EEM 451: Industrial Control Systems

Hakkı Ulaş Ünal
Outline

- Process Industry
  - Process Control
  - Relay
  - PLC
- Programmable Logical Controller (PLC)
  - Application Areas
  - Features
  - Structure of a PLC
  - Relay Logic
  - Programming Methods
Process Industry
Process Control

- Manual Control
- ON-OFF, PI, PID controller
- Direct Digital Controller (DDC)
- PLC, DCS
Relays

Gemlog Controls Ltd.
Rated Cur.: 5/10 A  
Rated Vol.: 10/20 V DC

Bosch
Rated Cur.: 10/20 A DC  
Rated Vol.: 12 V DC

Max. Switch Cur.: 7 A  
Max. Switch Vol.: 250 V AC/ 30 V DC

Rapid Electronics.
Nom. Vol.: 5/12 VDC  
Nom. Power.: 50/144 VDC

Rapid Electronics.
Max Vol.: 240 VAC/110 VDC  
Cont. Rate.: 10 A, 120 VAC/24 VDC

R.V.A.F. Co. Ltd.
Rated Vol.: 12 V  
Rated Cur.: 30 A
Inside of a Relay

http://www.howstuffworks.com/relay.htm
Working Principle of a Relay

http://www.bcae1.com/relays.htm
Small Demonstration on a Bosch Relay: Step 1

http://www.bcae1.com/relays.htm
Small Demonstration on a Bosch Relay: Step 2
http://www.bcae1.com/relays.htm
Small Demonstration on a Bosch Relay: Step 3
http://www.bcae1.com/relays.htm
Working Principle of a Relay

http://www.bcae1.com/relays.htm
Working Principle of a Relay

The spring keeps the armature away from the coil and keeps the movable contact tight against the NC ( Normally Closed) contact.

When the coil is energized, the electromagnet will pull the armature in. This will pull the movable contact away from the normally-closed contact and into contact with the NO ( Normally Open) contact.

The current would flow through the orange/red circuit when the coil is NOT energized. It would flow through the orange/green circuit when the coil is energized.
PLCs
Features

- Flexibility
- Surviving and Being Maintained in harsh industrial Conditions
- Low-Cost Systems
- Interfacing with existing sensors and equipments
- Communicating property with same PLCs
Connection of A PLC
Structure of A PLC

- Screw terminals for input lines
- PLC controller
  - Power supply
  - Communication
  - Line for Extension
  - Input adjustable level
  - Memory
  - CPU
  - Output adjustable level
- Screw terminals for output lines
- PC for PLC programming
INPUT INTERFACE

CPU

MEMORY UNIT

OUTPUT INTERFACE
Relay Logic

A Simple Relay Schematic

[Diagram showing a relay schematic with numbered points 85, 86, 87, 87a, and 30 connected in a circuit.]
Jack, H., “Automating Manufacturing Systems with PLCs”
Programming PLC: Programming Methods

- Sequential Function Charts (SFC)
- Instruction Method
- Ladder Diagram
Sequential Function Charts (SFC)

Basic Elements in Sequential Function Charts

- Wait Instruction
- Initial Step
- Step
- Macro Step
- Selection Branch (OR)
- Simultaneous Branch (AND)
A Simple Design in SFC

Start

Bottle damage check

Bottle is Damaged

2

Remove the Bottle

Bottle is undamaged

1

Fill the Bottle

Weigh the bottle

3

Label The Bottle

Count the \# of bottles

\# of bottles are \geq 10

\# of bottles are < 10

4

Put the filled bottled to the bottle box

5

Take the bottle box which contains 10 bottles to the transportation vehicle
Instruction (Mnemonic) Programming

Basic Commands in Instruction Programming

LD Load the input
LDI Load the inverse of the input
AND “AND” the input with the previous ones
ANI “AND” the inverse of the input with the previous ones
OR “OR” the input with the previous ones
ORI “OR” the inverse of the input with the previous one
OUT Output
ANB “AND” the input block with the previous ones
ORB “OR” the input block with the previous ones
END “END” the program
A Simple Design in Mnemonic Method

0  LD  X0  Open the Machine
1  LD  X1  Program 1
2  OR  X2  Program 2
3  OUT  Y0  Red Light
4  LD  Y0  Red Light
5  LD  X0  Open the Machine
6  AND  X1  Program 1
7  ANI  X2  Program 2
8  OUT  Y1  Green Light
9  END
Ladder Diagram

