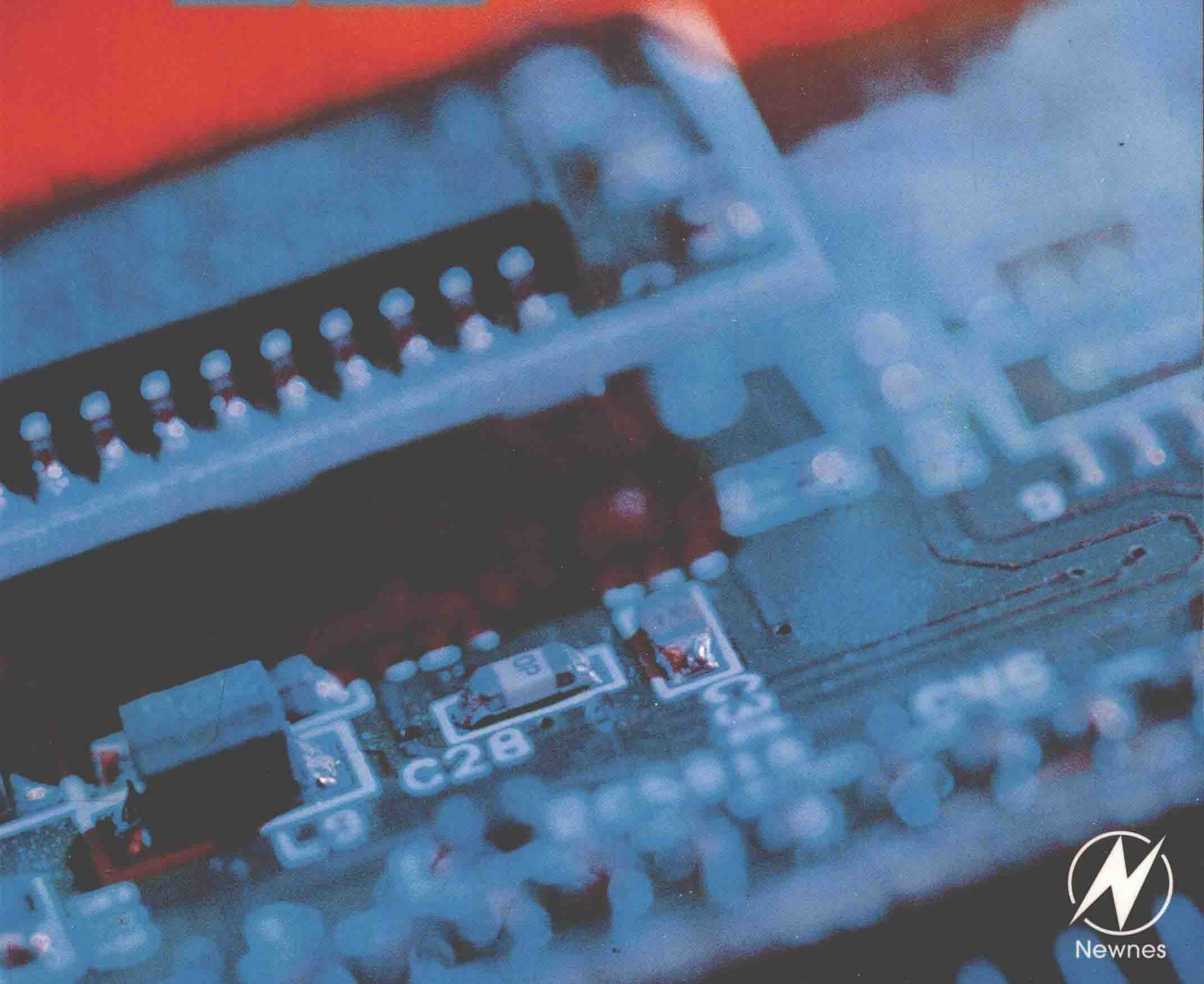
W. Bolton

Programmable Logic Controllers

Third Edition



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Programmable Logic Controllers

An Introduction

Third Edition

W. Bolton

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Programmable Logic Controllers

Preface

Technological advances in recent years have resulted in the development of the programmable logic controller and a consequential revolution of control engineering. This book is an introduction to programmable logic controllers and aims to ease the tasks of practising engineers coming first into contact with programmable logic controllers and also provide a basic course for students on courses such as Higher Nationals, company training programs and as an introduction for first year undergraduate courses in engineering.

