X028/12/01

NATIONAL QUALIFICATIONS 2013

THURSDAY, 6 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 6, 8 and 12.

A Flowchart symbol sheet is included for questions 2, 11, 12 and 13.

Worksheets are provided for questions 3(*a*), 5 and 10.

Marks

SECTION A

Attempt ALL questions in this Section (50 marks).

1. Figure Q1 illustrates the basic architecture of a microcontroller. All parts have been identified with the letters A, B, C, D, E, F and G.

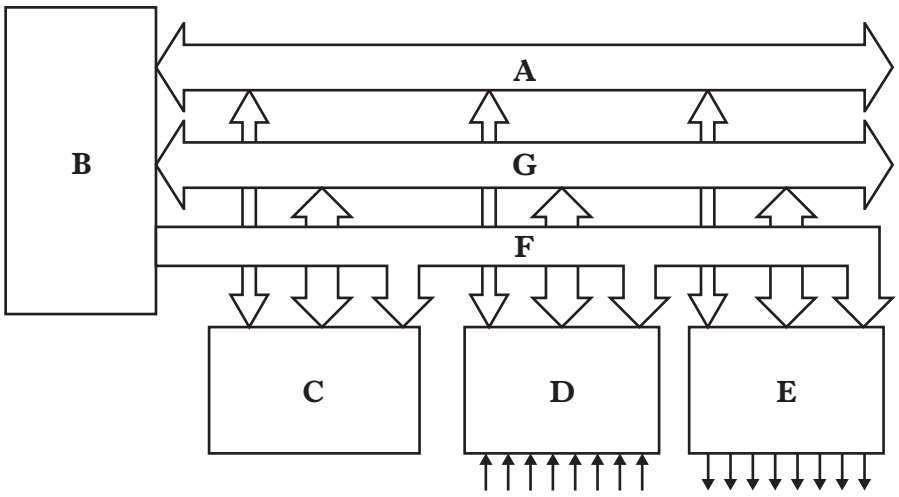


Figure Q1

(*a*) Match each of the unit names to the letters in Figure Q1.

- Input Interface Unit
- Output Interface Unit
- Central Processing Unit
- Memory Unit **2**

(*b*) Match each of the busses to the letters in Figure Q1.

- Address Bus
- Data Bus **2**

(*c*) With reference to Figure Q1, state which **one** of the following three statements correctly describes the nature of the data flow on the **control bus** in a microcontroller.

Statement 1: The data flow is bi-directional on the **control bus**.

Statement 2: The data flow is omni-directional on the **control bus**.

Statement 3: The data flow is uni-directional on the **control bus**. **1**

(5)

Marks

2. Figure Q2 illustrates a liquid level control system.

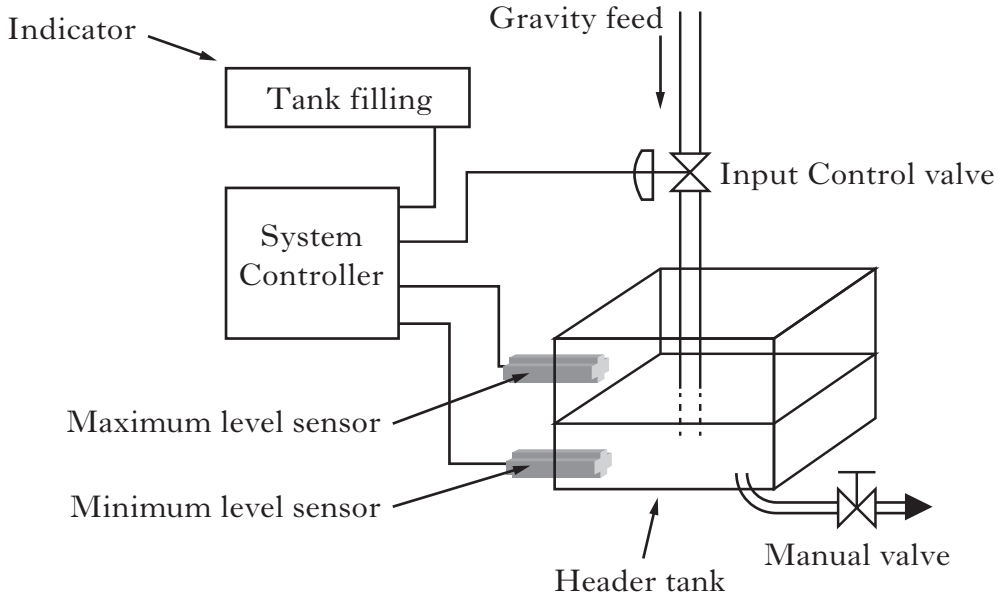


Figure Q2

The header tank liquid level is controlled between preset limits by a control system which opens/closes the Input Control valve when required. The manual valve is usually open and it is only closed during system maintenance. The header tank filling indicator illuminates while the Input Control valve is open.

