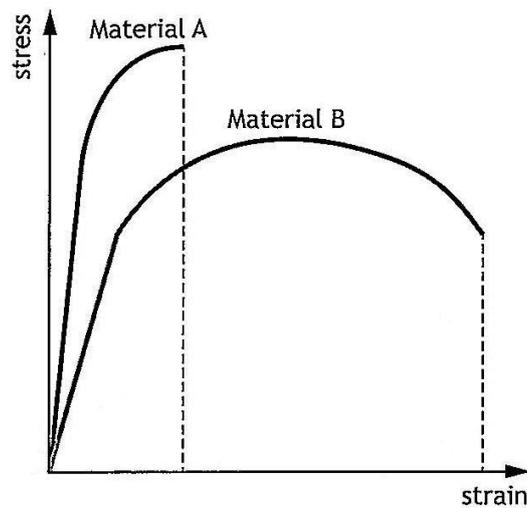


MARKS

SECTION 1 — 20 marks

Attempt ALL questions

1. The traces below show the stress-strain response of two materials when tested.



- (a) Name the value which may be found using stress and strain on the **straight-line** portion of each of the two.

1

Young's Modulus

- (b) State a material property of Material A and Material B that can be interpreted from the whole of these traces.

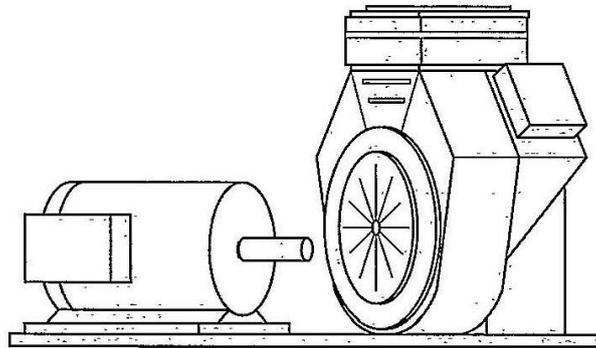
2

Material A Brittle

Material B Malleable / Ductile

MARKS

2. An electric motor drive shaft is to be connected to an air compressor using a clutch.

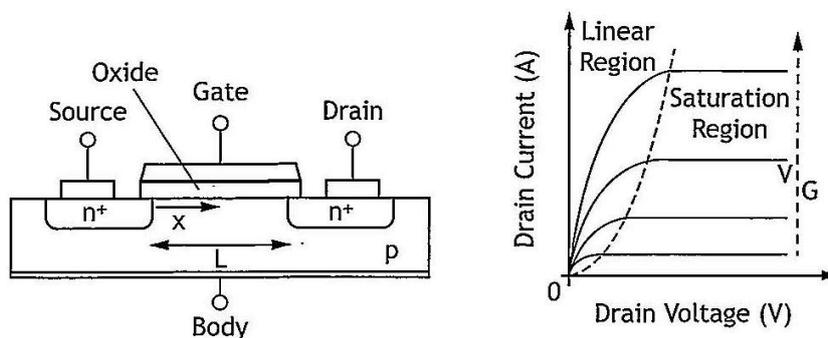


Explain one advantage and one disadvantage of using this coupling method.

- (a) Advantage The motor can be disconnected 2
from the compressor if so desired
Rather than it being permanently
connected by a coupling.
- (b) Disadvantage It requires energy to activate 2
the clutch to engage or disengage
the shaft into the compressor motor.

MARKS

3. Diagrams of a MOSFET and its characteristic operation curves are shown below. A MOSFET can be connected as a voltage operated switch.



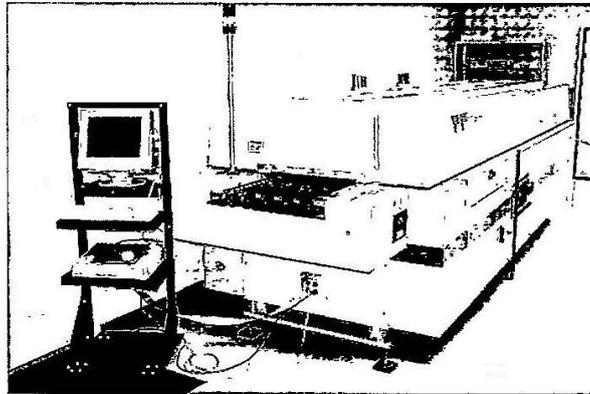
Describe the basic operation of a MOSFET switching device, making reference to the diagrams shown.

