2011 Mechatronics

Higher

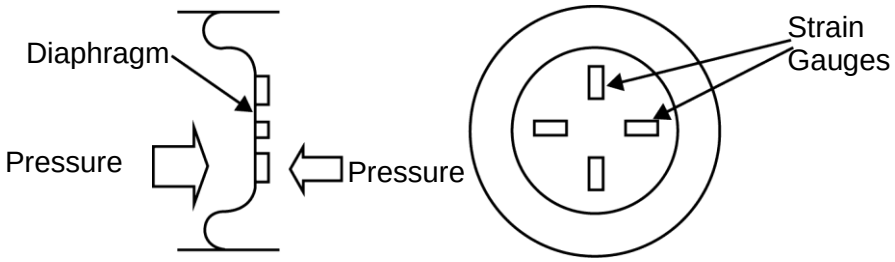
Finalised Marking Instructions

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

Deflecting Pressure Sensor or other appropriate answer.

note: Weight or force sensor is not acceptable unless relationship between weight or force and the associated applied area is clear. **1**

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



The differential pressure causes the diaphragm to flex and this is detected by the strain gauges and translated into pressure difference.

Or other suitable answer that matches the named sensor of part (a).

Two marks for answer which must include a sketch for full marks. **2**

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

Any two answers from:

- Pressure sensor in an air conditioning output unit
- Differential sensor across a filter system
- Sensing the pressure in an air reservoir
- Any other appropriate application.

2 x 1 mark per application = 2 marks. **2**

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.

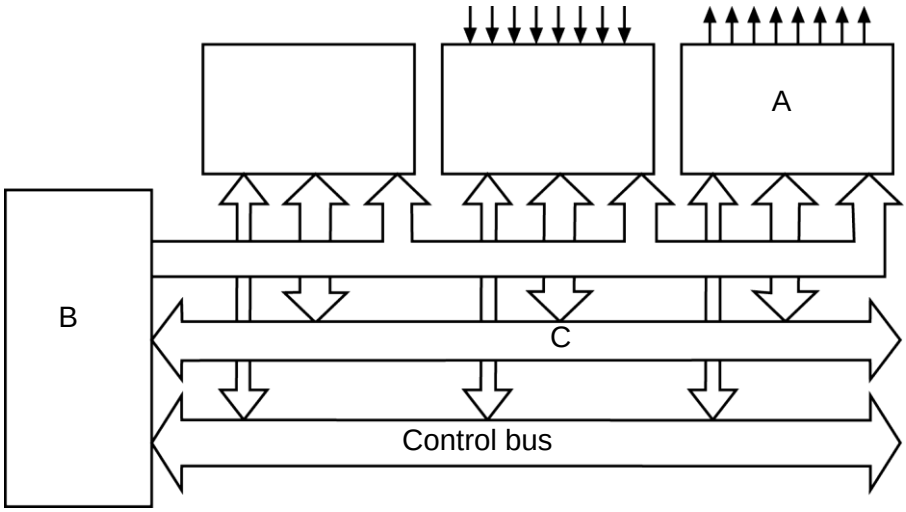


Figure Q2

(a) State which row 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

Table Q2(a)

ROW 3 is correct. **2**

(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 bidirectional on an address bus.
Statement 3: The data flow is unidirectional on an address bus.

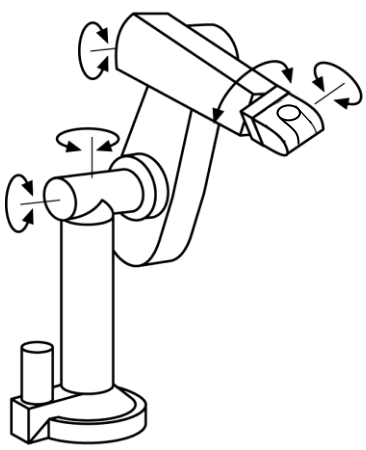
Statement 3 is correct. **1**

(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.

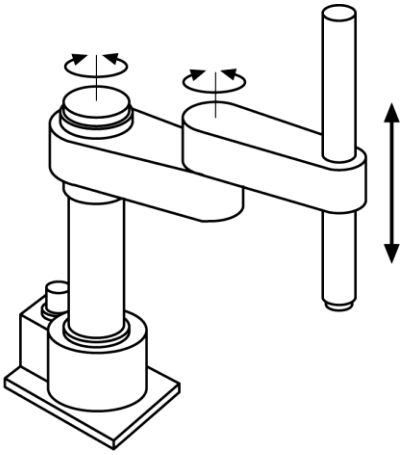
Any two from:
- Easily upgraded
- Reprogrammable
- Modular
- Customisable user interface
- Any other advantage EXCEPT cost.

2 x 1 mark per advantage = 2 marks. **2**

3. **(a)**



Robot A



Robot B

Figure Q3(a)

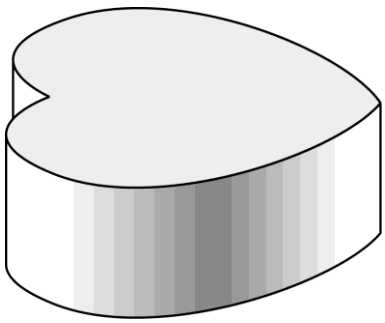
State the robot geometry and the number of axes of movement for Robot A.

Geometry is Revolute
Axes of movement is 5
2 x 1 mark per answer = 2 marks **2**

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

SCARA

Cardioid (heart shaped) or kidney shaped (only sketch needed not the description)



Cardioid shown **2**

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

Any **two** from:

- Magnetic
- Vacuum
- 2 or 3 fingered gripper
- Hydraulic
- Pneumatic
- Spray Gun
- Or any other.

(note: the way of gripping, the way of actuating or the application can be provided to describe the different types of end effector). **1**

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

Decimal	Code name = natural binary	Code name **= Gray Code**	Code name **= BCD or Binary Coded Decimal**
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	**0111**	**0100**	**0000 0111**
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	**1110**	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 x 1 mark per code name = 2 marks **2**

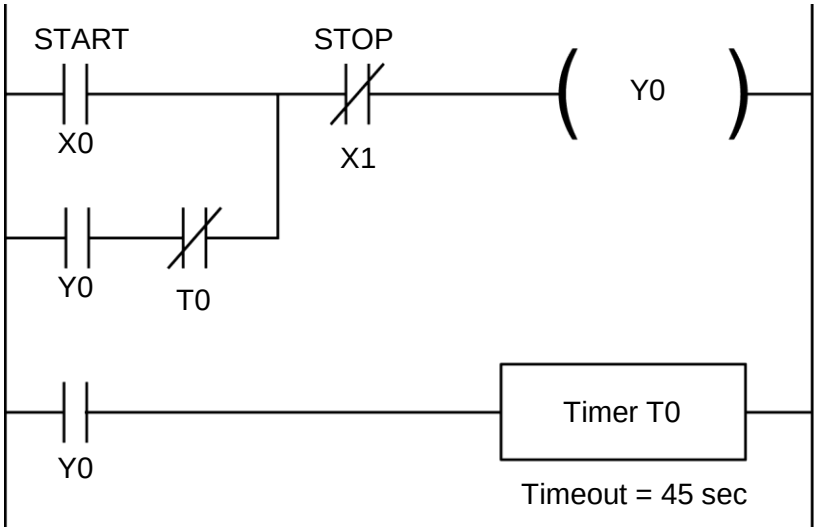
(ii) Inserting each of the **four** missing code values.

