X028/301

NATIONAL QUALIFICATIONS 2007

MONDAY, 4 JUNE 1.00 PM – 4.00 PM

MECHATRONICS HIGHER

100 marks are allocated to this paper.

Attempt **all** questions in Section A (50 marks).

Attempt any **two** questions from Section B (50 marks).

Use labelled diagrams and sketches to illustrate your answers where appropriate.

All calculations must be supported by working.

A PLC datasheet is included for questions 5 and 13.

Worksheets are provided for questions 1, 2, 4, 10 and 13.

PB X028/301 6/670

SECTION A

Attempt ALL questions in this Section (50 marks).

Marks

1. (*a*) Table Q1 identifies the movement of each joint of a robotic system as either Rotary or Linear. On **Worksheet Q1** complete Table Q1 by filling in the appropriate joint movement for the Cartesian and Cylindrical robots.

Robot	Joint 1	Joint 2	Joint 3
Polar	Rotary	Rotary	Linear
Cartesian	Linear		
Cylindrical	Rotary		

Table Q1 **2**

(*b*) **In your answer book**, briefly explain the differences between "walkthrough" and "lead-by-nose" programming with reference to robotic arms. **2**

(*c*) State **two** reasons why hydraulic actuators are often the preferred choice of drive system on large industrial robots. **1**

(5)

2. (*a*) The list below shows the names of five types of control system.

- ASIC
- Hardwired
- Microcontroller
- PLC
- PC

(i) From the list, select **two** systems where the controlling action can be altered by changing the program. **2**

(ii) Briefly describe how the controlling action of a hardwired system can be altered. **1**

2. (continued) *Marks*

(*b*) Table Q2 shows a code. **On Worksheet Q2** identify the code type represented and fill in the two missing codes.

Decimal	Code type =
0	0000
1	0001
2	0011
3	0010
4	0110
5	0111
6	0101
7	0100
8	
9	1101
10	1111
11	1110
12	1010
13	
14	1001
15	1000

Table Q2

2

(5)

3. (*a*) Give an example of a pressure sensor that could be used in a mechatronic system. **1**

(*b*) With the aid of a simple sketch, describe the basic operation of the sensor system chosen in Q3(*a*). **3**

(*c*) State an appropriate application for the sensor system chosen in Q3(*a*). **1**

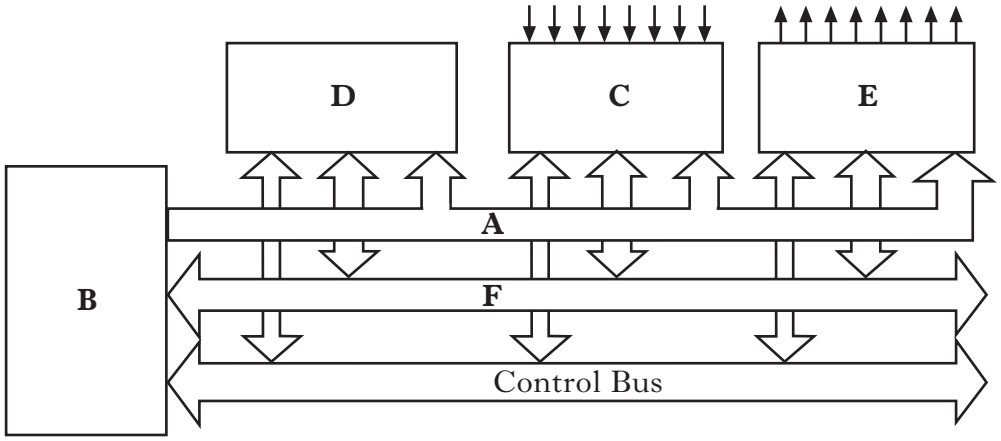
(5)

[Turn over

Marks

4. (*a*) State **two** advantages which a PLC (Programmable Logic Controller) based mechatronic system would have over a PC (Personal Computer) based mechatronic system. Assume that the application is within an industrial environment. **2**

(*b*) Figure Q4 illustrates the basic architecture of a microcontroller. Some elements have been labelled with the letters A to F. On **Worksheet Q4, Table Q4** enter the names of the elements labelled A to F.



3

Figure Q4 **(5)**

5. A mechatronic control system has to meet the following specification.

- The system has two inputs, **X0** and **X1** and one output, **Y0**.
- Output **Y0** is **only** high if both inputs are high.

(*a*) Construct a table showing the output for each of the **four** possible input combinations. **1**

(*b*) Construct a ladder diagram which would allow the control to be realised using a PLC (Programmable Logic Controller). **2**

(*c*) Redraw your diagram in Q5(*b*) to latch the output **Y0** and then also enable the output **Y0** to be switched off using an additional input **X2**. **2**

Note: the inserted PLC Datasheet Q5/Q13 gives the PLC instruction set. **(5)**

6. Figure Q6 illustrates a tank in which the level of water is controlled using a microcontroller. When the water level falls below the float switch, the water level will be raised by opening the inlet valve.

