X028/301

NATIONAL QUALIFICATIONS 2011

FRIDAY, 10 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.

A Flowchart symbol sheet is included for questions 6, 11 and 13.

Worksheets are provided for questions 4, 6, 10 and 13.

SECTION A

Marks

Attempt ALL questions in this Section (50 marks).

1. (*a*) State **one** type of pressure sensor that could be used in a Mechatronic System. **1**

(*b*) With the aid of a simple sketch, briefly describe the basic operation of the sensor chosen in Q1(*a*). **2**

(*c*) State **two** appropriate applications for the sensor chosen in Q1(*a*). **2**

(5)

Marks

2. The diagram in Figure Q2 shows the basic architecture of a microcontroller. Some elements have been labelled with the letters A, B and C.

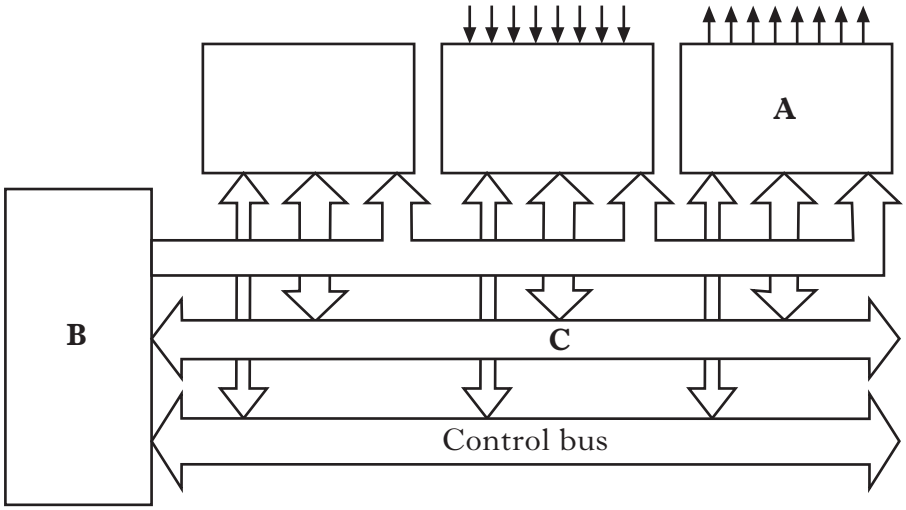


Figure Q2

(*a*) State which **one** of the rows in the Table Q2(*a*) correctly lists the names of the elements labelled A, B and C in Figure Q2.

Row	**Element A is the ...**	**Element B is the ...**	**Element C is the ...**
1	Input Unit	Memory Unit	Data Bus
2	Output Unit	Memory Unit	Address Bus
3	Output Unit	Microprocessor Unit	Data Bus
4	Input Unit	Microprocessor Unit	Address Bus

2

Table Q2(*a*)

(*b*) State which **one** of the following three statements below correctly describes the nature of the data flow on the **address bus** in a microcontroller.

Statement 1: The data flow is omni-directional on an address bus.

Statement 2: The data flow is bi-directional on an address bus.

Statement 3: The data flow is uni-directional on an address bus. **1**

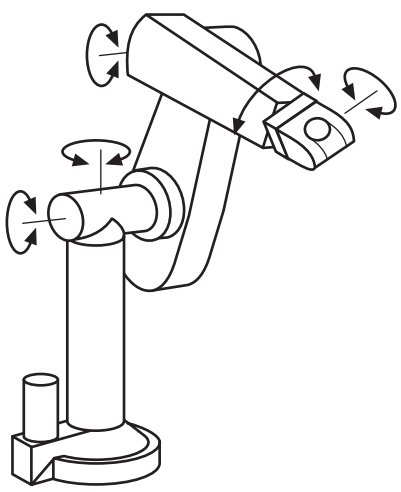
(*c*) A mechatronic control system is used within an industrial environment. Excluding cost, state **two** advantages that a Personal Computer (PC) based system has over a hard wired system. **2**

(5)

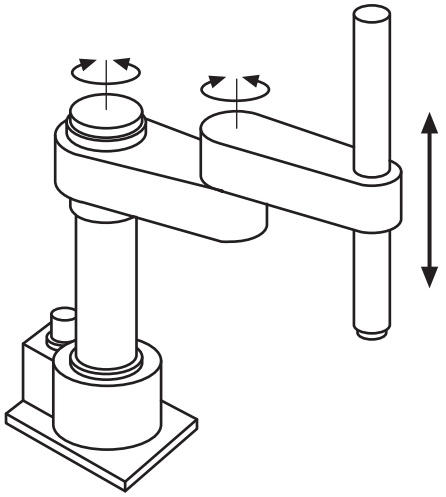
[Turn over

Marks

3.