4 x 0.5 mark per code value = 2 marks **2**

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

$= \frac{360}{1080} = \frac{1^\circ}{3}$ or $= \pm\frac{1^\circ}{6}$ either answer acceptable **1**

5. A mechatronics control system uses a Programmable Logic Controller (PLC). Ladder Diagram Q5 shows the PLC program.



Ladder Diagram Q5

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

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

Start activates X0 which energises Y0 (1 mark), Y0 contact causes latch across X0 (1 mark). Timer activated by Y0 press (1 mark) and after 45 seconds, T0 is activated to break latch in the first rung and deactivate Y0 (1 mark). At any time if X1 is activated then Y0 is deactivated (1 mark). **5**

6. Figure Q6 illustrates a component sorting system.

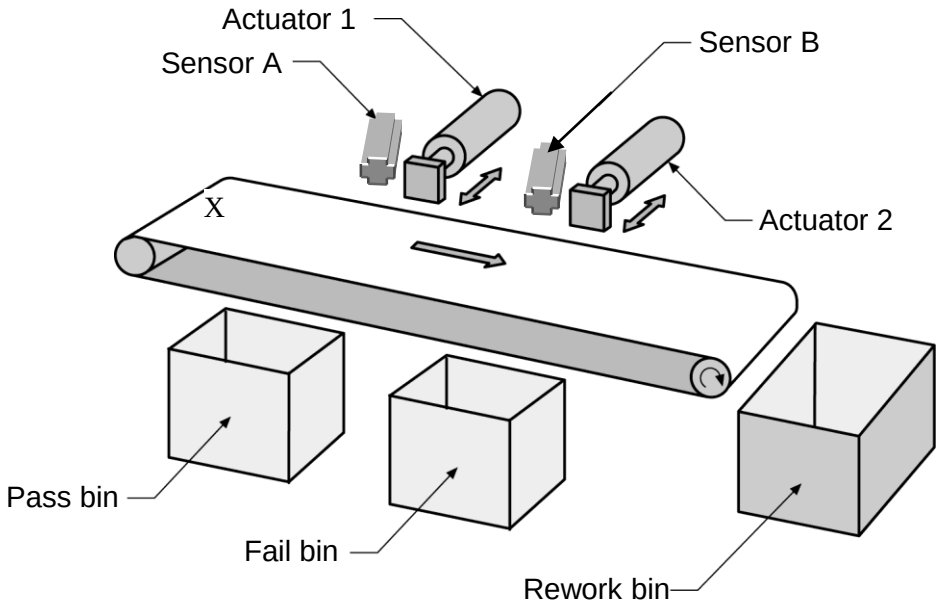


Figure Q6

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(a)**, 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)**.

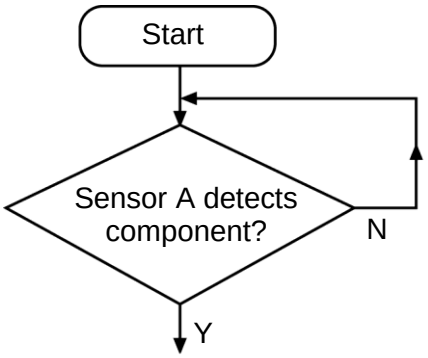
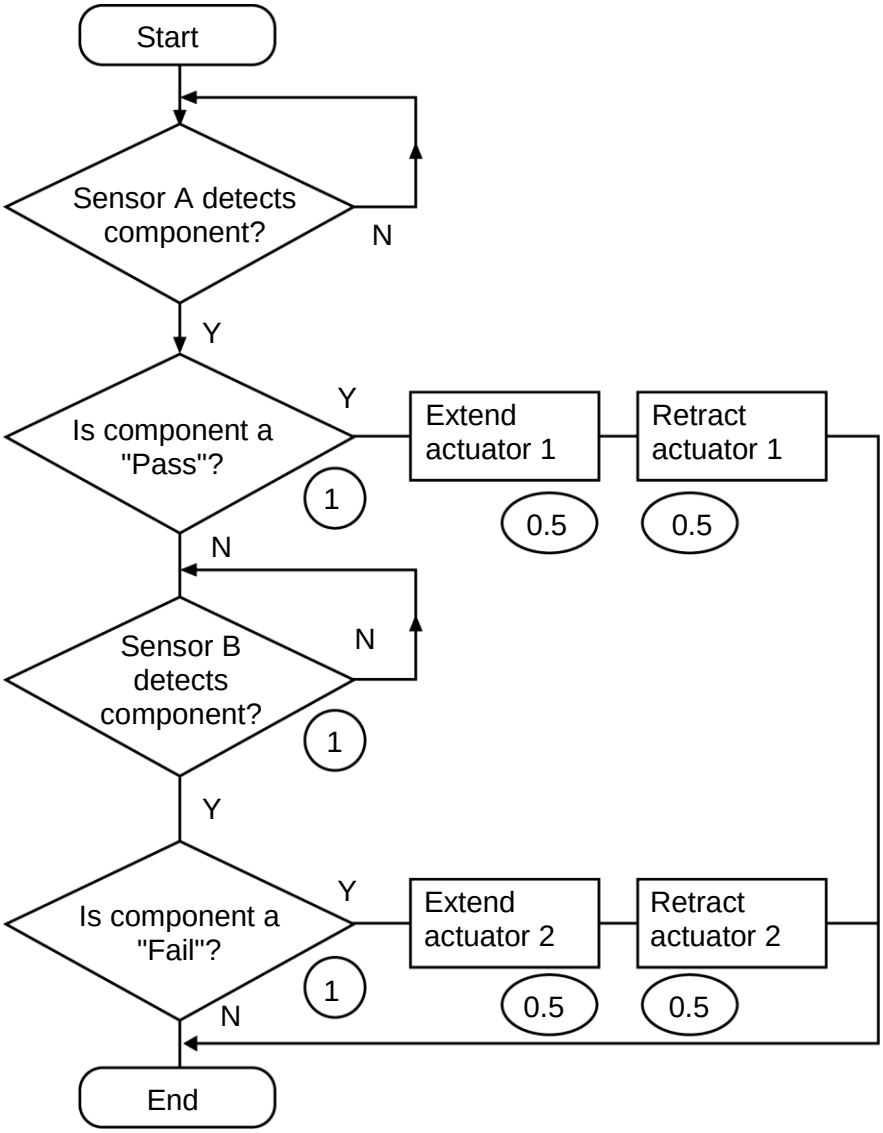