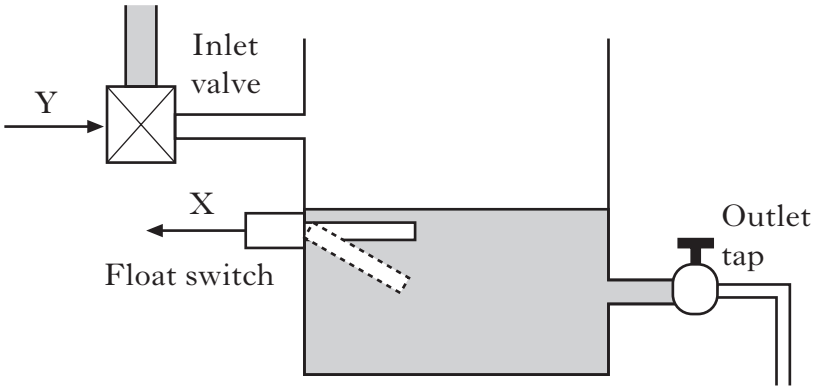


Figure Q6

Sketch a flowchart to describe how the system will respond to the opening of the outlet tap. Assume the water level is initially as shown in Figure Q6. **(5)**

7. (*a*) Control systems may be classed as **open loop** or **closed loop**.

(i) Sketch and label a block diagram of a **closed loop** system. **1**

(ii) Briefly describe a practical example of a system which uses **closed loop** control. **2**

(*b*) A computer mouse uses rotary optical relative encoders. Describe the basic principle of operation of a rotary optical relative encoder. **2**

(5)

[Turn over

Marks

8. Figure Q8 illustrates a box transfer system. It uses two pneumatic cylinders, A and B, to transfer boxes from the level of Conveyor 1 to the level of Conveyor 2.

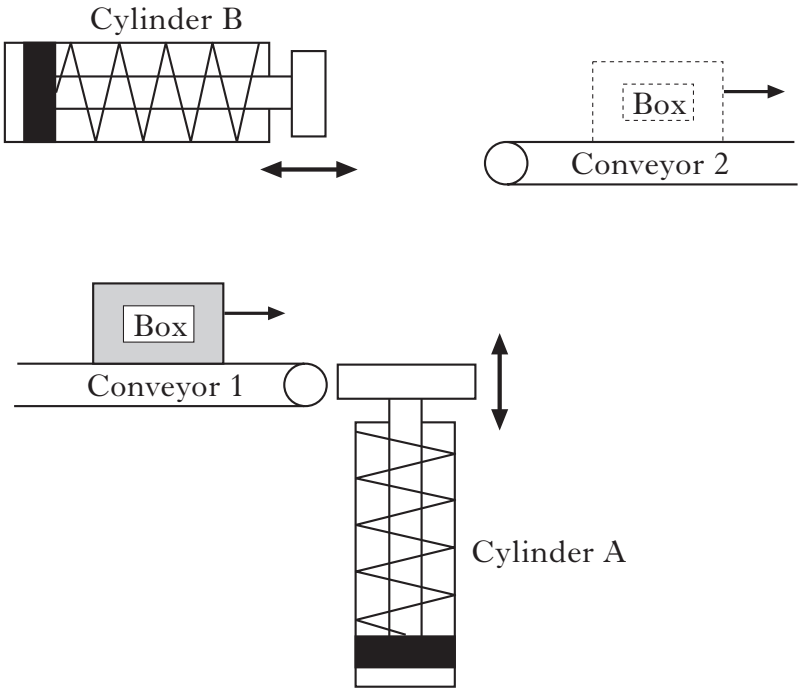


Figure Q8

The sequencing of the cylinders is critical in order to complete the transfer of each box successfully.

(*a*) Sketch a flowchart which shows the conditions of each of the cylinders for the transfer of one box from Conveyor 1 to Conveyor 2. Begin with Cylinder A being supplied with a box and each cylinder in the position shown in Figure Q8. In your flowchart simply state whether the appropriate cylinder is extended or retracted. **2**

(*b*) Describe a potential hazard if Conveyor 1 runs continuously and the boxes arrive in a continuous stream. **1**

(*c*) Describe **one** method of avoiding the hazard in Q8(*b*). **2**

(5)

Marks

9. A PCB drilling machine can move 1000 mm along the *x* axis and 500 mm along the *y* axis. The machine drilling head is driven by a combination of lead screws and electric motors. Each axis has an absolute encoder which permits a placement accuracy of 0·1 mm.

