June 2012 – Model Solution

Section 1

1.1. Control and movement may be achieved by electrical, mechanical or pneumatic systems. Compare the advantages and limitations of each system, giving an example of where each might be used. *(3 × 8 marks)*

While each system has its advantages and disadvantages, solutions to engineering programs typically require a combination of these three systems.

Electrical: Powered by the mains, batteries, solar cells or petrol/diesel generators, electricity is readily available as a source of power for different applications.
Advantages: Electrical systems can often (e.g. Stepper motor, servo) be precisely controlled and made to operate quickly through integration with microcontrollers or PLC modules. The outputs can be either high speed (e.g. DC motor) or low (e.g. stepper), with a range of torque depending upon the application. Electric motors require little maintenance (compared to a petrol engine, for instance), making them useful in environments such as space exploration. In addition to rotary outputs, linear motion can also be obtained through the use of solenoids. Some components can provide feedback (e.g. use of microswitches).
Disadvantages: Remote (e.g. jungle) locations may make sourcing power difficult, Some electronic components can cost thousands of pounds, not all components can provide feedback (e.g. DC motors) and will require additional hardware (e.g. LDR and LED) to build this into the system.
Application: A solenoid in a door lock, used to release a catch.

Mechanical: Flexibly powered (e.g. hand crank, petrol engine, DC motor, steam…) from variety of sources for their prime movers, mechanical systems combine gears, belts, pulleys and linkages to produce complex outputs.
Advantages: Mechanical systems can be build form steel or other alloys to make them tough and hard-wearing. They can be combined in many different ways to provide outputs for a variety of situations. They are usually able to exert higher amount of force than electrical systems alone, and can produce highly complex outputs, as seen in engines, for instance.
Disadvantages: Designing mechanical parts requires expensive machinery, and meticulous calculations and high precision manufacturing in order to ensure the mechanism will move as efficiently as possible. Metal mechanical parts experience a high level of friction under heavy loads or at high speed, and will need lubricating. Feedback can be obtained, if indexing (e.g. via a Geneva Drive mechanism) is used.
Application: A sewing machine will contain a motor, cams, belts and pulleys.

Pneumatic: Powered by compressed air fed from a compressor pump.
Advantages: Capable of exerting higher amounts of force than other systems, 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. In the event of a split hose, no liquids are released (as could happen in a hydraulic system), making them safer.
Disadvantages: 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.

Application: HGVs (Articulated Lorries) use air braking systems, which allow large amounts of force to be exerted on the tractor and trailer unit when the brakes are applied.

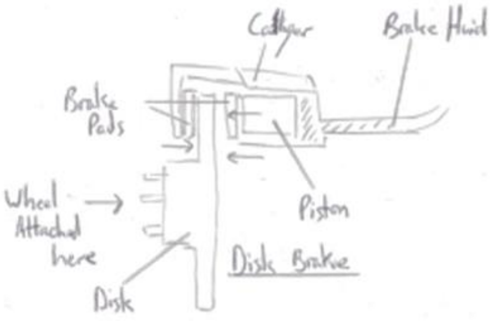
Further reading: http://www.bbc.co.uk/schools/gcsebitesize/design/systemscontrol/pneumaticsrev1.shtml

1.2. Explain the advantages of a closed loop control system for ensuring accuracy in manufacturing situations. *(4 marks)*

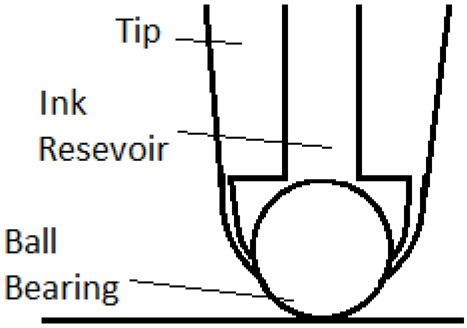
In a closed loop system, a feedback signal is sent once the process in question (e.g. soldering a component) has been completed. Doing so provides continual monitoring of a process, so that the engineers know the process is working correctly. If the feedback signal isn’t received within a certain time, a notification can be sent o the engineers. Feedback in closed loop systems also means that a process cannot continue until condition met, to ensure that the factory line can’t back up with work if a problem occurs, potentially damaging machinery or wasting source materials.

