2019 Paper 2 – Model Solution

1. Discuss the issues that a design engineer would need to consider when developing a new water pump for use in a remote rural village. Refer to information on pages 2, 3 and 4 of the Resource Booklet. [14]

Cost is always a consideration when designing a new product. In this specific context, the cost of manufacturing the pumps must be low enough that a large number of them can be produced to help as many people as possible. Additionally, the pumps will need to be transported from where they are made to areas are often in waste land (page 4, para 3) which may be difficult where there are no proper roads or energy infrastructure to power machinery.

When selecting materials to manufacture the pump housing and mechanism, the pump will need to be suitably hard-wearing that it can last many years without failing due to corrosion. The design should have as few moving parts as possible to make it easier to maintain and replacement parts should be cheaply and locally available (page 4, para 4) to that local villagers can keep the pump working reliably.

When designing the mechanism, the pump should avoid extracting more water than is required as this will quickly evaporate and be lost in the hot climate (page 4 para 2). Ergonomics should also be considered – women and children are the most common users of pumps (page 2, last para), and so the pump should not require excessive physical strength to operate it, and the height of the pump should be such that both adults and children can use it comfortably.

As the pump will be extracting Ground Water, while this is generally considered to be safer than other sources (page 3), the Engineers will need to have an understanding of where the Ground water is, how much is present and the issues that this can bring.

2. Using the information on page 5 of the Resource Booklet, calculate how many complete cycles of the pump handle will be required to fill one 20 litre container with water. Show your working. The formula for calculating the volume of a cylinder is $V = \pi r^2 h$ [6]

As there are 1000cc in a litre, use cm throughout (i.e. radius of piston is 5cm)

Volume of cylinder above plunger	$= \pi \times 5^2 \times 30$	$= 2{,}356.19\text{cm}^3$
Volume of rod	$= \pi \times 1.9^2 \times 30$	$= 340.23\text{cm}^3$
Volume of water per stroke	$= 2356.19 - 340.23$	$= 2{,}015.96\text{cm}^3$

20,000 / 2015.96 = 9.92 = **10 pump strokes**.

3. Calculate the minimum number of photovoltaic panels of the type shown that would be required to produce the energy output needed for the water pump. [6]

$E = A \times r \times H \times PR$

From the question: $E = 1890$ $r = 0.15$ $H = 2100$ $PR = 0.75$

Re-arrange to make A the subject…

$A = E / (r \times H \times PR) = 1890 / (0.15 \times 2100 \times 0.75) = 8\text{m}^2$

Area of 1 panel (in metres squared) is 1x0.5 = 0.5m^2. 8 / 0.5 = **16 panels needed**.

4. Critically evaluate the use of photovoltaic panels for powering water pumps in areas affected by water scarcity, considering the needs of stakeholders and users of the system. [14]

The introduction of PV cells will increase the start-up cost to the villagers/charities purchasing the system considerably. The panels and a motor/gearbox will need installing (by specialists) and will likely work best if they are paired with rechargeable batteries which will incur additional outlay. Circuitry will also be needed to handle the charge/discharge process. Once in place, someone will be required to replace batteries and cells as they fail and to keep the panels clean so that they work efficiently. If storage batteries were used, some of the energy created could be used for lighting or other applications for a nearby village.

From a maintenance engineers' perspective, the additional complexity of the system makes it more likely that there may be performance and reliability issues so additional spare parts would be required. Users would require a manual way of operating the pump designing into the system to keep it working in the event of hardware failure/theft.

