

Question 1

There is a variety of motor and controller technologies available to the design engineer for selection in hybrid electric and electric vehicles.

- a) Contrast the advantages and disadvantages of permanent magnet and electrically field excited dc machines. **5 marks**

The student should describe the basic layout of electrical machines

Voltage produced by changing magnetic flux, proportional to flux strength, winding length and speed.

In a motor EMF opposes applied voltage

In a generator EMF produces the output voltage

Rotor – goes round

Stator – stays still

Armature windings – commutator directs current to armature windings

Electrical power is provided and extracted via brushes

A sketch would be helpful

Requirement for a magnetic field

If permanent magnet.

- No electrical energy required – potentially good efficiency
- Constant flux field strength
- Considerable problems with rare earth magnet cost and supply security.

Explain the basic operation of; limitations of and control requirements for:

- b) Brushed dc machines **5 marks**

Requirement for a commutator and brushes

Maintenance required

Reasonable levels of control by voltage variation, simple and cheap

Rubbing brushes-surface speed limits effective motor speed.

Simple control system based on voltage, hence current. Mark space ratio etc.

High electrical noise

High torque at low speeds

Low torque ripple

Poor thermal behaviour etc

- c) Brushless dc machines **5 marks**

Need permanent magnets on rotor. Hence concerns of PMs.

Stator windings are switched by (complex) electronics

Controls requires accurate rotational position.

Therefore can have

Very high speed , controller switching.

Low inertia -torque characteristics

High torque density

Moderate torque ripple

High efficiency

Very low maintenance

Low electrical noise.

d) AC Induction machine **5 marks**

Simple mechanical construction

Can be operated by mains AC supply. However for speed control requires complex control.

Low torque ripple and noise

Reasonable torque

Moderate power density

QUESTION 2

- a) Calculate the tractive effort to enable the fully laden vehicle to achieve the required 13% gradient. **(5 marks)**
- b) Calculate the required useable battery capacity to enable the vehicle to achieve the required 13% gradient for 2150m. **(5 marks)**
- c) To improve operational effectiveness and to reduce charging costs and charging time-out events and brake wear the vehicle is equipped with regenerative braking.
- i) How much power could be captured if the vehicle returned down the 13% gradient at 19kph? **(3 marks)**
- ii) How much energy would be captured back into the batteries? **(3 marks)**
- d) A similar vehicle uses lead acid battery technology. With the following specification:
- 80V dc
 - Useable capacity 1000 Amp hours
 - Required minimum battery charge level 30%
 - Energy Density 35 Wh/kg
 - Power Density 250 W/kg
- Calculate the mass of the pack of batteries. **(4 marks)**

Question 2 answer

a)

$$\text{Rolling resistance} = (6477 \text{ kg} + 4000 \text{ kg}) \times 9.81 \times 0.015 = 1542 \text{ N}$$

$$\text{Gradient resistance} = m \cdot g \cdot \sin(\text{angle}) = 10477 \text{ kg} \times 9.81 \times 0.1287 = 13238 \text{ N}$$

$$\text{Total tractive effort} = 1542 \text{ N} + 13238 \text{ N} = 14779 \text{ N}$$

b)

$$\text{Velocity} = 19 \text{ kph} = 19 \times 1000 / (60 \times 60) \text{ m/s} = 5.28 \text{ m/s}$$

$$\text{Power} = \text{force} \times \text{velocity} = 14779 \text{ N} \times 5.28 \text{ m/s} = 78000 \text{ w or } 78 \text{ kw}$$

$$\text{Time taken} : 2150\text{m at } 5.28 \text{ m/s} = 2150\text{m} / 5.28 \text{ m/s} = 408 \text{ secs}$$

$$\text{Power} = \text{joules/secs} \quad \text{Energy} = \text{Power} \times \text{secs} = 78000 \times 408 = 31.8 \text{ MJoules (at the wheels)}$$

$$\text{System efficiency} = 81\%$$

$$\text{Energy from battery} = \text{energy at wheel} / \text{efficiency} = 31,800,000 / 0.81 = 39.3 \text{ MJoules}$$

c)

Gradient resistance – rolling resistance = harvestable force

$$13237 - 1542 = 11695 \text{ N}$$

$$\text{Power} = \text{force} \times \text{velocity} = 11695 \text{ N} \times 5.28 \text{ m/s} = 63.175 \text{ kw}$$

$$\text{Energy} = \text{power} \times \text{time} = 63175 \times 408 \text{ secs} = 25.7 \text{ MJoules (From the wheels)}$$

$$\text{Energy back into battery} = \text{energy available} \times \text{efficiency} = 25.7 \times 0.81 = 20.82 \text{ Mj}$$