2.1. With the aid of annotated sketches, explain in detail the operation of four different systems/devices that require a high level of frictional force for their operation. Your answers should clearly indicate how this high frictional force is achieved and why it is necessary. *(4 × 7 marks)*

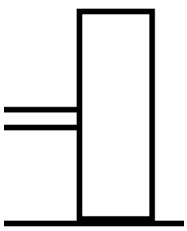
Disc Brakes: These use a ceramic pad which is forced against a steel disk using hydraulics when the brake is applied. The liquid (brake fluid in this case) in hydraulic systems doesn’t compress as much as the air in a pneumatic system, and so a far larger amount of force can be applied, to stop the vehicle moving. The frictional force is required to convert the kinetic energy in the vehicle into heat energy on the disks and brake pads.



Ballpoint Pen: When the pen is placed on the writing surface and drawn along it, friction between the ball bearing and the paper causes the ball to turn. As there is ink in the reservoir above it, gravity causes the top of the ball bearing to be constantly coated in a thin layer of ink, which is continually replenished, and transferred onto the paper as the user continues to write. When the pen is removed from the paper, no further ink flows, preventing the ink from drying up. The frictional force is needed to rotate the ball bearing, in order to facilitate the ink transfer.

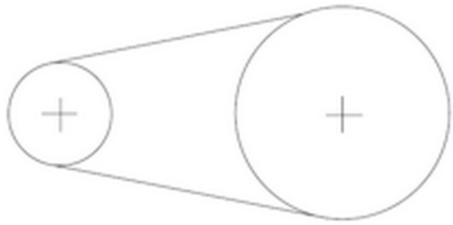


Slick Tyre on an F1 car: One of the ways that racing tyres for dry conditions differ from standard car tyres is that they have no treads built into them. In order to maximise traction, it is desirable to have maximum surface area in contact with the road. Road tyres need to be able to cope with wet conditions, and the tread patterns serve to displace surface water to help prevent the car from aquaplaning. The frictional force is exerted by

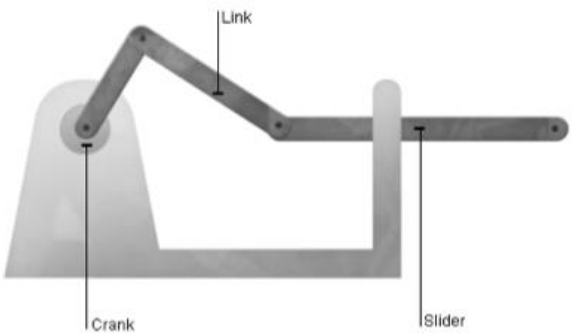


the weight of the car, through the axles, onto the wheels which are in contact with the road surface. The friction is required when the vehicle accelerates, decelerates or changes direction.

Belt and Pulley: A high frictional force is achieved by applying a high degree of tension across the pulleys with the belt. During operation, rotary kinetic energy from the prime mover is transferred into linear motion across the top of the belt (the friction allows the transfer), then friction between the belt and output pulley completes the operation. If the friction is inadequate, the belt will slip (or fail to turn the output pulley), reducing efficiency. If the level of tension on the belt is excessively high, it will pull the axles supporting the pulleys together, generating additional friction, and reducing efficiency.

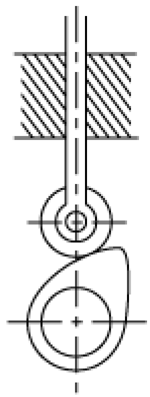


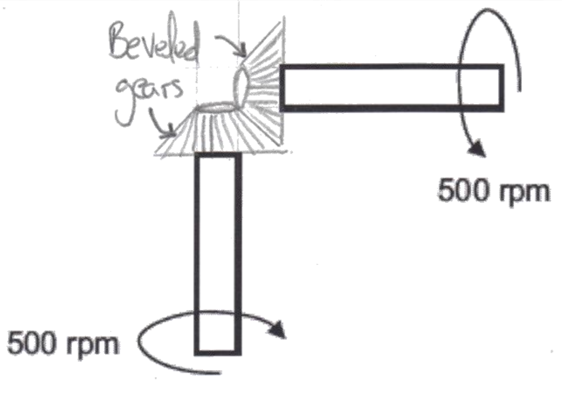
3.1. Sketch and describe the operation of two different systems for converting rotary motion into reciprocating motion. Name a suitable application for each. *(2 × 6 marks)*



Crank, Link and Slider: This system uses a rod connected to the prime mover, which in turn is connected to a link (con-rod) with a pivot at either end. The other end of the link rod has the output slider connected to it, which will need to be held in place with guiders, to ensure it follows the desired path.
Application: Used on steam trains with the prime mover being the reciprocating motion, and the output being the rotary motion on the wheels.