(*a*) Calculate the minimum number of code bits required to achieve the designed placement accuracy on the *x* axis. Show all your working in your answer. **3**

(*b*) Describe the difference between relative and absolute encoders, using the above mechatronic application as a practical example. **2**

(5)

10. Figure Q10 shows the block diagram for a control system.

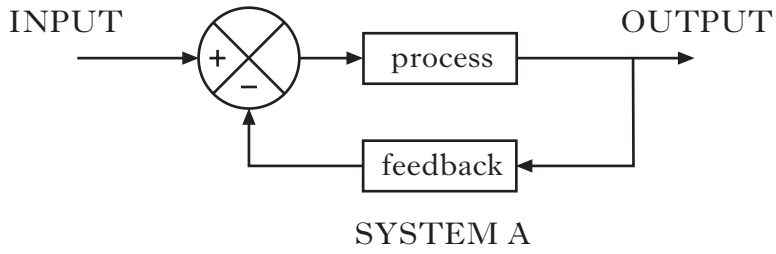


Figure Q10

(*a*) Describe the term "Proportional Action" when applied to control systems. **1**

(*b*) Describe the term "Offset" in relation to control systems. **1**

(*c*) System A, in Figure Q10, will have a certain response to an input step change in required temperature. On **Worksheet Q10** in the space provided on each graph enter the corresponding control strategy from the list below.

- ON/OFF control
- Proportional control
- PID control **3**

(5)

[*END OF SECTION A*]

[Turn over for SECTION B on *Page eight*

SECTION B

Attempt any TWO questions in this Section (50 marks).

Each question is worth 25 marks.

11. A manufacturer of a parts washer for industrial use has decided to change from a mechanical controller to a microcontroller based system.

The washer in Figure Q11 has two programs.

- Program 1 — Rinse only cycle
- Program 2 — Rinse, wash and dry cycle

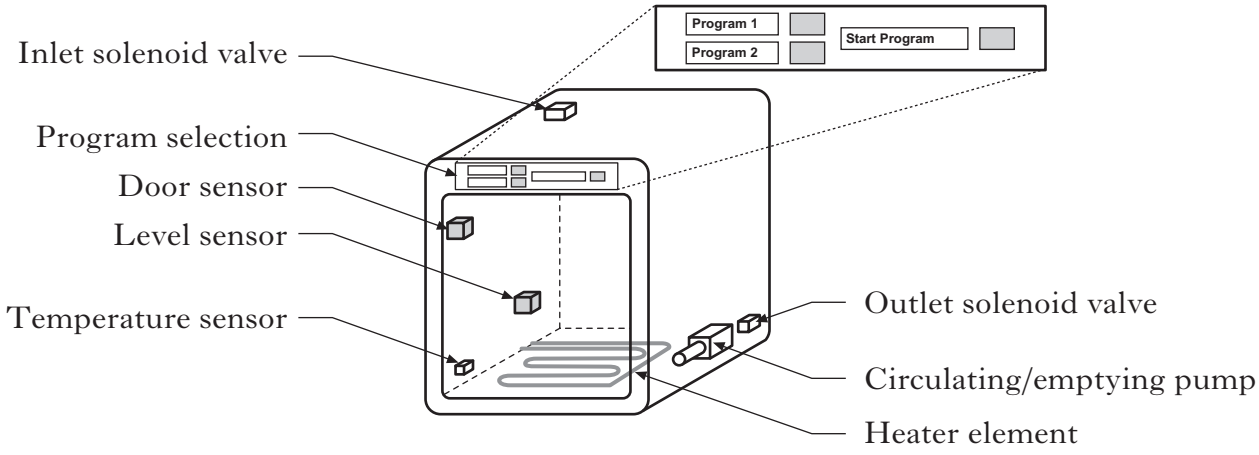


Figure Q11

The system operates at two temperatures — inlet water temperature and hot (90 °C). A door sensor enables the microcontroller to stop the cycle if the door is opened. If the door is then closed, the cycle continues from where it left off.

The system includes — an inlet solenoid valve (cold water only), a circulating/emptying pump, a heater element, an outlet solenoid valve, a level sensor, a temperature sensor, a door sensor, program selection switches and a start program switch.

The inlet solenoid valve controls the water supply whilst the outlet solenoid valve controls the circulation and emptying of the system. The water can only circulate while the outlet solenoid valve is closed **or** can only empty while the outlet solenoid valve is open.

11. (continued)

Program 1 consists of a rinse only cycle. Assume the system is loaded with parts which require rinsing, the inlet solenoid valve is closed, the outlet solenoid valve is open and the door is shut. The system operates as follows:

- the system is filled with water to the required level;
- then rinsing/circulation takes place for 5 minutes;
- after rinsing/circulation is complete, the circulating/emptying pump continues for a further 2 minutes to drain the system;
- the inlet and outlet solenoid valves are operated at the correct times in the cycle.

