X028/12/01

NATIONAL QUALIFICATIONS 2012

WEDNESDAY, 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 and 11.

A Flowchart symbol sheet is included for questions 7, 11, 12 and 13.

Worksheets are provided for questions 3, 10, 11, 12 and 13.

SQA ©

SECTION A

Marks

Attempt ALL questions in this Section (50 marks).

1. (*a*) The list below shows the names of three types of controller used in a mechatronic control system:

- ASIC
- Hardwired
- Microcontroller

State how the controlling action could be altered for **each** type of controller. **3**

(*b*) Sketch a block diagram of a closed loop control system. Identify each element on your sketch. **2**

(5)

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

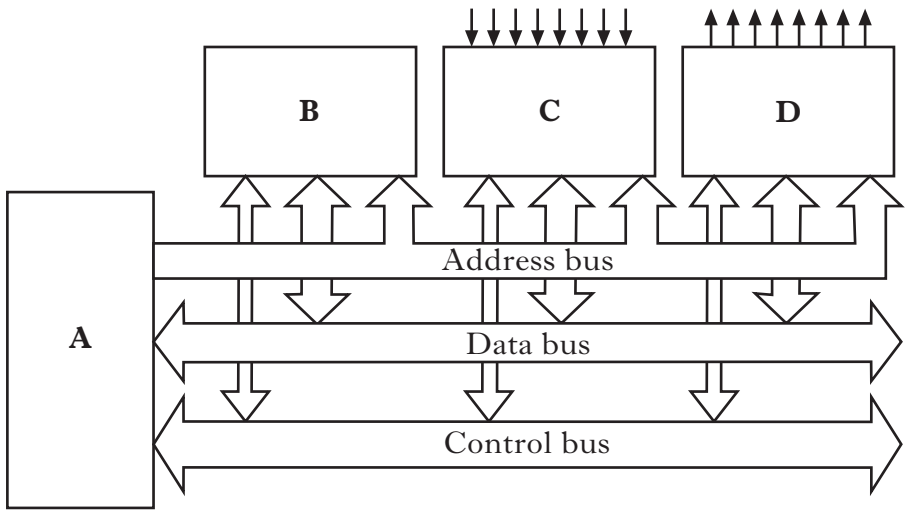


Figure Q2

(*a*) State the names of the elements labelled A, B, C and D in Figure Q2. **2**

(*b*) With reference to Figure Q2, state which **one** of the following three statements correctly describes the nature of the data flow on the **data bus** in a microcontroller.

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

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

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

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

(5)

Marks

3. Table Q3(*a*) shows a selection of 3 bit codes used in Mechatronic Systems.

Decimal	Code name =	Code name =
0	000	000
1	001	001
2	010	
3	011	
4		110
5		111
6	110	101
7	111	100

Table Q3(*a*)

(*a*) On **Worksheet Q3(*a*)**, complete Table Q3(*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 uses a 3 bit code. On **Worksheet Q3(*b*)**, calculate the angular resolution in degrees of the encoder disc. **1**

(5)

[Turn over

Marks

4. A mechatronic system uses a mechanical float valve system to sense and maintain the water level in a tank. The mechanical float valve system is to be replaced to allow remote level indication.

(*a*) State **one** type of sensor that could be used in the above mechatronic system to sense the water level. **1**

(*b*) With the aid of a simple sketch, briefly describe the basic operation of the sensor chosen in Q4(*a*). **2**

(*c*) Figure Q4(*c*) shows a bimetallic sensor used in a control system.

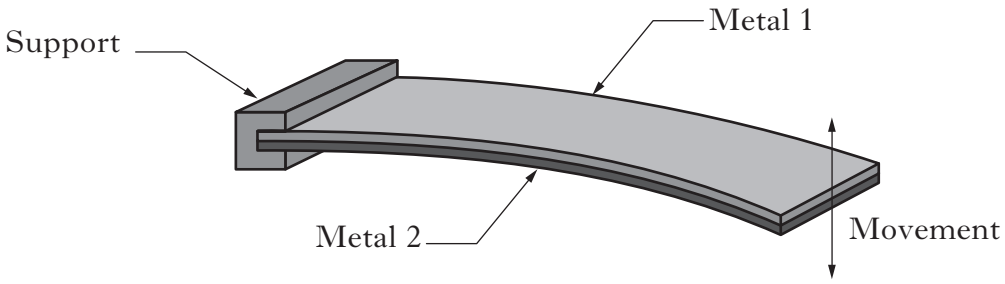


Figure Q4(*c*) Bimetallic sensor

Briefly describe the operation of this type of sensor. **2**

(5)

Marks

5.

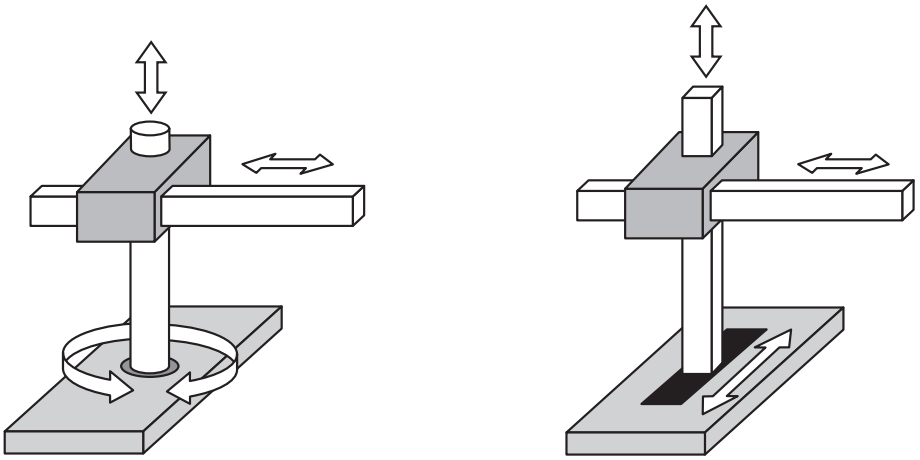


Figure Q5(*a*)