(*a*) Sketch a flowchart that shows the operation of the system. Start with an initial level maximum, Input Control valve closed and manual valve open. **3**

Note: the inserted Flowchart Symbol sheet Q2/Q11/Q12/Q13 gives a suitable selection of Flowchart Symbols.

(*b*) List the various inputs and outputs required by the system controller. Clearly identify which signals are inputs and which are outputs. **2**

(5)

[Turn over

Marks

3. (*a*) The movement of each joint of a robotic system can be described as **either** Rotary **or** Linear. Figure Q3(*a*) shows a labelled diagram of a Cartesian robot.

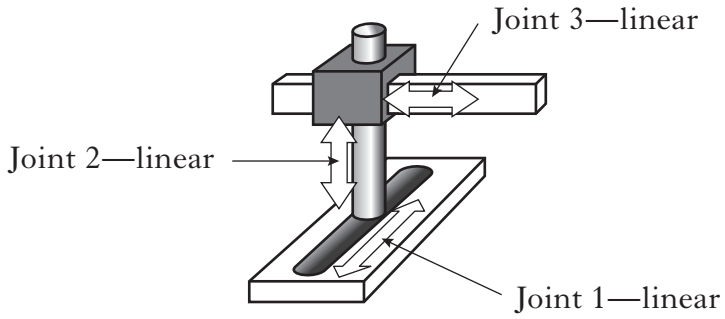


Figure Q3(*a*)

The movement for each joint of a Cartesian robot is shown in Table Q3(*a*). On **Worksheet Q3(*a*)**, complete Table Q3(*a*) by filling in the appropriate joint movement for a Polar and a Revolute robot.

Robot	**Joint 1**	**Joint 2**	**Joint 3**
Cartesian	Linear	Linear	Linear
Polar	Rotary		
Revolute	Rotary		

Table Q3(*a*) **2**

(*b*) **In your workbook**, briefly describe the basic operating principles of **either** a vacuum end effector **or** a magnetic end effector giving **one** practical application of your chosen end effector. You may wish to use a sketch to clarify your answer. **3**

(5)

Marks

4. Figure Q4 illustrates a set of electronic kitchen scales.

Figure Q4

(*a*) State a suitable sensor for this measurement application. **1**

(*b*) Describe the basic operation of your chosen sensor in Q4(*a*) making reference to the output signal of the sensor. **2**

(*c*) State **two** hazards that must be considered when using your chosen sensor in this environment. **2**

(5)

5. Figure Q5(*a*) illustrates a partially completed **pure/natural binary coded disc** for use in an optical rotary absolute encoder. On **Worksheet Q5**

(*a*) (i) Identify the number of bits represented.

(ii) Complete the shading of the disk.

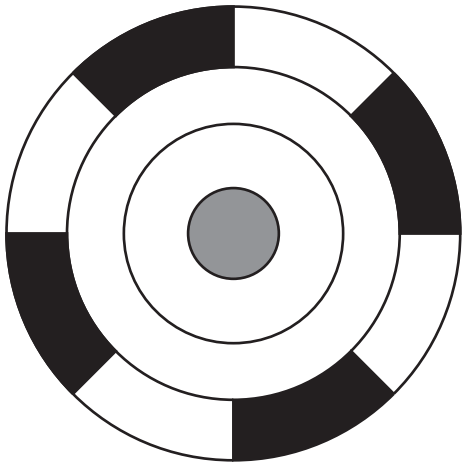


Figure Q5(*a*) **3**

(*b*) Briefly explain **one** major problem with using this disc code and state **one** solution to this problem. **2**

(5)

Marks

6. A PLC based control system meets the following specification.

- The system has two inputs, **X1** and **X2** and one output, **Y1**.
- Output **Y1** is **only** energised if **either or both** input switches, X1 and X2, are closed.

