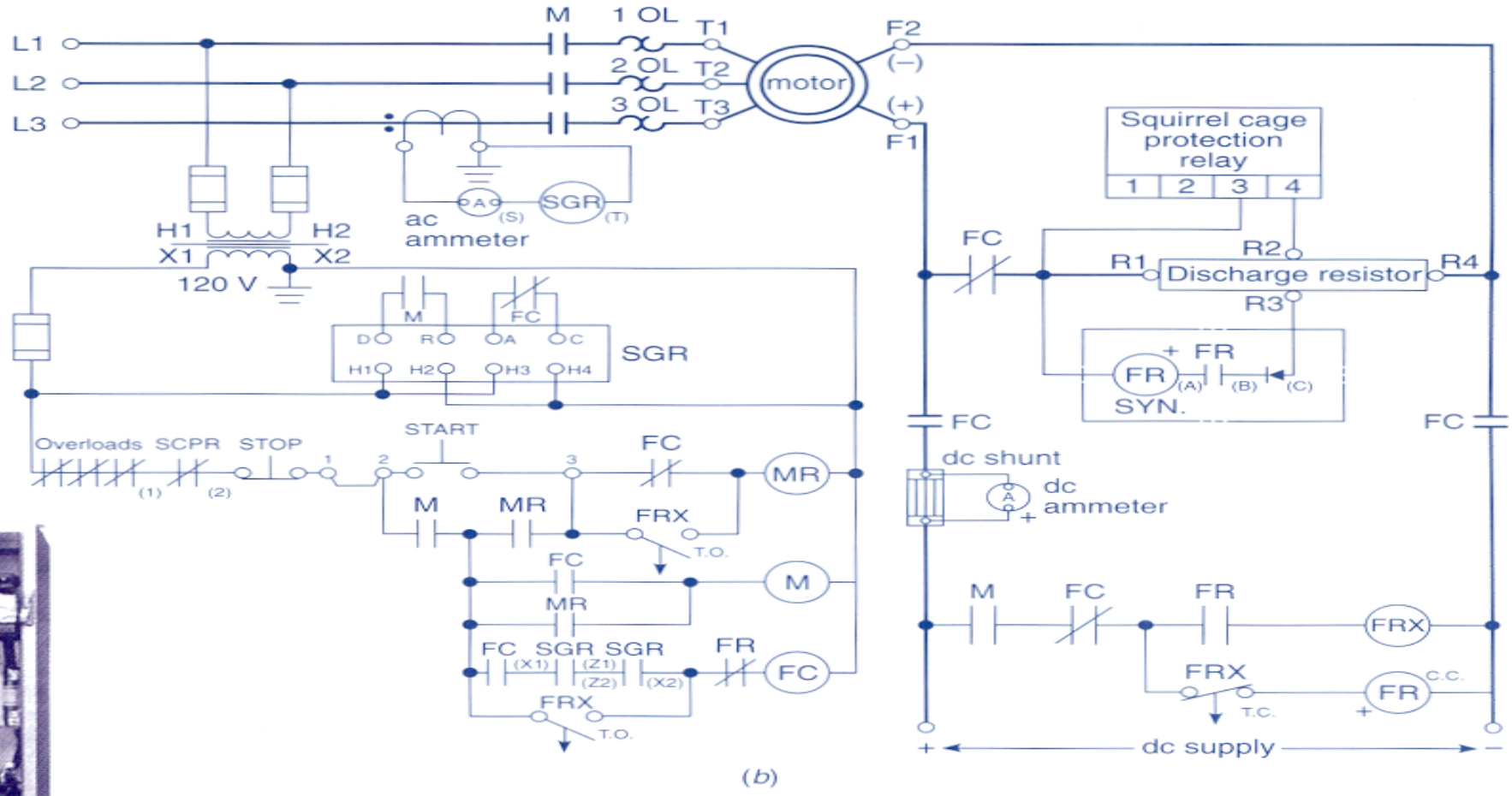
# Specific Components

## Factory example: production of aluminum packs

# Cabled Logic versus ...



(a)

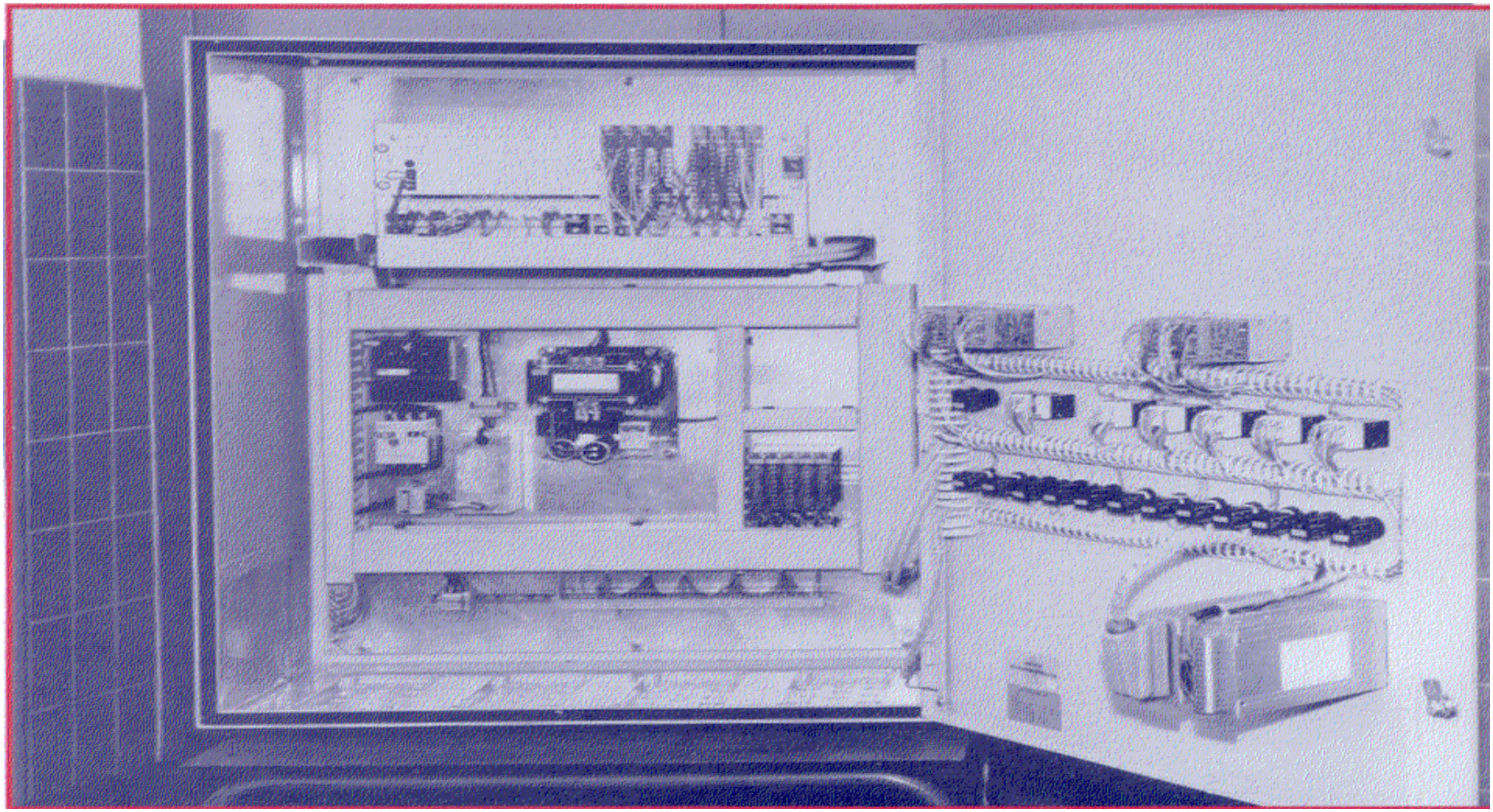



(b)

**Fig. 1-2**

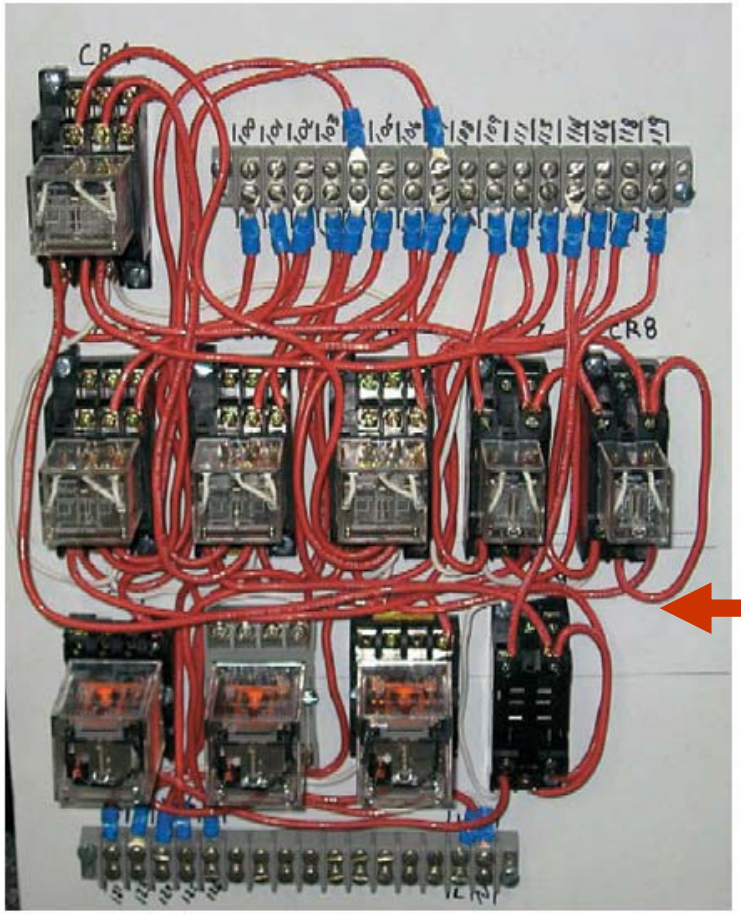
(a) Typical hard-wired controller panel. (b) Typical hardwired diagram. (Courtesy of Allen-Bradley Company, Inc.)