3

A mosfet is to provide more voltage to the circuit from the supply. It cannot exceed its saturation voltage, given by the graph. The mosfet is activated by the source and allows extra voltage from the supply to pass through it ~~and out of it~~ via the gate and pass out through the drain. The n⁺ Drain attracts the e⁻ voltage to it and passes out that way.

MARKS

4. The oven system shown is an example of the fact that the complexity of designing and producing many products has changed the traditional roles of engineers.



Electrical/electronic engineering requires specialisms in analogue electronics, digital electronics, programming and power.

Describe for one of these specialisms three specialist skills the engineer would require.

3

Skill 1 To be able to program effectively and to make sure the code he has wrote is efficient.

Skill 2 To be able to use transistors to active relays etc.

Skill 3 To be able to build NAND gate Circuits in order to complete a particular action or task.

MARKS

5. A local supermarket has decided to increase its floor area by one third. The current building is a framework assembly.

Describe the role of two engineers from different branches in the expansion project.

4

Engineer 1 Materials engineer

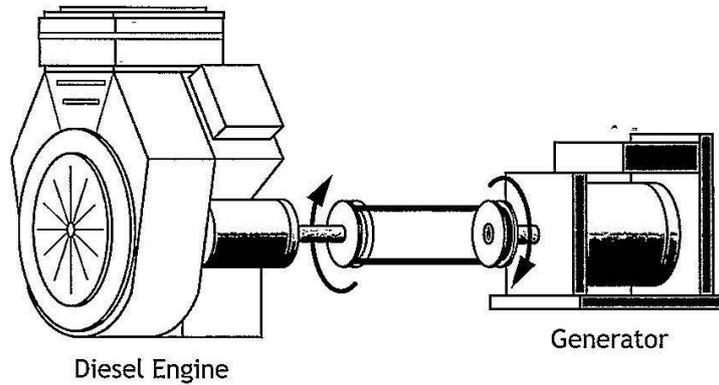
To calculate the young's modulus
of the framework material in that
situation to make sure it can
handle the task.

Engineer 2 Mechanical Engineer

To design how the framework
will lock/fit together in order to
build the framework for the building.

MARKS

6. A small portable generator driven by a diesel engine has an electrical load of 75A at 110V. The belt drive system has a 5% efficiency loss.



Calculate the power output from the diesel engine in kW.

3

$$\begin{aligned} &75\text{A at } 110\text{V} \\ &P = IV \\ &= 75 \times 110 \\ &= 8250\text{W} \\ &\text{loss} = 412.5\text{W} \end{aligned}$$
$$\begin{aligned} &5\% \\ &8250 - 412.5 \\ &= 7837.5\text{W} \\ &= \underline{\underline{7.8\text{ kW}}} \end{aligned}$$

MARKS

SECTION 2 — 70 marks

Attempt ALL questions

7. A home owner has asked an electronic engineer to design a burglar alarm system for a house. The house alarm system will sound a bell when the power switch is closed and either a pressure sensor under the carpet at the front door is closed or a switch is opened when any of the windows are lifted.

Assume all the switches to be a logic 0 when opened. A = Power switch, B = Pressure sensor, C = Window switches and Z = Bell.

- (a) (i) Write a Boolean expression for the control of the bell using the specification provided.