(*a*) State the robot geometries for Robot A and for Robot B in Figure Q5(*a*). **2**

(*b*) Sketch the work envelope for a Polar robot. **1**

(*c*) Sketch and briefly describe the basic operation of **either** a Vacuum type **or** a Magnetic type of end effector. **2**

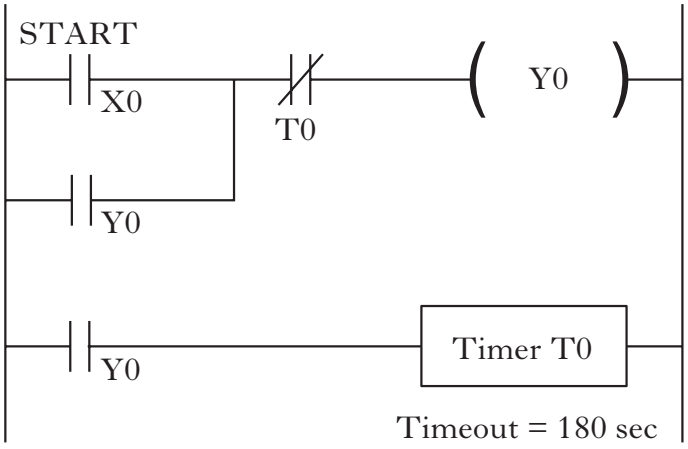
(5)

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

(*a*) Sketch a PLC ladder rung that shows an output, Y0, which is energised by the closure of **either** contact X0 **OR** contact X1. **1**

(*b*) Sketch a PLC ladder rung that shows an output, Y1, which is energised by the closure of contact X2 **AND** contact X3. **1**

(*c*) Ladder Diagram Q6(*c*) shows a PLC program.



Ladder Diagram Q6(*c*)

Describe the operation of Ladder Diagram Q6(*c*) starting from the press (and release) of the START button, X0. **3**

Note: the inserted PLC Datasheet Q6/Q11 gives the PLC instruction set. **(5)**

Marks

7. Figure Q7 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. Conveyor 2 runs continuously.

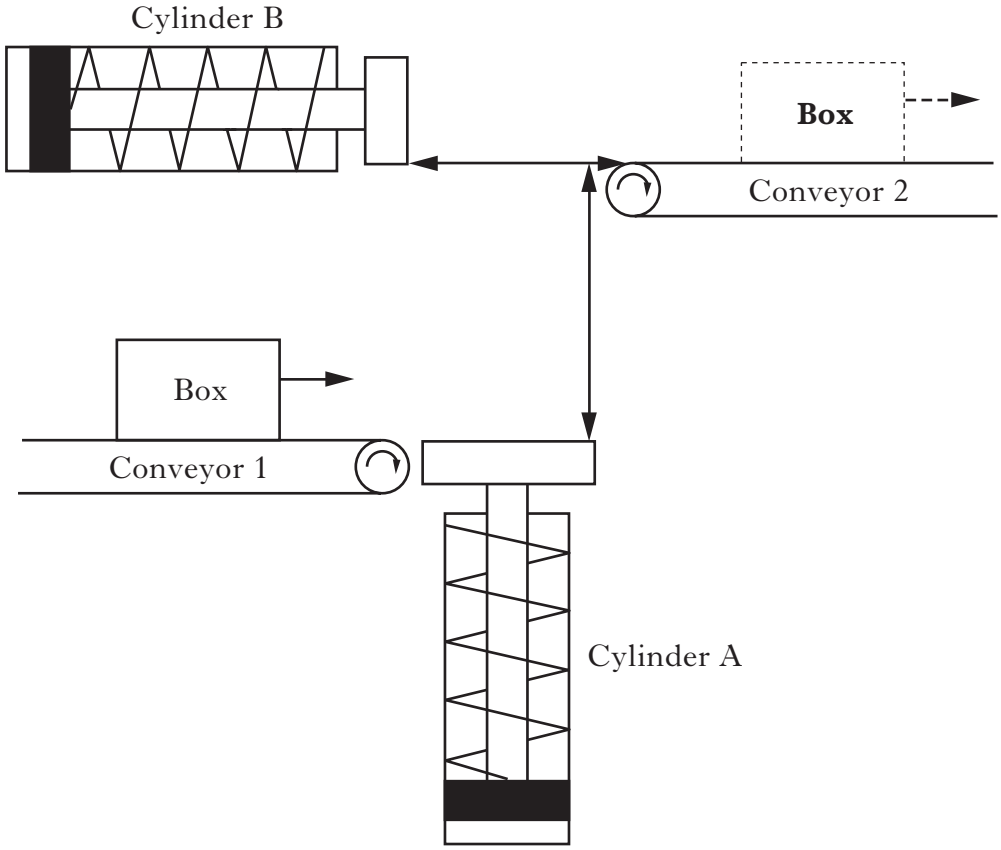


Figure Q7

(*a*) Sketch a flowchart which shows the sequence 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 Q7. In your flowchart simply state whether the appropriate cylinder is extended or retracted. **2**

Note: the inserted Flowchart Symbol Sheet Q7/Q11/Q12/Q13 gives a selection of suitable Flowchart Symbols.

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

(*c*) Describe **one** method of avoiding the potential problem described in Q7(*b*). **2**

(5)

Marks

8.