Robot A



Robot B

Figure Q3(*a*)

(*a*) State the robot geometry and the number of axes of movement for Robot A. **2**

(*b*) State the robot geometry and sketch the work envelope for Robot B. **2**

(*c*) Give **two** examples of different types of robot end effector. **1**

(5)

Marks

4. Table Q4(*a*) shows a selection of codes used in Mechatronic Systems.

Decimal	**Code name = natural binary**	**Code name =**	**Code name =**
0	0000	0000	0000 0000
1	0001	0001	0000 0001
2	0010	0011	0000 0010
3	0011	0010	0000 0011
4	0100	0110	0000 0100
5	0101	0111	0000 0101
6	0110	0101	0000 0110
7			
8	1000	1100	0000 1000
9	1001	1101	0000 1001
10	1010	1111	0001 0000
11	1011	1110	0001 0001
12	1100	1010	0001 0010
13	1101	1011	0001 0011
14		1001	0001 0100
15	1111	1000	0001 0101

Table Q4(*a*)

(*a*) On **Worksheet Q4(*a*)**, complete Table Q4(*a*) by:

(i) inserting each of the **two** missing code names; **2**

(ii) inserting each of the **four** missing code values. **2**

(*b*) An encoder disc has 1080 equally spaced slots. On **Worksheet Q4(*b*)**, calculate the angular resolution in degrees of the encoder disc. **1**

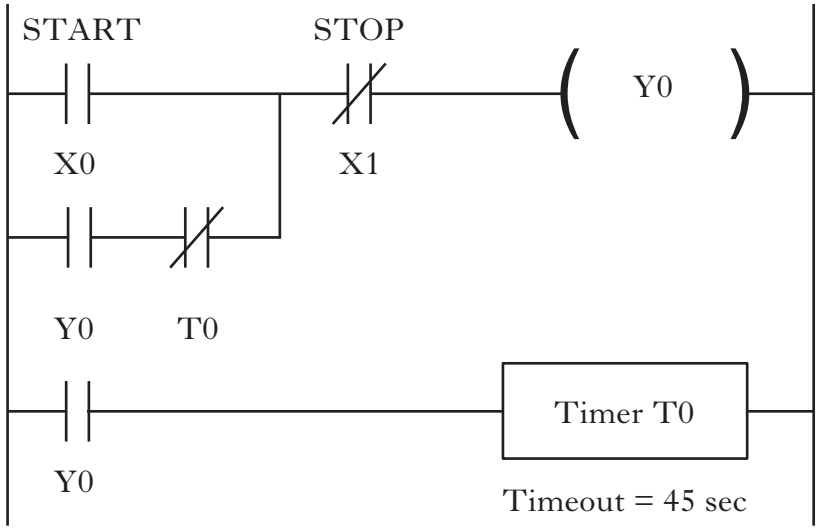
(5)

[Turn over

Marks

5. A mechatronic control system uses a Programmable Logic Controller (PLC).

Ladder Diagram Q5 shows part of the PLC program.



Ladder Diagram Q5

Describe the operation of Ladder Diagram Q5 starting from the press (and release) of the START button, X0. **(5)**

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

6. Figure Q6 illustrates a component sorting system.

Marks

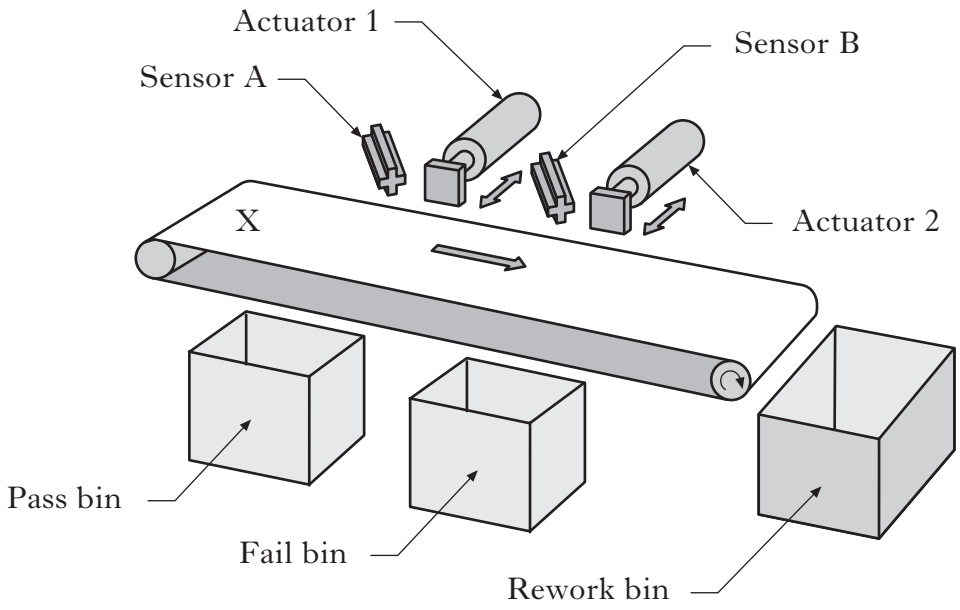


Figure Q6

The system operates as follows:

- Before being placed on the conveyor, each component is previously tested and identified as "Pass", "Fail" or "Rework".
- After identification, one component is placed on the conveyor at point X every 20 seconds.
- If the component detected by Sensor A is a "Pass", then it is pushed into the Pass bin by Actuator 1.
- If the component detected by Sensor B is a "Fail", then it is pushed into the Fail bin by Actuator 2.
- "Rework" components continue on into the Rework bin.
- Each actuator requires retraction after operation.
- The conveyor runs continuously.

