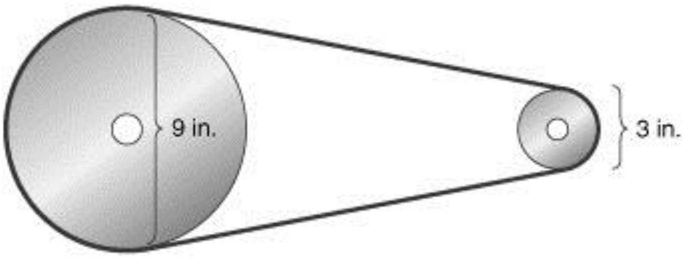
June 2010 – Model Solution

Section 1

1.1. With the aid of annotated sketches, describe two systems for transferring rotary motion between two parallel shafts. Explain the changes of rotary kinetic energy that take place in each system. *(2 x 8 marks)*

Method 1

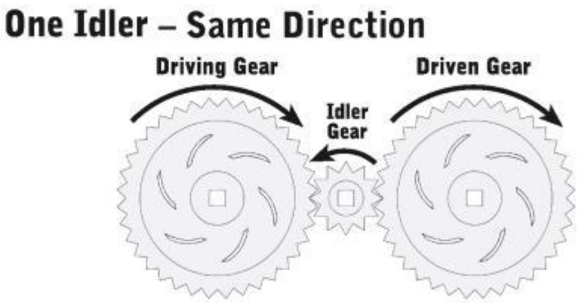
A pair of pulleys could be attached to both shafts. A belt could then be run between the two, and tensioned.



As the prime mover shaft transmits rotary kinetic energy into the pulley, the tension in the belt (designed to maximise friction) causes a transfer to linear kinetic energy. This then converted back into rotary kinetic energy at the other pulley, which is then transmitted into the output shaft. By decreasing the diameter of the output pulley, the overall speed of the output shaft can be increased.

Method 2

A gear could be attached to the end of either shaft, and a free-wheeling idler gear could be placed between them, to form a compound gear chain. This would ensure that the output shaft will rotate in the same direction as the prime mover.



The prime mover shaft will transmit rotary motion to the idler gear, which will rotate in the opposite direction as the teeth mesh together. The rotary kinetic energy is then converted (reversed once again) to kinetic rotary motion as it meshes with the driven gear, to give rotary output motion on the output shaft. By reducing the number of teeth on the driven gear, the output speed can be increased (although the available torque will decrease accordingly).

1.2. State the relative advantages and limitations of the two systems you described in **1.1.**

Belt and Pulley

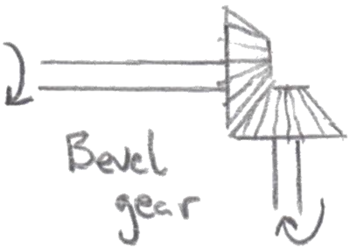
The system can span long distances and is relatively low-cost to implement, as the materials to make belts and pulleys are easy to obtain and manufacture. Unfortunately, belts are prone to slip as they age and naturally stretch over time. They also have a maximum power transfer limit of around 500hp.

Gears

As they can be cast from metals (e.g. steel), they are very strong and able to transfer larger amounts of force than pulleys and belts. Due to the meshing of the teeth, then are unable to slip in the way that a belt system can.

Gears need constant maintenance (e.g. lubrication) to keep them running well, as they use friction to transmit drive. Gears also need to be precisely designed in order to ensure they mesh together perfectly, which makes them expensive to install.

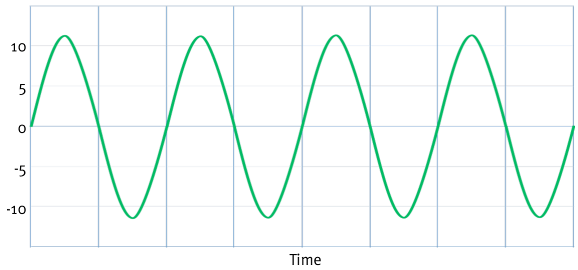
1.3. With the aid of an annotated sketch, describe one system for transferring rotary motion between two perpendicular shafts.