(*a*) Give **two** benefits of changing the system from a mechanical controller to a microcontroller based system. **2**

(*b*) For the microcontroller based system, list the

(i) input signals

(ii) output signals. **5**

(*c*) Sketch a detailed flowchart for Program 1 (the rinse only cycle). Your flowchart should clearly show the conditions and decisions required for the correct sequence of events to take place. **6**

(*d*) Sketch a top level flowchart of the system which describes the operation of the parts washer showing how each of the 2 programs is selected. **3**

Note: the rinse element of Program 2 is the same process as Program 1 and should be shown as a single labelled box.

(*e*) Suggest a suitable sensor for measuring the level of the water in the system and describe the principle of operation of your chosen sensor. **3**

(*f*) List **two** safety issues that should be considered in the design of this system. **2**

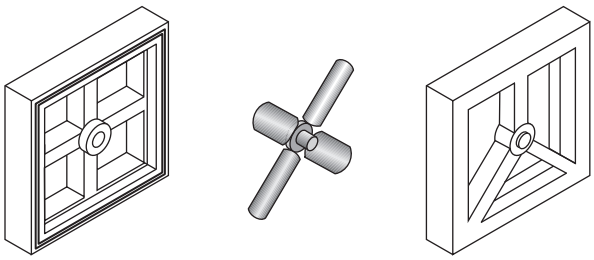
(*g*) The circulating/emptying system, as described, is a "time based" system. Describe how you could modify the system to be an "event based" system and how this could improve the system operation. **4**

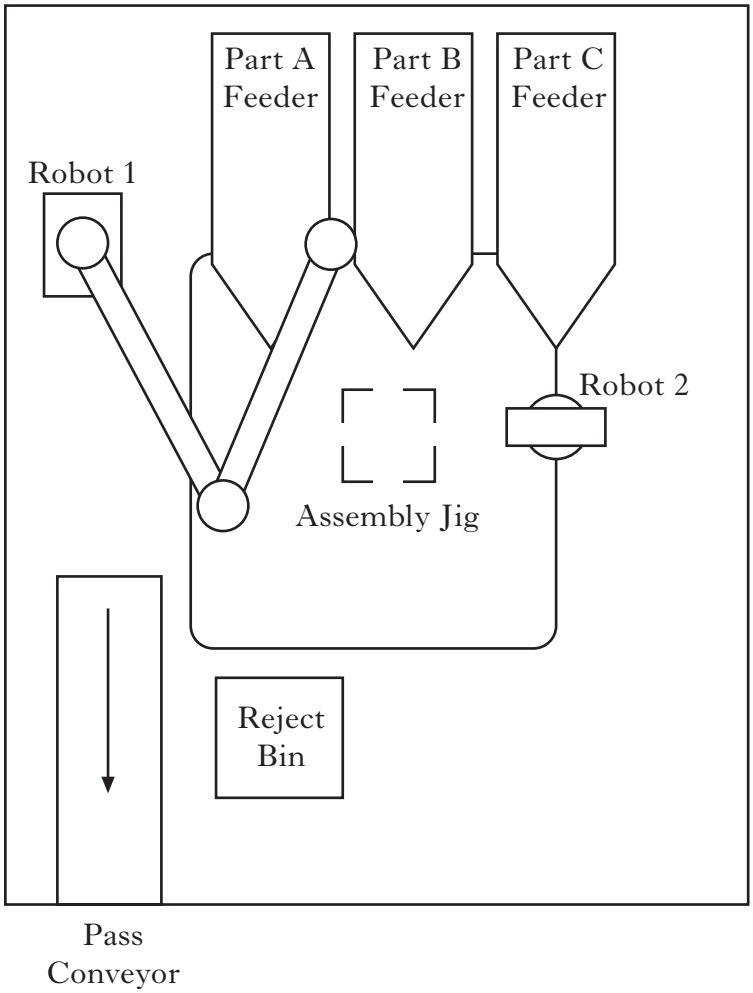
(25)

[Turn over

12. Two robots are used to assemble a 4 bladed motorised fan. One robot picks and places the supplied parts and the other robot applies adhesive during assembly. Robot 1 is a SCARA robot and Robot 2 is a revolute robot. The electrical supply for testing the assembly is fed through the assembly jig and switched on when Robot 1 is in its home position.

The assembly station layout is shown in Figure Q12.





Assembly Station Layout

Figure Q12

12. (continued)

Assume all feeders have parts and the robots are at their home positions.

The sequence of operation is as follows:

- Robot 1 picks up part A and places it in the assembly jig.
- Robot 1 picks up part B and places it in part A.
- Robot 2 applies adhesive to part A.
- Robot 1 picks up and places part C on part A.
- Robot 1 applies pressure to part C for 10 seconds to allow the adhesive to set.
- Each robot goes to its home position.
- Assembled fan is tested in the assembly jig.
- If assembled fan passes the test then Robot 1 picks up the fan and places it on the "Pass conveyor".
- If assembled fan fails the test then Robot 1 picks up the fan and drops it in the "Reject bin".