Basic Elements in Ladder Diagram

LD
LDI
AND
ANI
ORI
OR
OUT
A Simple Design in Ladder Diagrams

\[
\begin{align*}
\text{X} & 0 \quad \text{X} & 1 \\
\text{X} & 0 \quad \text{X} & 1 \\
\text{X} & 2 \\
\text{Y} & 0 \quad \text{X} & 0 \quad \text{X} & 1 \quad \text{X} & 2 \\
\text{Y} & 1
\end{align*}
\]

[END]
Corresponding in the Relay Wiring
### Boolean Algebra

<table>
<thead>
<tr>
<th>Status</th>
<th>HIGH (OR ON)</th>
<th>LOW (OR OFF)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

- **“AND” Operation** ⇒ $A \cdot B$
- **“OR” Operation** ⇒ $A + B$
- **“Exclusive OR” Operation** ⇒ $A \oplus B = \overline{A} \cdot B + A \cdot \overline{B}$
- **“NOT” Operation** ⇒ $\overline{A}$

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>AND</th>
<th>OR</th>
<th>XOR</th>
<th>NOT A</th>
<th>NOT B</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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</tr>
</tbody>
</table>
“AND” Operation

“OR” Operation
“NOT” Operation

“XOR” Operation
Ladder to Boolean
\[ A + B + C \]
\[ \overline{D} + \overline{E} \]
\[ Z = (A + B + C) \cdot (\bar{D} + \bar{E}) \cdot \bar{F} \cdot \bar{G} \]
Boolean To Ladder

\[ Z = (A + B \cdot C') \cdot D + \bar{E} \cdot F \]
\[ Z = (A + B \cdot C) \cdot D + \bar{E} \cdot F \]
\[ Z = (A + B \cdot C) \cdot D + \bar{E} \cdot F \]
\[ Z = (A + B \cdot C) \cdot D + \bar{E} \cdot F \]
\[ Z = (A + C \cdot B) \cdot D + \bar{E} \cdot F \]
## Reference Letters in Ladder Diagram

<table>
<thead>
<tr>
<th>“Bit Devices”</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>X:</td>
<td>All Direct Physical Inputs to the PLC</td>
</tr>
<tr>
<td>Y:</td>
<td>All Direct Physical Outputs from the PLC</td>
</tr>
<tr>
<td>T:</td>
<td>Timing Device which is contained within the PLC</td>
</tr>
<tr>
<td>C:</td>
<td>Counting Device which is contained within the PLC</td>
</tr>
<tr>
<td>M:</td>
<td>Used as an internal operation flags within the PLC</td>
</tr>
<tr>
<td>S:</td>
<td>Used as an internal operation flags within the PLC</td>
</tr>
</tbody>
</table>
Programming ...

LD (Load): Initially (NO) contact operation with devices: X,Y,M,S,T,C

LDI (Load Inverse): Initially (NC) contact operation with devices: X,Y,M,S,T,C

OUT (Output): Finally operation type coil drive with devices: Y,M,S,T,C
Programming ...

AND (AND): Serial Connection of (NO) contact with devices: X, Y, M, S, T, C

ANI (AND Inverse): Serial Connection of (NC) contact with devices: X, Y, M, S, T, C

OR (OR): Parallel Connection of (NO) contact with devices: X, Y, M, S, T, C

ORI (OR Inverse): Parallel Connection of (NC) contact with devices: X, Y, M, S, T, C
Some Remarks in Programming ...

Input Sequence       Output Sequence

\[ X_1 \uparrow (ON), X_2 \downarrow (OFF) \implies Y_1 \uparrow (ON), Y_2 \uparrow (ON), Y_1 \downarrow (OFF) \]
Input Sequence \hspace{2cm} Output Sequence

\[ X_1 \uparrow (ON), X_1 \downarrow (OFF) \Rightarrow Y_1 \uparrow (ON), Y_1 \uparrow (ON) \]
Usage of Timers and Counters in Programming as an Output

Symbol Description

nn ⇒ Identification number
Kmm ⇒ Duration time for activating the timer coil
Khh ⇒ Required pulses for activating the counter coil

\[
(T_{nn} \ K10) = 1 \text{ sec for } 0 \leq nn \leq 32
\]
\[
(T_{nn} \ K10) = 0.1 \text{ sec for } 32 < nn < 56
\]
X7 input

Time in seconds

Y0 output

Time in seconds
Internal Flags

Symbol | Description
-------|------------
nn ⇒    | Identification number
Basic Operations in Ladder Diagram

LOAD

- X0 input
- Y0 output

Time in seconds

X0 input

0 10 20 30 40 50 60 70 80 90 100

Y0 output

0 10 20 30 40 50 60 70 80 90 100
Inverse LOAD