On **Worksheet Q6**, sketch a flowchart which shows the operation of the automated sorting system for one component. The first part of the flowchart has been completed and is shown in Figure Q6(*a*). **(5)**

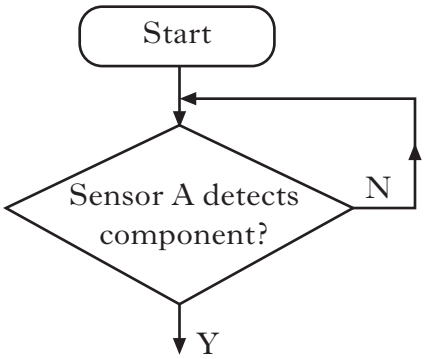


Figure Q6(*a*)

Note: the inserted Flowchart Symbol sheet Q6/Q11/Q13 gives a suitable selection of Flowchart Symbols.

Marks

7. (*a*) Describe with the aid of a sketch the term "ON/OFF control" with specific reference to an oven temperature control system. **2**

(*b*) Briefly describe each of the **three** elements of PID control. **3**

(5)

8. Figure Q8 illustrates a coded disc for use in an optical rotary absolute encoder.

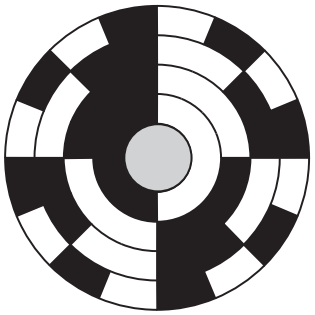


Figure Q8

(*a*) Identify the code represented on the disc in terms of:

(i) code type;

(ii) number of bits. **2**

(*b*) State the main problem with using this disc code type and state **one** solution to this problem. **2**

(*c*) Describe **one** method of improving the resolution of this type of coded disc. **1**

(5)

Marks

9. An automated hand dryer, shown in Figure Q9, consists of a controller, a proximity sensor, a heating element, a power on indicator and a motorised fan. The system is designed to blow warm air for 1 minute after the sensor is activated and then stop automatically. The heating element is interlocked to the motorised fan and it cannot operate until the fan is running. The heating element is switched off 5 seconds before the fan is stopped.

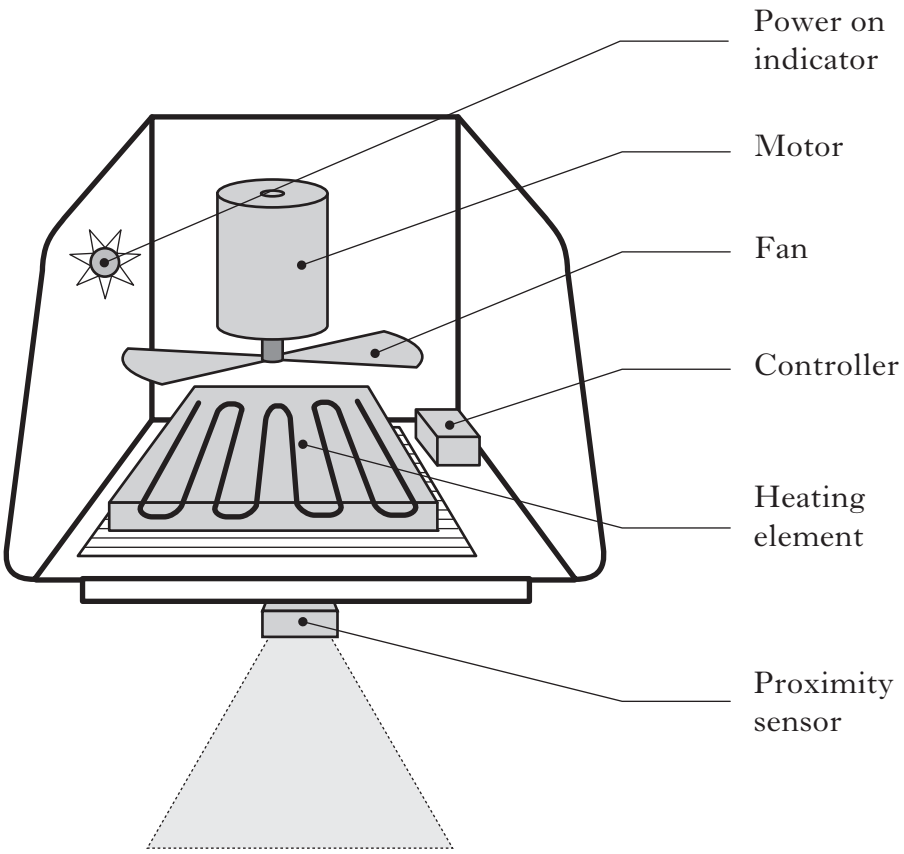


Figure Q9

(*a*) Create a table that clearly identifies all inputs, outputs and timing events in the above system. **3**

(*b*) State and briefly describe a suitable additional sensor that could be included to sense if the air flow has been reduced. **2**

(5)

[Turn over

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 bimetallic strip is a device used to sense

a temperature ☐
b pressure ☐
c flow ☐
d force ☐
e level. ☐

(*b*) A PID control system

a is an open loop system ☐
b is a closed loop system ☐
c has no feedback ☐
d runs with a large offset ☐
e uses ON/OFF control. ☐

(*c*) An example of a tactile sensor is

a an electric motor ☐
b a micro switch ☐
c a thermocouple ☐
d a Light Emitting Diode ☐
e a Hall effect device. ☐

(*d*) A solenoid is

a a sensor ☐
b a type of pneumatic motor ☐
c a control strategy ☐
d a mechatronic actuator ☐
e a coding system. ☐

(*e*) A strain gauge is a device used to sense

a time ☐
b heat ☐
c force ☐
d speed ☐
e light level. ☐

(5)

[*END OF SECTION A*]

[Turn over for SECTION B]

SECTION B

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

Each question is worth 25 marks

11. Figure Q11 shows a simplified schematic diagram of a semi-automated workstation that produces a small game which will be placed in a breakfast cereal box.