# ... versus Programmed Logic …



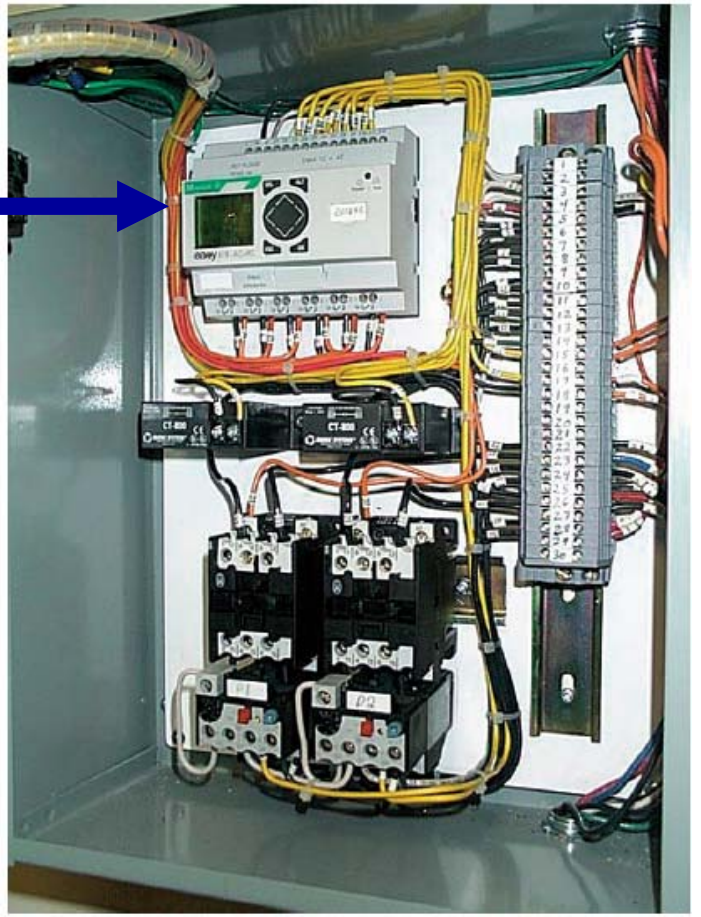
# Cabled Logic versus ...

## ... versus Programmed Logic …

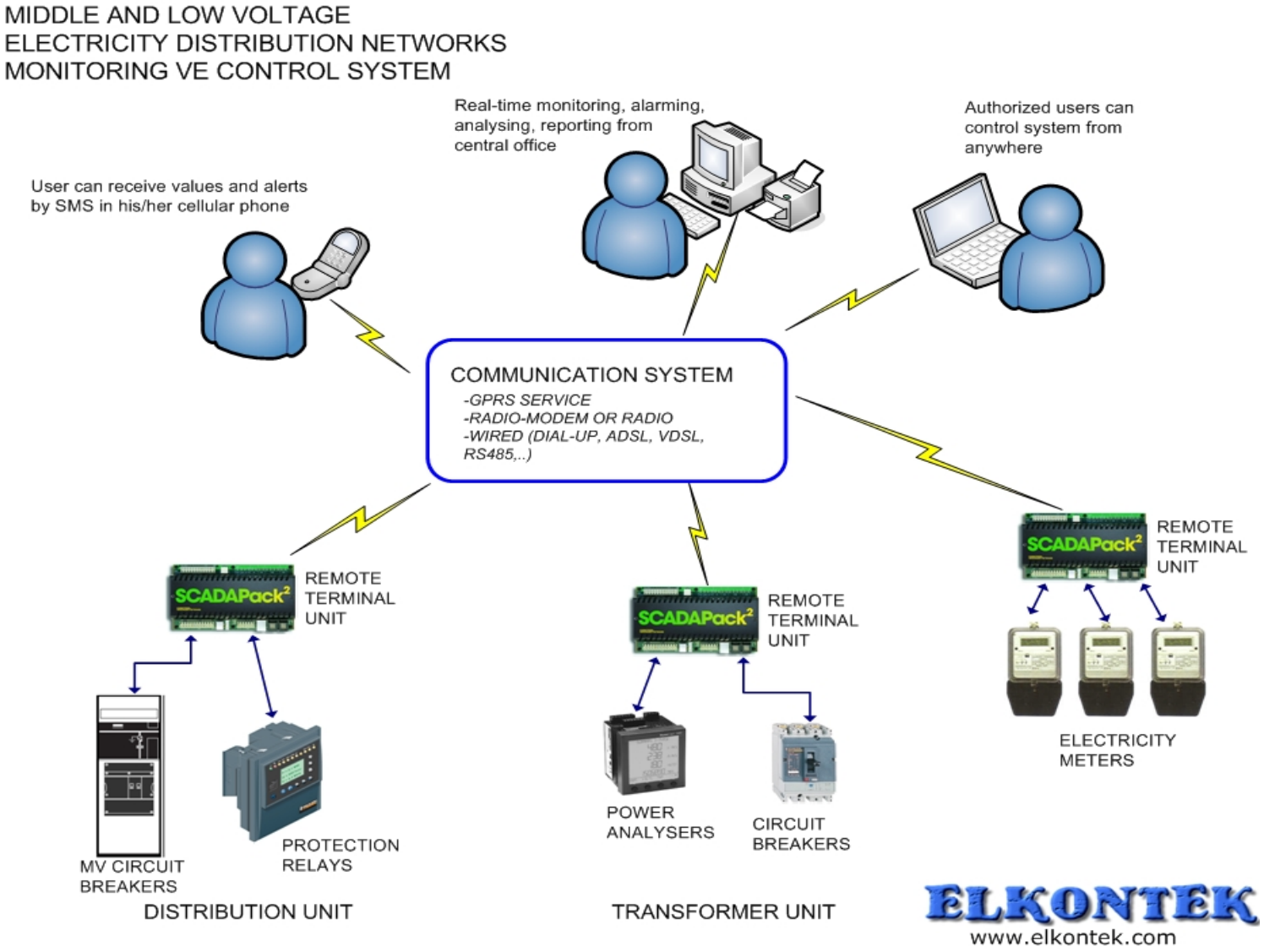


Relay control panel

PLC control panel



# ... versus Networked Logic



# Introduction to methodologies for problem modeling in Industrial Automation

Actuators
- Solenoide valve
- Command relay
- Pneumatic cylinder
- Electro pneumatic