Figure Q6(a)

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



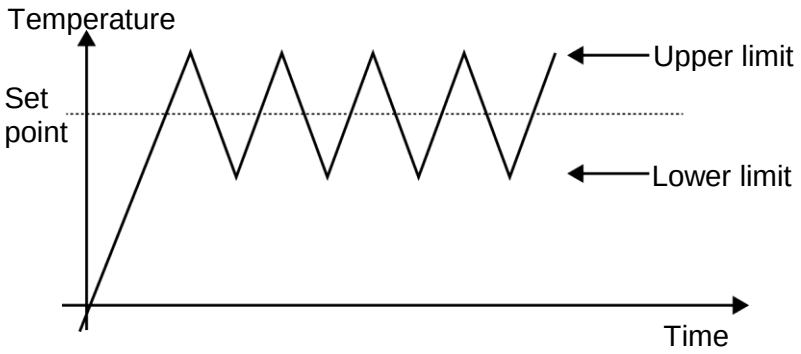
Because the question specifically mentions actuator retraction then that must be included in solution though it could be placed as a single box just before the End box.

Candidates may include an extra box near the end which states that the "Rework" components continue on into the Rework bin but this is NOT needed as this is the default operation of the system and requires no action for it to occur. But inclusion of this extra box should not be penalised.

Or any other suitable answer that works correctly. **5**

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

ON/OFF control will turn heaters on and off to control the temperature within two values and tends to produce a saw tooth type of output signal. When the heater is ON the temperature rises until it reaches the upper limit and when OFF the temperature falls until it reaches the lower limit.



Must have a sketch to gain full marks.

Note: the shape of the waveform may vary considerably, for example the waveform may be more like an exponential rise and fall. Other names may be used for terms such as "Desired Value" in place of "Set Point"

Or other suitable answers with sketch. **2**

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

P – Proportional Control – makes a change to the output that is proportional to the error signal
I – Integral Action – removes steady state offset in the output
D – Derivative Action – system response time is varied
Name only = 1, name and simple description = 2 marks, name and full description = 3 **3**

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

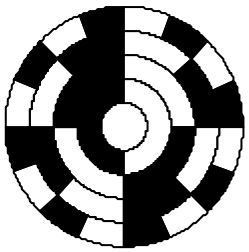


Figure Q8

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

(i) Code type

Binary, Simple Binary or Natural Binary **1**

(ii) Number of bits

4 bits **1**

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

At some of the changes between values, more than one bit changes simultaneously – if there is any discrepancy or misalignment then there can be problems as some intermediate codes are generated briefly.

One solution is to choose a Gray code so that only one bit changes each transition.

Or other appropriate answers.

1 mark for problem. 1 mark for solution. **2**

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

Any one answer such as:
- Anti-ambiguity track(s)
- Add more rings (which gives more bits)
- Any other suitable answers. **1**

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 cannot operate until the fan is running. The heating element is switched off 5 seconds before the fan is stopped.

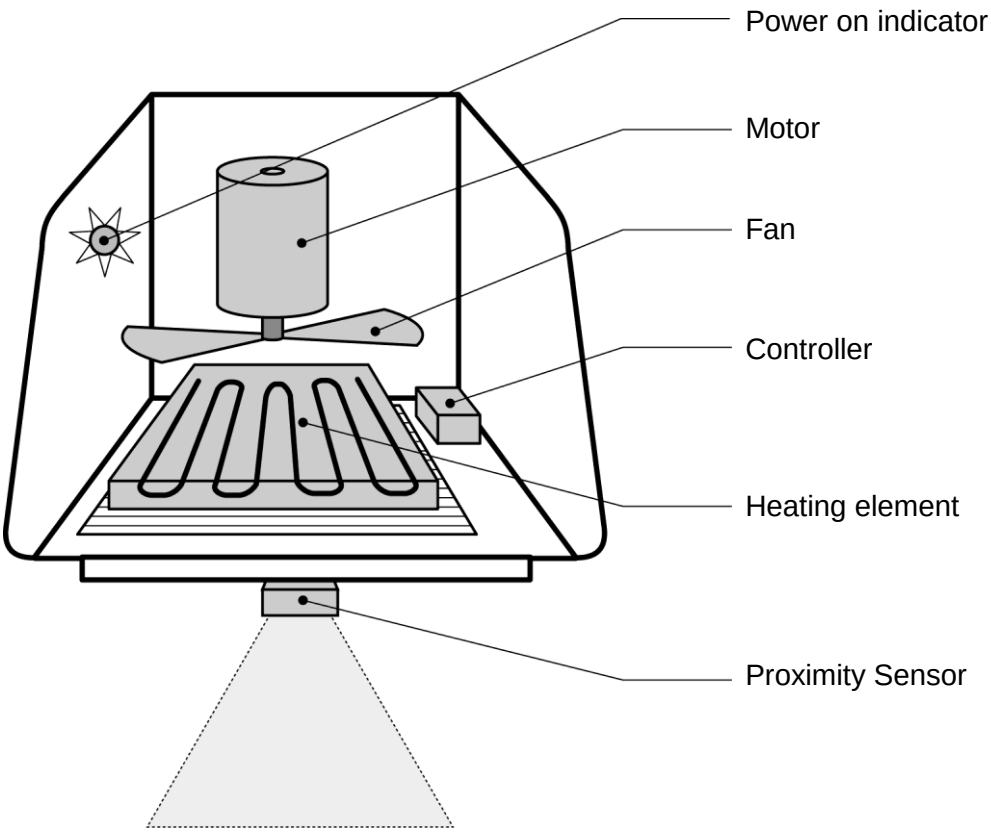


Figure Q9

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

Inputs
- Proximity sensor (may be called Hand sensor)

Outputs
- Fan
- Heater
- Power indicator

Timer
- 1 Timer on 60 seconds OR 1 Timer on 55 seconds
- 1 Timer off 5 seconds 1 Timer cooling 5 seconds

or equivalent answers

6 x 0.5 mark per code value = 3 marks **3**

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

Any suitable airflow sensor such as a paddle wheel airflow sensor which is capable of detecting change in air flow.

A paddle wheel sits in the flowing air and rotates at a rate which indicates the air flow. If the flow rate drops then the sensor rotates less or slower and so monitoring this enables a measurement of air flow. The monitoring could be by interrupted light beam or tachogenerator.