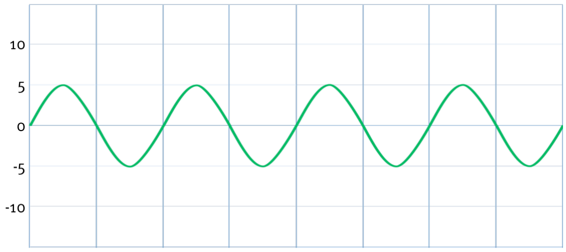
A pair of bevelled gears will transmit drive through 90˚. This system uses a pair of gears with teeth which are set at 45˚ to vertical. By using this configuration, the teeth on each gear will mesh together, allowing the transmission of drive.

2.1. Using annotated sketches to support your answer, describe with reasons four pieces of anthropometric data that would need to be taken into account when designing a mobile phone. *(4x 4 marks)*

a. Sensitivity to sound. The handset's ability to produce sound from the earpiece will need to be adjustable, so that its maximum volume is sufficiently loud that calls can be heard in loud environments, but not so loud as to risk causing damage to the user's hearing over extended period of time



High amplitude – Loud sound



Low amplitude – Quiet sound

b. Thumb Strength. The 'phone will likely have buttons (e.g. for volume and power). In order to avoid accidental button-pushes while in a user's pocket, the design engineers will need to assess an amount of force that the average user can comfortably exert on the handset, ensuring that they will not have to strain in order to depress the buttons. The distance the button will need to travel will also likely also need to be considered.

c. Visual Accuity. The minimum size text that an average adult can comfortably read from the mobile display then the UI is being designed. This will ensure that users do not suffer from eye strain when using the handset for extended periods.

Larger text is easier to read, but less content can be seen at any one time on the display.	Smaller text shows more content on the display at any time, but can be harder to read for those with weaker vision, or the elderly.

d. Wrist strength. The maximum amount of weight that the user can comfortably hold for an extended period. A heavier item (e.g. iPad) held up for an extended period can cause an RSI if it constantly puts the wrist under

strain. In the sketch, the user's wrist is constantly having to work to hold the device.

2.2. With reference to a product of your choice, explain in detail the necessity for good ergonomic design for control systems and information displays in potentially hazardous situations. *(12 marks)*

In a car, good ergonomics are important, as the driver needs to access and analyse a wide range of information at all times, to ensure their safety, that of other road users and of the driver's passengers.

The gear selector knob (a control system) needs to be carefully designed so that it is clear to the driver where each gear is located (e.g. some cars have reverse next to 1st, others have it below 5th). Additionally, the size of the selector should be easy to grip firmly when the driver has sweaty (or cold) hands, to ensure they can quickly and consistently select gears.

The dashboard speedometer should use a clear, well sized font, and be placed in a location where the driver can quickly access an unobstructed view of the vehicle's current velocity by taking their eyes off the road for the minimum possible time. Analogue displays are commonly used for this with a high-contrasting coloured needle (e.g. orange or white on a black background) – their reading can be quickly judged, further minimising the time spent reading the speed.

The hazard warning lights should be large and easily identifiable, so that they can be activated in an emergency. Ideally, accessible centrally in the cockpit, so that a passenger could activate the lights in the event of an emergency if the driver were incapacitated for any reason.

Failures in a car (e.g. ABS brakes, Engine problems) can be detected by sensors build into the individual systems. Where backlit icons are to be used, internationally recognised symbols should be used which should be located in the driver's field of peripheral vision (so they are noticed quickly). These should be accompanied with an audible beep, which should be suitably loud to attract the attention of the driver, but without causing them to jump (potentially triggering an accident). As an alternative to pictograms/icons, a short message could be displayed on an LCD information panel (if they car is equipped with one).

3.1. With reference to your own experience of designing and making, discuss the advantages and disadvantages of using computer simulations when developing an electronic circuit. *(16 marks)*

I designed a PIC controlled automated parking sensor for a car. It used ultrasonic sensors as an input, then LEDs and a speaker to provide supplementary audio feedback to the user.