Changes from the second edition

The main changes from the second edition are:

- More examples of programs.
- Introduction to Sequential Function Charts.
- Discussion of the design of fail-safe systems.
- More on fault detection techniques.
- An Appendix summarising the truth tables, symbols and ladder programs for AND, OR, NOT, NAND, NOR and XOR logic gates.

and, as before:

- Lots of illustrations of how to program PLCs, whatever the manufacturer, and make use of internal relays, timers, counters, shift registers, sequencers and data handling facilities.
- A large number of exercises to test whether the reader understands the principles and is able to write such programs.

The book has been designed to provide full syllabus coverage of the Higher National unit in PLCs from Edexcel and the Advanced GNVQ Unit in PLCs. It addresses the problem of different programmable control manufacturers using different nomenclature and program forms by describing the principles involved and illustrating them with examples from a range of manufacturers.

Aims

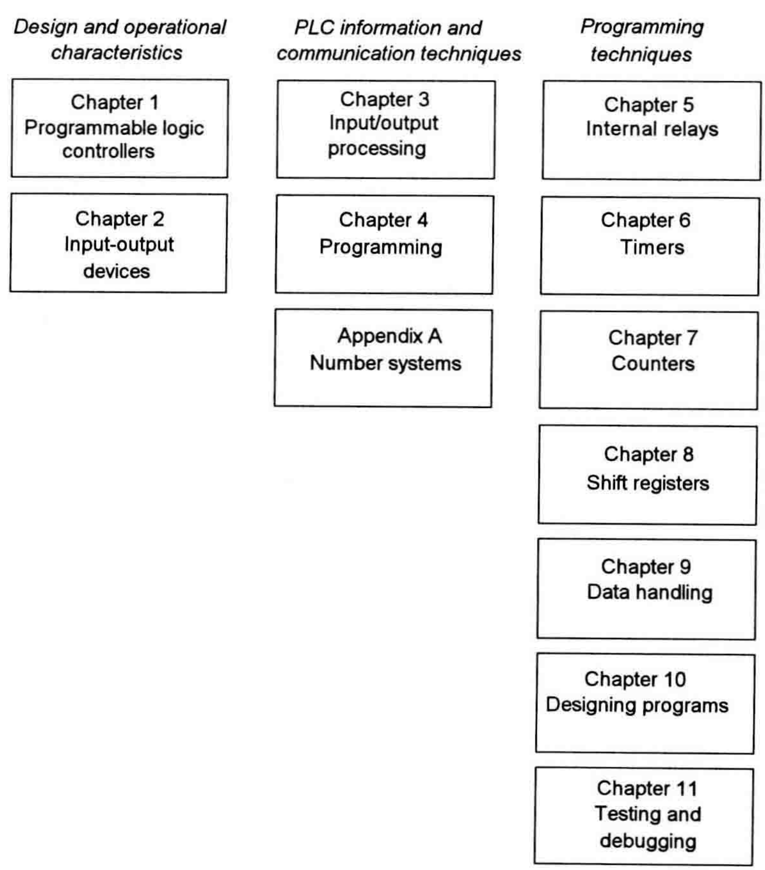
This book aims to enable the reader to:

- Identify and explain the main design characteristics and internal architecture of programmable logic controllers.

- Describe and identify the characteristics of commonly used input and output devices.
- Explain the processing of inputs and outputs by PLCs.
- Describe communication links involved with PLC systems.
- Develop ladder programs for the logic functions AND, OR, NOR, NAND, NOT and XOR.
- Develop ladder programs involving internal relays, timers, counters, shift registers, sequencers and data handling.
- Identify fail/safe methods for PLC systems.
- Identify methods used for fault diagnosis, testing and debugging.