Or other suitable description that matches the sensor chosen.

1 mark for sensor and 1 mark for brief description = 2 marks. **2**

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

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.

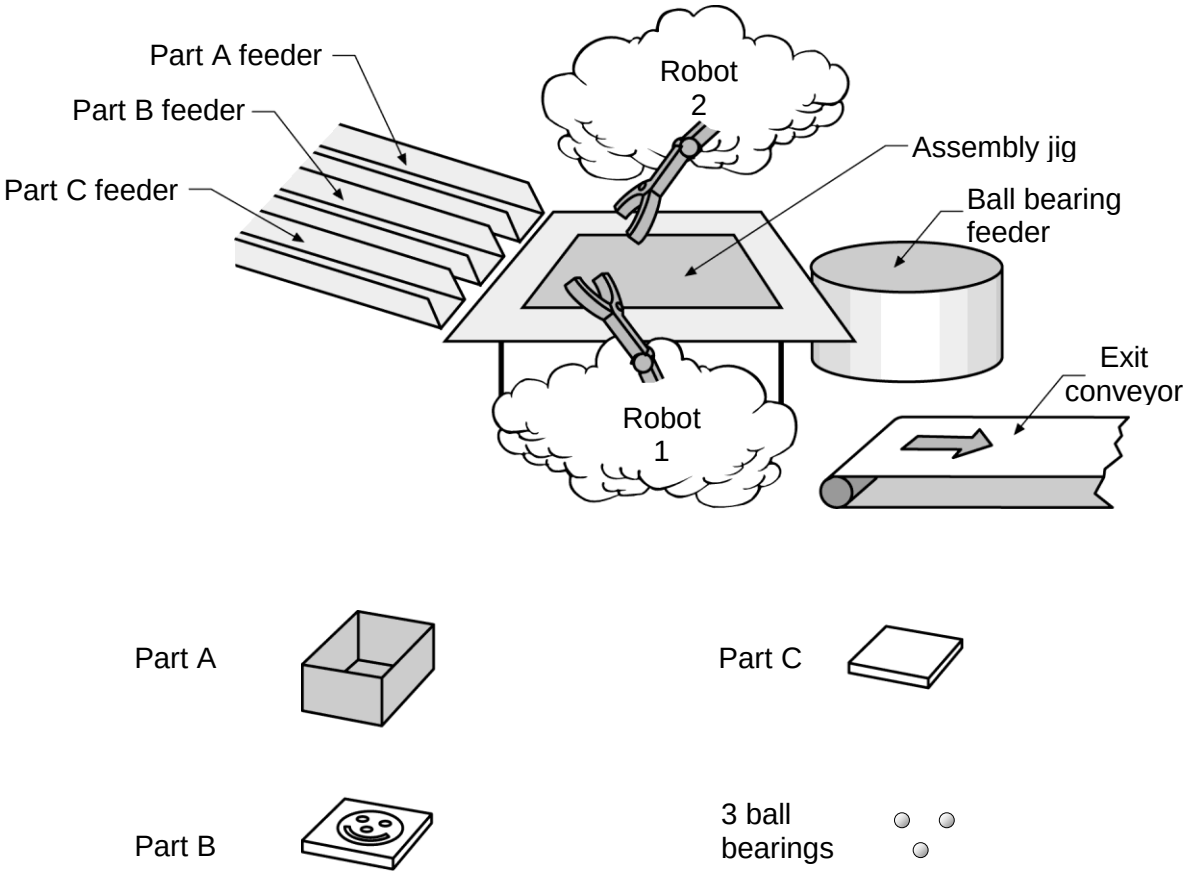


Figure Q11

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 bowl 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.

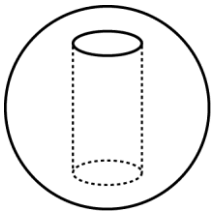
The ball bearings are supplied using the bowl feeder and are suitably presented for the gripper to lift three balls at the same time.

(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.

One reason from:
- Good movement in many directions
- Excellent access and reach
- Or other good reason. **1**

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



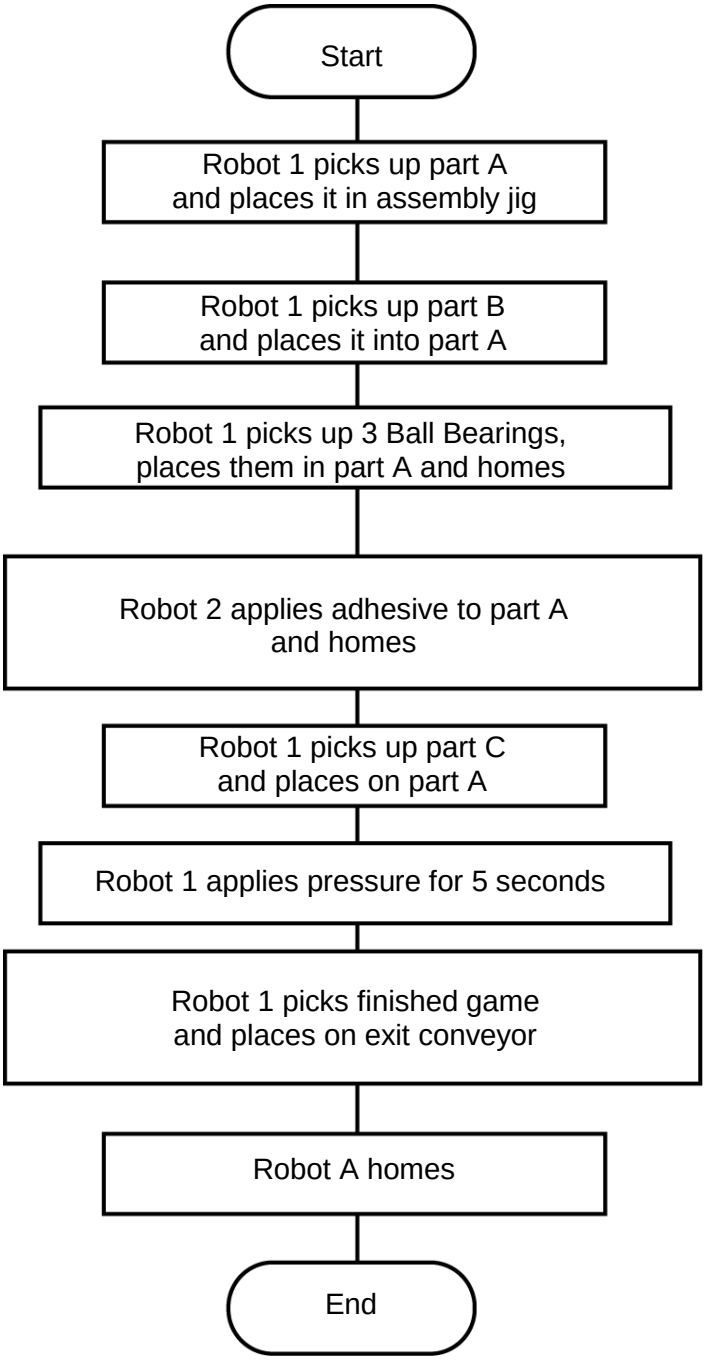
Nearly a complete spheroid (only the sketch is needed and the cylindrical space in the centre of the spheroid is optional). **1**

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

Two reasons from:
- Readily available in suitable ratings
- Power supply clean
- Low maintenance
- Any other suitable reasons. **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.