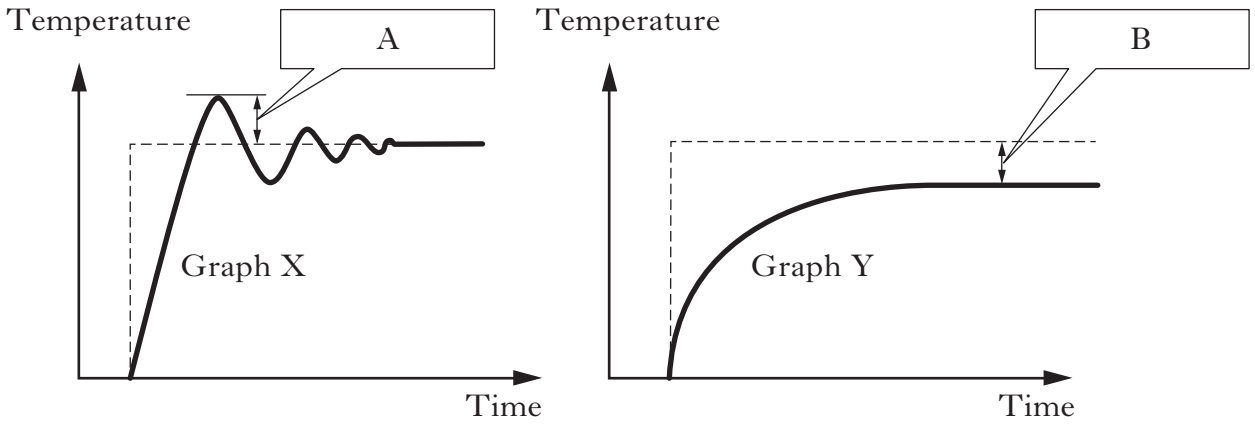


Figure Q8

Two types of control system step input response graphs are shown in Figure Q8.

(*a*) Referring to Figure Q8, name the feature indicated by

(i) A on graph X.

(ii) B on graph Y. **2**

(*b*) State which **one** of the following statements is true with reference to the graphs in Figure Q8.

Statement 1 Graph X shows PID control, graph Y shows Proportional control.

Statement 2 Graph X shows PID control, graph Y shows ON/OFF control.

Statement 3 Graph X shows ON/OFF control, graph Y shows Proportional control.

Statement 4 Graph X shows Proportional control, graph Y shows PID control. **1**

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

(5)

[Turn over

Marks

9. Figure Q9 shows a simplified schematic diagram of a sensing system used in an Olympic swimming pool. The system comprises Starting Block, Lane Pad A, Lane Pad B and Timer which are used to record the start and end times during the swimming events.

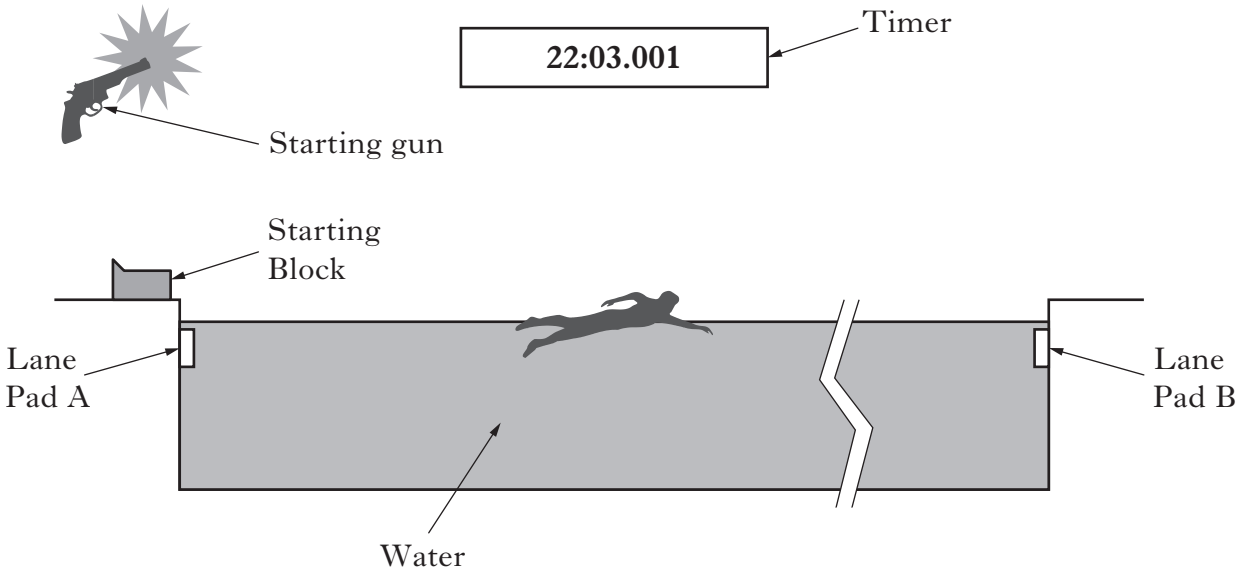


Figure Q9

(*a*) Traditionally a starting gun is used to start the race but false starts are an issue in this type of event. The sports agreed minimum reaction time of a competitor to the starting gun is 0·16 seconds. Briefly describe **a system** that could detect if a competitor left the Starting Block within 0·16 seconds of the starting gun having been fired. **2**

(*b*) State a suitable **sensor** that could be incorporated within the Starting Block that would detect when a competitor has left the block. **1**

(*c*) In a relay race, the team is disqualified if the waiting swimmer leaves the Starting Block within 0·16 seconds of Lane Pad A being activated by the arriving swimmer.

Describe how the system should respond to the Starting Block and Lane Pad A inputs. **2**

(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 questions by putting a tick ✓ in the correct box.

(*a*) In a mechatronic control system, PID stands for

a Proportionally Integrated Diode ☐
b Power Indication Display ☐
c Proportional Integral Derivative ☐
d Phase Inverting Driver ☐
e Passive Integrating Device. ☐

(*b*) An Event Based Control System

a uses only timers ☐
b must have at least one sensor ☐
c always uses timers and sensors ☐
d must have a timer ☐
e is always slow to complete the task. ☐

(*c*) The PLC contact shown in Figure Q10(*c*) is

a a normally open contact ☐
b an output ☐
c a timer ☐
d a normally closed contact ☐
e a counter. ☐

Figure Q10(*c*)

(*d*) A hydraulic ram is

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

(*e*) An example of a visual indicator is

a a buzzer ☐
b a thermistor ☐
c a thermocouple ☐
d a Light Emitting Diode ☐
e a strain gauge. ☐

(5)

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[*END OF SECTION A*]

SECTION B

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

Each question is worth 25 marks

11. A sports stadium goods entrance uses a roller shutter door as shown in Figure Q11. Exit by this door is **not** allowed. The roller shutter door is controlled by a Programmable Logic Controller (PLC) using sensors and actuators.