3

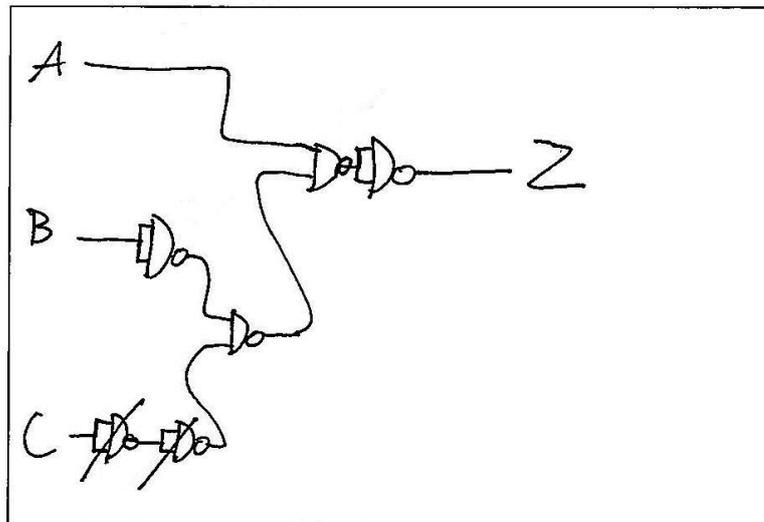
$$Z = A \cdot (B + C)$$

$$1 = 1 \cdot 1$$

$$\underline{\underline{Z = A \cdot (B + \bar{C})}}$$

- (ii) Draw an equivalent logic circuit for the Boolean expression using two input NAND gates only. Simplify if appropriate.

4



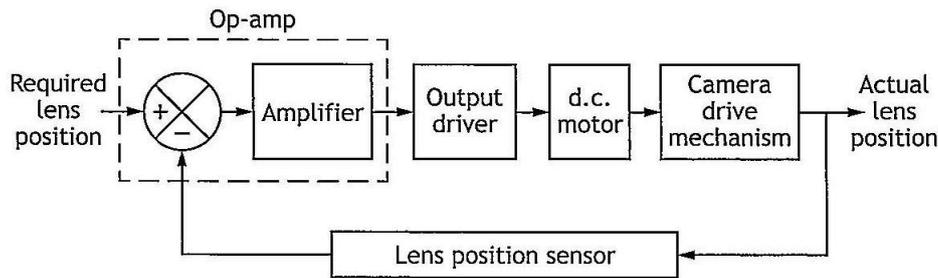
MARKS
D
W
M

7. (continued)

- (b) The home owner still has concerns over security, so has instructed the electronic engineer to install a camera into the system to monitor any intruders.

In order to focus an automatic camera, a control system uses information from the input sensors to create a signal representing the required lens position. It then adjusts the lens position by the means of a small d.c. motor.

The control diagram below shows the main sub-systems to the camera system.



- (i) State two possible configurations of op-amp that the engineer could have used in the design of the control system. 2

Difference Amplifier
Comparator

- (ii) Compare the operation of the two control systems containing the two configurations of op-amp and select the more suitable system. Justify your answer 4

Difference Amplifier as it
would eventually get to the right
position, whereas a comparator would
mean that it would constantly overshoot
its target. A Difference amplifier would
mean that if it is close to the position
it moves a little and if it is far, it moves
a lot. This means it is perfect for the output
to the motor.

MARKS

7. (continued)

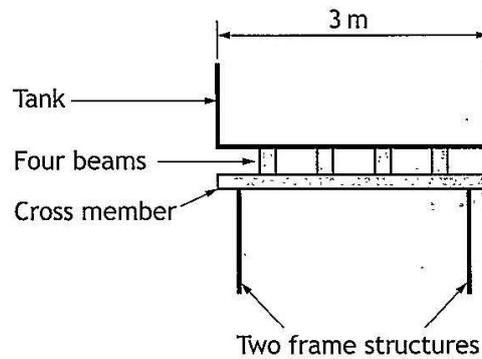
- (c) Explain how pulse width modulation control may be used to vary the speed of the camera.

If the camera needs to be moved ~~fast~~ ^{fast} 2
you would increase the mark size, if you
wanted it to move slower, you would increase
the space times.

MARKS:

8. The water storage system below shows a water tank which is filled by an electrical pump. The tank with dimensions $3\text{ m} \times 3\text{ m}$ sits on four timber beams. The beams are secured to a cross member at one end and fixed into the wall at the other. Each beam carries an equal share of the water tank's weight.

The cross member is supported by two frame structures.



Front View

- (a) Calculate the maximum uniformly distributed load exerted on each beam if the water level in the storage tank does not exceed 1.5 metres. Ignore the weight of the tank.

(1 m^3 of water has a mass of 1000 kg.)