Two robots are used to assemble the small game. Robot 1 is a revolute robot which picks and places the supplied parts from the feeders. Robot 2 is a Cartesian robot which applies adhesive to Part A at an appropriate stage during the assembly process.

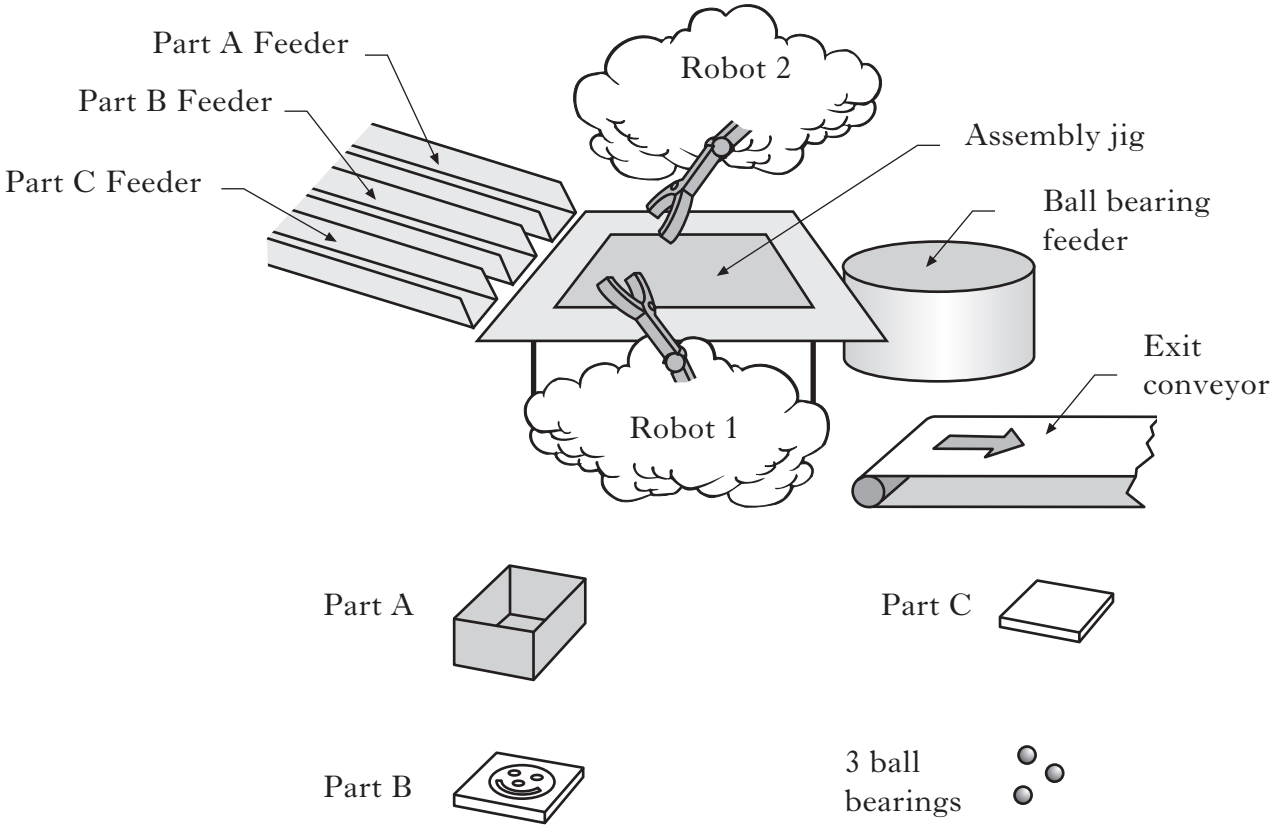


Figure Q11

The sequence of operation for the assembly of one game is as follows:

- Robot 1 selects Part A from feeder and places it in the assembly jig.
- Robot 1 selects Part B from feeder and places it in Part A.
- Robot 1 selects **three** ball bearings from the ball bearing feeder and places them into Part A and then Robot 1 goes to its home position.
- Robot 2 applies adhesive to Part A and then Robot 2 goes to its home position.
- Robot 1 selects Part C from feeder and places onto Part A.
- Robot 1 applies pressure to the assembly for 5 seconds while the adhesive cures.
- Robot 1 removes the assembled game from the jig and places it on the exit conveyor and then goes to its home position.

The ball bearings are supplied using the ball bearing feeder and are suitably presented for the gripper to lift three balls at the same time.

Marks

11. (continued)

(*a*) Robot 1 is a revolute robot.