To raise the roller shutter door, the reversible motor turns in the Forward (F) direction and an upper limit sensor senses when the door has reached the fully open position. To lower the roller shutter door, the motor turns in the Reverse (R) direction and a lower 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 Q11. One of the sensors, B, is a complete truck length inside the door.

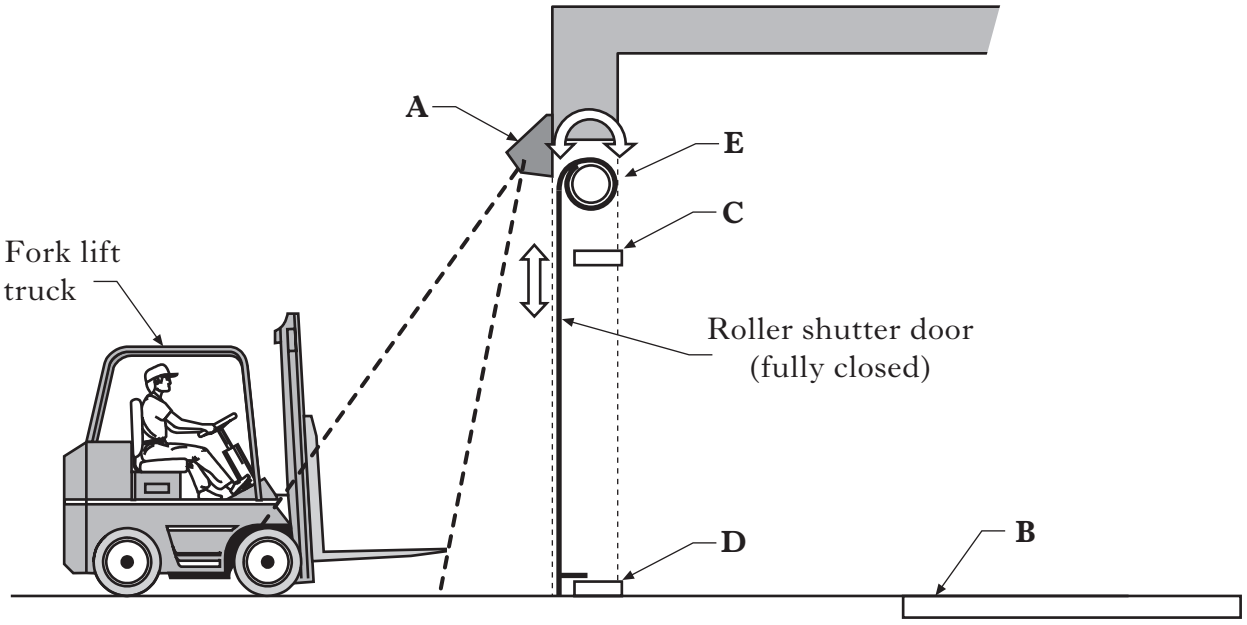


Figure Q11

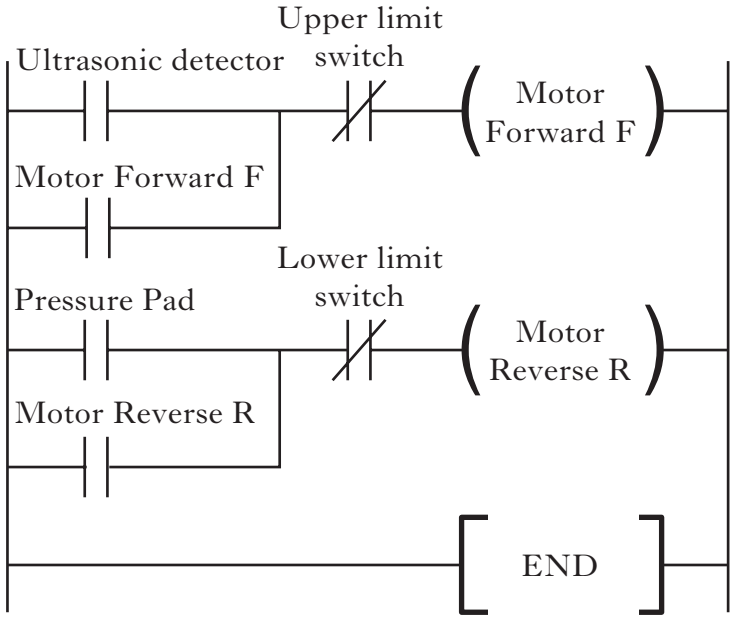
The basic operation of the entrance control system is as follows:

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 reversible motor. The motor then stops. The truck can now enter.

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

A basic ladder diagram program for use with the PLC in this application is shown in Ladder Diagram Q11.

11. (continued) *Marks*



Ladder Diagram Q11

Sensors and actuators are specified in Table Q11.

Sensors/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 the PLC.
Ultrasonic detector	When it detects any movement, provides a logic 1 to the PLC.
Reversible motor	There are 2 control connections, Forward (F) and Reverse (R). F R 0 0 – motor stop 1 0 – moves the door UP 0 1 – moves the door DOWN 1 1 – motor stop (alarm)

Table Q11

(*a*) With reference to the above information, on **Worksheet Q11**, in Table Q11(*a*):

(i) in the **Letter** column, enter the letters A to D shown against each device in Figure Q11. **2**

(ii) in the **Reason** column, state **one reason** why each sensor is placed in the position shown in Figure Q11. **2**

(iii) in the **PLC I/O** column, allocate the I/O to the sensors and actuators. **2**

Note: the inserted PLC Datasheet Q6/Q11 gives the PLC instruction set.

[Turn over for Question 11(*b*) to (*g*) on *Page twelve*

11. (continued)

(*b*) On **Worksheet Q11**, complete the labelling of the Ladder Diagram Q11(*b*) using your PLC I/O allocations from **your** Table Q11(*a*). **1**

(*c*) On **Worksheet Q11**, describe the operation of the Ladder Diagram Q11(*b*) in relation to the application. **5**

(*d*) **In your workbook**, sketch a flowchart of the desired sequence of operations for one complete cycle. Assume that the roller shutter door is initially closed and the fork lift truck is approaching the entrance control system. **6**

Note: the inserted Flowchart Symbol Sheet Q7/Q11/Q12/Q13 gives a selection of suitable Flowchart Symbols.