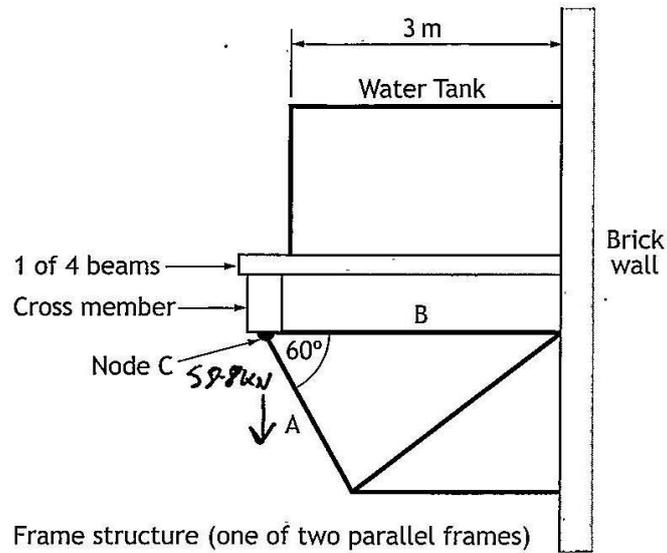
4

$$\begin{aligned}
 3 \times 3 &= 9\text{ m}^2 \\
 3 \times 3 \times 1.5 &= 13.5\text{ m}^3 \\
 13.5 \times 1000 &= 13500\text{ kg} \\
 w &= mg \\
 &= 13500 \times 9.8 \\
 &= 132300\text{ N}
 \end{aligned}$$

$$\begin{aligned}
 \text{Water} &= 13500\text{ kg} \\
 \text{each beam equal} & \\
 &= \frac{132300}{4} \\
 &= \underline{\underline{33075\text{ N}}}
 \end{aligned}$$

MARKS

8. (continued)



Side View

- (b) The figure above shows one of the frame structures which support the tank. The force exerted by the water in the tank at node C is 58.8 kN.
- (i) Calculate the magnitude and determine the nature of the forces in members labelled A and B.

3

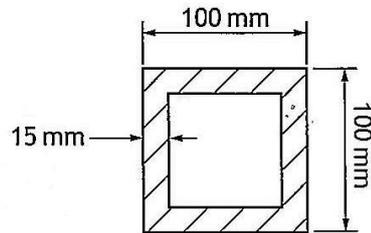
$$A: F = \frac{FV}{\sin(60)} = \frac{58.8}{\sin(60)} = \underline{\underline{67.9 \text{ kN Strat}}}$$

$$B: FH = F \cos \theta = 67.9 \times \cos(60) = \underline{\underline{33.95 \text{ kN Tie}}}$$

MARKS

8. (b) (continued)

Member A is a 100 mm × 100 mm square tubular section with a uniform wall thickness of 15 mm as shown below.



$$F = 67.9 \text{ kN}$$

(ii) Calculate the stress present in member A.

3

$$\sigma = \frac{F}{A} = \frac{67.9}{5100}$$

$$= 13.3 \text{ kN/m}^2$$

$$100 - 30 = 70$$

$$100 \times 100 = 10000$$

$$70 \times 70 = 4900$$

$$10000 - 4900 = 5100$$

$$= 5100$$

MARKS

8. (continued)

- (c) The water tank is filled using an electrical pump, rated at 230V and 15A, which is located at ground level. The pump is 75% efficient and the filling pipe is located 6 metres above ground level.

Calculate the time it will take to fill an empty tank to a level of 1.5 metres.

5

$$\begin{array}{l}
 230V \quad 15A \quad 75\% \text{ eff} \qquad 6m \uparrow \\
 P = IV \\
 = 15 \times 230 \\
 P = 3450 \text{ W} \\
 75\% \text{ of } 3450 = 2587.5 \text{ W} \\
 \cancel{sh = \frac{1}{2} v^2} \\
 \cancel{9.8 \times 1.5 = 0.5 v^2} \\
 \cancel{v = \frac{9.8 \times 1.5}{0.5} = 5.42} \\
 \text{from } 8a) \\
 E_p = mgh \\
 E_k = \frac{1}{2} m v^2 \\
 E_e = I t V \\
 \cancel{E_p = mgh} \\
 \cancel{= 132300 \times 1.5} \\
 \cancel{= 198450 \text{ J}}
 \end{array}$$

$$t = \frac{E}{P} = \frac{198450}{2587.5} = 76.69565217 \\
 = \underline{\underline{76.75}}$$

MARKS
WRT
TI
MAI

9. The Queensferry Crossing is the largest civil engineering project undertaken in Scotland for a generation. The cable-stayed bridge is designed to relieve the pressure on the Forth Road Suspension Bridge, shown below, which is slowly weakening due to design flaws and a traffic volume double its design capacity.