Structure of the book

The following figure outlines the structure of the book and its relationship to the three unit outcomes of the BTEC specification:



To assist the reader to develop the skills necessary to write programs for programmable logic controllers, many worked examples, multi-choice questions and problems are included in the book with answers to all multi-choice questions and problems given at the end of the book.

W. Bolton

Contents

Consider a situation requiring latch circuits where there is an automatic machine that can be started or stopped using push-button switches. A latch circuit is used to start and stop the power being applied to the machine. The machine has several outputs which can be turned on if the power has been turned on and are off if the power is off. It would be possible to devise a ladder diagram which has individually latched controls for each such output. However, a simpler method is to use an internal relay.

Figure 5.7 shows such a ladder diagram. The first rung has the latch for keeping the internal relay IR 1 on when the start switch gives a momentary input. The second rung will then switch the power on. The third rung will also switch on and give output Out 2 if input 2 contacts are closed. The third rung will also switch on and give output Out 3 if input 3 contacts are closed. Thus all the outputs can be switched on when the start push button is activated. All the outputs will be switched off if the stop switch is opened. Thus all the outputs are latched by IR 1.

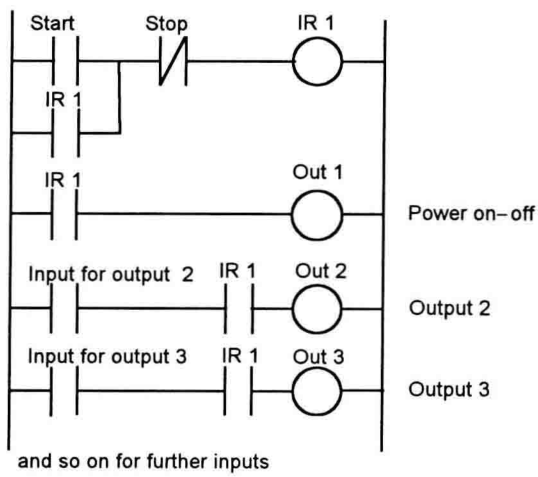


Figure 5.7 *Starting of multiple outputs*

5.3 Battery-backed relays

If the power supply is cut off from a PLC while it is being used, all the output relays and internal relays will be turned off. Thus when the power is restored, all the contacts associated with those relays will be set differently from when the power was on. Thus, if the PLC was in the middle of some sequence of control actions, it would resume at a different point in the sequence. To overcome this problem, some internal relays have battery back-up so that they can be used in circuits to ensure a safe shutdown of plant in the event of a power failure and so enable it to restart in an appropriate manner. Such battery-backed relays retain their state of activation, even when the power supply is off. The relay is said to have been made *retentive*.

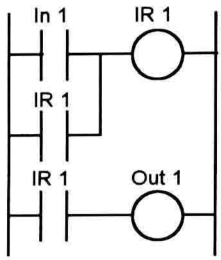


Figure 5.8 *Battery-backed relay program*

As an example of the use of such a relay, Figure 5.8 shows a ladder diagram for a system designed to cope with a power failure. IR 1 is a battery-backed internal relay. When input 1 contacts close, output IR 1 is energised. This closes the IR 1 contacts, latching so that IR 1 remains on even if input 1 opens. The result is an output from Out 1. If there is a power failure, IR 1 still remains energised and so the IR 1 contacts remain closed and there is an output from Out 1.

With Mitsubishi PLCs, battery-backed internal relay circuits use M300 to M377 as addresses for such relays. Other manufacturers use different addresses.

5.4 One-shot operation

One of the functions provided by some PLC manufacturers is the ability to program an internal relay so that its contacts are activated for just one cycle, i.e. one scan through the ladder program. Hence it provides a fixed duration pulse at its contacts when operated. This function is often termed *one-shot*.