Sensors
- Pressure switch
- Temperature sensors
- Proximity sensors

Relay diagram / Ladder diagram

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

# Solenoide Valve

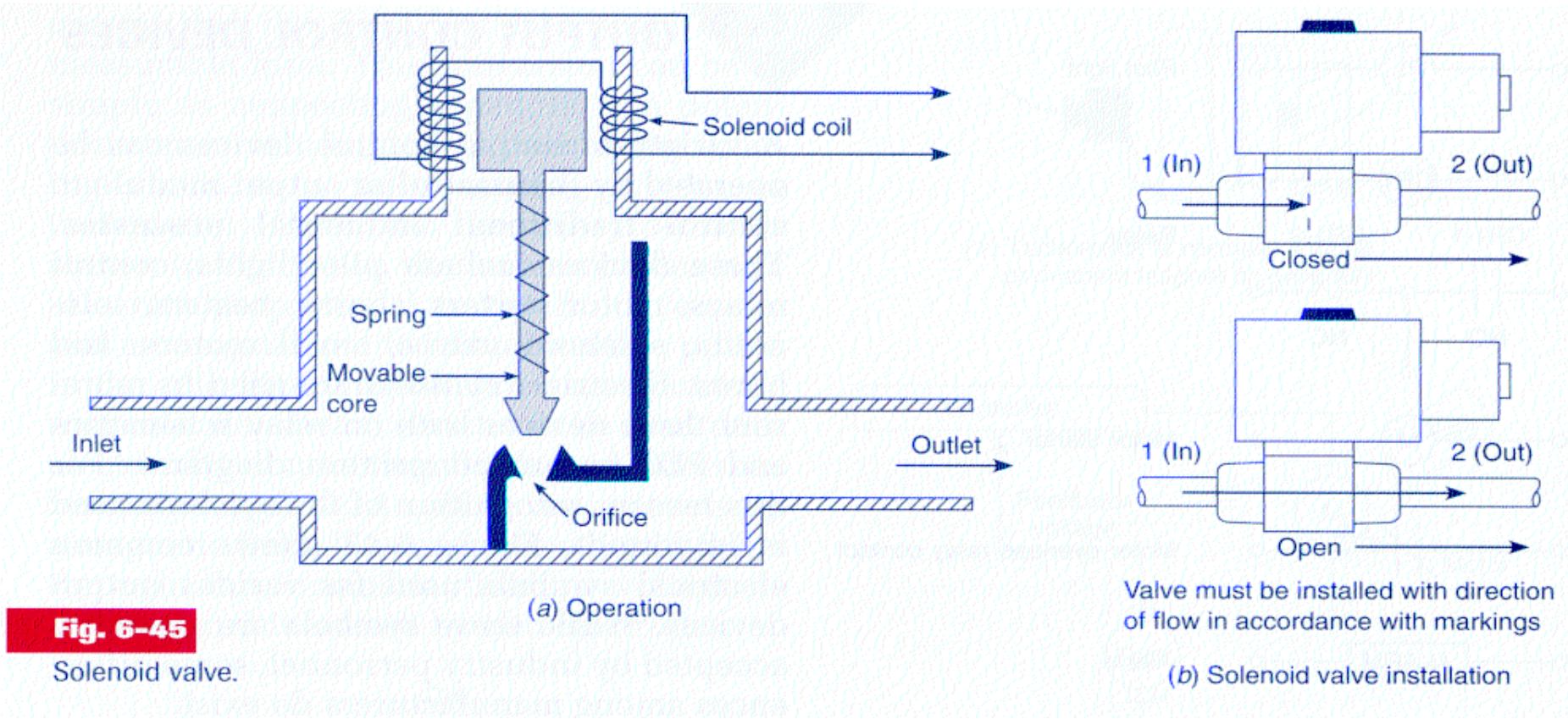
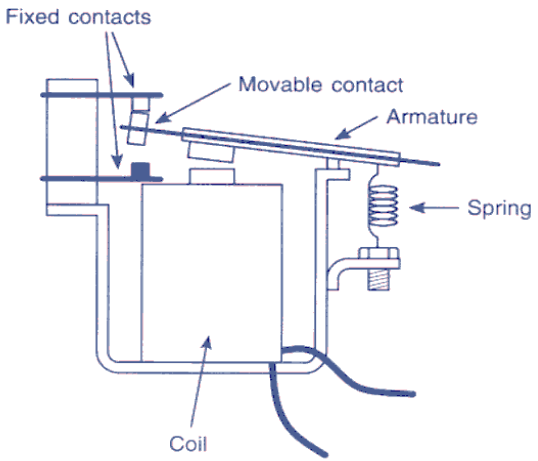
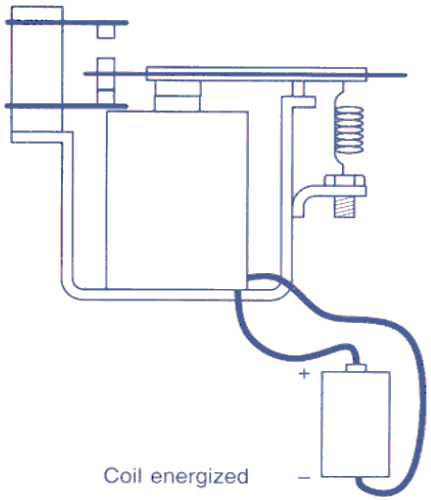



**Fig. 6–45**
Solenoid valve.

# Command Relay

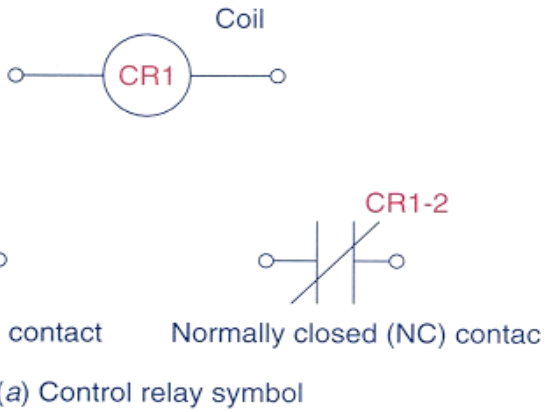



Coil de-energized

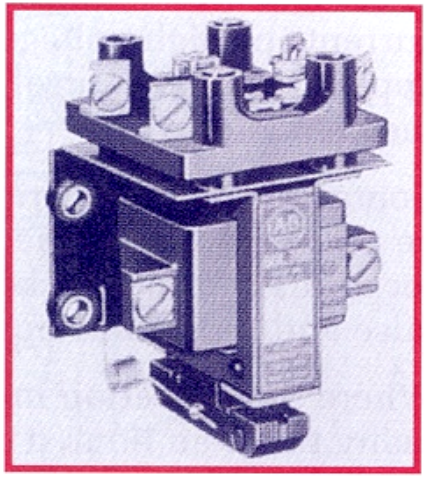



Coil energized

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



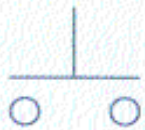

(*a*) Control relay symbol



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

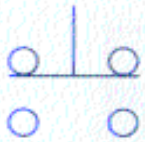
**Fig. 6–2**
Control relay.

# Push buttons



Normally open (NO) pushbutton

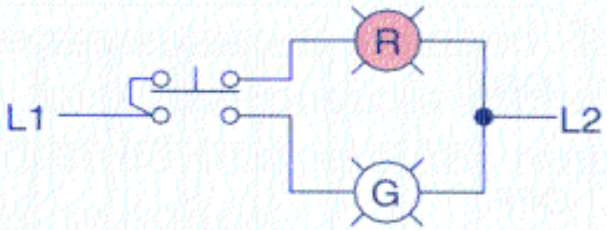
Normally closed (NC) pushbutton

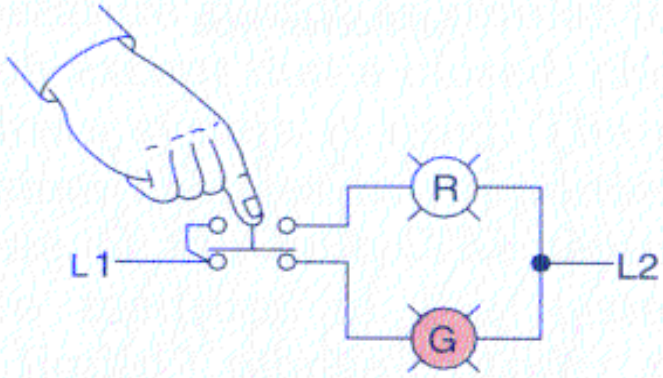


Break-make pushbutton

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

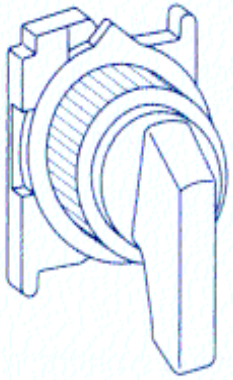
(*a*) Pushbutton switches



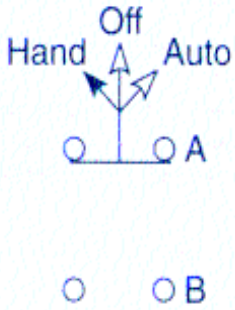




(*b*) Control circuit using a combination break-make pushbutton

# Selector with three positions

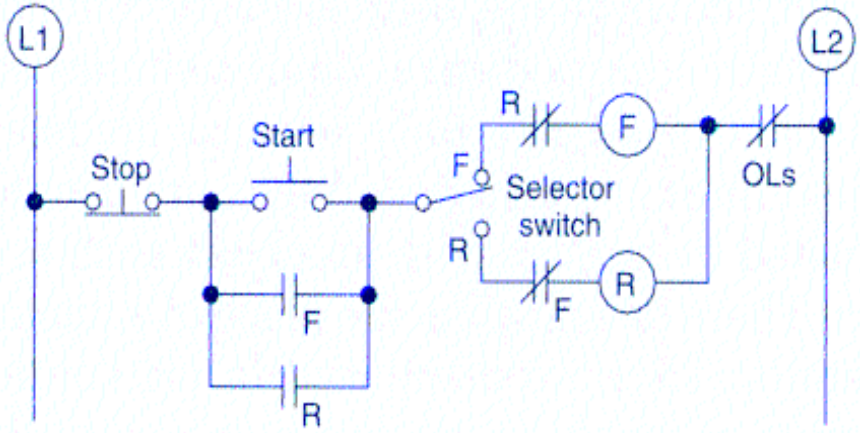


(*a*) Selector switch operator




| | Contacts | |
|---|---|---|
| Position | A | B |
| Hand | X | |
| Off | | |
| Auto | | X |