The Forth Road Suspension Bridge

- (a) Describe one social, one economic and one environmental benefit of this project.

3

Social The project will pull people from all over to visit Edinburgh so and also create job, for people that live in the city.

Economic More people will be able to visit the city as there will be less traffic, they will spend money there, boosting the economy.

Environmental Less people will have to wait in their cars because of traffic so less carbon dioxide will be released into the atmosphere as they are not waiting as long.

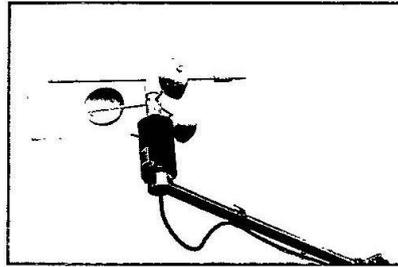
9. (continued)

- (b) The bridge control room continuously monitors conditions which could affect the safe operation of the bridge. One of the most important is wind speed.

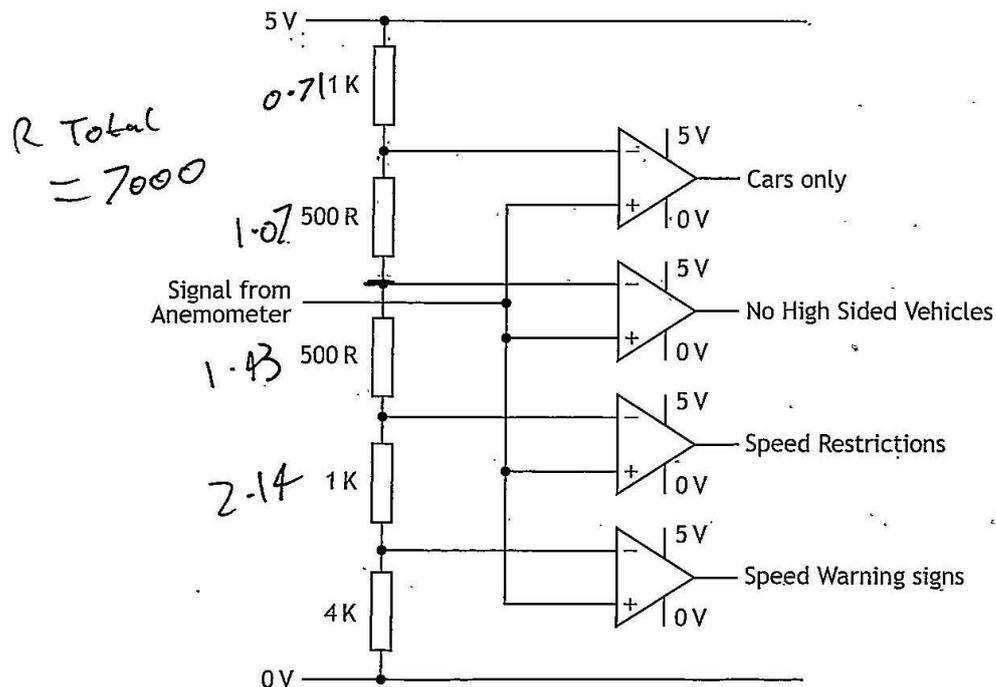
As wind strength increases there are four levels of response:

- Speed warning signs will be switched on.
- Speed restrictions are put in place.
- High sided vehicles are diverted away from the bridge.
- The bridge is closed to all vehicles except cars.

The wind is monitored by the anemometer shown below.



The anemometer gives an increasing voltage of 0.07V per ms^{-1} as the wind speed increases. Part of the control circuit is shown below.



MARKS

9. (b) (continued)

With reference to the circuit diagram opposite, calculate the wind speed which will:

- (i) switch on the Speed Warning signs;

2

$$\begin{aligned}V_{out} &= \frac{R_1}{R_T} \times V_{CC} \\ &= \frac{3000}{7000} \times 5 \\ &= 2.142857 \\ &= \underline{\underline{2.14V}}\end{aligned}$$

- (ii) switch on the No High Sided Vehicle signs.