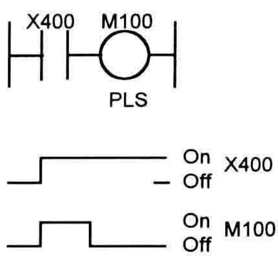


Figure 5.9 *Pulse operation*

Figure 5.9 illustrates this with a simple ladder diagram for a Mitsubishi PLC. When X400 contacts close, the output internal relay M100 is activated. Under normal circumstances, M100 would remain on for as long as the X400 contacts were closed. However, if M100 has been programmed for pulse operation, M100 only remains on for a fixed period of time, one program cycle. It then goes off, regardless of X400 being on. The programming instructions that would be used are:

LD	X400
PLS	M100

The above represents pulse operation when the input goes from off to on, i.e. is positive-going. If, in Figure 5.9, X400 is made normally closed, rather than normally open, then the pulse occurs when the input goes from on to off, i.e. is negative-going.

Other manufacturers have different forms for such a ladder program and use different programming instructions. For example, Sprecher+Schuh would have the ladder diagram shown in Figure 5.10 and the following programming instructions:

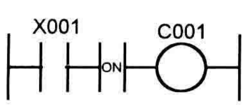


Figure 5.10 *Pulse operation*

STR	X001
F-05	DION
OUT	C001

The IEC symbol for a pair of pulse contacts is either |P| for a positive-going signal or |N| for a negative-going signal. In the above, a ready-made pulse function was available. Some manufacturers, however, use basic logic elements to build up such a function. See Section 5.5 for examples.

Such a pulse providing relay, or built-up function, is used to create pulses for the resetting of counters and timers and marking the start of cycles.

5.5 Set and reset

Another function which is often available is the ability to set and reset an internal relay. The set instruction causes the relay to self-hold, i.e. latch. It then remains in that condition until the reset instruction is received. The term *flip-flop* is often used.

Figure 5.11 shows an example of a ladder diagram involving such a function. Activation of the first input, X400, causes the output Y430 to be turned on and set, i.e. latched. Thus if the first input is turned off, the output remains on. Activation of the second input, X401, causes the output Y430 to be reset, i.e. turned off and latched off. Thus the output Y430 is on for the time between X400 being momentarily switched on and X401 being momentarily switched on. Between the two rungs indicated for the set and reset operations, there could be other rungs for other activities to be carried out, the set rung switching on an output at the beginning of the sequence and off at the end.

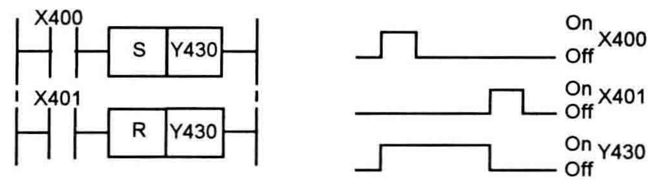


Figure 5.11 *Set and reset*

The programming instructions for the ladder rungs are:

```
LD      X400
S       Y430
Other program rungs
LD      X401
R       Y430
```

Figure 5.12 shows the equivalent ladder diagram for the set-rese function with a Siemens PLC, the programming instructions (F being used to indicate an internal relay) then being:

```
A       I0.0
S       F0.0
A       I0.1
R       F0.0
A       F0.0
=       Q2.0
```