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

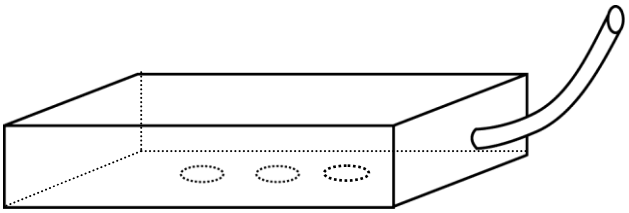


0.5

Marks per stage

There may be extra boxes covering intermediate home actions but basically 0.5 marks per stage
8 x 0.5 marks = 4 marks. **4**

(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.



Solution shown is a Vacuum gripper end effector. The attached pipe is connected to a vacuum source which causes a partial vacuum in the box. When the three holes are placed near some balls, the sucking effect will enable the gripper to pick up three balls simultaneously (the hardest task). When the three balls are successfully picked up then a vacuum will be detected – if one ball doesn't get picked up then the vacuum will fail and be detectable. (Note there is no need to pick up the balls in any pattern shape such as the face). When in the correct position, the vacuum is broken and the balls released.

Or other suitable solutions.
Note must include both sketch and linked description. **4**

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

Any two issues and associated resolutions from:

- Automated can start working without warning – so warnings needed of operation or impending operation
- Certain areas must be isolated from humans except during setup – so guards and interlocks needed
- Parts may be dropped or thrown by robots – containment and protective grills needed
- Or other suitable safety issues and resolutions.

(1 mark for issue and 1 mark for resolution) x 2 = 4 marks. **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.

A method of automatically detecting the presence of parts in feeders is needed and this would require a sensor in each feeder. The output of these sensors could be fed to the controller and if any of the sensors detected absence of parts (this is an OR function) then an alarm condition would be raised. Typical sensors might be tactile ones such as microswitches. To alert an operator of the problem then visual or audible alarms would be needed.

Extra hardware would be a sensor per feeder, logic to OR the outputs (or this could be done by the controller), alarm indicator or sounder.

Description – 2 marks plus 3 sensors x 0.5 plus 1 alarm x 0.5 = 4 marks

Or other suitable description and hardware list. **4**

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

The duration can be controlled by a timer. A load cell could be used in the assembly jig to sense the applied force when the adhesive is curing.

Or other suitable answer which covers both time and pressure.

Note the above solution could also have the load cell in the robot arm or end effector.

Sensing time = 1 mark, sensing pressure = 1 mark **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** the top is glued in position.

A visual system could be used to recognise the presence of the three balls within the game prior to the top being glued. The visual system would require some form of optical sensor such as a camera and suitable part identification software to be set up. Tilting the game to get the three balls in a known area and suitable game colouring and lighting would make the task easier.

Note: the most obvious fault conditions are "less than three" and "more than three" balls but candidates need not state this.

Or other suitable description of a system that takes account of the objects (three small mobile balls) and the stage of assembly. **3**

Total = 25 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.

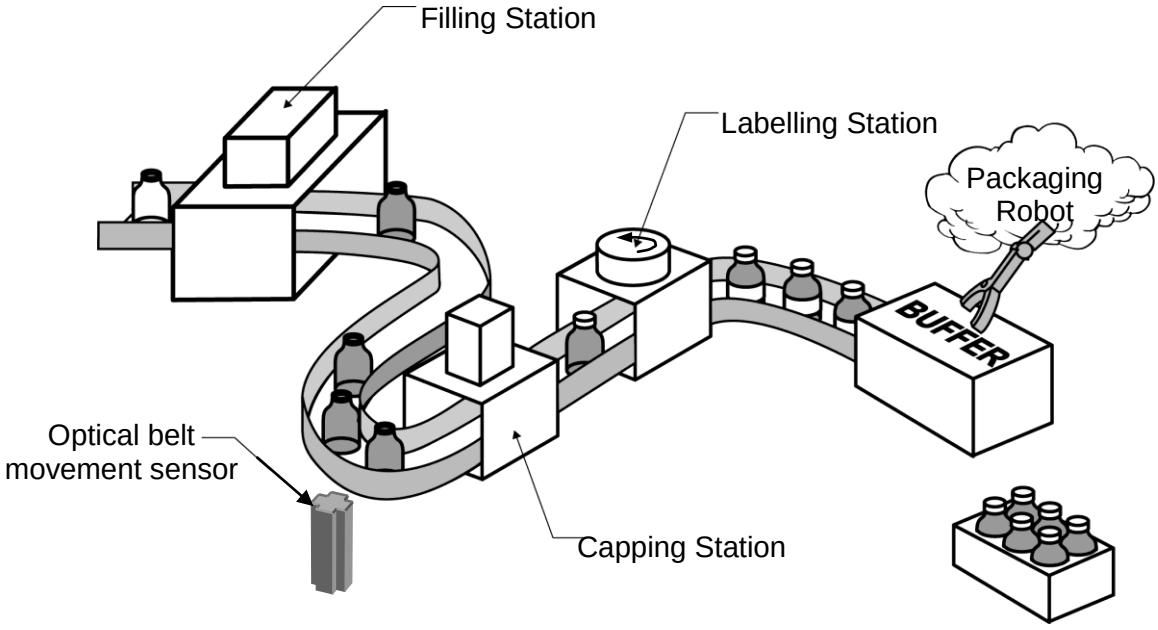
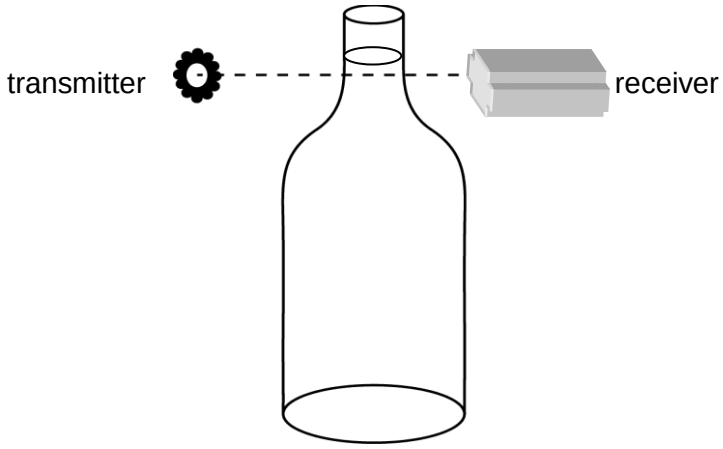


Figure Q12

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

Light beam through bottle neck.