(*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 realized using a PLC (Programmable Logic Controller). **2**

Note: the inserted PLC Datasheet Q6/Q8/Q12 gives the PLC instruction set.

(*c*) Redraw your ladder diagram in Q6(*b*) to change the operation such that the output **Y1** can be latched and also enable the output **Y1** to be de-energised at any time using an additional input **X3**. **2**

(5)

7. Figure Q7 illustrates a cut away view of an optical incremental encoder.

Figure Q7

(*a*) Explain the basic operation of this type of encoder and describe the type of signal generated by this device. Illustrate your answer with a labelled sketch of this signal. **3**

(*b*) An encoder disk has 180 equally spaced slots and is rotated through 3 turns. State the count that would be accumulated in a counter if the initial count was zero. **1**

(*c*) It takes 1·5 seconds to accumulate the count in Q7(*b*), what is the rotational speed of the encoder in rpm? **1**

(5)

Marks

8.

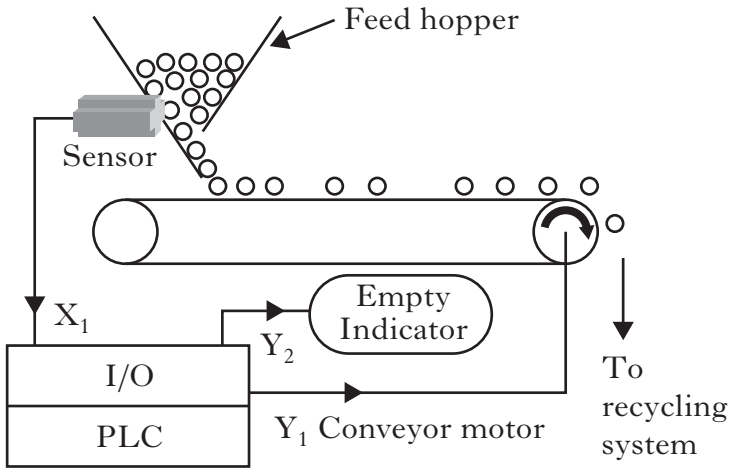
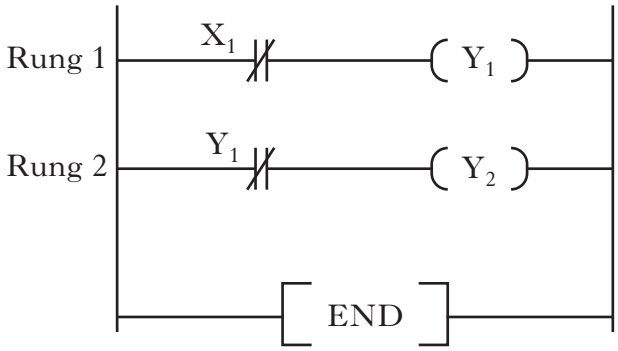


Figure Q8

Figure Q8 illustrates a simplified feed system for a recycling system controlled by a PLC.

- When the feed system is in operation, the conveyor runs continuously and feeds material to the recycling system.
- When the feed hopper sensor detects an empty hopper, Normally Closed contact X1 opens, the conveyor motor (Y1) will stop and the "EMPTY" indicator (Y2) will be illuminated.
- Ladder Diagram Q8 shows the ladder diagram program. The first two rungs have been numbered for convenience.



Ladder Diagram Q8

Describe the operation of the program in relation to the feed system, assuming initially:

- the feed hopper is full;
- the conveyor is running and;
- the EMPTY indicator is not illuminated. **(5)**

Note: the inserted PLC Datasheet Q6/Q8/Q12 gives the PLC instruction set.

Marks

9. (*a*) Sketch and label a basic block diagram of a closed loop control system. **2**

(*b*) State how an open loop control system generally differs from a closed loop control system when applied to the same process in terms of:

(i) Accuracy; **1**

(ii) Complexity. **1**

(*c*) State the main **advantage** of incorporating an integral element into a proportional control system. **1**

(5)

Marks

10. This question consists of a series of multiple choice questions and answers for a number of mechatronic related themes. On **Worksheet Q10**, answer the multiple choice question by putting a tick ✓ in the correct box.