(*e*) Explain the nature of the hazardous conditions which could arise if fork lift trucks arrive in quick succession. **2**

(*f*) To meet a design change, the roller shutter door is to remain open to allow closely following fork lift trucks through. State what changes would be required to the system hardware and/or PLC program. **2**

(*g*) Safety is an important consideration in the design of this system.

(i) State and briefly describe **one** suitable sensor that could detect if the lower edge of the closing roller shutter door makes contact with an obstacle. **2**

(ii) Suggest **one** further change to the system that will improve its safety. **1**

(25)

12. Figure Q12 illustrates a schematic diagram of a fully automated bicycle frame assembly station.

Each frame design assembled can be EITHER a Frame type X OR a Frame type Y. Each frame type consists of 3 frame tubes and 3 housings. The main assembly station components are an assembly jig, two revolute robots (Robot 1 and Robot 2), Housing feeders, Tube feeders and a Completed frame conveyor.

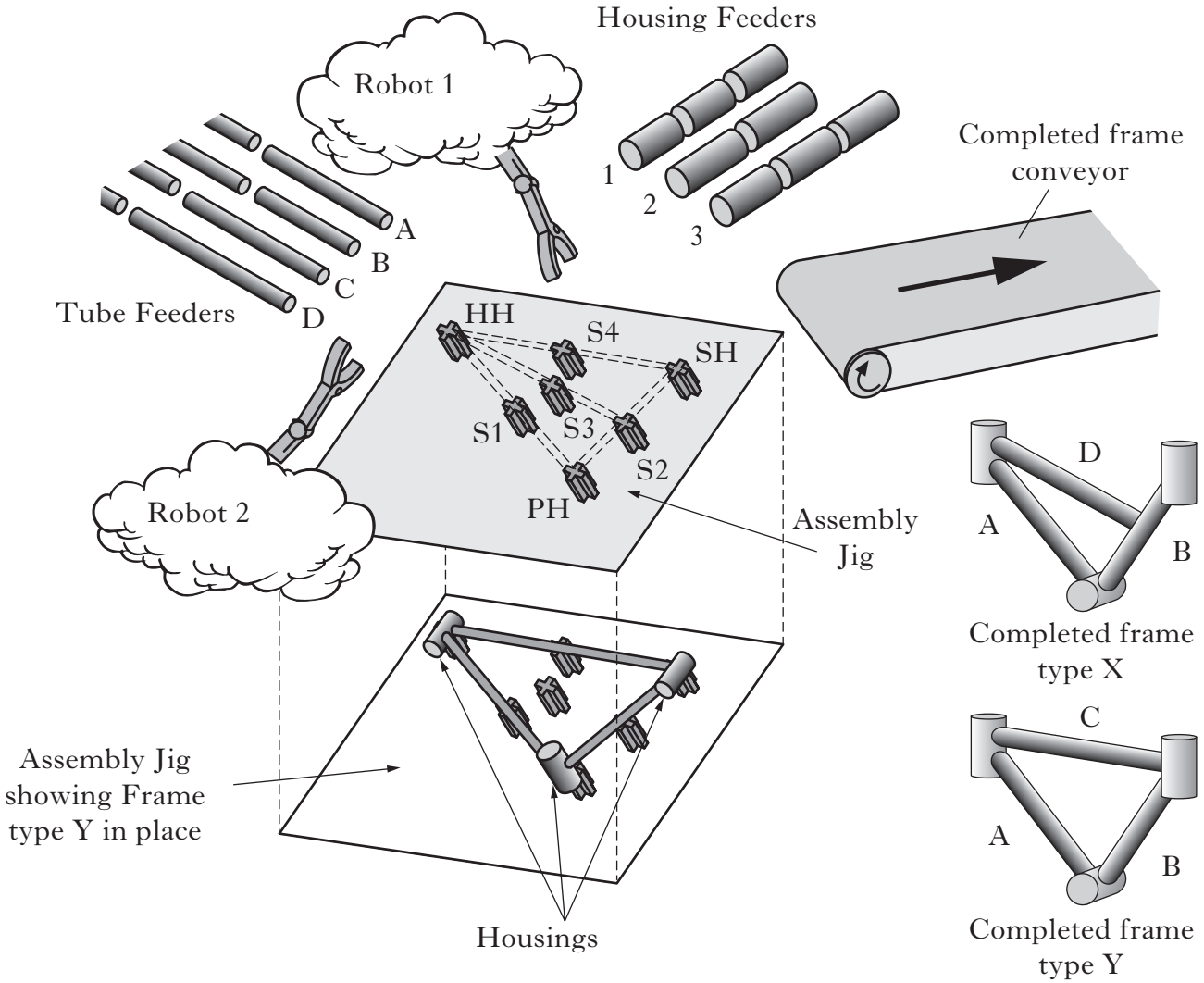


Figure Q12

The system operates in the following way:

Before the assembly process starts, an initial system check is performed. This system check ensures that all feeders have parts, both robots are in their home position and the assembly jig is empty. If these conditions are met, then the assembly process starts. If any of the conditions are not met, then an alarm is sounded and manual intervention is required.

Robot 1 selects and places the handlebar housing in location HH, seat housing in location SH and pedal housing in location PH on the assembly jig. These housing parts are supplied via the Housing feeders 1, 2 and 3 respectively.

The system controller generates a frame design signal (X or Y) which informs Robot 1 which 3 of the 4 possible frame tube types are needed. Robot 1 selects the three frame tubes from the Tube Feeders (A, B and **either** C **or** D) and places them into position on the assembly jig. Robot 1 homes.

12. (continued)

The assembly jig has 4 microswitch tube sensors, labelled S1, S2, S3 and S4 which detect the presence of frame tubes A, B, C and D respectively.