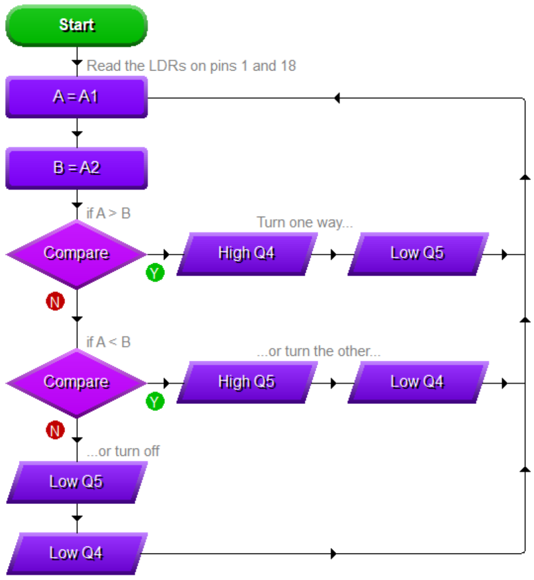
In terms of the users, they would benefit as the pump would be considerably less labour intensive to use, and would produce the required water more quickly than pumping by hand. There is a risk that with an automated system, the pump could be accidentally left running although this could be mitigated by having a PTM switch that needs to be held down for the pump to operate.

5i. A program flowchart or code with annotation is required for the PICAXE microcontroller so that the photovoltaic array will move to follow the sun across the sky. [8]

The flowchart starts by reading the ADCs on pins 1 and 8 of the microcontroller (*labelled as C1 and C2 on the datasheet shown on page 7*) to get the light levels from the LDRs.

Two compare statements then determine whether the values are equal. If one is greater than the other, then the H-bridge is energised to drive the motor one way or another.

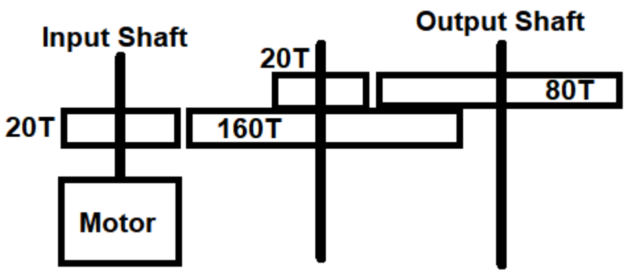
If A is not greater than B and B is not greater than A, then both are the same – at this point, the H-bridge (and therefore the motor) is turned off.



5ii. A gear system is required using only the available spur gears that would produce a 32:1 gear ratio. [8]

In the diagram, three shafts have been used, with compound gears set up in a gear chain.

Ratio = Driven teeth / Driver teeth
R_1 = 160/20 = 80/10 = 8/1 = 8
R_2 = 80/20 = 8/2 = 4/1 = 4
Ratio = R_1 x R_2 = 8x4 = **32**
Gears used: 1x160T, 1x80T, 2x20T.



6. Critically evaluate the design of the trolley in Fig. 11 of the Resource Booklet making suggestions for improvement for the task specified. [14]

Broadly, the trolley already meets the needs of the target market, as it comfortably meets the weight requirements (40kg) of a family by stacking two containers on top of each other, with additional capacity that could be used for other things. It would be easier to use of the base were made wider so that water containers could be placed side by side, negating the need for a child to lift a 20kg container to place it on top of the first one. It would also lower the centre of mass of the overall trolley, making it more comfortable to operate.

The cost of the unit at £39 is likely largely due to the bulk of the trolley being made from aluminium, which is expensive to purchase and manufacture with compared to steel. Aluminium will be have been selected due to its lower density and because it won't corrode over time. The lighter weight would likely be welcomed by the target market (women and children). The cost could be improved by using tube-steel and protecting it by galvanising with zinc – I suspect the percentage of overall weight-gain would be minimal compared to the weight of water when fully loaded.

The steel axle at the bottom of the trolley will experience a great deal of friction under load (40L of water is 40kg of weight), plus the weight of the containers themselves). To make it easier to use, bearings would be needed to reduce the energy lost due to friction as the user moves it.

The wheels look to be rather small, and made of plastic or rubber – this is not explained on the booklet. Whatever the case, the wheels look to have a relatively small diameter and look to be quite thin. On rough waste-land (page 4, para 3) or sandy surfaces, it is likely that they will dig into the ground and could result in water containers falling off the trolley. The tyres could be designed to be much wider, possibly with a tread pattern introduced to make them travel along the ground better.