(*a*) A pneumatic based Mechatronic System

A is maintenance free ☐
B uses compressible fluid ☐
C always provides linear motion ☐
D uses incompressible fluid ☐
E always provides rotary motion. ☐

(*b*) A PID control system

A is an open loop system ☐
B has no feedback ☐
C provides closed loop control ☐
D runs with a large offset ☐
E uses ON/OFF control. ☐

(*c*) An absolute linear encoder system **directly** measures

A pressure ☐
B flow ☐
C force ☐
D movement ☐
E temperature. ☐

(*d*) BCD is

A a type of robot geometry ☐
B a type of pneumatic motor ☐
C a control strategy ☐
D a mechatronic actuator ☐
E a coding system. ☐

(*e*) A thermocouple is a device used to sense

A time ☐
B heat ☐
C force ☐
D speed ☐
E light level. ☐ **(5)**

[*END OF SECTION A*]

SECTION B

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

Each question is worth 25 marks.

11. Figure Q11 illustrates the main parts of a fan-assisted shortbread oven with circulating air flow as shown.

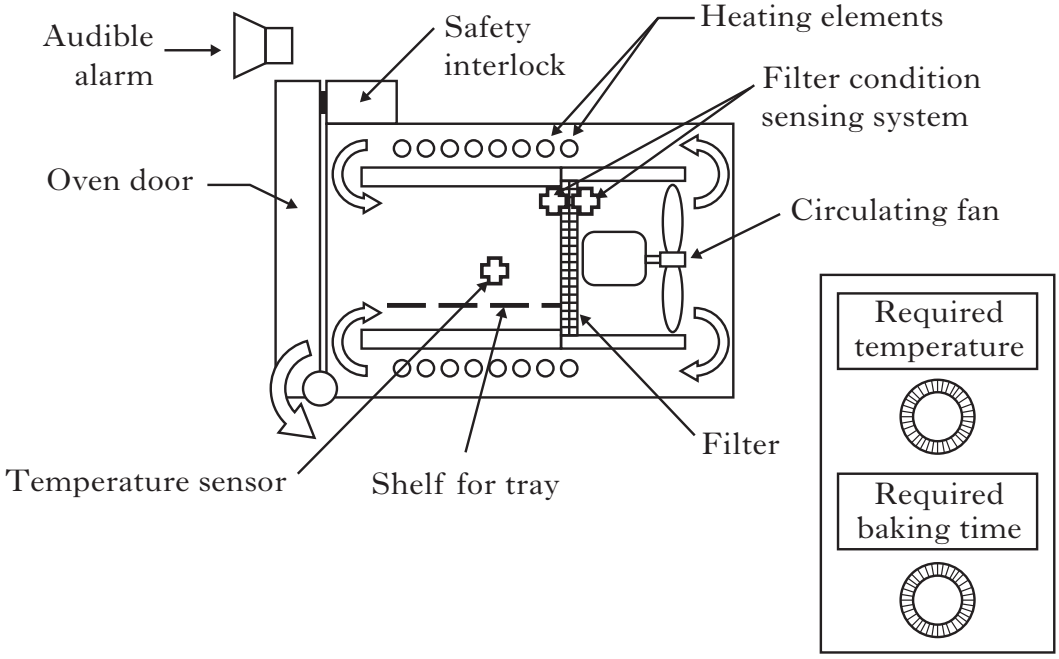


Figure Q11

A microcontroller is used to control the oven.

The oven door has an independent safety interlock that provides a signal to the microcontroller to indicate the door status, "door open" or "door closed".

The operator opens the oven door, places the shortbread tray on the shelf, selects the required baking time and required temperature and then closes the oven door.

During oven operation, the temperature sensor informs the microcontroller of the actual oven temperature. The microcontroller uses ON/OFF control of the heating elements to control the oven temperature.

The circulating fan runs constantly to ensure a continual flow of heated air.

The filter condition sensing system detects the filter condition and provides a filter condition signal. The audible alarm is activated when the filter needs to be cleaned or replaced.

(*a*) (i) Construct a table that clearly identifies all of the Input signals to the microcontroller.

(ii) Construct a table that clearly identifies all of the Output signals from the microcontroller. **4**

11. (continued)

Marks

(*b*) Assuming the oven door is closed, sketch a flowchart which shows how the ON/OFF decision is made for the control of the heating elements during one cycle of operation of the "temperature controlling process".