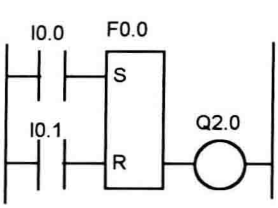


Figure 5.12 *Set and reset*

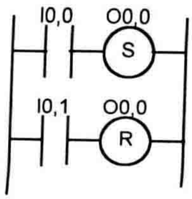


Figure 5.13 *Set and reset*

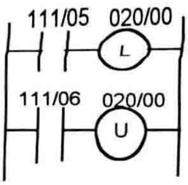


Figure 5.14 *Latch and unlatch*

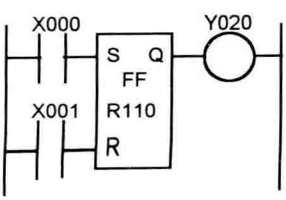


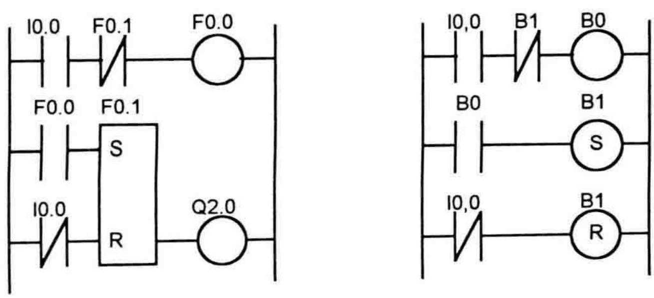
Figure 5.15 *Flip-flop*

With a Telemecanique PLC the ladder diagram would be as shown in Figure 5.13 and the programming instructions would be:

L	I0,0
S	O0,0
L	I0,1
R	O0,0

With an Allen Bradley PLC, the term latch and unlatch is used. Figure 5.14 shows the ladder diagram. Toshiba uses the term flip-flop and Figure 5.15 shows the ladder diagram.

Figure 5.16 shows how the set-reset function can be used to build the pulse (one-shot) function described in the previous section. Figure 5.16(a) shows it for a Siemens PLC (F indicates internal relay) and Figure 5.16(b) for a Telemecanique PLC (B indicates internal relay). The mode of operation is the same for each. An input (I0.0, I0,0) causes the internal relay (B0, F0.0) in the first rung to be activated. This results, second rung, in the set-reset internal relay being set. This setting action results in the internal relay (F0.1, B1) in the first rung opening and so, despite there being an input in the first rung, the internal relay (BO, F0.0) opens. However, because the rungs are scanned in sequence from top to bottom, a full cycle must elapse before the internal relay in the first rung opens. A pulse of duration one cycle has thus been produced. The system is reset when the input (I0.0, I0,1) ceases.



(a) (b)

Figure 5.16 *Pulse function, (a) Siemens PLC, (b) Telemecanique PLC*

5.6 Master control relay

When large numbers of outputs have to be controlled, it is sometimes necessary for whole sections of ladder diagrams to be turned on or off when certain criteria are realised. This could be achieved by including the contacts of the same internal relay in each of the rungs so that its operation affects all of them. An alternative is to use a *master control relay*.

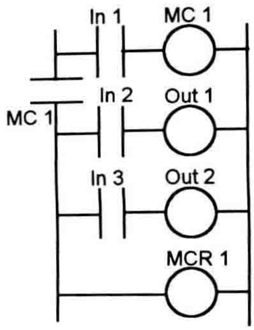


Figure 5.17 *Use of a master control relay*

Figure 5.17 illustrates the use of such a relay to control a section of a ladder program. With no input to input 1, the output internal relay MC 1 is not energised and so its contacts are open. This means that all the rungs between where it is designated to operate and the rung on which its reset MCR or another master control relay is located are switched off. Assuming it is designated to operate from its own rung, then we can imagine it to be located in the power line in the position shown and so rungs 2 and 3 are off. When input 1 contacts close, the master relay MC 1 is energised. When this happens, all the rungs between it and the rung with its reset MCR 1 are switched on. Thus outputs 1 and 2 cannot be switched on by inputs 2 and 3 until the master control relay has been switched on. The master control relay 1 acts only over the region between the rung it is designated to operate from and the rung on which MCR 1 is located.