Alternatively the student could use potential energy

$$\text{Height} = 2150\text{m} \times \sin 7.4 \text{ degs} = 277\text{m}$$

$$\text{Potential energy} = m \times g \times h = 10477 \text{ kg} \times 9.81 \times 277 = 28.5 \text{ Mj}$$

$$\begin{aligned} \text{Energy from rolling resistance losses} &= \text{rolling resistance} \times \text{distance} \\ &= 1542 \text{ N} \times 2150 \text{ m} = 3.3 \text{ Mj} \end{aligned}$$

$$\text{Energy available} = 28.5 \text{ Mj} - 3.3 \text{ Mj} = 25.2 \text{ Mj}$$

$$\text{Energy into battery} = 25.2 \times 0.81 = 20.41 \text{ Mj}$$

Battery capacity

$$1000 \text{ amp hours at } 80\text{v} = 80,000 \text{ watt hours}$$

$$\text{Lead acid} = 35 \text{ wh/kg}$$

$$80,000 \text{ wh} / 35 \text{ wh/kg} = 2285 \text{ kg}$$

But need 30% extra capacity to avoid draining the capacity too low

$$2285\text{kg} \times 1.3 = 2971 \text{ kg. so about 3 tonnes.}$$

Question 3

Thwaites of Warwickshire produce a range of light and heavy dump trucks. Their all wheel drive 2 tonne articulated dump truck has proved very popular especially in the new high density developments. It is being increasingly used in smaller urban land 'in-fill' developments. The small size and manoeuvrability are it's best assets.

Some developers have enquired if a hybrid version may become available.

Potential customers are interest in:

- Reduced fuel consumption

- Lower emissions

- Reduced running costs

- Quieter operation to enable a longer working day in residential areas

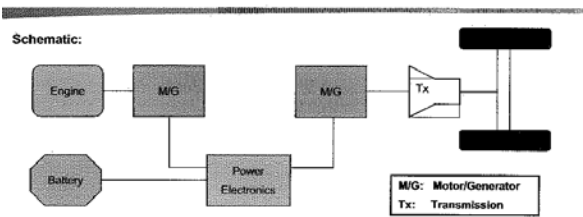
- Whilst retaining current operational effectiveness

Q3 Answer

- a) Analyse alternative hybrid vehicle architectures
(2 marks)

The student should explain and contrast series and parallel hybrid architectures

Series Hybrid



• Defining Features

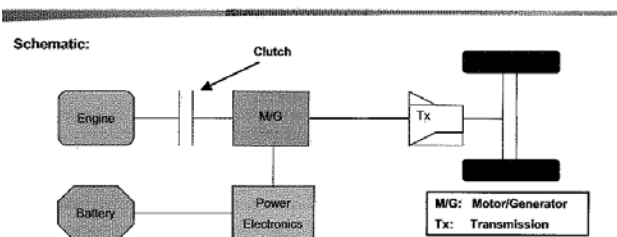
- Genset and motor
- EV operation or electric drive with engine as 'range extender'
- Electric machine drives wheels

• Examples

- Many PSVs
 - A-D Enviro 200H
 - Eneco Epack
- Many initial concepts
 - GM Series EV1, Kia KEV4

And parallel hybrid

Full Parallel Hybrid



• Defining Features

- Engine only, EV only and motor-assist modes of operation possible
- Regenerative braking
- Motive charging

• Examples

- Audi Duo
- Hino HIMR system (PSV)

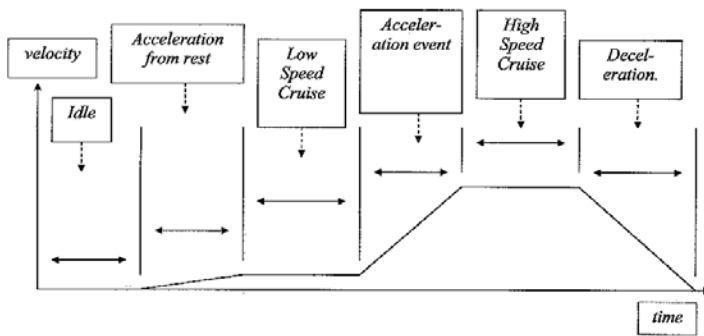
- b) Investigate and contrast alternative technologies for
- 1) Combustion engine
 - ICE diesel or petrol, possible gas or hydrogen??
 - Gas turbine

- 2) Energy storage
 - Battery technologies
 - LiON, NiMH, Pb acid, hot Zebra
 - Super Caps
 - Possible flywheel

Student should discuss, energy density, power density, number of cycles, acceptable SOC's (state of charge), any memory effects

- 3) Transmission and driveline
 - CVT/IVT,
 - 4) Drive / electrical machine
- (3 marks)**

- c) Develop a brief typical drive cycle
- (2 marks)**



The student should note

- Base to base operation
- Very consistent duty cycle
- Low speed low load level running
- Low average power demand
- Steep gradient climbs, tractive effort requirements. Peak power demand
- Steep grade descents with opportunity for kinetic energy recovery?

Recommend a hybrid dumper solution and demonstrate how it may meet their requirements **(10 marks)**

Students should (hopefully) use information above.

Very low average speeds = low average power

Series hybrid a good option. (but not the only solution, need to confirm urban only usage)

Low speed and power best suited to large battery capacity.

Low power, high efficiency ICE unit, turbo diesel is suitable,

Better to identify gas turbine technology (size, efficiency, kerosene)

Gas engines could be considered.

Large battery capacity required

For extreme tractive hill climbing and rolling resistance

For possibility of stopping ICE when vehicle is stationary, loading/unloading etc.

Distances covered are likely to be small

Possible plug-in for initial charging to reduce early morning noise.

However need to ensure that batts have sufficient power capacity to cover peak load demand