AS Level Physics

Chapter 4 – Work, Energy and Power

4.3.2 Power and Efficiency

Worked Examples

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POWER AND EFFICIENCY

Exam Style Question 1:

a) Power can be measured in watts. Define the watt.

b) An electric motor-driven crane is used to raise a load of bricks of mass $700\ kg$ through a vertical height of $8.5\ m$ in a time of $45\ s$. The efficiency of the motor-driven crane is 30%. Calculate:

  i) The gravitational potential energy E_p gained by the bricks,

  ii) The output power of the motor-driven crane,

  iii) The input power to the motor-drive crane.

POWER AND EFFICIENCY

Exam Style Question 1:

Answers:

a) Define the watt.

1 watt is equal to 1 joule of energy transferred per second.

bi) The GPE gained by the bricks

$$E_p = mgh$$
$$E_p = 700\ kg \times 9.81\ m\ s^{-2} \times 8.5\ m$$
$$E_p = 58369.5\ J$$
$$E_p = 5.84 \times 10^4\ J$$

bii) The output power of the motor-driven crane.

Use: $power = \frac{energy}{time}$

$$power = \frac{5.84 \times 10^4\ J}{45\ s}$$
$$power = 1297.77777\ W$$

Therefore, the output power is $1.3 \times 10^3\ W$.

biii) The input power to the motor-driven crane.

Use: $efficiency\ (\%) = \frac{useful\ power\ output}{total\ power\ input} \times 100$

$$30\% = \frac{1.3 \times 10^3\ W}{total\ power\ input} \times 100$$

Rearrange to find the total power input

$$total\ power\ input = \frac{1.3 \times 10^3}{0.3}$$
$$total\ power\ input = 4333.33333$$

Therefore, the input power to the motor drive crane is $4.3 \times 10^3\ W$

POWER AND EFFICIENCY

Exam Style Question 2:

Fossil fuels will eventually run out. This has led to scientists looking for alternative sources of energy. Tidal stream systems use the kinetic energy of seawater to generate electrical energy during the incoming and outgoing tides. Fig. 7.1 shows a twin-turbine system in which flowing seawater turns the turbine blades.

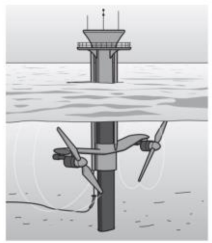

Fig. 7.1

When operating, $9.7 \times 10^5\ kg$ of seawater travelling at a speed of $3.0\ m\ s^{-1}$ passes through each turbine every second. Each turbine generates $1.2 \times 10^6\ W$ of electrical power.

a) Define power.

b) The input power to each turbine is the kinetic energy of the seawater that flows through each turbine in one second.

Show that the input power to each turbine is $4.4 \times 10^6\ W$.

c) Calculate the percentage efficiency of each turbine.

d) In one second, a cylinder of seawater of mass $9.7 \times 10^5\ kg$ passes through each turbine at a speed of $3.0\ m\ s^{-1}$. Calculate the radius of each turbine.

The density of seawater is $1030\ kg\ m^{-3}$.

e) Tidal stream systems require less space than conventional wind turbines that are found in windy regions of this country.

Suggest one further advantage of tidal stream systems over conventional wind farms.

POWER AND EFFICIENCY

Exam Style Question 2:

Answers:

a) Define power:

$power = \frac{work\ done}{time}$ or the rate of work done.

b) Show that the input power to each turbine is $4.4 \times 10^6\ W$.

$$KE = \frac{1}{2}mv^2$$

$$KE = \frac{1}{2}(9.7 \times 10^5\ kg\ s^{-1})(3.0\ m\ s^{-1})^2$$

$$KE = 4365000\ J$$

$$\therefore \mathbf{power = 4.4 \times 10^6\ W}$$

Input power to each turbine is the kinetic energy of the seawater flowing through it.. So calculating the KE will give us the input power:

c) Calculate the percentage efficiency of each turbine.

$$\%\ efficiency = \frac{useful\ energy\ output}{total\ energy\ input} \times 100$$

$$\%\ efficiency = \frac{1.2 \times 10^6\ W}{4.4 \times 10^6\ W} \times 100$$

$$\mathbf{\%\ efficiency = 27\%}$$

The turbines generate $1.2 \times 10^6\ W$ of useful electrical power and the input power to each turbine is $4.4 \times 10^6\ W$.

d) Calculate the radius of each turbine.

Use: $density = \frac{mass}{volume}$

$$mass\ per\ second = density \times volume\ per\ second$$

$$9.7 \times 10^5\ kg = 1030\ kg\ m^{-3} \times (3.0\ m\ s^{-1} \times \pi \times r^2)$$

$$\therefore r^2 = \frac{9.7 \times 10^5}{(1030)(3\pi)}$$

$$r = \sqrt{\frac{9.7 \times 10^5}{(1030)(3\pi)}} = 9.996125295$$

Therefore, the radius of the turbine is $10\ m$.

Volume per second is measured in $m^3\ s^{-1}$. You can get $m^3\ s^{-1}$ by multiplying the speed of the turbine by the area the turbine covers. Remember the turbine spins in a circle and therefore the area it covers is equal πr^2.

POWER AND EFFICIENCY

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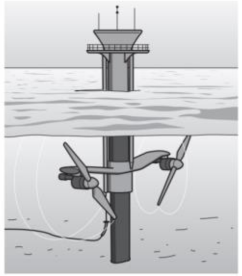

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e) Tidal stream systems require less space than conventional wind turbines that are found in windy regions of this country.