All components are manufactured from mild steel.

Upon receiving a signal from Robot 1, Robot 2 welds the joints between the housings and the frame tubes. The position of the welds will differ depending upon which type of frame, X or Y, is being produced. Upon completion of the welding task, Robot 2 homes and signals Robot 1 which then removes the completed assembly and places it on the Completed frame conveyor. Robot 1 homes.

(*a*) Sketch and describe a suitable gripper which could be used for Robot 1 to transfer the housings and frame tubes to the assembly jig. **3**

(*b*) The assembly jig has 4 microswitch tube sensors.

(i) On **Worksheet Q12**, briefly describe the operation of this sensor system to ensure all frame tubes are in place for the frame design (X or Y) selected before welding commences. **1**

(ii) On **Worksheet Q12** complete the sensor activation Table Q12(*b*) to show which tube sensors need to be activated prior to the correct welding program being activated. **3**

Tube Sensor	Frame X	Frame Y
Sensor 1 (S1)	ON	ON
Sensor 2 (S2)		
Sensor 3 (S3)		
Sensor 4 (S4)		

Table Q12(*b*)

(*c*) On **Worksheet Q12**, complete the flowchart for the assembly process, for **one** frame, ensuring the initial system check is carried out. **6**

Note: the inserted Flowchart Symbol Sheet Q7/Q11/Q12/Q13 gives a selection of suitable Flowchart Symbols.

(*d*) **In your workbook** state **two** reasons why revolute robots have been chosen for this assembly station. **2**

(*e*) Robot 2 was programmed to weld each joint using the "**lead by nose**" technique. Describe this method of programming a robotic arm. **2**

(*f*) State **two** potential safety hazards with this type of automated assembly system and briefly describe how they could be addressed at the design stage. **4**

Marks

12. (continued)

(*g*) The designers have decided to incorporate a suitable inspection system into the assembly station to verify the housings and frame tubes have been placed in the correct location and orientation. Briefly describe a suitable system and identify any additional hardware requirements. **2**

(*h*) Robots 1 and 2 use electric motors for drive. State **two** reasons why electric motors are suitable for this application. **2**

(25)

[Turn over

13. Figure Q13 illustrates a Microcontroller controlled semi-automatic injection machine, which manufactures plastic gears. The Injector is pneumatically actuated and the Die assembly mechanism is hydraulically actuated.

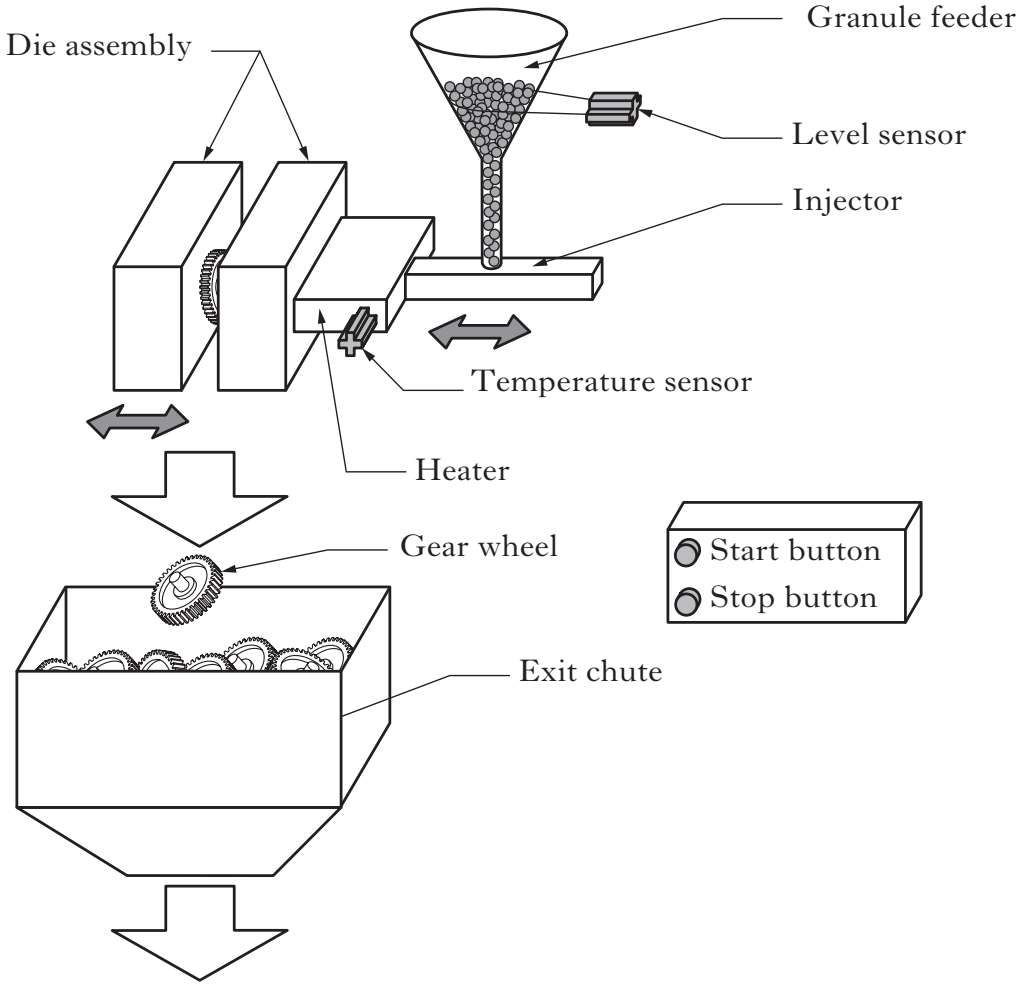


Figure Q13

The system is initially activated with a Start button. The system is then initialised with the Injector retracted and the Die assembly closed.

After initialisation, a pre-determined volume of granules are gravity fed from the feeder into the pneumatic Injector. The injector Heater is switched on and the granules melt when the required temperature is reached. The Injector is then extended and the hot melt is forced under pressure into the Die assembly. The injector Heater is switched off and after 20 seconds the Injector is retracted. The Die assembly opens and the plastic gear wheel falls into the Exit chute. The Die assembly then closes and the cycle is repeated.