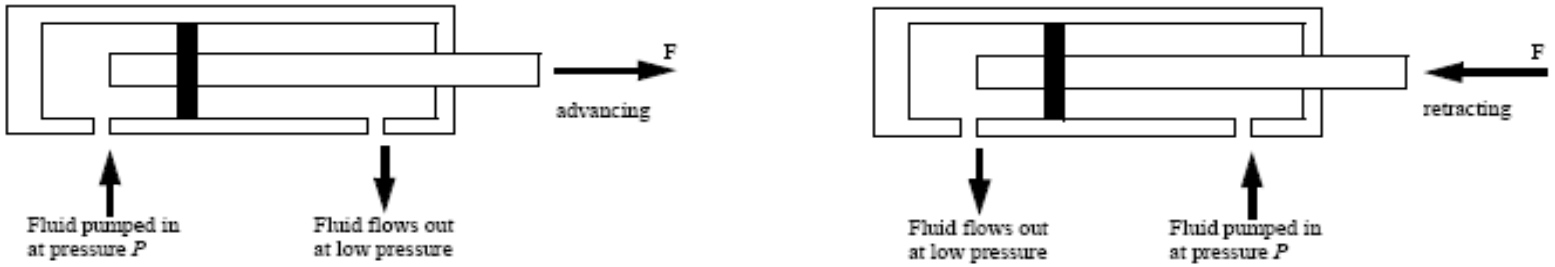
(*b*) Three-position selector switch and truth table




(*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.

# Cylinders (Pneumatics)




For Force:

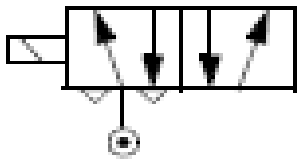
$$P = \frac{F}{A} \qquad F = PA$$

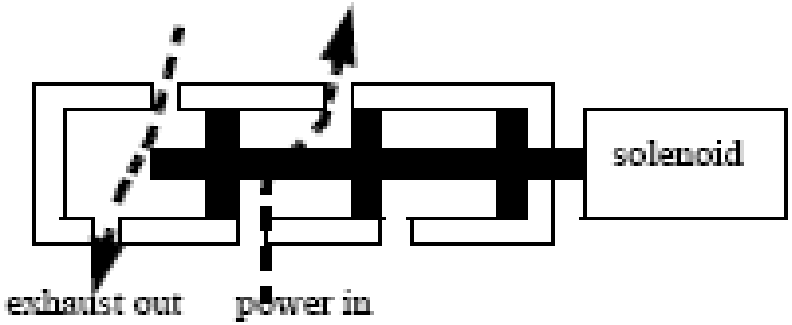
where,

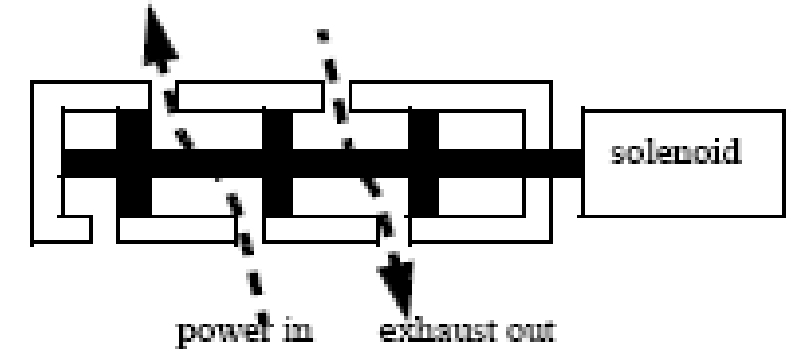
P = the pressure of the hydraulic fluid
A = the area of the piston
F = the force available from the piston rod

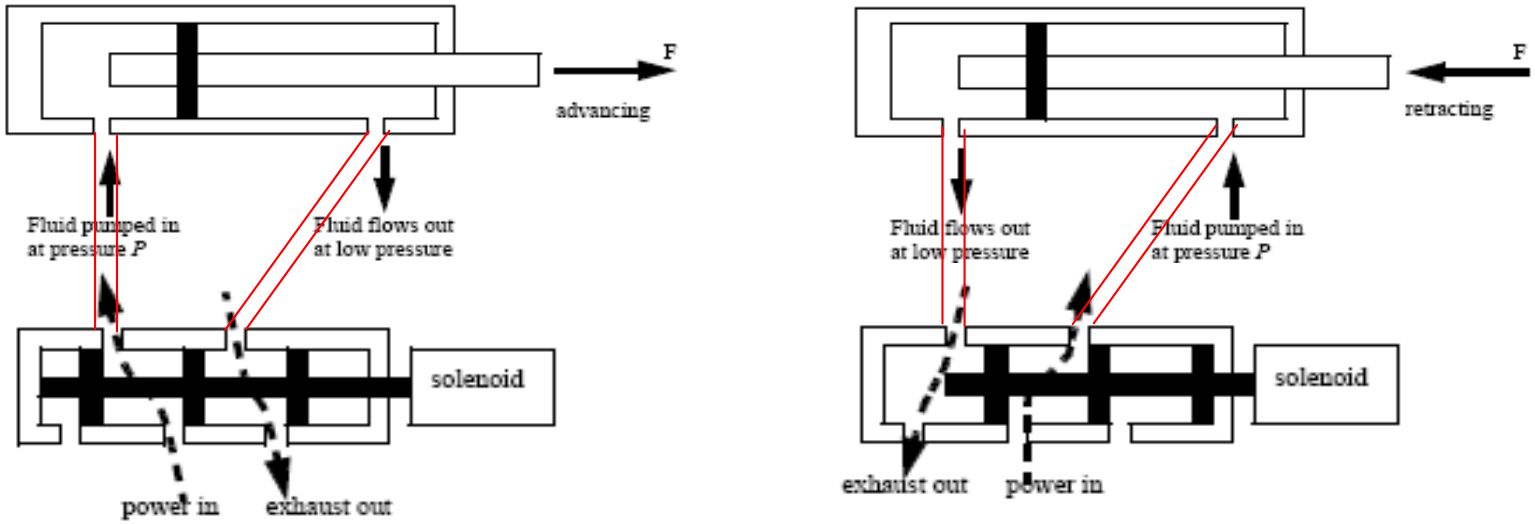
# Valves (Electro-pneumatics)

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.