Computer simulations are useful during the design stage, as I was able to create my circuit design, and see the electron flow through the circuit, which gave me confidence that the components were all connected correctly before proceeding to the breadboard stage. I was then able to write the program for the PIC, which I could see working with my input/output components to provide me with an idea of how the circuit would perform when made in real life.

With the circuit design complete, I created a PCB for my circuit. The software enabled me to route (and re-route) tracks on my PCB, so as a consequence I was able to create a far smaller design than I would have come up with if I had hand-drawn the artwork. I was also able to simulate the PCB running live afterwards, with virtual off-board inputs and outputs, and to see the current flow live.

The advantages of using computer simulations are:

Early diagnosis of problems,
Large variety of parts available,
Virtual instruments (e.g. Oscilloscope) are available for troubleshooting,
PIC Programs can be tested and improved,
Enables circuit development anywhere there is a computer,
No wastage of components in prototyping,
Zero cost to reset a “blown” component.

The disadvantages of using computer simulations are:

Simulation isn’t always accurate,
Initial cost of buying software can be expensive,
Software may require training to use,
Size on screen is not indicative of PCB size,
Not all components will be available in the simulation.

3.2. With reference to a product of your choice, explain where and why models may have been used in its development. *(12 marks)*

Using my parking sensor project as an example, I used models at several points in the creation of my project.

I used a cardboard model to create early models of my housing and display system, so that I could get some visual examples of how my product might look. Using cardboard, staples and masking tape meant I could swiftly create aesthetic prototypes for user-feedback.

After this, I also used 3D visualisation software (Cinema4D) to create quick renders of how my housing might look. This allowed me to apply different textures to my models, and include other artefacts in the render (e.g. the model located on a car dashboard) to provide visual context.

In terms of my electronics, I produced a breadboard model of my circuit after I’d made my circuit simulation. This way, I was able to see exactly how my electronic components would work in the real World when manufactured. As I’d already made a software model, I was reasonably confident that this would work, which (as it turned out) it did. The breadboard brought to my attention a number of minor software tweaks needed in my PIC program, which I wouldn’t have spotted if I’d not taken this step.

When the design was further along, I then created a 3D SolidWorks model. I made this model part by part, fully defining each part of the assembly, then fitting them together in software. By doing this, I was able to create Stereo Lithography (.STL) files which could be manufactured using CNC machines to create all the parts for my actual project, in the knowledge that all parts would fit together perfectly when manufactured. I was able to bring in a DXF of my PCB design, so that my mounting holes aligned perfectly, and I was able to ensure that my PCB and wiring run would all work together when the parts were made, and the batteries fit inside the unit as intended.

Section 2

4.1. With the aid of annotated sketches, describe an automatic system for providing precise angular positioning of a turntable to an accuracy of 0.05 of a degree. *(14 marks)*

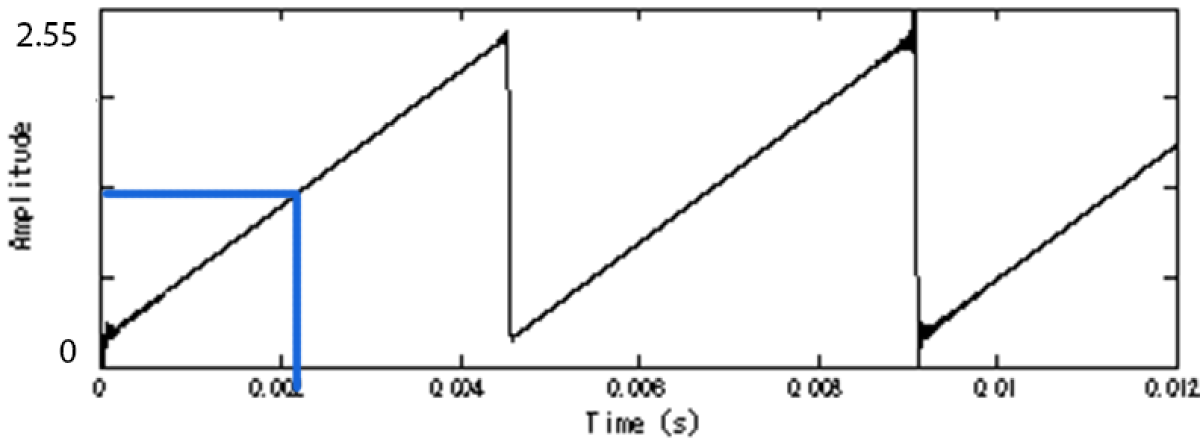
In order to achieve 0.05˚ steps, 7200 steps (360 / 0.05 = 7200) would be required to turn through a full 360˚ circle. While different step-sizes are available, bipolar stepper motors typically tend to move 1.8˚ per step (so 200 steps to turn 360˚).