Assumes neck of bottle is devoid of labels and presence of liquid modifies light beam

Or other suitable answer such as weighing a bottle with the correct amount of liquid.

Note: Sensing issue is "amount" which may be considered as either level or weight – either acceptable. Also a single detection level is expected not two or three levels.

2

(b) The conveyor moves the bottles 80mm every 3 seconds. On the edge of the conveyor belt, holes are placed every 2mm 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.

80mm every 3 seconds
Holes are 2mm apart therefore 40 holes (or 39 holes)
To count up to 40 needs …
$2^5 = 32$ is too few
$2^6 = 64$ which is OK
Therefore 6 bits needed.

Answers using mathematical methods such as "bits need to be integer greater than $\log_2(40) = 5.32$" are equally acceptable. **3**

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

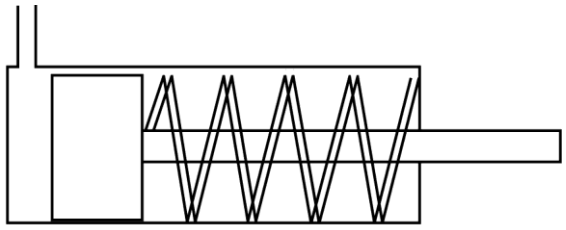
(i) Give **two** reasons, other than cost, why pneumatics is a suitable choice for this physical process and working environment.

Any two answers from:
- Cleanliness (drinks present)
- Breakage unlikely to lead to contamination when compared with hydraulics
- Forces not too excessive
- Or any other suitable answers.

2 x 1 mark per answer = 2 marks **2**

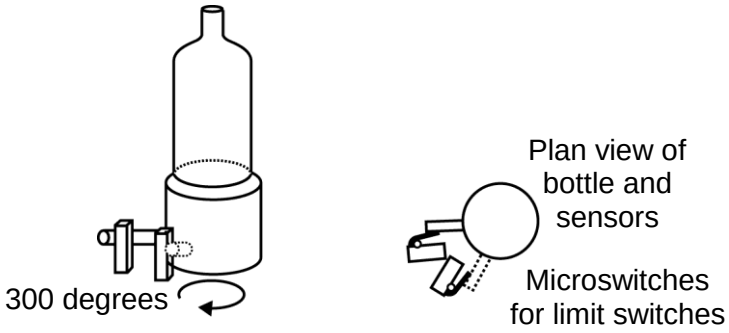
(ii) The pneumatic crimping system incorporates a **single acting** cylinder, describe the term "single acting" with reference to pneumatic actuators.

Single acting cylinder means that the piston is only extended using fluids in one direction. The return stroke, the retraction, is carried out automatically on removal of actuating fluid. Note: typically this retraction is done by using a spring but the actual mechanism is NOT needed. Also sketch is NOT needed. **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.

Motor drive to provide rotary action with limit switches

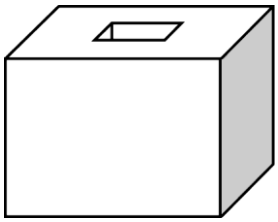


The rotary actuator needs to engage with the bottle bottom and provide the rotation. The limit switches are set to allow 300 degrees of rotation. A sketch and brief explanation must BOTH be included for full marks.

Or other suitable answer such as motor drive with encoder or rotary stepper motor. **3**

(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**



Note: the rectangle in the centre of the cuboid is NOT required in the sketch. Only a sketch is required with no explanations or description needed.

(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.

Any four from:
- Able to handle load
- Matched to handle bottle shape
- Able to carry three bottles
- Compliant faced jaws to prevent damage to bottles
- Able to sense if bottle is missing
- Or other suitable answers. **2**

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

Any two from:
- Automated machine/system need to keep people away – use guards, notices, training.
- Danger of glass shattering – use guards to prevent flying glass
- Noisy system – provide ear defenders and visual indications rather than audible
- System may need stopping if fault occurs – provide stop buttons
- Liquid spillage – provide containment and alarms
- Any other suitable answers containing hazard AND solution. **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.

Any two from:
- Sensors could get contaminated
- Actuators could introduce contamination
- Liquid could result in false reading
- Broken glass could affect operation
- Any other suitable issues **2**

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

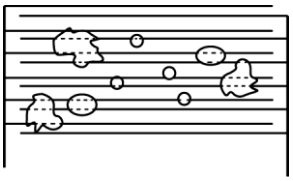
Liquid leakage or spillage could be detected by some sensor able to detect the presence of liquid. A sump area could collect and direct the liquid to a detection area. The sensor which might be resistive or a float switch could activate an alarm and stop the system.

Additional hardware would be:
- Sump
- Liquid detector/sensor
- Alarm indication
- Stop circuitry
- Control

Or other suitable answer for system and corresponding hardware. **4**

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

A resistive matrix similar to those used on a car windscreen for automatic windscreen wiper activation. Liquid on the sensor area provides a partial resistive short between electrodes.



Note: name of sensor and sketch are NOT needed if explanation clear.

or other suitable sensor capable of performing the task in Q12(g)(i).

Note: single phrase answers such "moisture detector" is not acceptable as question asks for brief description not a name. **1**