The flowchart should start with "read actual oven temperature" and should use the signals:

- required temperature and;
- actual oven temperature. **2**

Note: the inserted Flowchart Symbol sheet Q2/Q11/Q12/Q13 gives a suitable selection of Flowchart Symbols.

(*c*) Sketch a flowchart which describes the **overall** operation of the oven which includes:

- the door status signal;
- filter condition check;
- the "temperature controlling process" in Q11(*b*); **(This should be shown as a single labelled box)**
- the duration of operation (required baking time) at the required temperature.

Assume the circulating fan runs constantly and need **not** be shown on your flowchart. **5**

(*d*) Sketch and briefly describe a suitable differential pressure sensor that could be used in the filter condition sensing system. **3**

(*e*) The Microcontroller uses ON/OFF control of the heating elements to control the oven temperature. Describe with the aid of a sketch how the oven ON/OFF control operates. Your description and sketch should make reference to:

- heater ON time
- heater OFF time
- required temperature
- actual oven temperature. **4**

(*f*) The manufacturer wishes to improve the energy efficiency of the oven when there is no tray in the oven. This is to be achieved by ensuring that the heating elements' energy input is reduced to 20% of full power and the fan speed reduced to 10% of full speed.

(i) Briefly describe **one** method of reliably detecting when there is no tray in the oven. **2**

(ii) Describe **one** method of reducing **either** the energy input to the heating elements **or** the speed of the circulating fan. **3**

(*g*) State **one** hazard in this system and briefly describe how this hazard could be overcome. **2**

(25)

Marks

12. Figure Q12 shows an inspection system controlled by a PLC.

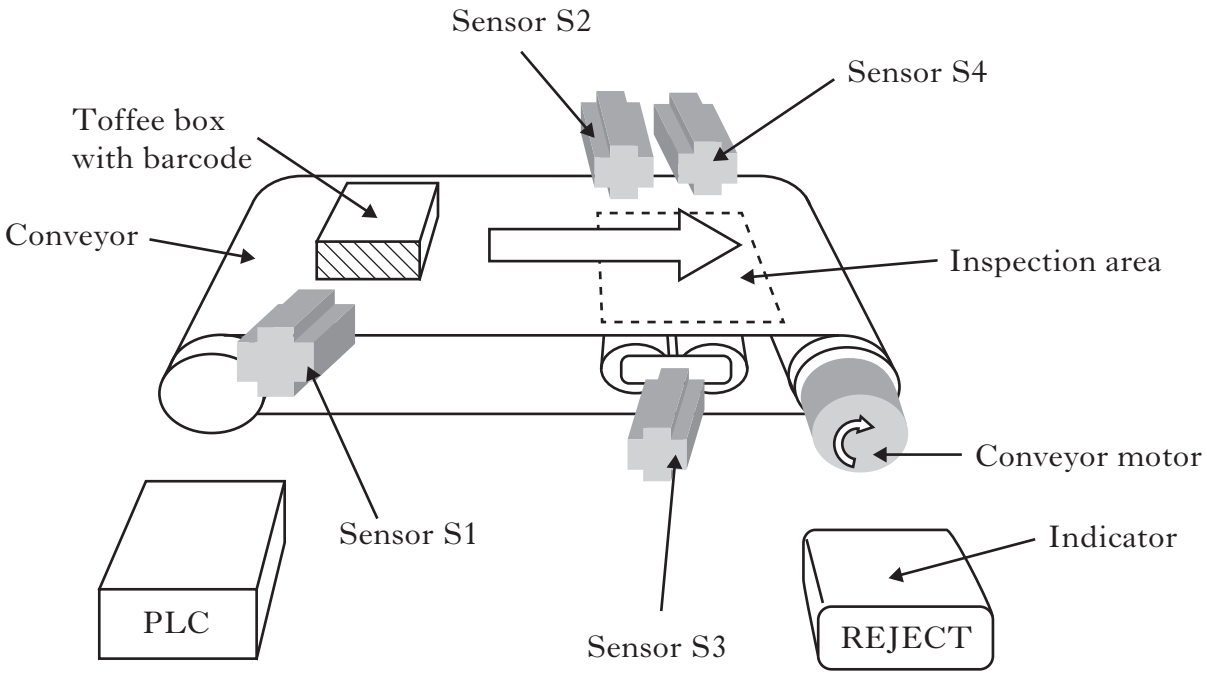


Figure Q12

The system operates as follows.