With a Mitsubishi PLC, an internal relay can be designated as a master control relay by programming it accordingly. Thus to program an internal relay M100 to act as master control relay contacts the program instruction is:

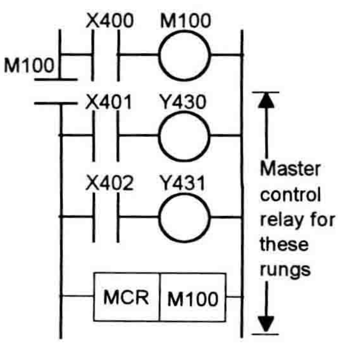


Figure 5.18 *Use of a master control relay*

MC	M100

To program the resetting of that relay, the program instruction is:

MCR	M100

Thus for the ladder diagram shown in Figure 5.18, being Figure 5.17 with Mitsubishi addresses, the program instructions are:

LD	X400
OUT	M100
MC	M100
LD	X401
OUT	Y430
LD	X402
OUT	Y431
MC	M100

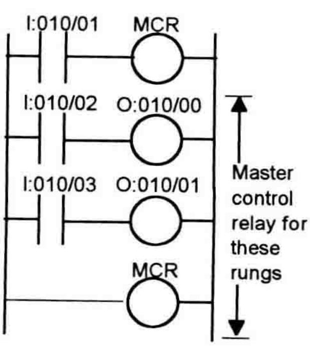


Figure 5.19 *Use of a master control relay*

Figure 5.19 shows the format used by Allen Bradley. To end the control of one master control relay (MCR), a second master control relay (MCR) is used with no contacts or logic preceding it. It is said to be programmed unconditionally.

A program might use a number of master control relays, enabling various sections of a ladder program to be switched in or out. Figure 5.20 shows a ladder program in Mitsubishi format involving two master control relays. With M100 switched on, but M101 off, the sequence is: rungs 1, 3, 4, 6, etc. The end of the M100 controlled section is indicated by the occurrence of the other master control relay, M101. With M101 switched on, but M100 off, the sequence is: rungs 2, 4, 5, 6, etc. The end of this section is indicated by the presence of the reset. This reset has to be used since the rung is not followed immediately by another master control relay.

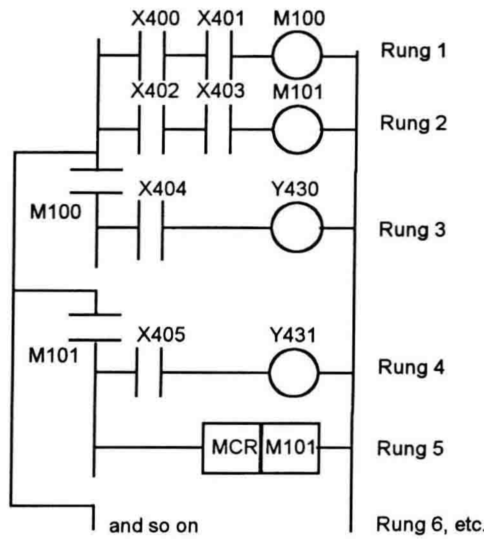


Figure 5.20 *Example showing more than one master control relay*

The program instruction list for Figure 5.20 is:

```
LD    X400
AND   X401
OUT   M100
LD    X402
AND   X403
OUT   M101
MC    M100
LD    X404
OUT   Y430
MC    M101
LD    X405
OUT   Y431
MCR   M101
and so on.
```

Such an arrangement could be used to switch on one set of ladder rungs if one type of input occurs, and another set of ladder rungs if a different input occurs.

5.7 Jump

A function often provided with PLCs is the *conditional jump*. If the appropriate conditions are met, this function enables part of a ladder program to be jumped over. Figure 5.21 illustrates this in a general manner. When there is an input to In 1, its contacts close and there is an output to the jump relay. This then results in the program jumping to the rung in which the jump end occurs, so missing out intermediate program rungs. Thus, in this case, when there is an input to In 1, the program jumps to rung 4 and then proceeds with rungs 5, 6, etc. When there is no input to In 1, the jump relay is not energised and the program then proceeds to rungs 2, 3, etc.