Total = 25 marks

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

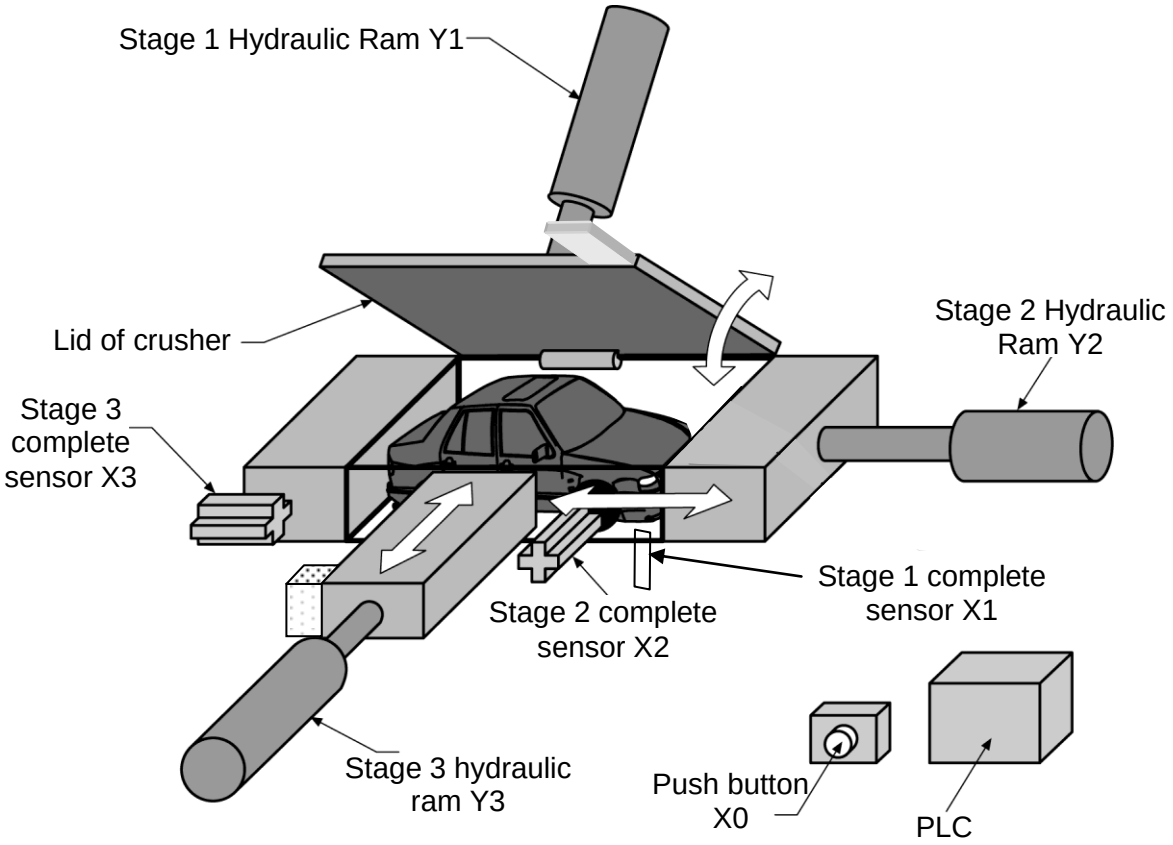


Figure Q13

The crusher operates as follows:

- The lid of the crusher is open and a car has been 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.
- 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 data sheet Q5/Q13 gives the PLC instructions set.

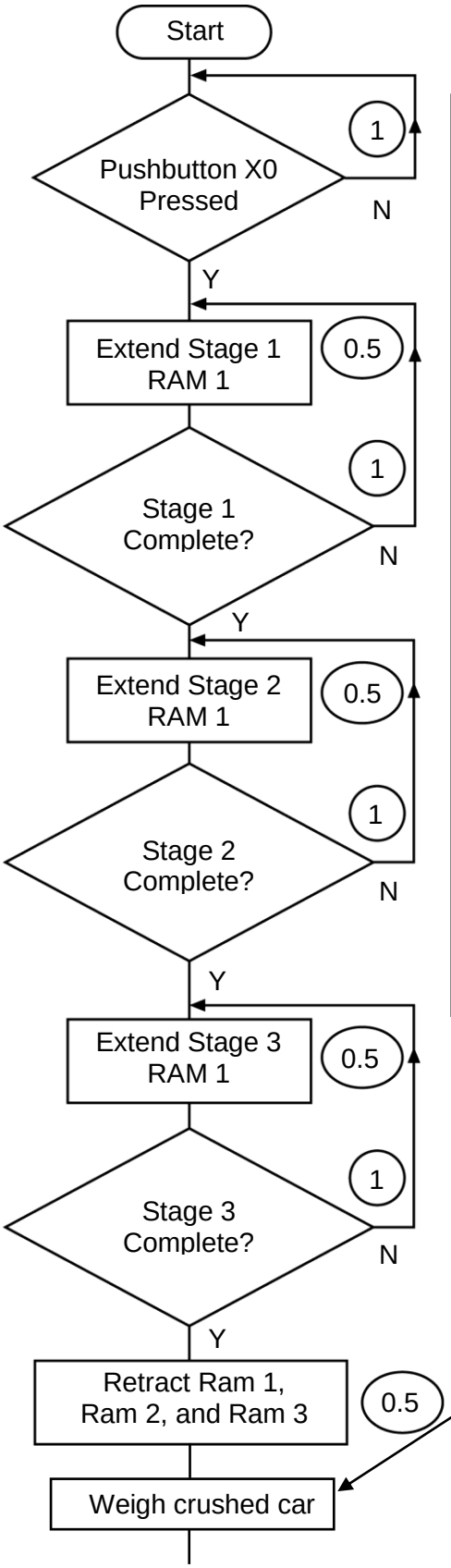
Input		Output		Timer	
Pushbutton Start	X0	***Stage 1 hydraulic ram***	***Y1***	No Timers	
Stage 1 complete sensor	X1	Stage 2 hydraulic ram	Y2		
Stage 2 complete sensor	X2	Stage 3 hydraulic ram	Y3		
Stage 3 complete sensor	X3				

Y1 is already given in question. 0.5 marks for each correct input and output. There should be no timers. If a timer was included for the weighing then this should NOT be penalised.

Note: if a candidate introduces extra output contracts, say Y4 to Y6 to act as retract signals then the solution should be marked accordingly and marks deducted for problematic areas and not for the resulting ongoing problems. Such a solution would result in considerable differences to part (e) solutions.

6 x 0.5 marks = 3 marks **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 position of the loop back within each stage can be given in a number of ways.
As shown the loop goes back BEFORE the Extend command which suggests the RAM keeps being extended until it completes its task.

There is quite a complex issue regarding the extension, locking and retraction of hydraulic rams. Here the rams are shown as only extending and retracting and the possibility of locking is not included. In reality the ram might be locked rather than continuing to be extended but candidates at the level of this paper are NOT expected to have either theoretical or physical knowledge of these issues so any exclusion or inclusion should NOT be penalised if it performs satisfactorily.

As shown the flowchart just shows a flow from START to one point later – it does not show the STOP or a LOOP function as neither of these are called for in the question.
A candidate including a stop should not be penalised.