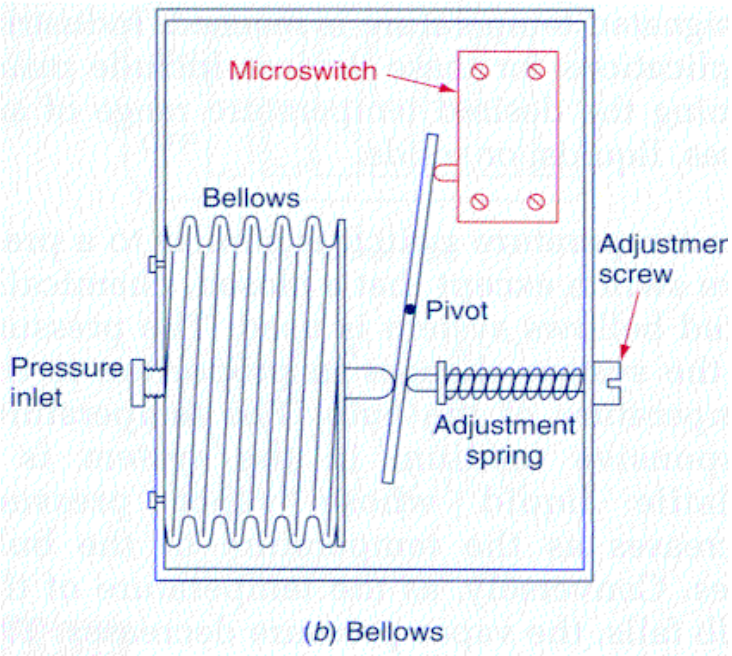


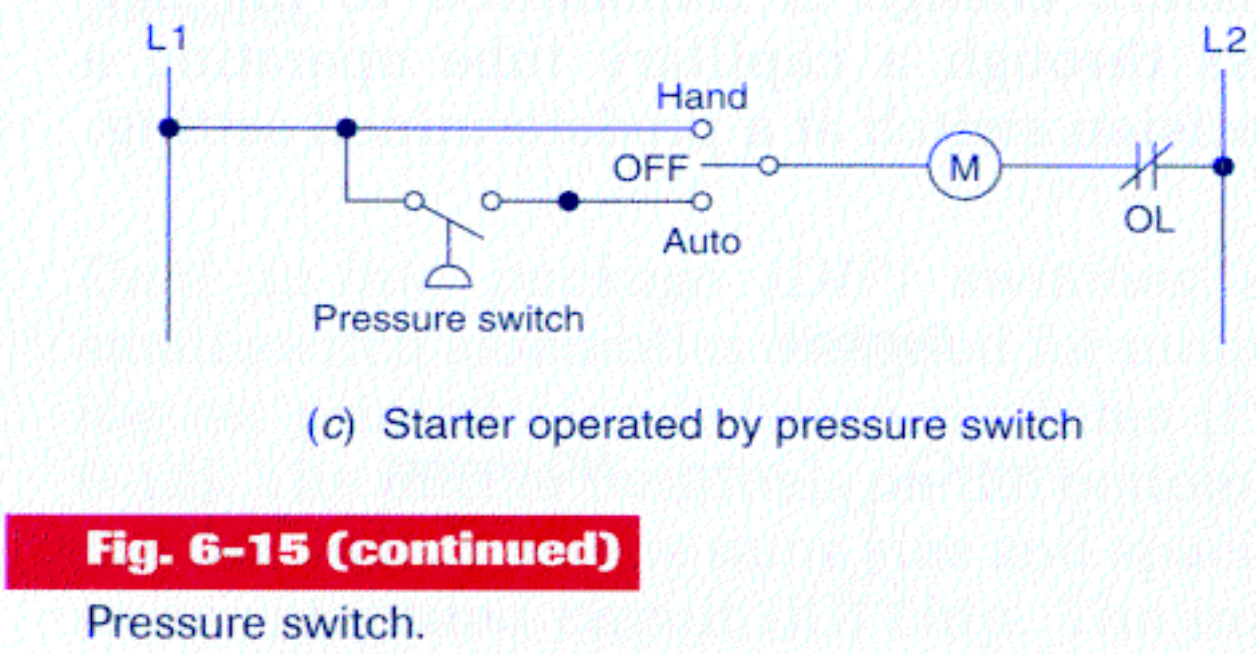

F
advancing
Fluid pumped in
at pressure P
Fluid flows out
at low pressure
solenoid
power in
exhaust out
F
retracting
Fluid flows out
at low pressure
Fluid pumped in
at pressure P
solenoid
exhaust out
power in

# Sensors

## Pressure Switch




(*b*) Bellows




(*c*) Starter operated by pressure switch

**Fig. 6–15 (continued)**

Pressure switch.

# Temperature Sensors

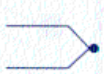
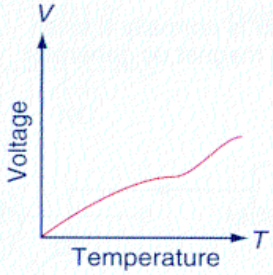
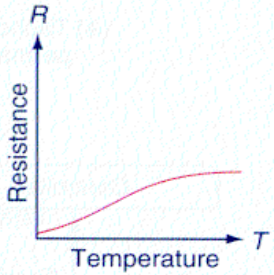
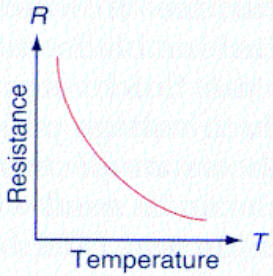
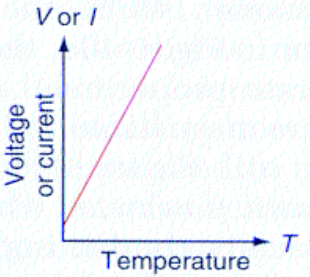
| | Thermocouple | RTD | Thermistor | IC Sensor |
|---|---|---|---|---|
| |  | | | |
| |  |  |  |  |
| Advantages | • Self-powered<br>• Simple<br>• Rugged<br>• Inexpensive<br>• Wide variety<br>• Wide temperature range | • Most stable<br>• Most accurate<br>• More linear than thermocouple | • High output<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.

# Thermocouple

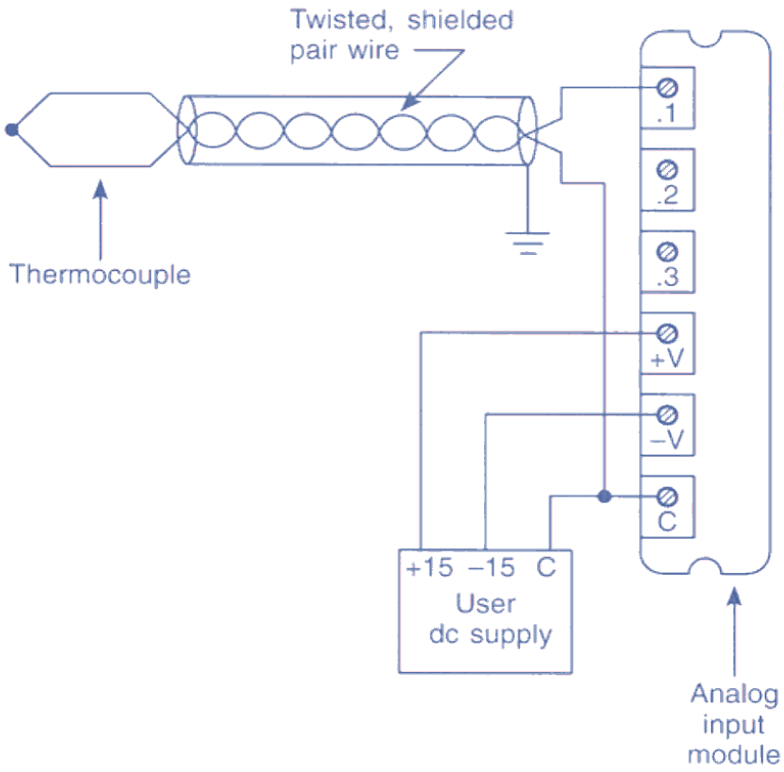



**Fig. 2-12**

Typical thermocouple connection to an analog input module.

# Proximity detector

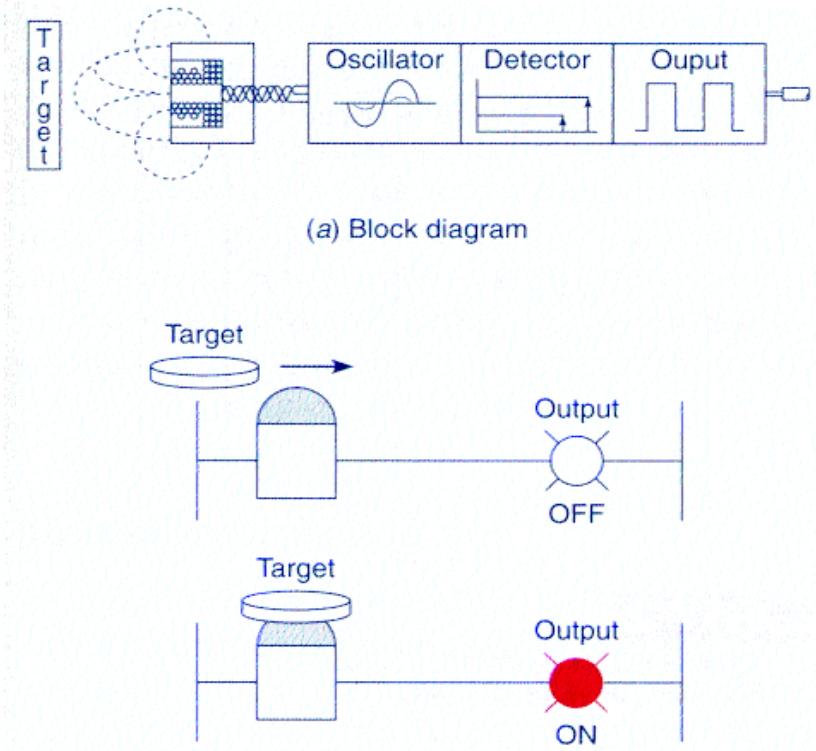



**Fig. 6-20**

Inductive proximity sensor.