- The conveyor is initially stopped with no box present.
- When a toffee box is loaded, Sensor S1 sends a "Box loaded" signal to the PLC.
- The PLC then starts the conveyor which should carry the box to the Inspection area.
- When the box is in the Inspection area Sensor S2 sends a "Box Present" signal to the PLC.
- The PLC stops the conveyor when it receives the "Box Present" signal.
- If the weight of the box is unacceptable, Sensor S3 sends a "Weight Error" signal to the PLC.
- If the barcode is incorrect, Sensor S4 sends a "Barcode Error" signal to the PLC.
- If **either** the "Weight Error" **or** the "Barcode Error" signal is received then the "REJECT" indicator is illuminated by the PLC.

A separate handling system loads and unloads each box.

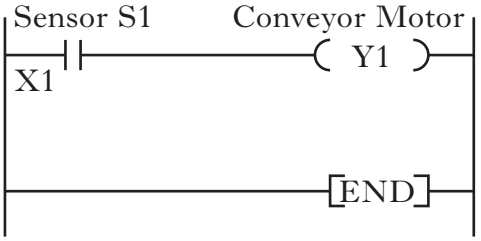
(*a*) Sketch a flowchart which shows the operation of the system. Start with the initial conditions:

- Conveyor stopped;
- Conveyor empty. **6**

Note: the inserted Flowchart Symbol sheet Q2/Q11/Q12/Q13 gives a suitable selection of Flowchart Symbols.

12. (continued)

(*b*) With reference to the initial Ladder Diagram Q12(*b*), briefly explain why a box loaded at Sensor S1 will NOT reach the inspection area and Sensor S2.



Ladder Diagram Q12(*b*) **2**

Note: the inserted PLC Datasheet Q6/Q8/Q12 gives the PLC instruction set.

(*c*) Produce a table which shows the PLC I/O allocation for the inspection system shown in Figure Q12. **3**

(*d*) Redraw the initial Ladder Diagram Q12(*b*) showing how it could be modified to ensure that the conveyor motor continues to run **until** the box is detected in the inspection area. **2**

(*e*) Add another rung to your ladder diagram which reads the "Weight Error" and "Barcode Error" signals to produce the required output for the "REJECT" indicator. **3**

(*f*) It normally takes a box 30 seconds to travel from Sensor S1 to Sensor S2. As an upgrade to the existing system, an audible alarm, Y3, is to be activated if a box has **not** arrived at S2 after 40 seconds.

Sketch a ladder diagram that includes **only** this upgrade and briefly describe its operation—there is no need to redraw other parts of the ladder diagram that remain unchanged. **4**

(*g*) State a suitable type of sensor for use as Sensor S1. **1**

(*h*) Identify **two** safety hazards inherent in the entire inspection system and state how **each** safety hazard could be reduced. **4**

(25)

[Turn over

Marks

13. Figure Q13 illustrates a powder coating system in which domestic radiators are manually loaded onto the overhead linear conveyor. The radiators come in three sizes (small, medium and large). The radiators move through the various work sections and are then manually unloaded as a coated product.