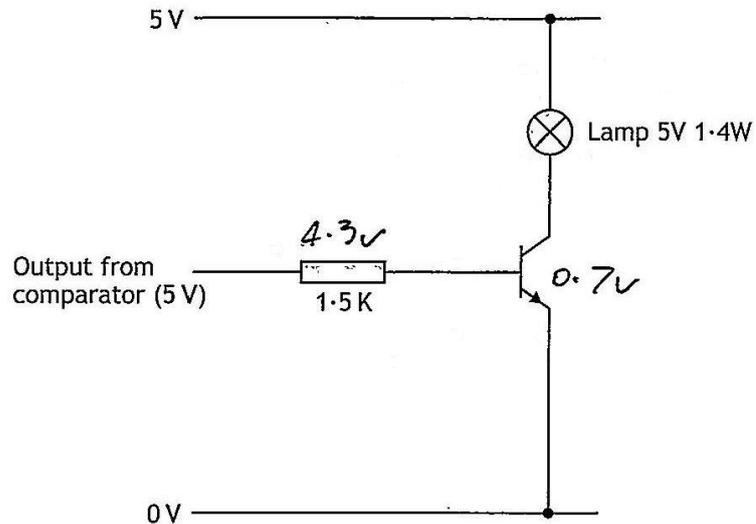
2

$$\begin{aligned}V_{out} &= \frac{R_1}{R_T} \times V_{CC} \\ &= \frac{1500}{7000} \times 5 \\ &= \underline{\underline{1.07V}}\end{aligned}$$

MARKS:

9. (continued)

- (c) The warning lights on the controller's console have 5 V lamps which have a power rating of 1.4 W. The driver circuit for each light is shown below. The transistor is fully saturated when $V_{BE} = 0.7 \text{ V}$.



Calculate the minimum current gain required by the transistor.

4

$$h_{fe} = \frac{I_C}{I_B} = \frac{0.28}{2.86} = \underline{\underline{0.098}}$$

$$V = IR$$

$$I = \frac{V}{R} = \frac{4.3}{1.5} = 2.86 \text{ A}$$

$$P = IV$$

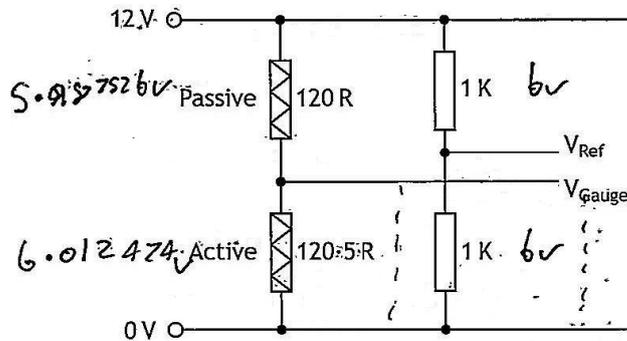
$$1.4 = I \times 5$$

$$I = \frac{1.4}{5} = 0.28 \text{ A}$$

MARKS

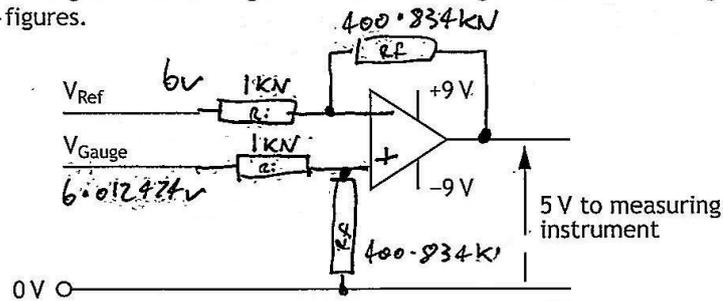
9. (continued)

The instantaneous load at various points on the bridge is monitored using strain gauges attached to the support cables. When the cable is under maximum permitted strain, the resistance of the active gauge rises to 120.5Ω and the passive gauge remains at 120Ω . The sensing part of the circuit at maximum permitted strain is shown below.



The measuring instrument requires a voltage of 5 V to give a reading showing the maximum permitted strain.