A reducing linkage would be required which would need to produce a 36:1 ratio (7200 / 200 = 36). If I were designing this system, I'd mount a 100T gear to my stepper motor, then mesh this directly to a parallel shaft containing a 3600T gear and the turntable from the question. This way, each individual step would be the desired 0.05˚.

I would use a PIC chip connected to a L293D H-bridge motor driver to control this system. By powering each of the coils in the correct order (available from the relevant datasheet), each individual step can be sent exactly when required.

4.2. With the aid of a diagram, explain how an analogue electrical signal ranging between 0 volts and 2.55 volts can be converted to an 8 Bit digital code. *(14 marks)*

There are several ways to implement an ADC. One is to use a ramp-compare method, whereby a sawtooth wave (the ramp) is constantly generated, ranging from 0-2.55V. Each time the wave is renewed, a timer is started. When the ramp voltage matches the input signal, a comparator (e.g. an op-amp) is fired, and the analogue value can be calculated based upon the time at that point.

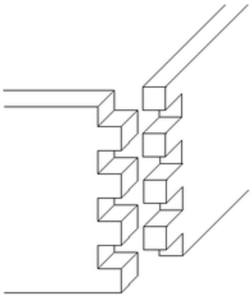


In the sketch above, the input voltage is around 1.75V, which is detected just after 0.002s – this would be interpreted as 175 by the ADC algorithm.

When an analogue component (e.g. LDR) is connected to the analogue input on a PIC chip, the voltage level is interpreted as an integer depending on the resolution of the ADC. An 8-bit ADC would provide a value between 0-255 (11111111 in binary).

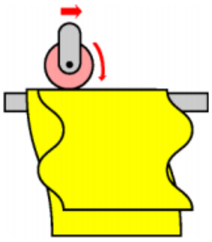
The ADC reports a ratiometric value, reporting the source voltage (2.55V in this case) as 255, 0V as 0 and anything between. In this specific case, 0.01V represents 1 on the ADC - 1.00V = 100, for instance.

5.1. Using annotated sketches, explain in detail two different methods of permanently joining pieces of plastic. *(2 x 5 marks)*



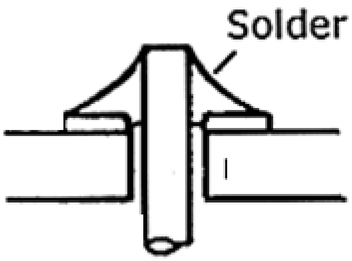
Method 1. If the plastic in question is acrylic, then solvent cement (e.g. Tensol) can be used to permanently join two pieces. To ensure a strong bond, both surfaces should be cleaned thoroughly to remove any grease or dirt. Prior to applying the adhesive, the surface area between the two surfaces should be maximised. One way of doing this along an edge could be to use finger joints (shown in the sketch to the right, for instance).

Prior to applying the Tensol, the two pieces should be clamped together (perhaps using a trigger clamp), then the solvent sparingly applied to the seam. The solvent will be drawn into the joint through a capillary action. Excess Tensol can then be wiped away, and the work-piece left to dry for about an hour.