(*a*) Sketch the arm geometry of a revolute robot and its work envelope. **4**

(*b*) Sketch and describe a suitable design for a gripper which could handle each of the various parts **and** provide a signal if a part is present in the gripper. **6**

(*c*) Suggest a suitable sensing system for the three part feeders to each produce a "Part Feeder OK" signal. Explain how these three signals could be combined to produce a single signal which indicates "All Part Feeders OK". **3**

(*d*) The specification for the fan demands that its rotational speed is greater than 1500 rpm in a clockwise direction.

(i) Describe a sensor system that could be used to measure the speed of rotation of the fan. **3**

(ii) Describe a sensor system which would be capable of sensing the direction of airflow of the fan. **3**

(*e*) Give **three** safety measures which could be incorporated into the assembly station. **3**

(*f*) Suggest **three** further improvements that could be made to the assembly station and explain why they should be undertaken. **3**

(25)

[Turn over

13. A factory has an entrance control system which uses a roller shutter door. Exit by this door is **not** allowed. The factory entrance, as shown in Figure Q13, is controlled by a PLC (Programmable Logic Controller) with sensors and actuators as specified in Table Q13.

The motor turns in the Forward (F) direction to move the door UP and a limit sensor senses when the door has reached the fully open position. The motor turns in the Reverse (R) direction to move the door DOWN and a limit sensor senses when the door has reached the fully closed position.

The sensors and actuators have been carefully positioned and are identified by the letters A to E in Figure Q13. One of the sensors, E, is a complete truck length inside the door.

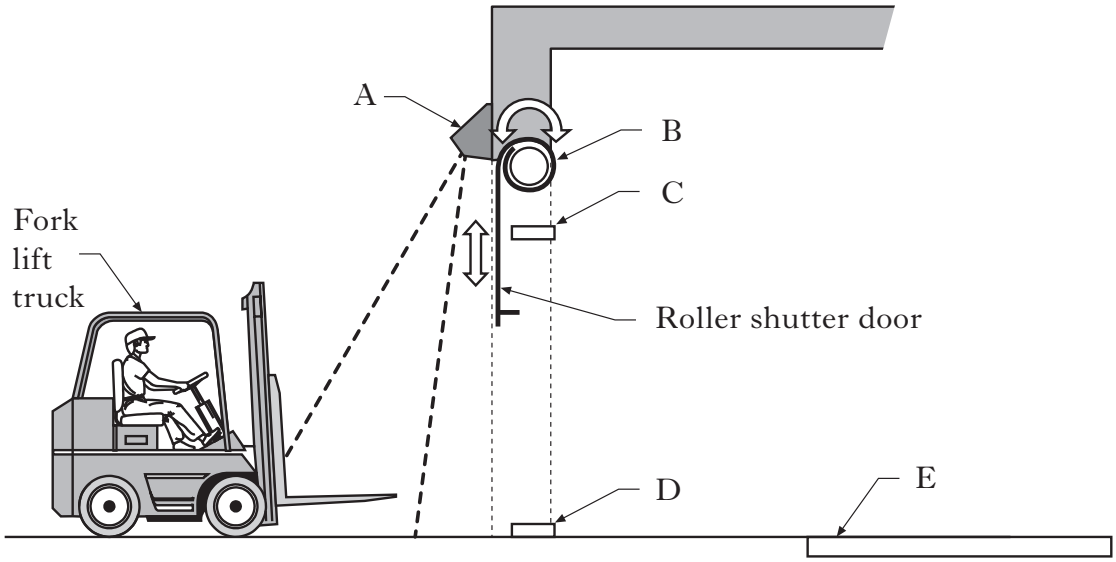


Figure Q13

Sensors and Actuators	Details
Microswitch 1	Normally Open (NO) contact.
Microswitch 2	Normally Open (NO) contact.
Pressure pad	When truck is fully sited on the pad it provides a logic 1 to PLC.
Ultrasonic detector	Floods area with ultrasonic beam. When it detects any movement, provides a logic 1 to PLC.
Reversible motor	Requires 2 connections, Forward (F) and Reverse (R). When F = 1 and R = 0 the door will move UP. F R 1 0 – moves the door UP 0 1 – moves the door DOWN 0 0 – stop