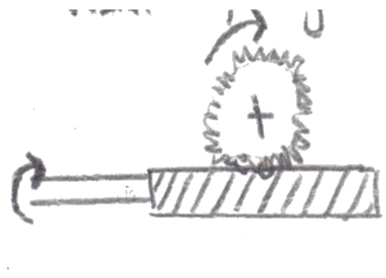
Cam and Follower: Through careful design, many different types of output motion can be achieved (the sketch shows a pear cam). This work by the prime mover turns, and the rise, dwell and drop of the cam forces the follower to move up and down to track the cam. As with the crank, link and slider, guides (top of sketch) will be needed to ensure the follower moves as designed.
Application: Cams are used in automatons, where a cam can drive a limb to provide a waving action, for instance.





3.2. Sketch and describe the operation of two different systems for transferring rotary motion between perpendicular rotating shafts. Name a suitable application for each. *(2 × 5 marks)*

Bevelled Gears: Through the use of a pair of gears, which have a 45˚ chamfered edge on them. By doing so, the two gears can mesh together, allowing drive to be transmitted through 90˚.
Application: Roller shutters on shop doors.

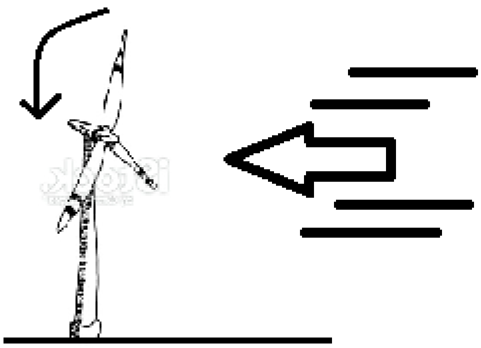


Worm Drive and Spur Gear: The use of a worm drive as prime mover, meshed with a spur gear at 90˚ will transfer perpendicular drive. As the gear ratio is usually so high, this system has the added advantage that the spur can't drive the worm. This configuration also provides a great deal of torque.
Application: Garage car lift (so that a power cut won't drop the car)

3.3. Give two reasons why mechanisms are not 100% efficient and suggest how the efficiency might be improved. *(2 × 3 marks)*
Reason 1: In order for parts to move together, friction has to be overcome. This can never be eliminated, but can be reduced through the use of lubrication.
Reason 2: Parts themselves have mass, which also needs to be overcome to start the mechanism moving. This can be improved upon by reducing the weight of the parts (e.g. making them from aluminium instead of steel where possible).

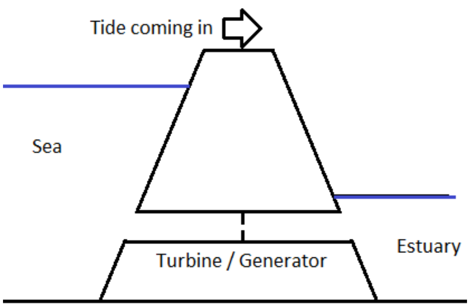
Section 2

4.1. With the aid of sketches, describe in detail a method of converting the energy from the wind into electrical power. Your answer should clearly show the energy conversions that take place. *(10 marks)*



The wind (input) arrives in the form of linear motion, which passes through the blades of the turbine, converting into rotary motion. The force exerted by the wind is thus harnessed, and the blades spin a shaft, which is then connected to a gearbox. This spins a generator, which generates electricity (the output).

4.2. With the aid of sketches, describe in detail a method of converting the energy from tidal rise and fall into electrical power. Your answer should clearly show the energy conversions that take place. *(10 marks)*



A tidal barrage can be used to achieve power this way. When the tide is coming in (pictured), the barrage only allows the water to come in by passing through a series of holes (linear kinetic energy), which have turbine/generators in them. The linear motion is converted into rotary via the turbine, then through a gearbox (to increase the torque), and finally through a generator to produce output.

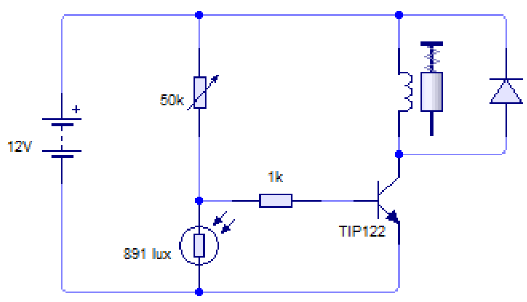
4.3. Discuss the advantages and disadvantages of using fossil fuels as a method of producing electrical energy in the UK. *(8 marks)*

Fossil fuels allow for 24/7 energy production, with no dependence on weather conditions or time of day (as would be found with solar or wind energy supplies).

Advantages in the UK are that coal is readily available, and coal mines in the UK can be re-commissioned easily in order to provide coal for many years to come. Coal and gas are proven and well-established technologies that work with a high degree of efficiency, and are compact in the space they take up compared to a wide area which would be needed to get the equivalent amount of wind energy.