- (d) Complete the circuit below, showing all component values, to provide the signal conditioning described. Working should be to six significant figures.



$$V_o = \frac{R_2}{R_1} \times V_{CC}$$

$$= \frac{120.5}{120} \times 12$$

$$= 6.012474$$

$$V_o = (V_2 - V_1) \times \frac{R_F}{R_i}$$

$$5 = (0.012474) \times \frac{R_F}{1k}$$

$$\frac{R_F}{1k} = \frac{5}{0.012474}$$

$$= 400.834k$$

$$R_F = 400.834k\Omega$$

$$R_i = 1k\Omega$$

[Turn over

MARKS

9. (continued)

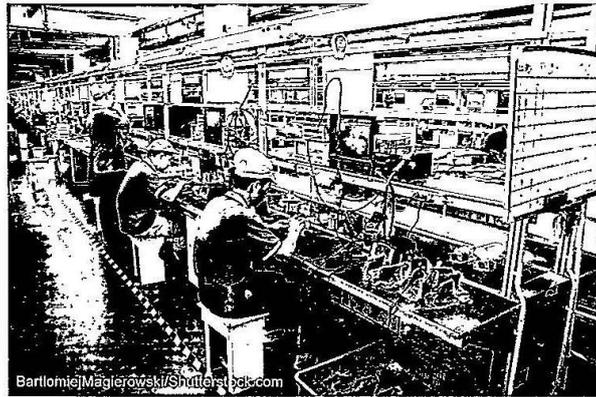
The maximum force on any cable is calculated at 4.7MN. Each cable is made up of a number of strands of mild steel wires, each of which is 13 mm in diameter. A safety factor of 10 is applied.

(e) Calculate how many strands of wire will be required in the cable.

5

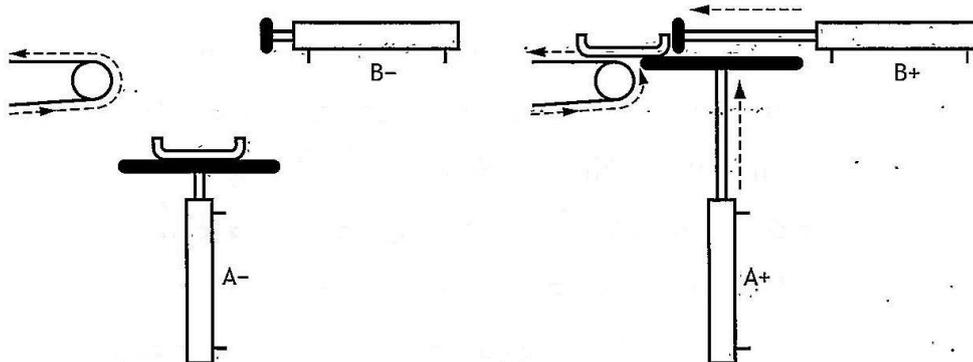
$$\begin{aligned}
 F &= 4700000 \text{ N} && \text{mild steel } 13\text{mm } d \\
 & && \text{factor of } 10 \\
 \sigma &= \frac{F}{A} && 220 \text{ N/mm}^2 \\
 220 &= \frac{(4700000)}{A} \\
 A &= \frac{4700000}{220} = 21363.6 \\
 A &= \pi r^2 && 21363.6 \\
 &= \pi \left(\frac{13}{2}\right)^2 && 132.7 \\
 &= 132.7322896 \\
 &= 132.7 \\
 & && = 1609.917 \\
 & && = \underline{\underline{1610 \text{ strands}}}
 \end{aligned}$$

10. A factory which assembles smartphones uses a cellular assembly system.



Each cell is occupied by a technician who assembles the phone units. Each finished unit is then placed in a protective cradle before being carried off to the testing station on a conveyor belt. A two-cylinder automatic pneumatic system is used to raise the cradle up to the conveyor belt level and push the cradle on to the belt. When the technician presses a button the sequence will be A+ B+ B- A-.

A+ B+ B- A-



When designing the circuit it was found that the sequence could not be achieved using a single 5/2 valve for each cylinder. A third 5/2 valve to provide two "groups" of air was required.