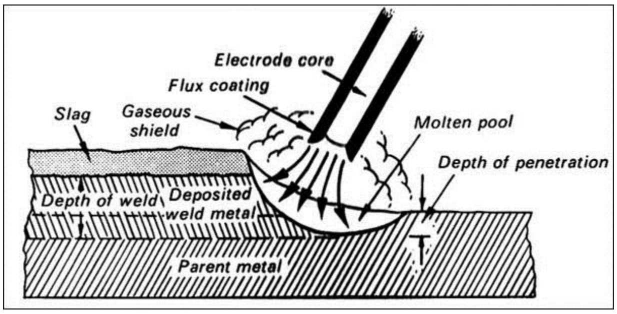


Method 2. With polyethylene (found in food bags), two pieces can be welded together by rolling a heated wheel over the two pieces that are to be bonded together along a straight line. This provides a permanent, air-tight join, but is only practical for thin materials.

5.2. Using annotated sketches, explain in detail two different methods of permanently joining pieces of non-ferrous metal. *(2 x 6 marks)*



Method 1 - Soldering: Used in plumbing and electronics, this is the process of bonding the leg of an electronic component to the copper track on a PCB through the use of a soldering iron, heated to around 300˚C. The leg and track are heated with the iron for around 3s, then the solder (usually pre-fluxed) is inserted, so that it flows cleanly over the component leg and track to form a peak. The soldering iron is then removed, and the component leg trimmed.



Method 2 – Arc welding: This is where a high current is used to form an intensely heated electric arc which is used to bond two metals together. While difficult to weld due to its low melting point, Aluminium could be used in this example. Safety gear is essential before starting to weld. Skin should be covered, gauntlets worn, and a welding mask worn while working. The area needs to be suitably well ventilated.

To start with, the two surfaces to be joined should be clean from grease/grime, precisely machine to ensure they fit closely together and burr-free. The work is placed on the (grounded) welding bench, and to start the arc, the welding rod is momentarily tapped against the work, then quickly moved back a small amount to form the arc. While welding, the rod should be kept 10-20˚ from vertical, and slowly moved towards the welder. A line of slag will form along the length of the weld. This will need to be chipped off after the weld has cooled.

5.3. Describe three possible problems associated with jointing methods that involve the use of heat. *(3 x 2 marks)*

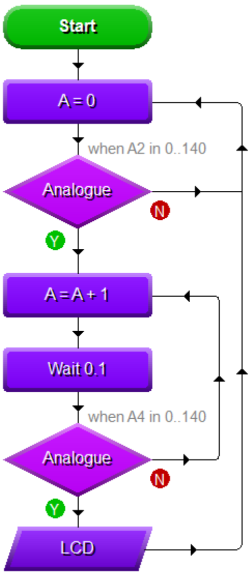
<u>Problem 1:</u> When soldering, some electronic components (e.g. ICs) are susceptible to the effects of heat, and if exposed, can fail. To get around this problem, chip carrier sockets are used, so that the IC never needs to be exposed to any heat at all. This has the downside of slightly increasing the overall build cost (by a few pence) and the height of the PCB by a few millimetres.

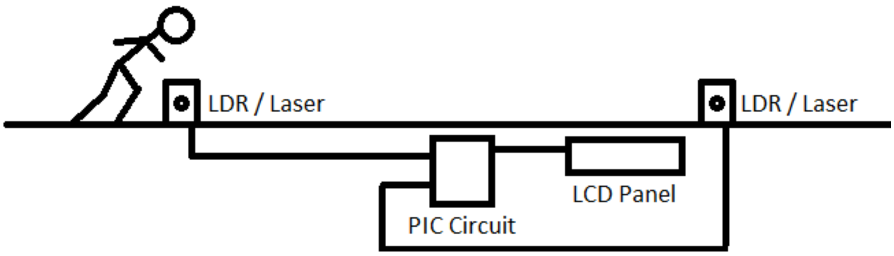
<u>Problem 2:</u> Metals are good conductors of heat. When welding, the heat applied to the area being worked on will spread through the rest of the work-piece. This can cause the metal to deform, so that it no longer meets the clients requirements for manufacturing tolerances.