(i) Give **one** reason why this may be considered a good choice of robot type for this application. **1**

(ii) Sketch the work envelope for a revolute robot. **1**

(iii) Robot 1 uses small electric motors for the joint drives. State **two** reasons why electric motors are a suitable choice for this robot. **2**

(*b*) Sketch a flowchart of the system for one complete cycle of assembly. Start with both robots at their home positions, the assembly jig empty and all the feeders having an adequate supply of parts. **4**

Note: the inserted Flowchart Symbol sheet Q6/Q11/Q13 gives a suitable selection of Flowchart Symbols.

(*c*) A gripper is required for Robot 1 that can pick and place the three ball bearings and also be able to detect if all three parts are present in the gripper. Sketch and briefly describe a suitable design for the gripper. **4**

(*d*) Identify **two** safety issues that arise when designing automated workstations and state how each issue could be resolved. **4**

(*e*) At present the feeders for Parts A, B and C have to be manually checked to see if any of them are empty. The system is to be enhanced to include hardware to sense if **any** of the three part feeders are empty and **alert the operator**. Briefly describe how the enhancement would work and list the additional hardware required. **4**

(*f*) Briefly describe how the time **and** the pressure applied to Part C could be sensed while the adhesive cures. **2**

(*g*) The small game will not function correctly if the **three** ball bearings are not enclosed within the assembly. Suggest and describe a suitable system which could be used to check if the **three** ball bearings are inside the game **before** Part C is glued in position. **3**

(25)

[Turn over

Marks

12. Figure Q12 shows a schematic diagram of a filler, capper, labeller and packaging robot used as part of a drinks bottling plant.

The clean empty glass bottles travel along the conveyor system and are filled, capped and labelled at the appropriate station. The process at the filling station takes 3 seconds.

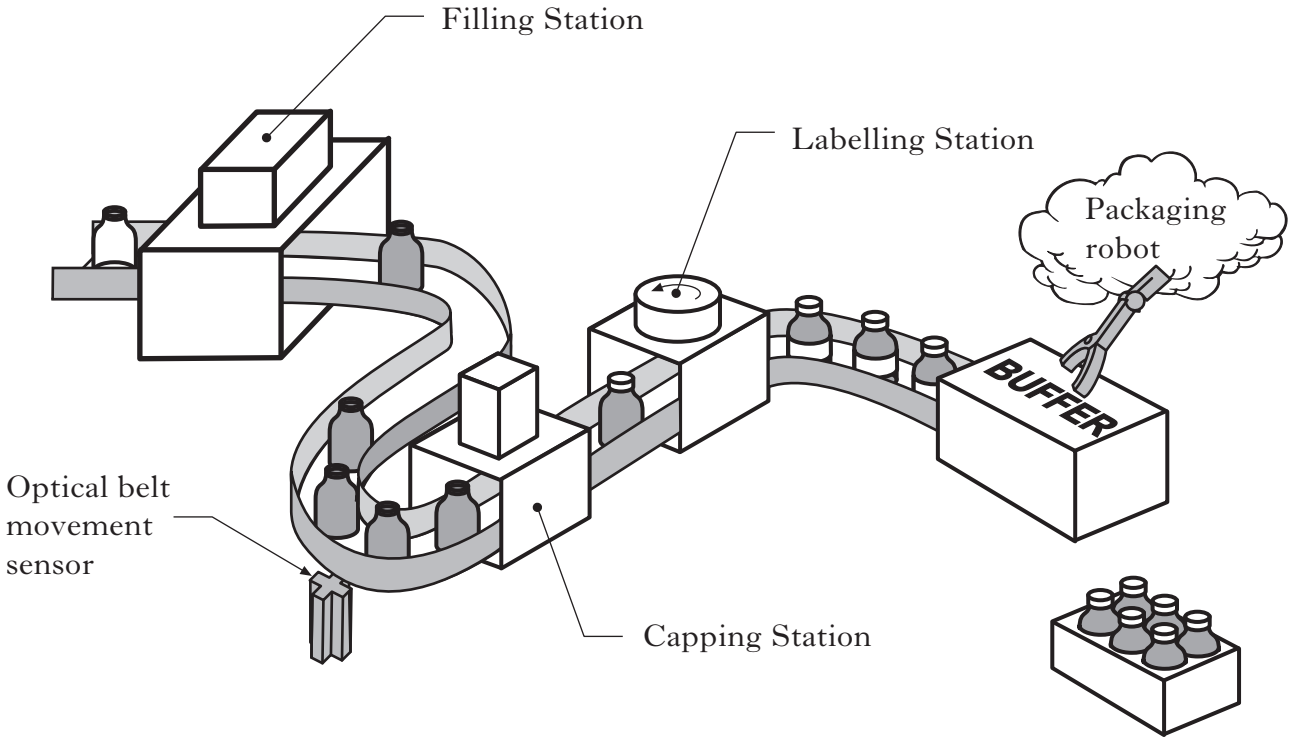


Figure Q12

(*a*) Choose and briefly describe a suitable sensor which would allow the amount of liquid **in the filled bottle** to be sensed. **2**

(*b*) The conveyor moves the bottles 80 mm every 3 seconds. On the edge of the conveyor belt, holes are placed every 2 mm to enable optical counting of the belt movement. Calculate how many binary data bits are required to count the number of holes passing the optical sensor every three seconds. **3**

(*c*) The capping unit is a pneumatic crimping system which places and squeezes the caps on the bottles.