Disadvantages of fossil fuels are that oil is running out in the North Sea, and while around a decade of gas can be obtained from newly emerging fracking technology, this is unproven though, and there are questions surrounding links with earthquakes in the USA. Otherwise, gas needs to be imported to the UK, which puts the country at the mercy of International market fluctuations. Fossil fuels are also not sustainable, as they are not being replenished quickly, and they produce pollution (e.g. CO_2 emissions, soot, acid rain).

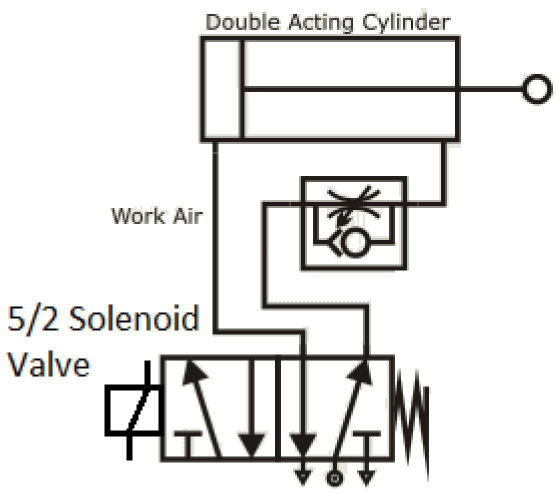
5.1. With the aid of an annotated sketch, describe how a double acting cylinder could be made to extend slowly when a light beam has been broken and retract quickly when the light beam is reinstated. *(16 marks)*



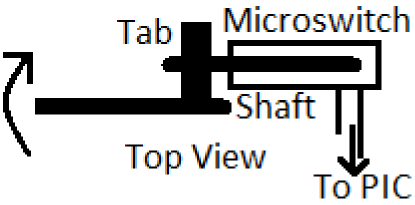
For the detection of the light beam, a simple potential divider circuit could be used, as shown below (the variable resistor will allow the circuit to be tuned once in situ). Placing the LDR at the bottom means that when the light level drops (and the resistance increases sufficiently), the base of the transistor will receive >0.7V, so that the solenoid is actuated (and released when the light beam is reinstated).

In terms of pneumatics, the 5/2 valve is set up so that it its resting state (when the solenoid isn't actuated), the second port is connected to the airline, holding the cylinder in its in-stroke position. When the solenoid is energised, the valve moves into its 2nd condition, driving air in behind the piston, and pushing the cylinder into its outstroke position.

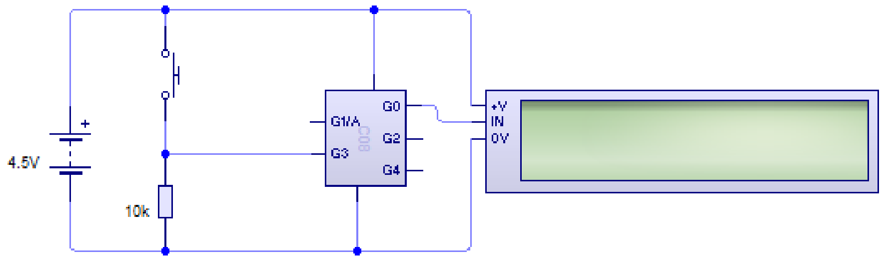
To provide slower speed on the out-stoke, a unidirectional restrictor has been fitted to the second port, slowing the exhaust on the out-stroke, but not the in-stroke.



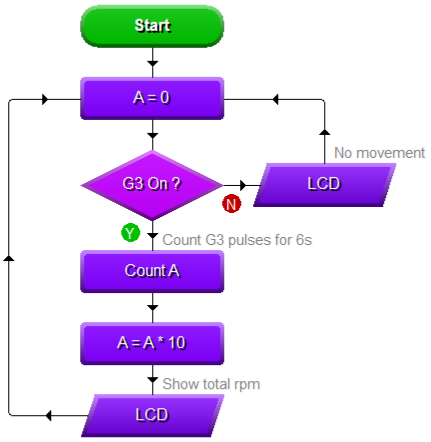
5.2. With the aid of a diagram, show a system that could automatically count and display the number of revolutions of a shaft in one minute. *(12 marks)*



In terms of hardware, a simple way to count the pulses would be to create a tab on the shaft. This could be achieved by tapping a thread into the shaft, and inserting an M3 machine screw. The micro-switch could then be connected directly to a PIC.