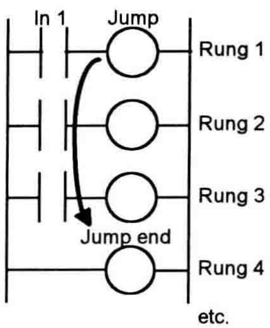


Figure 5.21 *Jump*

Such a facility enables programs to be designed such that:

> If certain conditions are met then certain events occur, if they are not met then other events occur.

Thus, for example, we might need to design a system so that if the temperature is above 60°C a fan is switched on, and if below that temperature no action occurs.

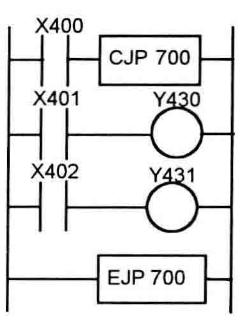


Figure 5.22 *Jump*

Figure 5.22 shows the above ladder program in the form used by Mitsubishi. The jump instruction is denoted by CJP (conditional jump) and the place to which the jump occurs is denoted by EJP (end of jump). The condition that the jump will occur is then that there is an input to X400. When that happens the rungs involving inputs X401 and X403 are ignored and the program jumps to continue with the rungs following the end jump instruction with the same number as the start jump instruction, i.e. in this case EJP 700.

With the Allen Bradley PLC-5 format the jump takes place from the jump instruction (JMP) to the label instruction (LBL). The JMP instruction is given a three-digit number from 000 to 255 and the LBL instruction the same number. Figure 5.23 shows a ladder program in this format.

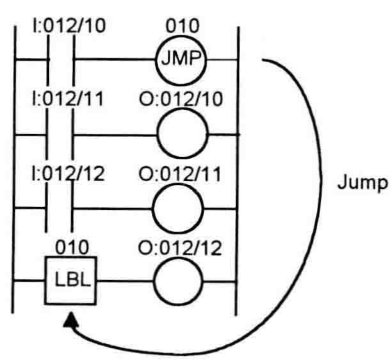


Figure 5.23 *Jump*

Jumps within jumps are possible. For example, we might have the situation shown in Figure 5.24. If the condition for the jump instruction 1 is realised then the program jumps to rung 8. If the condition is not met then the program continues to rung 3. If the condition for the jump instruction 2 is realised then the program jumps to rung 6. If the condition is not met then the program continues through the rungs.

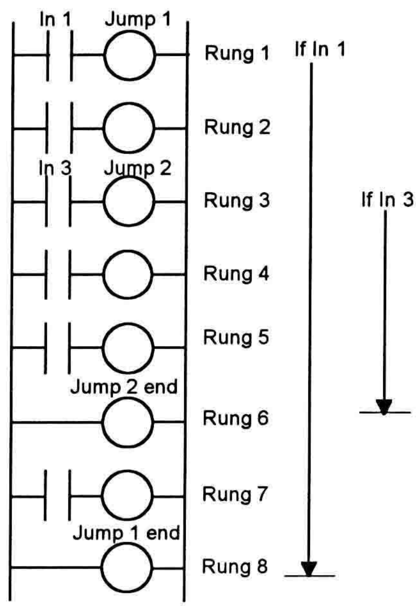


Figure 5.24 *Jumps within jumps*

Thus if we have an input to In 1, the rung sequence is rung 1, 8, etc. If we have no input to In 1 but an input to In 3, then the rung sequence is 1, 2, 6, 7, 8, etc. If we have no input to In 1 and no input to In 3, the rung sequence is 1, 2, 3, 4, 5, 6, 7, 8, etc. The jump instruction enables different groups of program rungs to be selected, depending on the conditions occurring.

5.8 Examples of programs

The following looks at a program which illustrates the uses of master control relays. The program is being developed for use with a pneumatic valve system involving the movement of pistons in cylinders in order to give a particular sequence of piston actions. First, however, we show how latching might be used with such systems in order to maintain actions.

Consider a pneumatic system with single-solenoid controlled valves and involving two cylinders A and B, with limit switches a–, a+, b–, b+ detecting the limits of the piston rod movements (Figure 5.25), with the requirement being to give the sequence A+, B+, A–, B– .