(i) Give **two** reasons, other than cost, why pneumatics is a suitable choice for this physical process and working environment. **2**

(ii) The pneumatic crimping system incorporates a **single acting** cylinder. Describe the term "single acting" with reference to pneumatic actuators. **1**

(*d*) The bottle labels are applied by rotating each bottle through 300 degrees at the labelling station. Sketch and briefly describe a suitable actuator system which would enable this rotary action to be carried out. **3**

12. (continued)

(*e*) There is a small buffer station which allows the filled bottles to collect. The Cartesian packaging robot then transports **three** bottles at a time into the packing case.

(i) Sketch the work envelope for a Cartesian robot. **1**

(ii) List **four** considerations you would take into account when designing an end effector for the packaging robot to carry out the pick and place task. **2**

(*f*) (i) Outline **two** safety hazards associated with the automated bottling plant process and how each may be addressed at the design stage. **4**

(ii) Briefly describe **two** practical issues, in addition to safety issues, which could arise when actuating and sensing within an environment containing liquids, glass and a final product destined for human consumption. **2**

(*g*) (i) The system is to be enhanced to include hardware to sense if there is **any** liquid leakage or spillage, to stop the system and **alert the operator**. List the additional hardware required and briefly describe how the enhancement would work. **4**

(ii) Briefly describe the basic operation of a suitable sensor which could be used in Q12(*g*)(i) for this modification. **1**

(25)

[Turn over

13. Figure Q13 shows a simplified PLC controlled industrial car crusher.

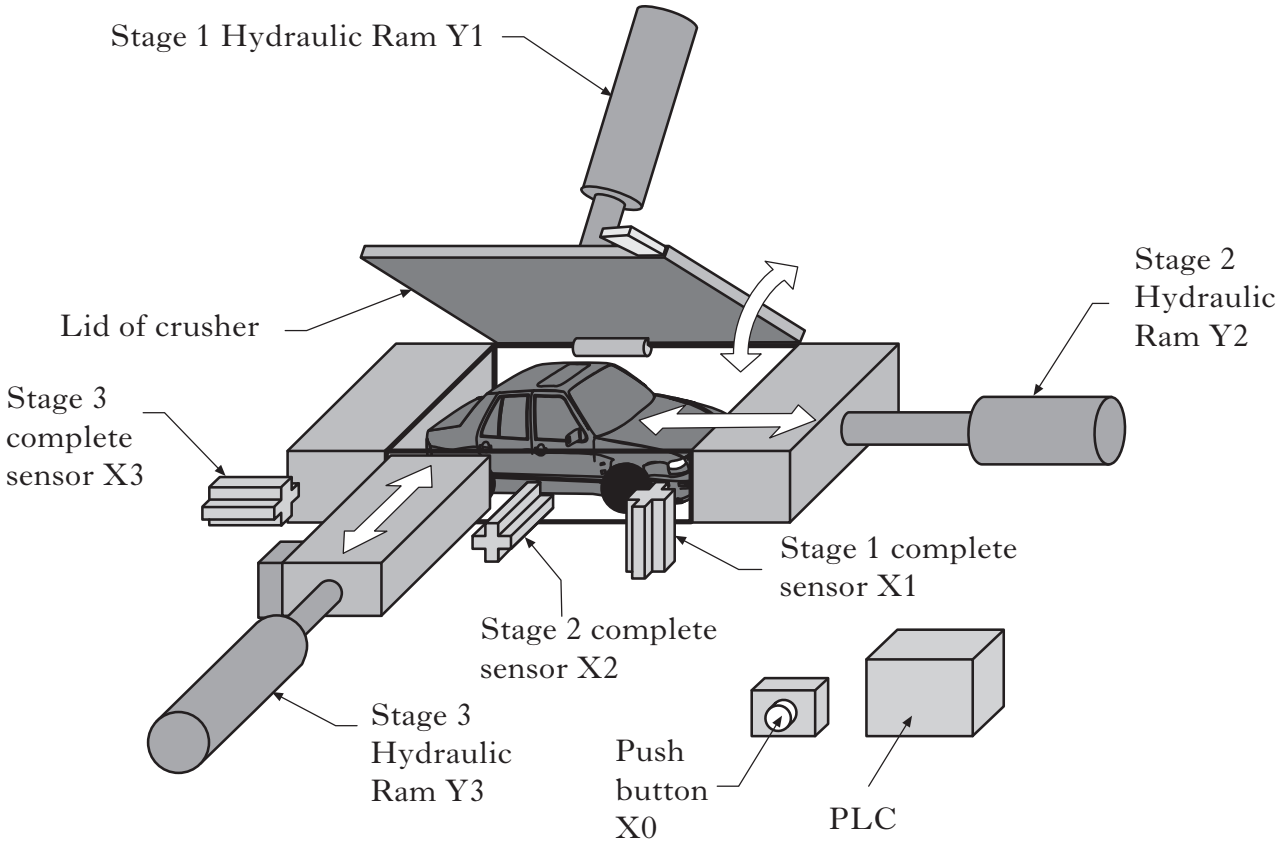


Figure Q13

The crusher operates as follows:

- The lid of the crusher is opened and a car is placed in the crusher.
- A push button is used to start the crusher sequence. It is connected to PLC input X0.
- On pushing the button (X0) the Stage 1 hydraulic ram (Y1) is "latched" on and the lid closes over the car.
- Stage 1 complete sensor is connected to PLC input X1, this senses when the hydraulically operated lid is closed. The Stage 1 hydraulic ram remains fully extended in this position.
- When X1 is activated the Stage 2 hydraulic ram (Y2) is "latched".
- Stage 2 complete sensor is connected to PLC input X2, this senses when the Stage 2 crushing is complete. The Stage 2 hydraulic ram remains fully extended in this position.
- When X2 is activated the Stage 3 hydraulic ram (Y3) is "latched".
- Stage 3 complete sensor is connected to PLC input X3, this senses when the car is finally a cube shape.