Suggest one further advantage of tidal stream systems over conventional wind farms.

POWER AND EFFICIENCY

Exam Style Question 2:

Answers:

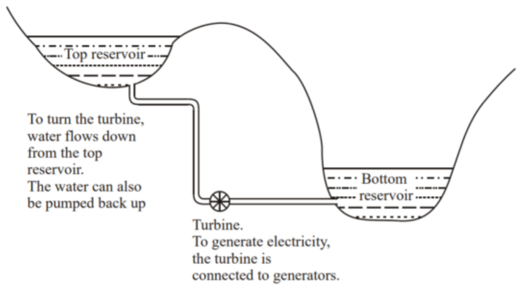
e) Suggest one further advantage of tidal stream systems over conventional wind farms.

- Cannot be seen
- Not noisy
- Doesn't occupy space on the land
- Predictable energy (with in and out tides)

POWER AND EFFICIENCY

Exam Style Question 3:

A certain power station generates electricity from falling water. The diagram shows a simplified sketch of the system.



ai) In what form is the energy of the water initially stored?

aii) What energy form is this transformed into in order to drive the turbine?

b) State the principle of conservation of energy.

c) The force of the water at the turbine is $3.5 \times 10^8\ N$ and the output power generated is $1.7 \times 10^9\ W$. Use this data to calculate the minimum speed at which the water must enter the turbine.

d) Explain why, in practice, the speed at which the water enters the turbine is much greater than this.

e) When working at this output power, $390\ m^3$ of water flows through the turbine each second. The top reservoir holds $7.0 \times 10^6\ m^3$ of water. For how long will electricity be generated?

f) This power station is used at peak periods, after which the water is pumped back to the top reservoir. The water has to be raised by $500\ m$. How much work is done to return all the water to the top reservoir? (The density of water is $1000\ kg\ m^{-3}$.)

POWER AND EFFICIENCY

Exam Style Question 3:

Answers:

ai) In what form is the energy of the water initially stored?
Gravitational potential energy

aii) What energy form is this transformed into in order to drive the turbine?
Kinetic energy

b) State the principle of conservation of energy.
Energy can neither be created nor destroyed but it can be transformed from one form to another.

c) Calculate the minimum speed at which the water must enter the turbine.
Use: $power = force \times velocity$

$$1.7 \times 10^9\ W = 3.5 \times 10^8\ N \times v$$

Rearrange to find v:

$$v = \frac{1.7 \times 10^9\ W}{3.5 \times 10^8\ N}$$

$$v = 4.857142857\ m\ s^{-1}$$

Therefore, the minimum speed at which the water must enter the turbine is $4.86\ m\ s^{-1}$.

d) Explain why, in practice, the speed at which the water enters the turbine is much greater than this.
The actual speed required is much greater than the minimum speed we calculated due to the fact that not all the energy of the falling water is transferred to the output of the power. So energy is lost in other forms such as heat to the surroundings or sound. This means the system is not 100% efficient.

POWER AND EFFICIENCY

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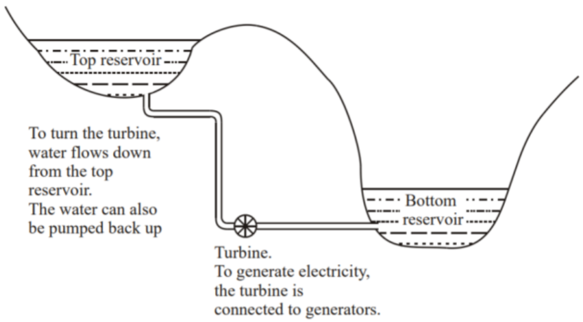

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POWER AND EFFICIENCY

Exam Style Question 3:

Answers:

e) For how long will electricity be generated?

We know $390\ m^3\ s^{-1}$ of water flows through the turbine.

Top reservoir holds $7.0 \times 10^6\ m^3$ of water.

Therefore:

$$time = \frac{7.0 \times 10^6\ m^3}{390\ m^3\ s^{-1}}$$

$$time = \frac{17{,}948.71795\ s}{60}$$

$$time = 299.1452991\ minutes$$

By dividing it by 60 seconds we are finding time in minutes.

Therefore, electricity will be generated $299\ minutes$.

f) How much work is done to return all the water to the top reservoir.

Use: $work\ done = force \times distance$

As it is the water, we are moving up to the top reservoir we need to find the force of the water. However, we only have the volume of water the top reservoir holds and the density of water, therefore we can use:

$$density_{water} = \frac{mass_{water}}{volume_{top\ reservoir}}$$

$$mass_{water} = density_{water} \times volume_{top\ volume}$$

$$mass_{water} = 1000\ kg\ m^{-3} \times 7.0 \times 10^6\ m^3$$

$$mass_{water} = 7.0 \times 10^9\ kg$$

Using the calculated mass, we can calculate the force using:

$$F = mg$$

$$F = 7.0 \times 10^9\ kg \times 9.81\ m\ s^{-2}$$

$$F = 6.867 \times 10^{10}\ N$$

Now use: work done $= F \times d$

$$work\ done = 6.867 \times 10^{10}\ N \times 500\ m$$

$$work\ done = 3.4335 \times 10^{13}\ J$$

Therefore, the work done to return all the water to the top reservoir is $3.4335 \times 10^{13}\ J$.

Please see '4.3.1 Power and Efficiency notes' pack for revision notes.

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