# Magnetic detector

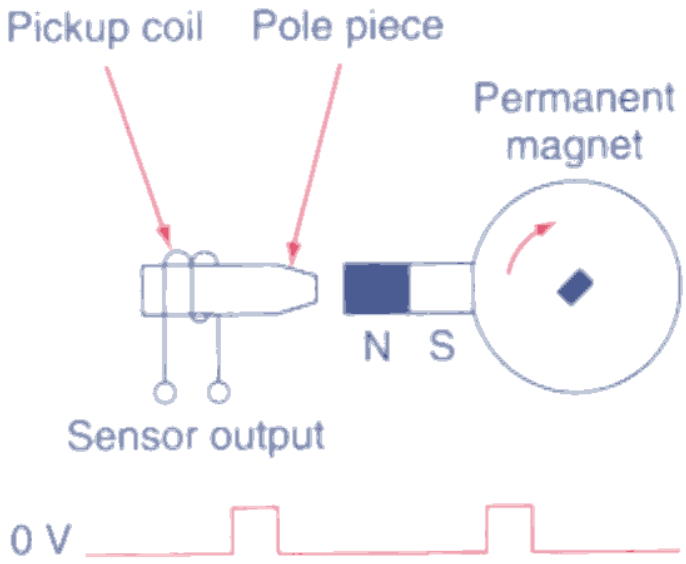



**Fig. 6-42**
Magnetic pickup sensor.

# Magnetic switch

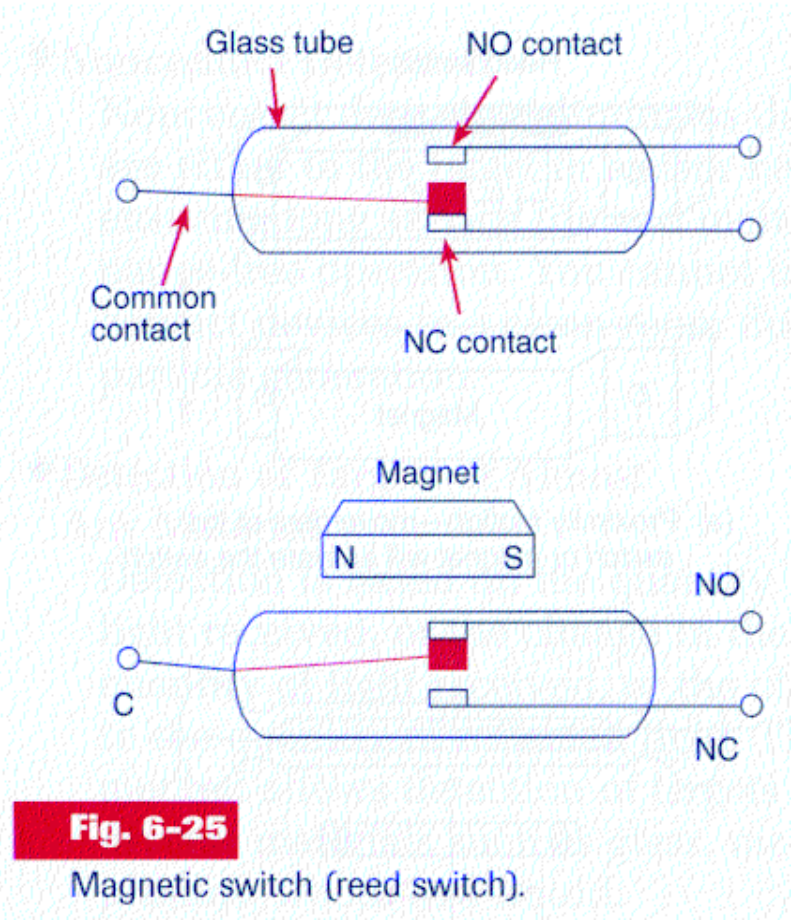
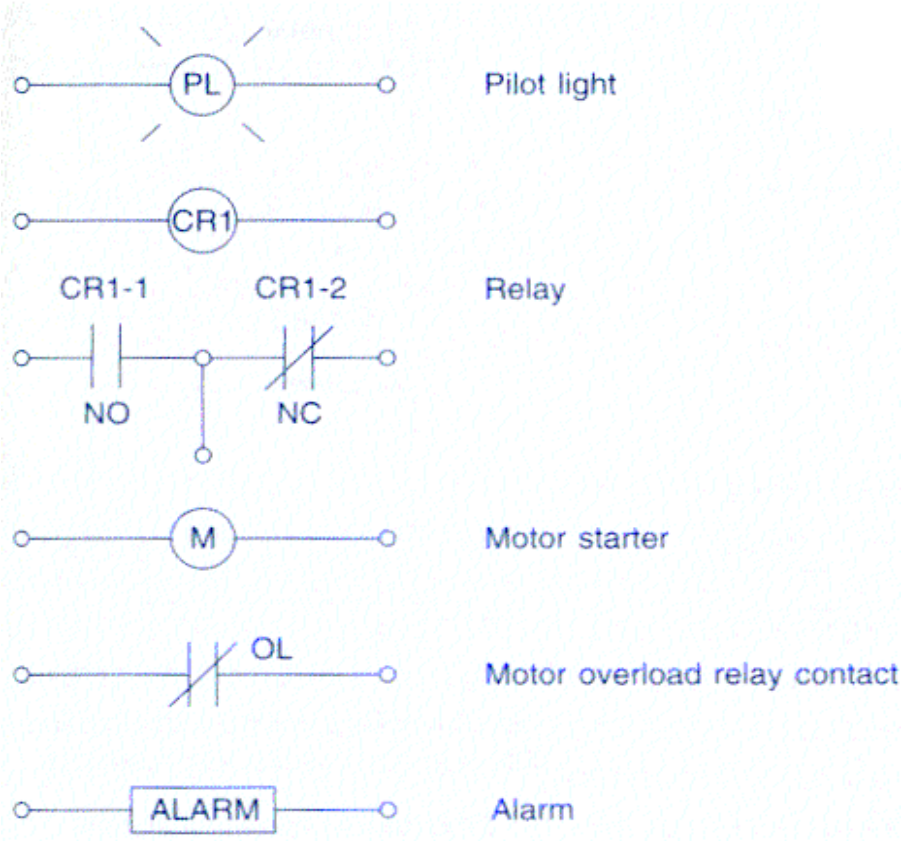



**Fig. 6-25**
Magnetic switch (reed switch).

# *Symbols associated to all components*

## Standards



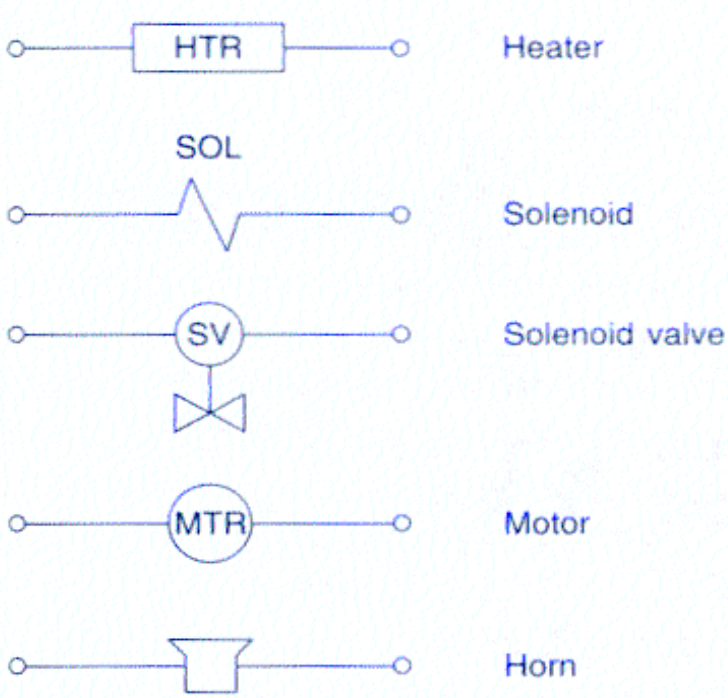
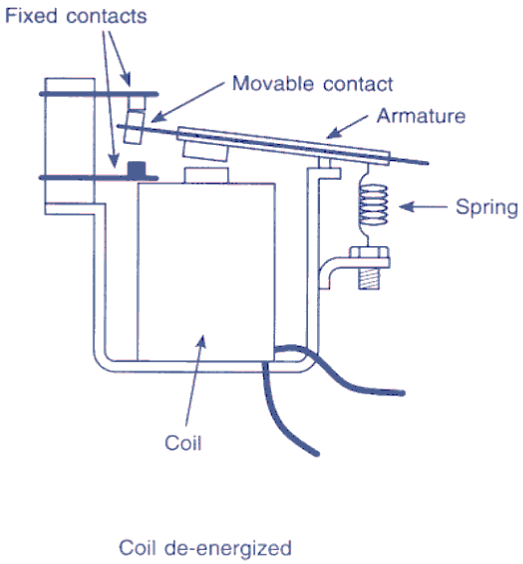
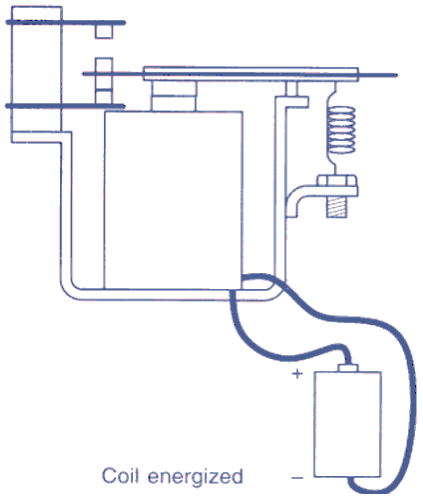