13. (continued)

- When X3 is activated all three hydraulic rams are unlatched and retracted in preparation for the removal of the crushed car and the loading of the next car.
- After the car is crushed, its weight is sensed.
- The process is now complete until the start button is pressed again.
- The three hydraulic rams have their own hydraulic control circuitry which means each ram extends when the PLC sends a control signal for them to extend and **automatically retracts** when that extend control signal is removed.

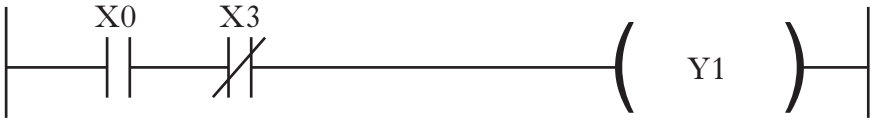
(*a*) On **Worksheet Q13(*a*)** complete I/O allocation table for the PLC.

Note: the inserted PLC Datasheet Q5/Q13 gives the PLC instruction set. **3**

(*b*) On **Worksheet Q13(*b*)**, draw a flowchart of the complete car crusher system that shows the process flow from when the start button is pressed to the point where the crushing is completed and all the hydraulic rams are retracted.

Note: the inserted Flowchart Symbol sheet Q6/Q11/Q13 gives a suitable selection of Flowchart Symbols. **6**

(*c*) On **Worksheet Q13(*c*)**, Ladder Diagram Q13(*c*) shows the initial rung of the PLC program. Modify the Ladder Diagram to ensure that the hydraulic ram continues to apply the crushing force **after** the Start button is released. **1**



Ladder Diagram Q13(*c*)

(*d*) Making reference to the diagram you modified in Q13(*c*), add a rung to your Ladder Diagram on **Worksheet Q13(*c*)** that would latch the operation of the Stage 2 hydraulic ram Y2 when triggered by the closure of X1. **3**

(*e*) On **Worksheet Q13(*e*)** sketch a Ladder Diagram of the final PLC program. Ensure your Ladder Diagram includes the operation of Stage 3 crushing and all **three** rams are retracted. Briefly describe the operation of Stage 3 and the retraction of rams. **4**

(*f*) The closed position of the crusher lid is detected by a sensor. **In your workbook**, suggest a suitable sensor and briefly describe its operation. **2**

(*g*) An electric motor drives the hydraulic pump. A system malfunction can cause the motor to overheat. State **two** types of temperature sensor which could be used to sense the motor temperature. Briefly describe the operation of **one** of your chosen sensors. **3**

[Turn over for Question 13(*h*) and (*i*) on *Page eighteen*]

Marks

13. (continued)

(*h*) When the crushing process is complete, a method of measuring the weight of the crushed car is required. State a suitable sensor for measuring this weight. **1**

(*i*) State **two** safety issues associated with this car crushing system. **2**

(25)

[*END OF QUESTION PAPER*]

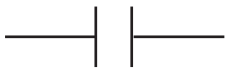
[BLANK PAGE]

[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 (NO)	X, Y, M, T
Input		Normally closed contact (NC)	X, Y, M, T
Output		Output	M, Y
Timer	 Timeout = ? sec	Timer	T
End			

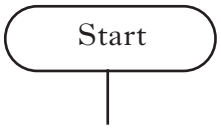
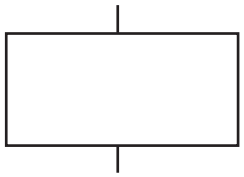
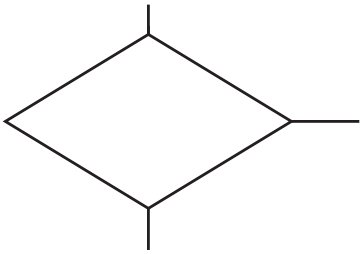
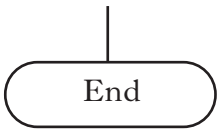
Operands

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 Q6, Q11, 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

Total Marks | | |

X028/302

NATIONAL QUALIFICATIONS 2011

FRIDAY, 10 JUNE
1.00 PM – 4.00 PM

MECHATRONICS HIGHER

Worksheets for Q4, Q6, 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.

Worksheet Q4

(*a*) Complete Table Q4(*a*) by:

(i) inserting each of the **two** missing code names;

(ii) inserting each of the **four** missing code values.

Decimal	**Code name = natural binary**	**Code name =**	**Code name =**
0	0000	0000	0000 0000
1	0001	0001	0000 0001
2	0010	0011	0000 0010
3	0011	0010	0000 0011
4	0100	0110	0000 0100
5	0101	0111	0000 0101
6	0110	0101	0000 0110
7			
8	1000	1100	0000 1000
9	1001	1101	0000 1001
10	1010	1111	0001 0000
11	1011	1110	0001 0001
12	1100	1010	0001 0010
13	1101	1011	0001 0011
14		1001	0001 0100
15	1111	1000	0001 0101

Table Q4(*a*)

(*b*) An encoder disc has 1080 equally spaced slots. Calculate the angular resolution in degrees of the encoder disc.