Table Q13

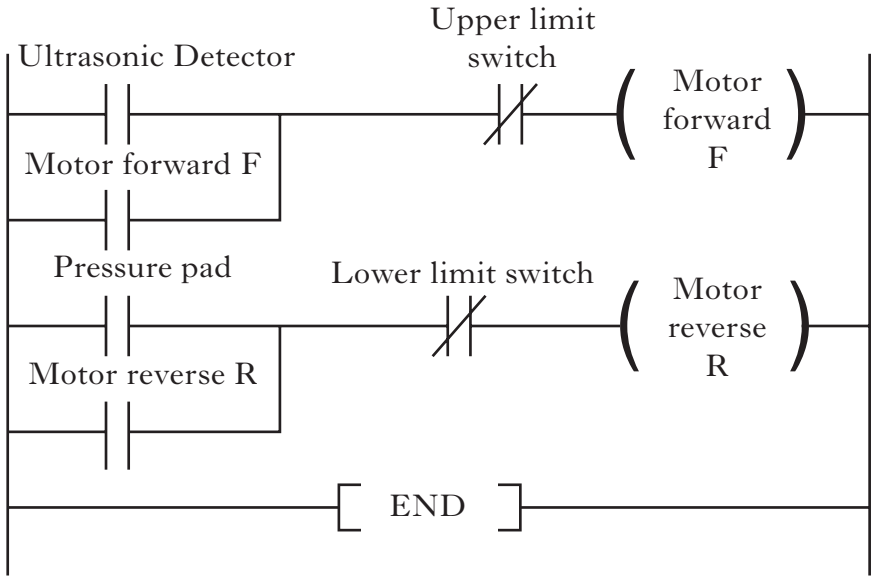
13. (continued)

The basic operation of the entrance control system is as follows.

When the approach of a fork lift truck is sensed, the roller shutter door will be moved UP to the fully open position by the motor. The motor then stops.

When the fork lift truck is fully inside, the roller shutter door will be moved DOWN to the fully closed position by the motor. The motor then stops.

A basic ladder diagram program for use with the PLC in this application is shown in the Ladder Diagram Q13.



Ladder diagram Q13

Note: the inserted PLC Datasheet Q5/Q13 gives the PLC instruction set.

(*a*) On **Worksheet Q13**

(i) in Table Q13(*a*) enter the letters A to E from Figure Q13, indicating the position, against each device and enter one reason for each choice. **4**

(ii) in Table Q13(*a*) allocate the sensors and actuators to the PLC I/O. **3**

(iii) label Ladder Diagram Q13(*a*)(iii) using your PLC I/O allocations from Q13(*a*)(ii) above. **1**

(*b*) In your **answer book**, describe the operation of the Ladder Diagram Q13 in relation to the application. **4**

(*c*) Sketch a flowchart of the desired sequence of operation for one complete cycle. Assume that the roller shutter door is initially closed and the fork lift truck is approaching the entrance control system. **7**

(*d*) Explain the nature of the hazardous conditions which would arise if fork lift trucks arrive in quick succession. **3**

(*e*) Suggest **three** changes to the system that will improve its operation and safety. **3**

(25)

[*END OF SECTION B*]

[*END OF QUESTION PAPER*]

[BLANK PAGE]

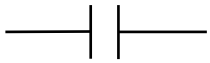
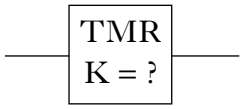
[BLANK PAGE]

[BLANK PAGE]

PLC Datasheet Q5/Q13

PLC Programming Details for Ladder Diagram Programming

Functions

Function type	*Function symbol*	*Function name*	*Function operand (see following table)*
Input		Normally open contact	X, Y, M, T
Input		Normally closed contact	X, Y, M, T
Output		Output	M, Y
Timer		Timer	
End			

Operands

Operand	*Range*	*Type*
X	0 – 7	Input (I/P) terminal contact
Y	0 – 7	Output (O/P) terminal contact
M	0 – 49	Memory/auxiliary contact
T	0 – 49	Timer (see below)
K	Any integer value multiplier of 0·1 s	Constant

The timer functions begin a timeout for the set duration of time. When timeout occurs, the timer contact(s) are activated. If continuity of the timer rung is broken during timeout, the timeout will immediately reset.

[BLANK PAGE]

FOR OFFICIAL USE

Total Marks | | |

X028/302

NATIONAL QUALIFICATIONS 2007

MONDAY, 4 JUNE
1.00 PM – 4.00 PM

MECHATRONICS
HIGHER
Worksheets for Q1, Q2, Q4, Q10 and Q13

Fill in these boxes and read what is printed below.

Full name of centre

Town

Forename(s)

Surname

Date of birth
Day Month Year

Scottish Candidate number

Number of seat

To be inserted inside the front cover of the candidate's answer book and returned with it.

PB X028/302 6/670

Worksheet Q1

Complete the Table Q1 by filling in the appropriate joint movement for the Cartesian and Cylindrical robots.

Robot	Joint 1	Joint 2	Joint 3
Polar	Rotary	Rotary	Linear
Cartesian	Linear		
Cylindrical	Rotary		

Table Q1

Worksheet Q2

Identify the code type represented and fill in the two missing codes.