A single production run of the system produces plastic gear wheels until the feeder is empty. The system will then stop and sound an alarm. The feeder must be refilled before the process is restarted.

Marks

13. (continued)

(*a*) Produce a list of :

(i) the system Inputs

(ii) the system Outputs

that will require interfacing to the microcontroller. **3**

(*b*) On **Worksheet Q13(*b*)** complete the flow chart showing one single production run of the system. **6**

Note: the inserted Flowchart Symbol Sheet Q7/Q11/Q12/Q13 gives a selection of suitable Flowchart Symbols.

(*c*) **In your workbook**, state and briefly describe a suitable sensor that may be used to monitor the level of granules in the Granule feeder. **2**

(*d*) State **three** advantages, excluding cost, of using pneumatics compared with using hydraulics within the injection system. **3**

(*e*) Sketch and briefly describe a suitable actuator system that could be used to clamp/unclamp the Die assembly and state **one** reason why hydraulics is a suitable choice for this system. **3**

(*f*) List **three** potential safety risks associated with this injection machine and clearly state how **two** of these risks could be addressed at the system design stage. **5**

(*g*) During operation, it has been found that the plastic gear wheels have a tendency to stick in the Die when it is opened. Briefly describe a modification to overcome this problem. You may wish to use a sketch to illustrate your modification. List any additional hardware required and clearly identify any Input and/or Output signal changes. **3**

(25)

[*END OF QUESTION PAPER*]

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PLC Datasheet Q6, Q11

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			

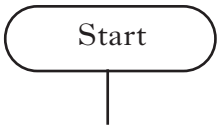
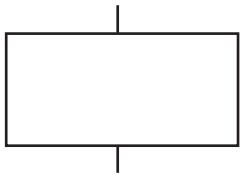
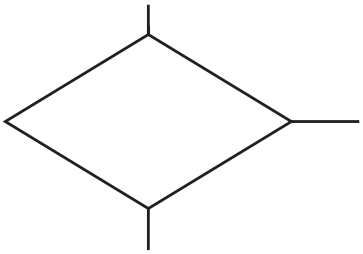
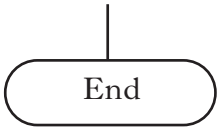
Operands

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 Q7, 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 2012

WEDNESDAY, 6 JUNE
1.00 PM – 4.00 PM

MECHATRONICS HIGHER

Worksheets for Q3, Q10, Q11, Q12 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.

SQA ©

Worksheet Q3

Table Q3(*a*) shows a selection of 3 bit codes used in Mechatronic systems

Decimal	**Code name =**	**Code name =**
0	000	000
1	001	001
2	010	
3	011	
4		110
5		111
6	110	101
7	111	100

Table Q3(*a*)

(*a*) Complete Table Q3(*a*) by

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

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

(*b*) An encoder disc uses a 3 bit code. Calculate the angular resolution in degrees of the encoder disc.

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 questions by putting a tick ☑ in the correct box.

(*a*) In a mechatronic control system, PID stands for

a Proportionally Integrated Diode ☐
b Power Indication Display ☐
c Proportional Integral Derivative ☐
d Phase Inverting Driver ☐
e Passive Integrating Device. ☐

(*b*) An Event Based Control System

a uses only timers ☐
b must have at least one sensor ☐
c always uses timers and sensors ☐
d must have a timer ☐
e is always slow to complete the task. ☐

(*c*) The PLC shown in Figure Q10(*c*) is

a a normally open contact ☐
b an output ☐
c a timer ☐
d a normally closed contact ☐
e a counter. ☐

Figure Q10(*c*)

(*d*) A hydraulic ram is

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

(*e*) An example of a visual indicator is

a a buzzer ☐
b a thermistor ☐
c a thermocouple ☐
d a Light Emitting Diode ☐
e a strain gauge. ☐

Worksheet Q11

(*a*) With reference to the system description, in Table Q11(*a*):

(i) in the **Letter** column, enter the letters A to D shown against each device in Figure Q11.

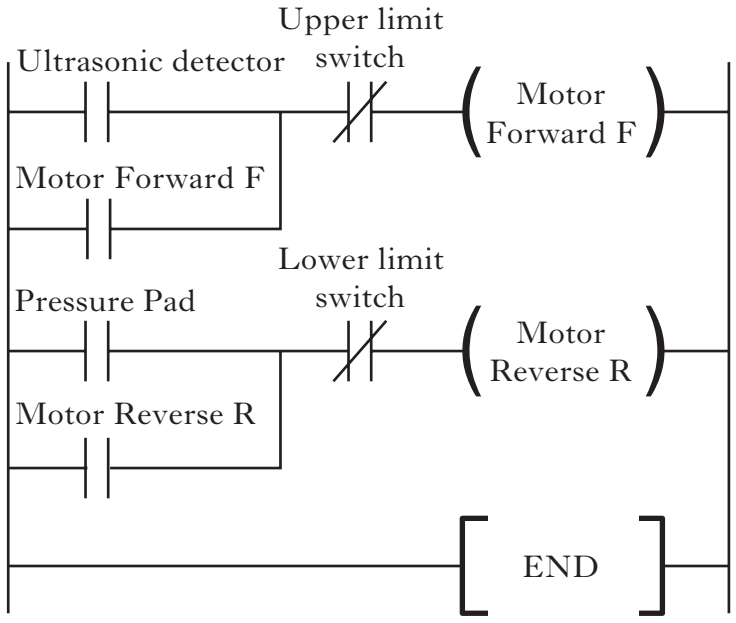
(ii) in the **Reason** column, state **one reason** why each sensor is placed in the position shown in Figure Q11.

(iii) in the **PLC I/O** column, allocate the I/O to the sensors and actuators.

Note: the inserted PLC Datasheet Q6/Q11 gives the PLC instruction set.