Angular Resolution = _____

Worksheet Q6

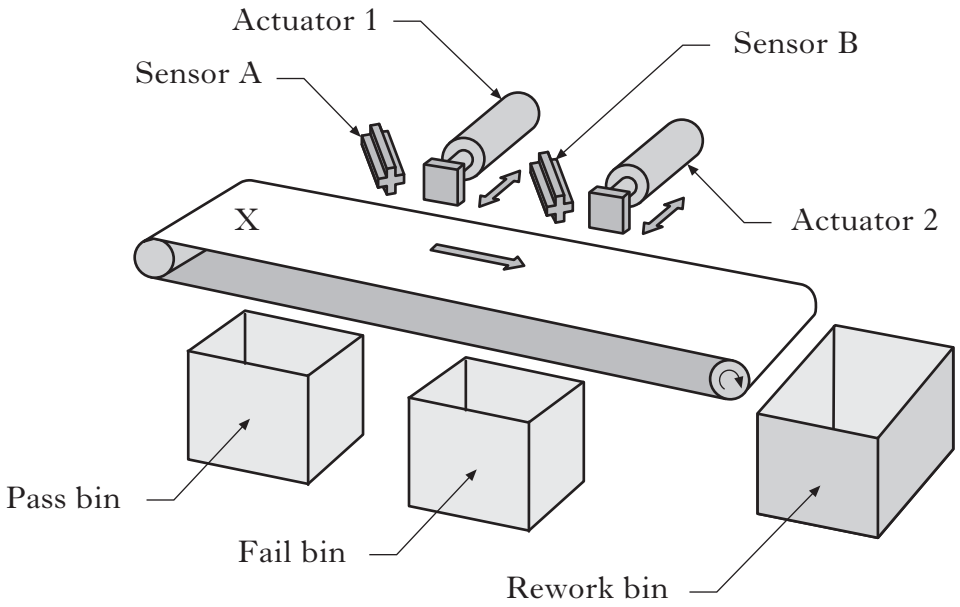


Figure Q6

Sketch a flowchart which shows the operation of the automated sorting system shown in Figure Q6 for one component. The first part of the flowchart has been completed and is shown in Figure Q6(*a*).

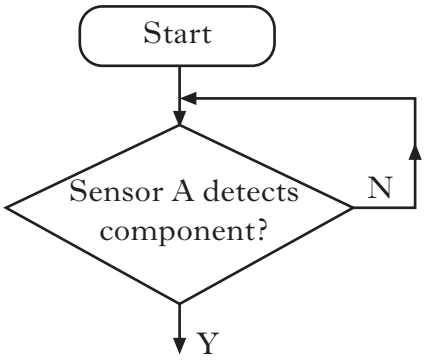


Figure Q6(*a*)

Note: the inserted Flowchart Symbol sheet Q6/Q11/Q13 gives a suitable selection of Flowchart Symbols.

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 bimetallic strip is a device used to sense

a temperature ☐
b pressure ☐
c flow ☐
d force ☐
e level. ☐

(*b*) A PID control system

a is an open loop system ☐
b is a closed loop system ☐
c has no feedback ☐
d runs with a large offset ☐
e uses ON/OFF control. ☐

(*c*) An example of a tactile sensor is

a an electric motor ☐
b a micro switch ☐
c a thermocouple ☐
d a Light Emitting Diode ☐
e a Hall effect device. ☐

(*d*) A solenoid is

a a sensor ☐
b a type of pneumatic motor ☐
c a control strategy ☐
d a mechatronic actuator ☐
e a coding system. ☐

(*e*) A strain gauge is a device used to sense

a time ☐
b heat ☐
c force ☐
d speed ☐
e light level. ☐

Worksheet Q13

(*a*) Complete I/O allocation table for the PLC.

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

Input		Output		Timer	
		Stage 1 hydraulic ram	Y1		

[Turn over

Worksheet Q13 (continued)

(*b*) Draw a flowchart of the complete car crusher system that shows the process flow from when the start button is pressed to the point where the crushing is completed and all the hydraulic rams are retracted.

START

Note: the inserted Flowchart Symbol sheet Q6/Q11/Q13 gives a suitable selection of Flowchart Symbols.

Worksheet Q13 (continued)

(*c*) Ladder Diagram Q13(*c*) shows the initial rung of the PLC program. Modify the Ladder Diagram to ensure that the hydraulic ram continues to apply the crushing force **after** the Start button is released.

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

Ladder Diagram Q13(*c*)

(*d*) Making reference to the diagram you modified in Q13(*c*), add a rung to your Ladder Diagram that would latch the operation of the Stage 2 hydraulic ram Y2 when triggered by the closure of X1.

[Turn over for Worksheet Q13(*e*)

Worksheet Q13 (continued)

(*e*) Sketch a Ladder Diagram of the final PLC program. Ensure your Ladder Diagram includes the operation of Stage 3 crushing and all **three** rams are retracted.

Briefly describe the operation of Stage 3 and the retraction of rams.

[*END OF WORKSHEETS*]