Note this stage should NOT be shown as this takes place after the Final retraction action

Marks

Decisions	= 4 x 1 mark
Actions	= 4 x 0.5 marks
	= 6 marks total

6

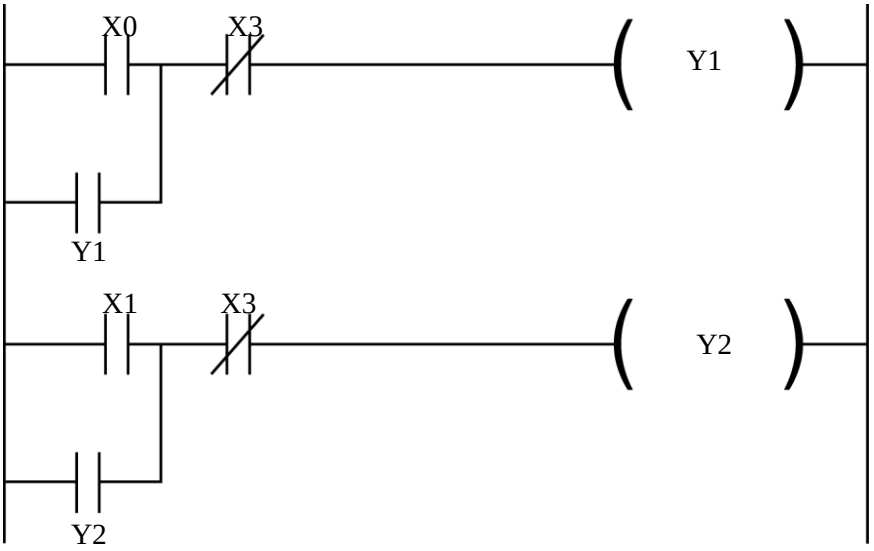
(c) Ladder Diagram Q13(c) shows the initial rung of the PLC program. Modify the ladder diagram to ensure that the hydraulic ram continues to apply the crushing force after the Start button is released.

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

Ladder Diagram Q13(c)

1 mark for contact Y0 across the X0 only or any alternative that is correct. **1**

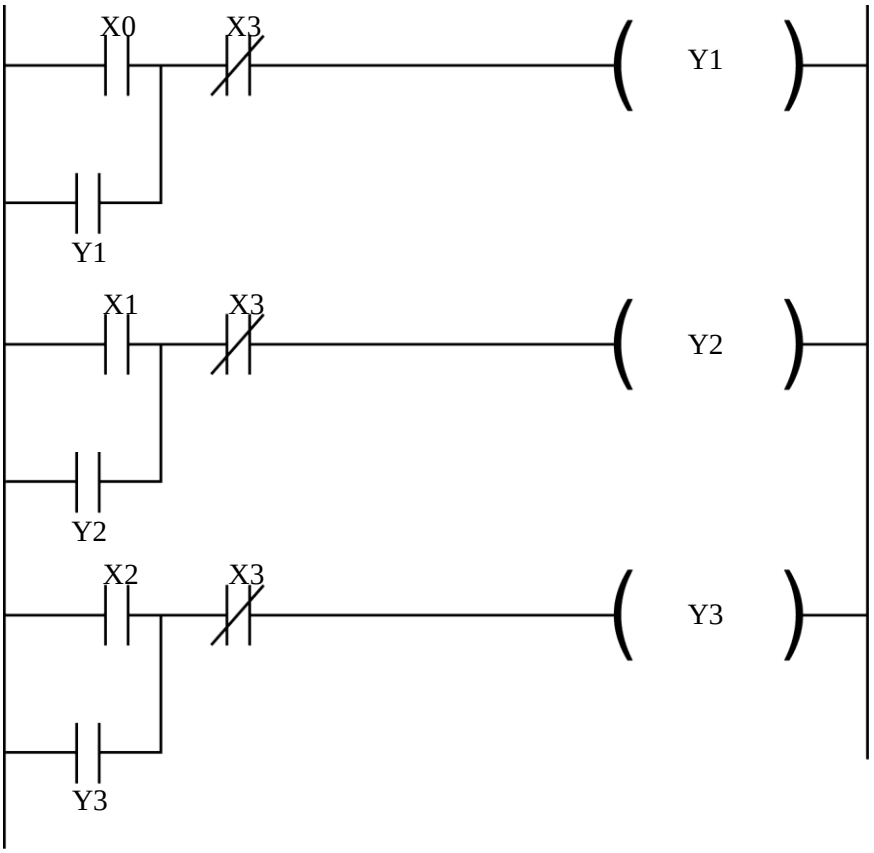
(d) Making reference to the diagram you modified in Q13(c), add a rung to your ladder diagram on which would latch the operation of the Stage 2 ram Y2 when triggered by the closure of X1.



The X1 contract must be latched by Y2 as the description explains. It is not sufficient to say that the X1 will continue to hold because X1 will remain extended.

Note: a separate ladder diagram is not necessarily required but the answers may be combined with previous part of question. **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.



The third rung starts when Stage 2 is complete (signalled by X2 operating). X2 operating operates Y3 with its latching contact Y3 bridging the X2 contact. When the Stage 3 ram is fully extended (this occurs when the crushing is complete) then X3 operates which releases ALL THREE rungs and the three rams retract.

Note: This circuit works provided the rams automatically retract as described in the question (making them Single Acting though unlikely to be spring driven owing to power involved). If **automatic retraction** was NOT included then each ram would require at least two signals to extend and retract (and maybe one to hold). The candidate is NOT required to know the detailed operation of the hydraulics cylinders and valve arrangements. **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.

Any suitable sensor such as a tactile microswitch or an optical sensor.

Brief description of a microswitch. This is a tactile sensor (fixed to the body of the crusher) where a piece of metal is in contact with the moving part (lid) and the movement of this operates an electrical contact. If the moving part moves away then the contact breaks.

For information (not expected from candidate): the "micro" part of the name refers to the small movement or small force required to operate the switch – a microswitch may be quite big physically and in this application would need protection from damage and dirt.

Or other suitable sensor and brief description. Note: a sketch is NOT required but may help if included. **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.

Two types from the following list
- thermistor
- thermostat
- thermocouple
- any other suitable temperature sensor

2 x 1 mark per stated sensor = 2 marks

Brief description of a thermistor. A thermistor is a resistor made of a material which has a known and marked response to temperature changes. Supplied with a known current or voltage the change in resistance can be measured and the temperature calculated. In this application the sensor could be placed within the motor windings to measure temperature there.

Or other suitable descriptions temperature sensor.

1 mark for correct brief description of one of the named sensors (description must correspond to name). **3**

(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 weight.

One type of sensor from the following list
- load cell
- strain gauges
- LDVT
- any other suitable weight measuring sensor compatible with the likely weight range

1 mark per stated sensor **1**

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

Any **two** suitable safety issues

- No stop buttons included
- Guarding needed
- Visible and/or audible indications/warning
- Possible dangerous fluids or materials being handled
- Or any other suitable safety issues

Only the issue needs naming and no mitigation measures are requested.

2 x 1 mark per safety issue = 2 marks **2**

[END OF MARKING INSTRUCTIONS]