**Fig. 6-43**
Symbols for output control devices.

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

## *Device: Relay*




## *Contact Diagram* or *Ladder Diagram*

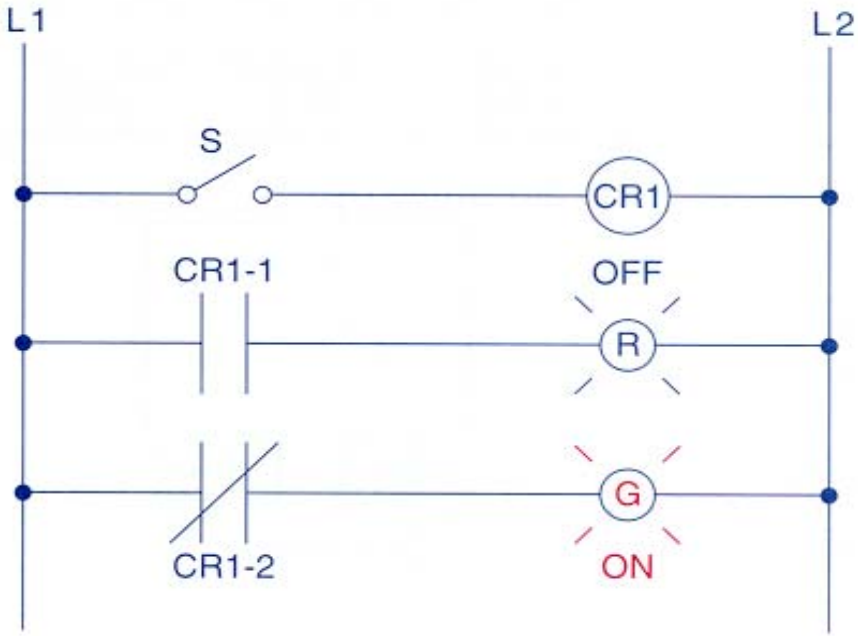



**Fig. 6-3**

Relay circuit—switch open.

***Ladder Diagram***

***Or***

***Contact Diagram***

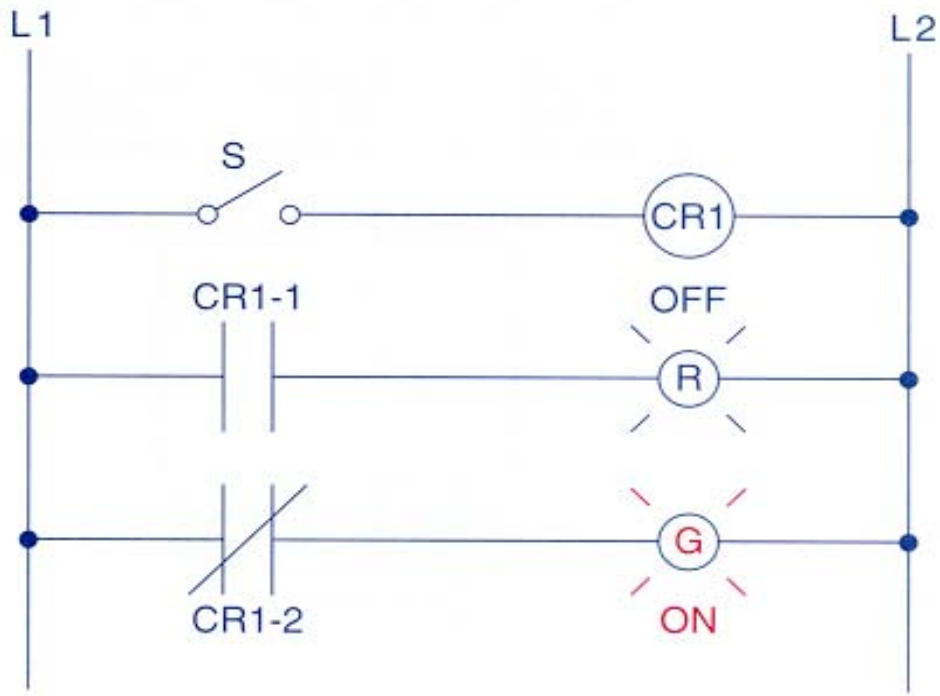



**Fig. 6-3**
Relay circuit—switch open.

# Methodologies for the implementation of solutions in industrial automation

***Contacts diagram***

Example

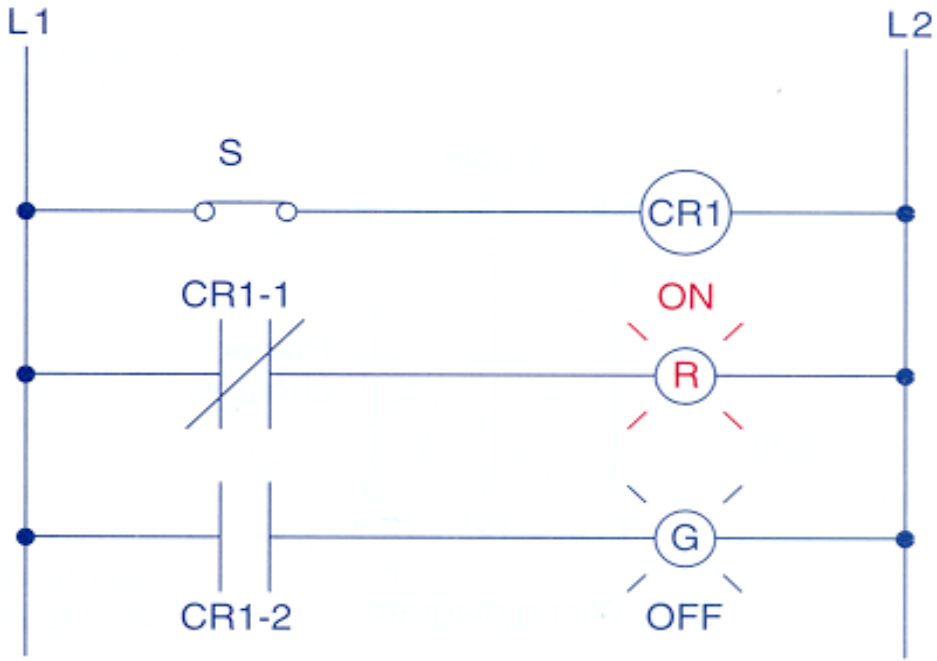



**Fig. 6-4**
Relay circuit—switch closed.

# Example:

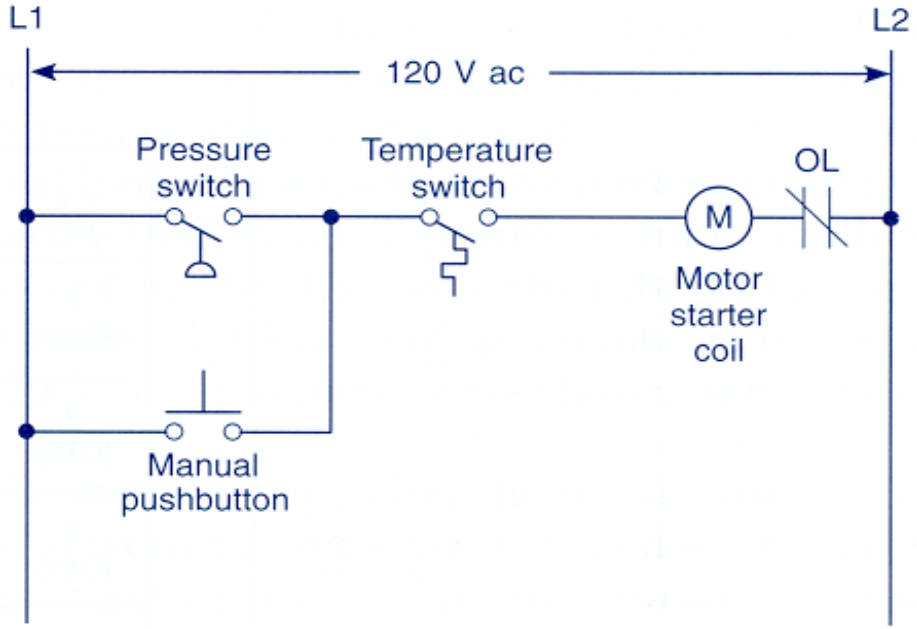



**Fig. 1-13**
Relay ladder diagram for modified process.

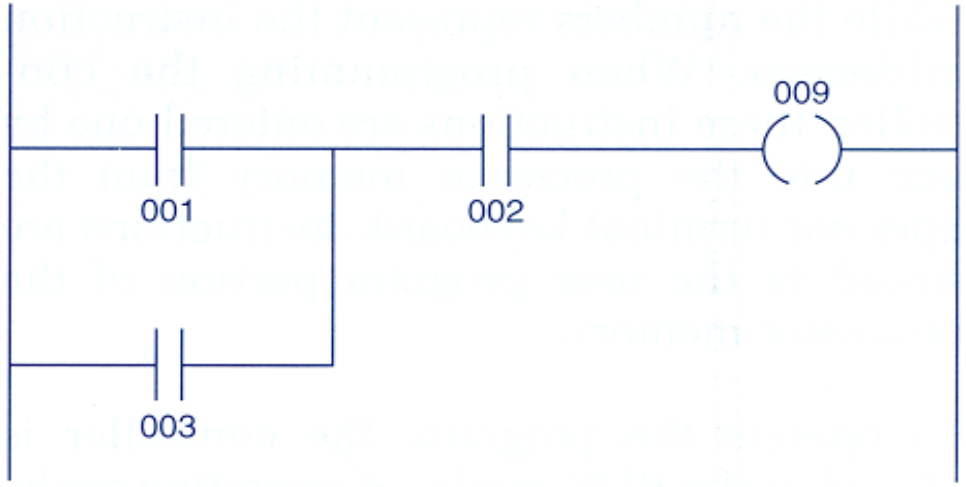
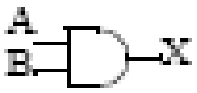