Decimal	Code type =
0	0000
1	0001
2	0011
3	0010
4	0110
5	0111
6	0101
7	0100
8	
9	1101
10	1111
11	1110
12	1010
13	
14	1001
15	1000

Table Q2

Worksheet Q4

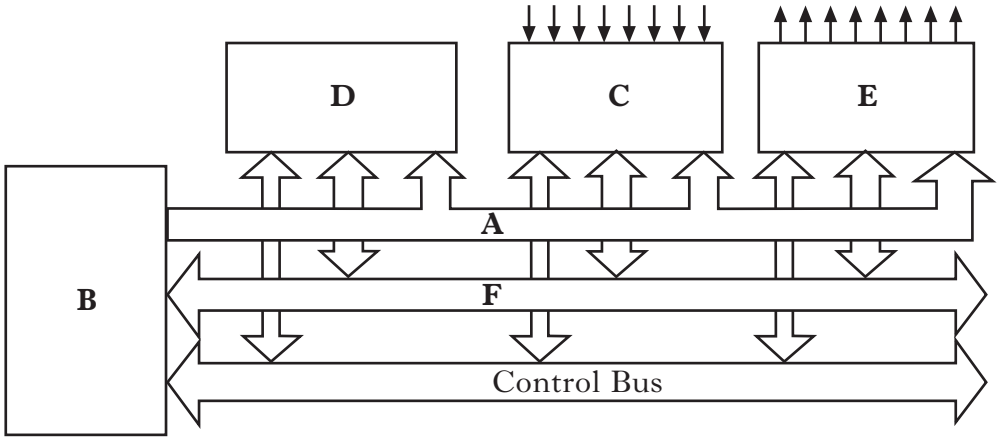


Figure Q4

Enter the names of the elements labelled A to F in Table Q4.

Label	Element
A	
B	
C	
D	
E	
F	

Table Q4

[Turn over

Worksheet Q10

In the space provided on each graph, enter the corresponding control strategy from the list below.