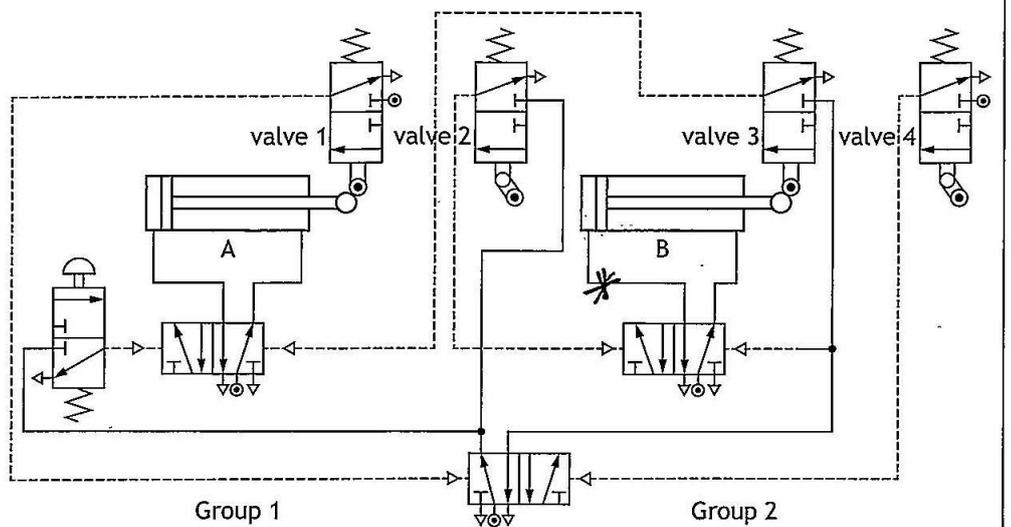
- (a) Explain, for this sequence, why this is the case.

2

Otherwise both A and B would extend at the same time and there is no guarantee B would be last. The 5/2 valve would be used to extend A, then B, then retract B, then A.

10. (continued)

(b) The circuit diagram for this operation is shown below.



Describe the operation of the circuit starting when the technician presses the button.

7

The 3/2 valve changes state and causes the pilot air actuated 5/2 valve to change state. This extends cylinder A. It trips valve 2, it then actuates another 5/2 valve via pilot air. It extends B which trips valve 4, it trips a 5/2 valve causing it to change state. This makes ~~the~~ another 5/2 valve change state and retract B, it trips valve 3. This causes the 5/2 valve on A to change state and cause A to ~~retract~~ retract, it trips valve 1 causing the 5/2 valve to change state and be ready for push button input again.

MARKS

10. (continued)

It was found that the outstroke of cylinder B was too rapid, so a uni-directional restrictor was added to slow it down.

- (c) State and explain where the uni-directional restrictor should be placed in the circuit.

3

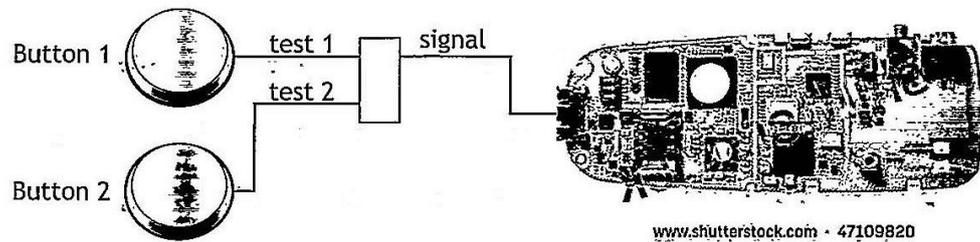
Position (* on diagram) in line to bottom of piston

Explanation it prevents all of the air going to the piston so it slows its outstroke. It needs to be on that line otherwise it would slow its in stroke.

MAR

10. (continued)

Once at the testing station the phone circuit board undergoes a range of tests by applying signals to it. A microcontroller is used to provide these signals. The sequence of one of the test procedures is shown below.



- When the test 1 button is pressed the signal goes high for 320 ms and then goes low.
- When the test 2 button is pressed the signal is pulse width modulated in a 10 times repeat loop.
- Initially the MARK = 10 and the SPACE = 3
- Each time around the loop the MARK is decreased by 1 and the SPACE increased by 1

10. (continued)

(d) Draw a flowchart for this sequence.

8