In terms of the control circuit, a simple PIC design will accept the digital inputs from the micro-switch (*expressed as a PTM in this diagram*). A program can then be written to count the pulses, and display then on an LCD display. Alternatively a series of 7-segment displays connected together with 7-segment decode ICs could have been used, but this solution requires less components, and provides a more attractive output.



In order to display rpm, the program would work as follows:

1. If the input isn't triggered, display "No movement".
2. Once movement is detected, count the number of pulses from the micro-switch over a 6s period, and store in variable A.
3. Multiply A by 10 (to give an rpm value).
4. Display the value.
5. Reset A to 0, and restart the program.

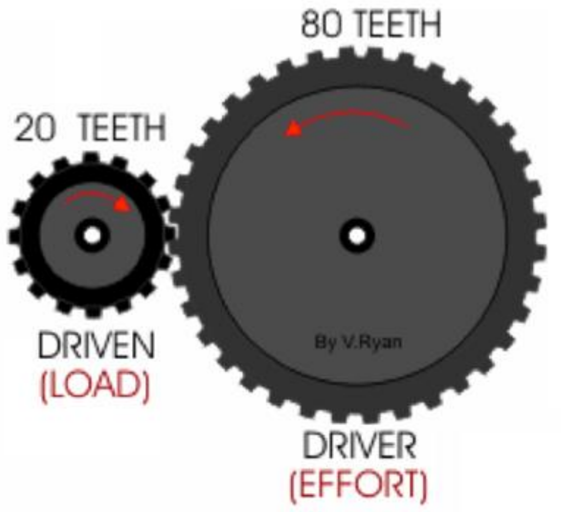
6.1. With the aid of annotated sketches and reference to specific examples / situations, describe in detail four different systems for transferring and amplifying the following:

- speed of rotation
- torsional force
- linear distance moved
- linear force.

In each case you should state the limitations of the system chosen. (4 × 7 marks)

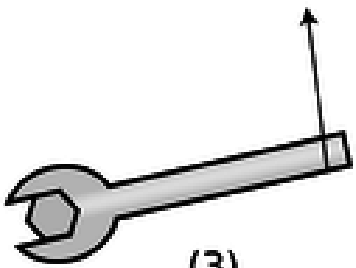
Solution over the page…

Speed of rotation: This can be accomplished by using gears. In the sketch to the right, the prime mover is connected to a gear with 80 teeth on it. This is meshed with a gear on the output shaft which contains only 20 teeth. There is a 2:8 = 1:4 ratio between the gears, effectively quadrupling the speed of rotation on the output shaft (although quartering the available torque).
These can be seen in cars, industrial machinery and bicycles. The limitations of gears are the high cost of designing and manufacturing them, as well the maintenance that is required to keep them lubricated (to reduce friction).



Torsional Force: Amplifying torque (measured in Nm) can be achieved by using an extension bar on the part that requires turning force. A spanner performs this task, for example. The longer the extension arm on the spanner, a smaller force is required (albeit over a greater distance) to rotate the nut in the middle.

Torque = Force x Distance



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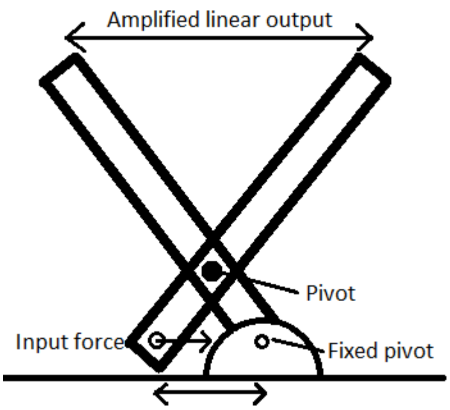
The limitations of using systems such as these is that where particularly large forces are needed, the amount of extension required may become infeasible. Secondly, there may not always be space to swing a lengthy torque multiplier bar through 360˚ - adding a ratchet system can help here.

Linear distance moved: A scissor linkage (or several connected together) will increasingly amplify the amount of output linear motion as the central pivot is moved closer to the inputs. As the sketch here shows, the small linear input provides a considerable amount of amplification. Parallel scissor linkages are used in commercial car lifts, using worm-gears meshed with rack gears so that the car isn't suddenly dropped if the power fails.



The limitation of scissor linkages is that the pivot points need to be strong, as they carry the full force of the movement, and that they represent a potential pinch point where fingers of limbs could be accidentally caught, causing injury.

Linear Force: To amplify linear force, a class 1 lever could be used. In the example shown here, the output force is doubled, by moving the pivot twice as far away from the input force (right-hand side). A limitation of using a lever are that an increasingly large arc needs to be drawn by the end of the lever, which will require a large amount of space.