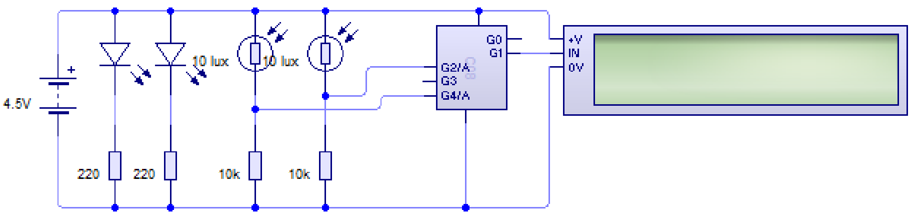
<u>Problem 3:</u> Each time a material is heated, the bonds between the molecules in the metal are weakened, and after cooling, the material won't be as strong as it was previously. If the material is repeatedly heated and cooled, it will become significantly weaker over time.

6.1. With the aid of annotated sketches, describe a system that will measure the time it takes a long jumper to complete their run up. Your answer should make reference to:

- the sensing system
- the timing system
- the type of output display used and how this is driven. *(16 marks)*







In my design, a pair of laser-beams are shone straight onto LDRs at foot level, so that as the runner starts, the ADC on the PIC detects that the beam has been broken. This can be seen in the first decision diamond in the program I have sketched above. Once the beam is broken, a variable is incremented once every 0.1s until the second light beam is broken. When this happens, the LCD panel displays the jumper's time (bottom flowchart symbol), which can be expressed to the nearest 0.1s. Should a more precise time be needed, the program could be amended to work to the nearest hundredth of a second easily. The time remains visible until the next jumper begins their jump, at which point the timer is reset, and the process starts anew. Alternatively, I could have used 7-segment displays with decoder driver ICs to show the time instead. Given the flexibility offered by an LCD, I feel this is the better solution, however.

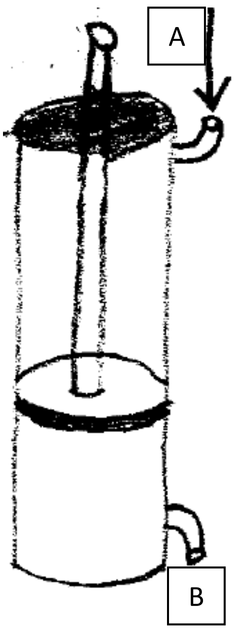
6.2. Describe in detail, the advantages and disadvantages of using pneumatic cylinders for providing linear motion. *(8 marks)*

Pneumatic systems offer a number of unique characteristics that make them useful in certain large-scale industrial processes.

In terms of their advantages, they can be used to exert very large forces, and can both push and pull. By controlling the rate at which air is driven into (or released from) the cylinder, the speed (and length) of the strokes can be controlled, and because they use air, the amount of force exerted is consistent at all points of the stroke. They also contain very few parts, and as such are straightforward to manufacture.

The disadvantages of pneumatics are that they require a compressed air source, and can be very noisy in their operation. The equipment is also costly to purchase, and requires maintenance to ensure all the seals remain airtight to keep the system working efficiently. Compressed air also condenses easily, and so the air coming into the system needs conditioning to ensure it is dry, and contains a small amount of lubricant to keep all the parts moving smoothly.

6.3. Explain why a double acting cylinder cannot produce the same force on the out and in stroke of its cycle. *(4 marks)*



A double-acting cylinder has a piston rod (*where the force is exerted to output components*) running through the middle of the cylinder, connected to its piston. When compressed air is sent into port A, port B is opened up as an exhaust, causing the "instroke" to take place, until the piston reaches its negative position.

When the outstroke is required, port A is opened for exhaust, and compressed air is sent in via port B, driving the piston back to the home position.

Because the rod occupies volume inside the top-half of the cylinder, it reduces the area that can be occupied by compressed air, reducing the area for the air pressure to act on (**Force = Air Pressure x Surface area**). The rod is not present in the bottom half of the cylinder (the section containing port B), and therefore a slightly greater force is exerted in the outstroke.