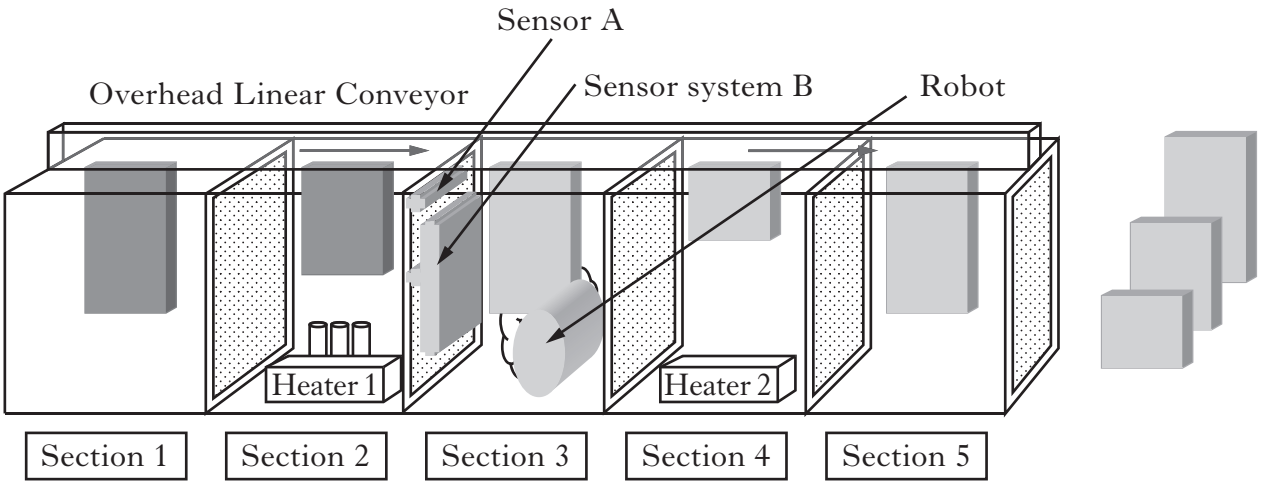


Figure Q13

The overhead linear conveyor runs continuously at a constant speed. Closed loop control ensures the overhead conveyor speed remains constant regardless of how many radiators are loaded on or unloaded from the conveyor.

- In Section 1 (load area), each radiator is manually loaded onto the overhead linear conveyor.
- In Section 2 (clean and dry), each radiator is preheated to 35 °C and is cleaned by blasting it with compressed air.
- In Section 3 (powder coat), Sensor A detects the arrival of a radiator. Sensor system B detects the radiator size and this information is used to decide which **one of three** coating programs is to be carried out by the robot. The radiator is powder coated by the automated robot.
- In Section 4 (dry and cure), the coated radiator spends 5 minutes at 85 °C where the coating hardens and dries.
- In Section 5 (unload area), the radiators are manually unloaded and are collected in batches for transportation to the final baking ovens (not shown).

(*a*) State and briefly describe **one** type of sensor which would be appropriate for sensing the speed of the overhead linear conveyor. **3**

(*b*) Briefly explain **two** safety hazards associated with this system and describe how they could be minimised or resolved at the design stage. **4**

Marks

(*c*) The rotary position of one axis of the robot used in Section 3 is sensed using an optical rotary encoder which uses an 8 bit Gray code.

(i) Calculate the resolution in degrees for this Gray code if the 8 bit code is distributed evenly over the full 360 degrees of the encoder disc. **2**

(ii) State **one** suitable robotic drive system and give **two** reasons, other than cost, that justify your choice. **3**

(*d*) The robot programs were created using a "lead-by-nose" technique. Describe this method of programming robots and justify its suitability for this application. **3**

(*e*) Sensor system B in Section 3 (powder coat) is used to detect the size of each radiator. Briefly describe the operation of a suitable sensing system stating the sensors being used. **3**

(*f*) Describe the operation and process decisions carried out as a radiator passes through Section 3 (powder coat). Start your description with the radiator entering Section 3 and make reference to your sensing system chosen in Q13(*e*). Either a written descriptive answer or Flowchart can be used. **3**

Note: the inserted Flowchart Symbol sheet Q2/Q11/Q12/Q13 gives a suitable selection of Flowchart Symbols.

(*g*) A sensor is required to monitor the flow rate of the powder being fed to the robot during the powder coating process in Section 3.

State and describe with the aid of a sketch a suitable sensor. **4**

(25)

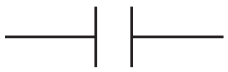
[*END OF QUESTION PAPER*]

[BLANK PAGE]

PLC Datasheet Q6, Q8, Q12

PLC Programming Details for Ladder Diagram Programming

Functions

Function type	***Function symbol***	***Function name***	***Function operand (see following table)***
Input		Normally open contact (NO)	X, Y, M, T
Input		Normally closed contact (NC)	X, Y, M, T
Output		Output	M, Y
Timer	 Timeout = ? sec	Timer	T
End			

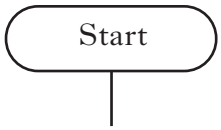
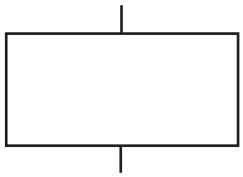
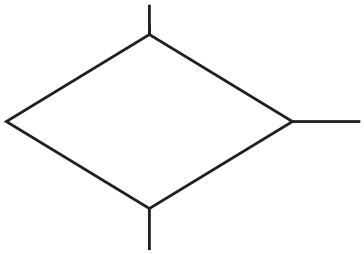
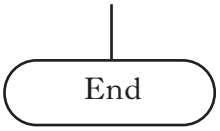
Operands

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

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.