**Fig. 1-14**
PLC ladder logic diagram for modified process.

# Logic Functions

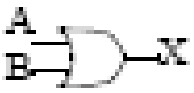
AND




$X = A \cdot B$

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

OR




$X = A + B$

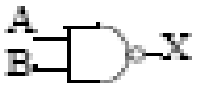
| A | B | X |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 1 |

NOT

$X = \overline{A}$

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

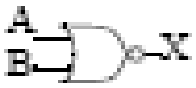
NAND




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

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

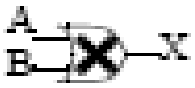
NOR




$X = \overline{A + B}$

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

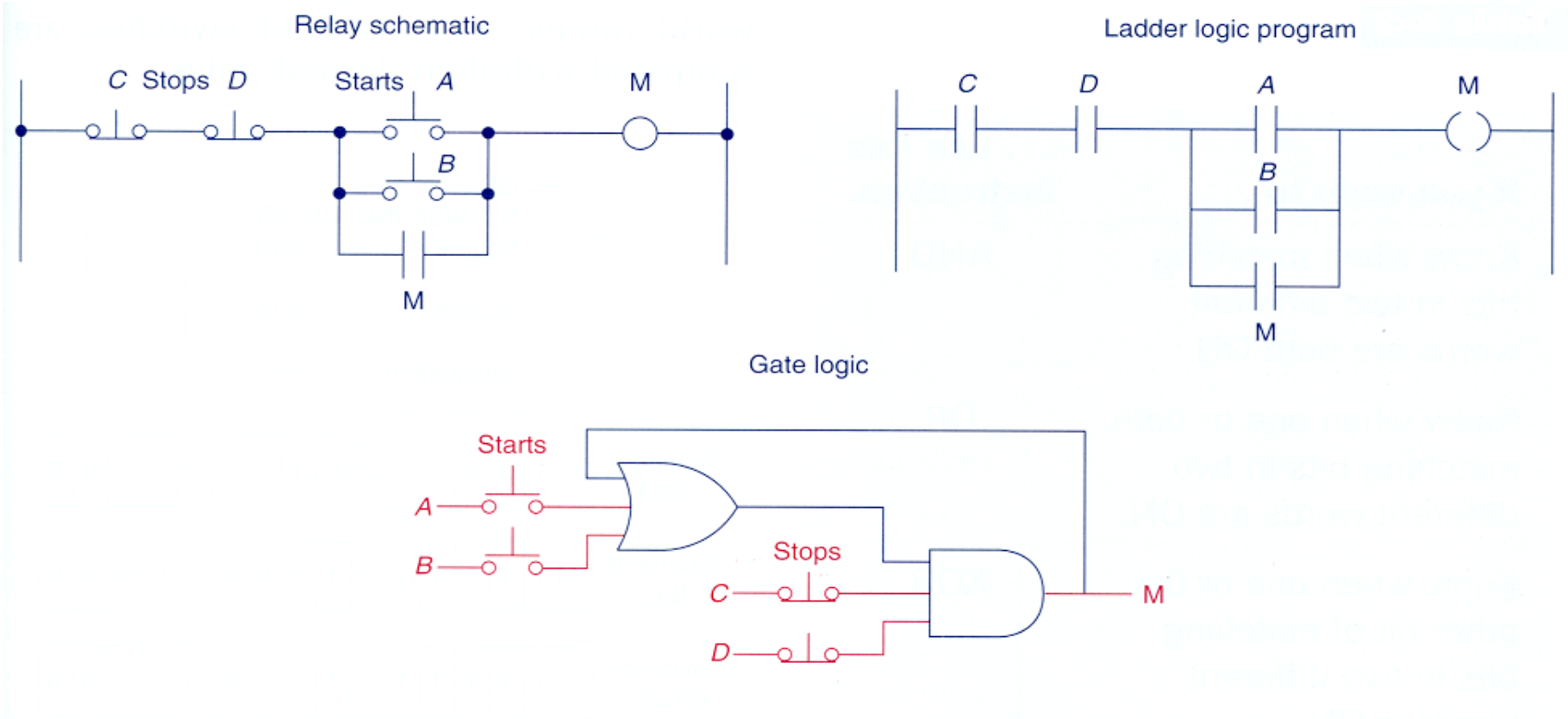
EOR



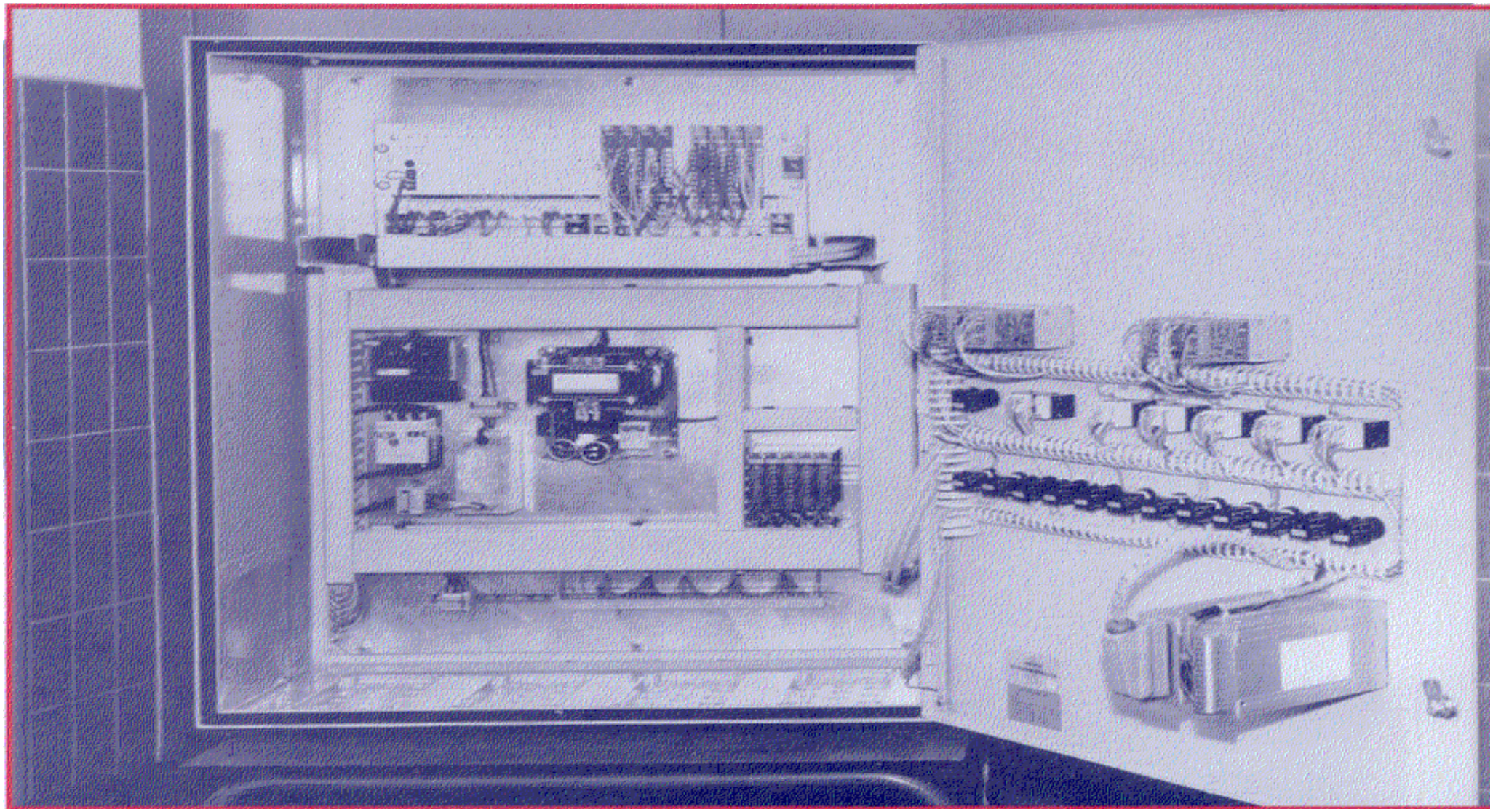

$X = A \oplus B$

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

# Example:




**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.

# To exploit the advantages of Programmed Logic