Device	Letter	Reason	PLC I/O
Microswitch 1			
Microswitch 2			
Pressure pad			
Ultrasonic detector			
Motor Forward (F)	E	This position matches where the motor can move the door up and down.	
Motor Reverse (R)			

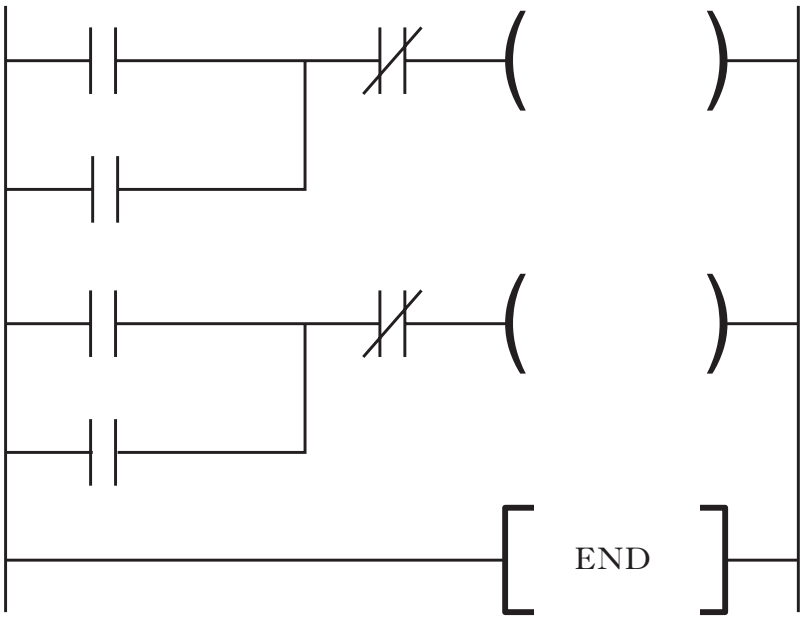
Table Q11(*a*)



Ladder Diagram Q11

Worksheet Q11 (*b*) (continued)

(*b*) Complete the labelling of Ladder Diagram Q11(*b*) using your PLC I/O allocations from **your** Table Q11(*a*).



Ladder Diagram Q11(*b*)

(*c*) Describe the operation of the Ladder Diagram Q11(*b*) in relation to the application.

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Worksheet Q12

(*b*) The assembly jig has 4 microswitch tube sensors.

(i) Briefly describe the operation of this sensor system to ensure all frame tubes are in place for the frame design (X or Y) selected before welding commences.

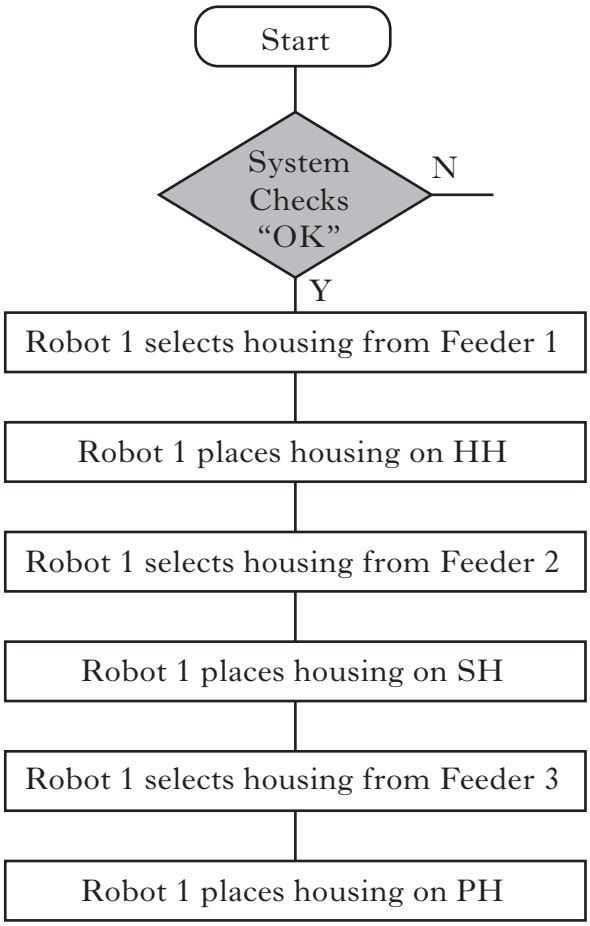
(ii) Complete the sensor activation Table Q12(*b*) to show which tube sensors need to be activated prior to the correct welding program being activated.

Tube Sensor	Frame X	Frame Y
Sensor 1 (S1)	ON	ON
Sensor 2 (S2)		
Sensor 3 (S3)		
Sensor 4 (S4)		

Table Q12(*b*)

Worksheet Q12 (continued)

(*c*) Complete the flowchart for the assembly process for **one** Frame, ensuring the initial system check is carried out.



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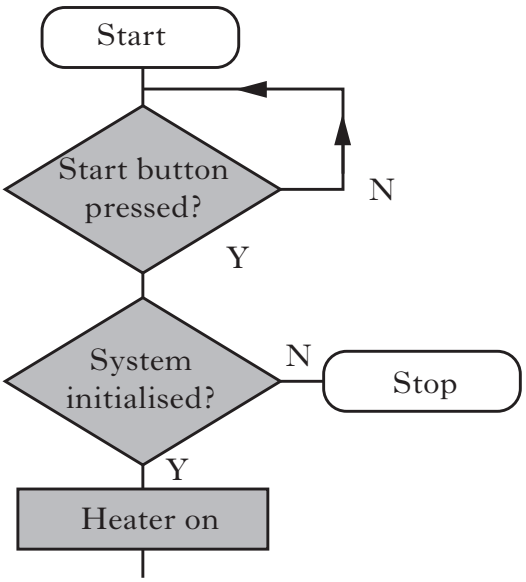
Worksheet Q13

(*b*) Complete the flowchart showing one single production run of the system.

Note: the inserted Flowchart Symbol Sheet Q7/Q11/Q12/Q13 gives a selection of suitable Flowchart Symbols.



[*END OF WORKSHEETS*]