Flowchart Symbol Sheet Q2, Q11, Q12, Q13

The following table shows a selection of Flowchart Symbols suitable for use in answering the questions.

Symbol	***Use***
	Starting Point for the flowchart
	Process / Action Box
	Decision Box
	Ending Point(s) for the flowchart

FOR OFFICIAL USE

X028/12/11

NATIONAL QUALIFICATIONS 2013

THURSDAY, 6 JUNE
1.00 PM – 4.00 PM

MECHATRONICS HIGHER

Worksheets for Q3(*a*), Q5 and Q10

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.

Worksheet Q3(*a*)

3. (*a*) The movement of each joint of a robotic system can be described as **either** Rotary **or** Linear. Figure Q3(*a*) shows a labelled diagram of a Cartesian robot.

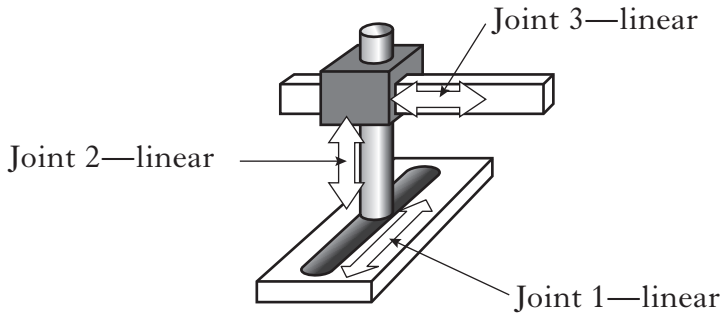


Figure Q3(*a*)

The movement for each joint of a Cartesian robot is shown in Table Q3(*a*). Complete Table Q3(*a*) by filling in the appropriate joint movement for a Polar and a Revolute robot.

Robot	**Joint 1**	**Joint 2**	**Joint 3**
Cartesian	Linear	Linear	Linear
Polar	Rotary		
Revolute	Rotary		

Table Q3(*a*)

Worksheet Q5

5. Figure Q5(*a*) illustrates a partially completed **pure/natural binary coded disc** for use in an optical rotary absolute encoder.

(*a*) (i) Identify the number of bits represented.

No of bits = _____

(ii) Complete the shading of the disk.

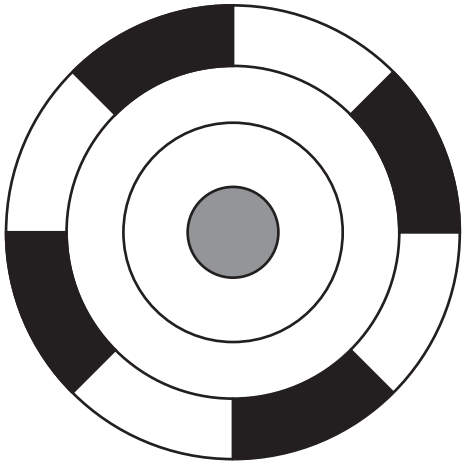


Figure Q5(*a*)

(*b*) Briefly explain **one** major problem with using this disc code and state **one** solution to this problem.

_____

_____

_____

_____

_____

_____

Worksheet Q10

10. This question consists of a series of multiple choice questions and answers for a number of mechatronic related themes. Answer the multiple choice question by putting a tick ✓ in the correct box.

(*a*) A pneumatic based Mechatronic System

A is maintenance free ☐
B uses compressible fluid ☐
C always provides linear motion ☐
D uses incompressible fluid ☐
E always provides rotary motion. ☐

(*b*) A PID control system

A is an open loop system ☐
B has no feedback ☐
C provides closed loop control ☐
D runs with a large offset ☐
E uses ON/OFF control. ☐

(*c*) An absolute linear encoder system **directly** measures

A pressure ☐
B flow ☐
C force ☐
D movement ☐
E temperature. ☐

(*d*) BCD is

A a type of robot geometry ☐
B a type of pneumatic motor ☐
C a control strategy ☐
D a mechatronic actuator ☐
E a coding system. ☐

(*e*) A thermocouple is a device used to sense

A time ☐
B heat ☐
C force ☐
D speed ☐
E light level. ☐

[*END OF WORKSHEETS*]