- ON/OFF control
- Proportional control
- PID control

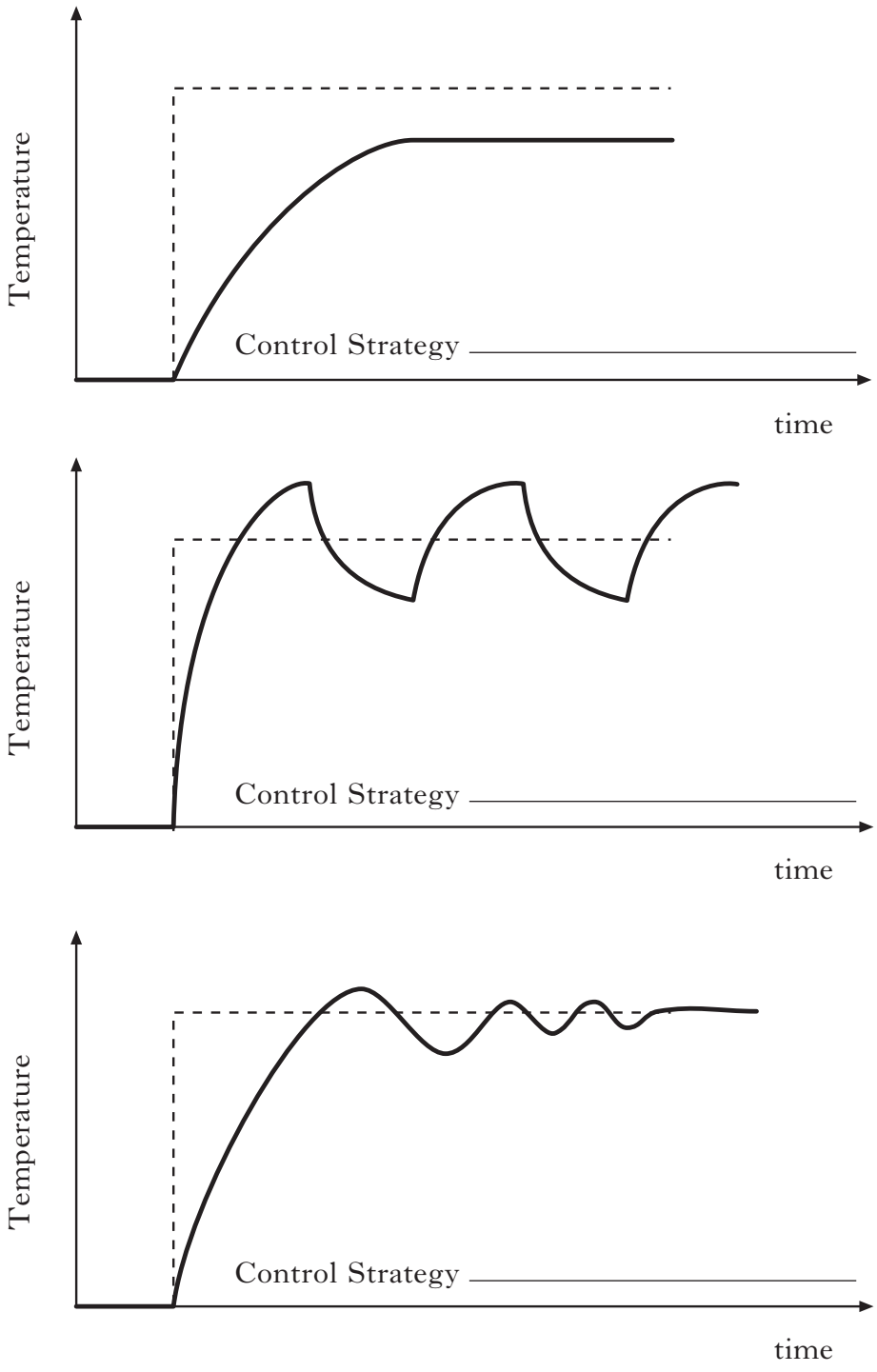


Figure Q10

Worksheet Q13

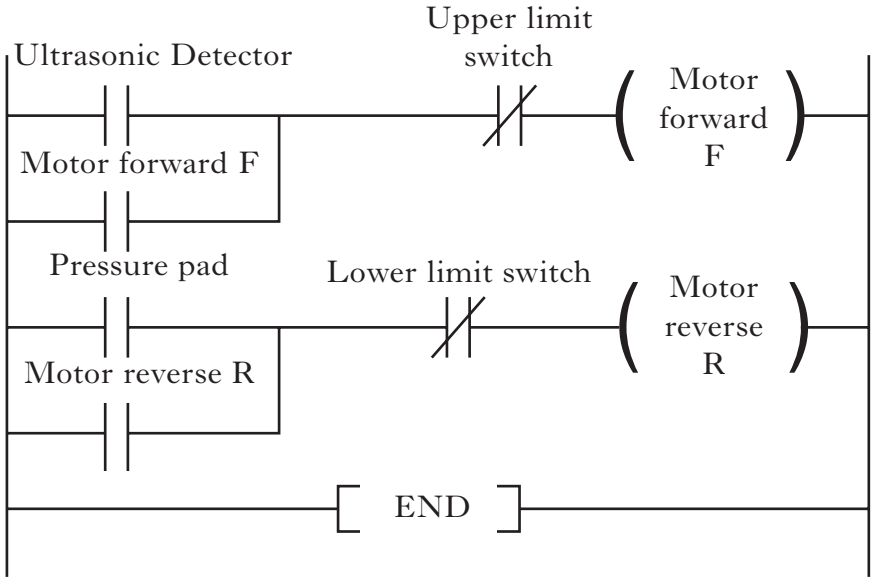
In Table Q13(*a*):

(i) enter the letters A to E from Figure Q13, indicating the position, against each device and enter one reason for each choice.

(ii) in Table Q13(*a*) allocate the sensors and actuators to the PLC I/O.

Device	Letter	Reason	PLC I/O
Microswitch 1			
Microswitch 2			
Pressure pad			
Ultrasonic detector			
Reversible motor			

Table Q13(*a*)

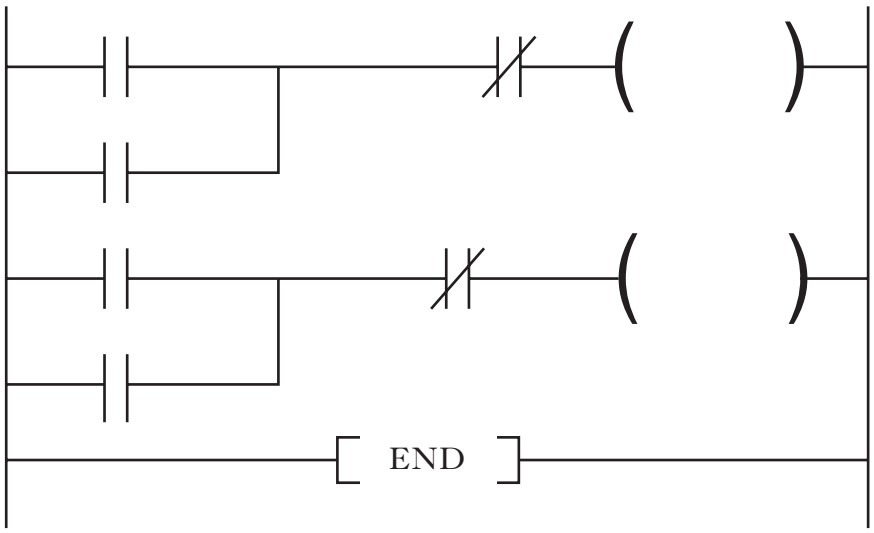


Ladder diagram Q13

[Turn over

Worksheet Q13 (continued)

(iii) Label Ladder Diagram Q13(*a*)(iii) using your PLC I/O allocations from Table Q13 on previous page.



Ladder diagram Q13(*a*)(iii)

[*END OF WORKSHEETS*]

[BLANK PAGE]

[BLANK PAGE]