

EXAMINATIONS 2016

May

FACULTY OF : APPLIED DESIGN AND ENGINEERING

NAME OF COURSE/PROGRAMME

BSc Motorsport/Automotive/Motorcycle Eng

YEAR OR LEVEL :

Yr 3 Level 6

NAME OF MODULE/UNIT/EXAM PAPER

Electric and Hybrid Propulsion Control

DATE OF EXAMINATION

???????

EXAMINATION TIMES

START TIME

FINISH TIME

TIME ALLOWED

INSTRUCTIONS TO CANDIDATES :

Answer TWO questions from Three

All questions are equally weighted.

Calculators may be used

MS

Question 1



Elio Motors are an American start-up vehicle company that are currently developing a three wheeled vehicle with the following specification:

- Fuel-injected, SOHC petrol-powered, Variable Valve Lift, 3 cyl., 0.9 liter, liquid-cooled, automotive engine
- 8-Gallon Tank / Targeted 84 MPG (Highway)
- Standard 5-speed manual or available automatic transmission
- Top speed over 100 MPH
- 0-60 speed in 9.6 seconds
- 55 HP and 55 LB-FT of torque
- 12:1 Compression

The vehicle is currently targeted at American commuters that wish to reduce their fuel bills and carbon footprint. The vehicle is cheap with a target \$7,000 sale price, it is expected to be an additional vehicle to the owners current vehicle. Many potential purchasers have expressed interest in a Plug-in Hybrid Electric Drivetrain for the vehicle. They hope to gain the following improvements:

- Reduced fuel consumption
- Lower emissions
- Lower running costs
- A greener image

Use diagrams, graphs and basic calculations to support your answers. State any assumptions made where information is missing.

- Analyse alternative electric, hybrid and fuel cell vehicle architectures
(4 marks)
- Investigate and contrast alternative technologies for
 - Energy storage
 - Re-fuelling
 - Drive / electrical machine**(6 marks)**
- Develop a brief typical drive cycle and discuss typical vehicle requirements.
(3 marks)

- d) Recommend a Plug-in Hybrid Electric Drivetrain solution and demonstrate how it may meet their customers' requirements.
(7 marks)

Question 2



Parry People movers produce low carbon light rail vehicles. The rail vehicles are powered by a steel flywheel that is recharged when the rail vehicle is at the stations.

The Technology exists around a fly wheel with the following specification

Plain disc steel flywheel

Outer Diameter 1m

Mass 300kg

Maximum speed 2500 rpm

- a) Calculate the flywheel thickness (density of steel = 7820 kg/m^3) **2 Marks**
- b) Calculate the rotational inertia of the flywheel **2 marks**
- c) The Parry People Mover is expected to recharge the flywheel at the stations whilst passengers get off and on the rail vehicle. Parry's have stated that it takes 30 seconds to charge the flywheel. What torque is required to fully charge the flywheel from rest to maximum speed? **3 marks**

Parry's produce a larger rail vehicle with the following specification

Width 2m. Height 3m

Coefficient of drag (CD) 0.7

Density of air = 1.2 kg/m^3

For a steel wheel on a steel rail rolling (force) resistance (newtons) = 0.005 N per applied N of vertical force.

Vehicle operating speed 40 kph

Vehicle acceleration 1 m/s^2

Vehicle deceleration with regenerative capacity 1 m/s^2

Unladen weight 5500kgs

Passenger capacity 20 seated (assume one person plus luggage = 100kgs)

The rail vehicle utilises a Linde hydrostatic transmission with an 85% efficiency in both directions.

The flywheel has an inertia of 62.5 kg.m^2

Maximum flywheel operating speed 2500 rpm.

The rail operates on level ground between two stations 1500m apart (Point A to Point B).

Ignoring aerodynamic drag during the acceleration and deceleration phases of the journey.

The Parry Mover begins a cycle at point A.

It then accelerates up to operational speed at point B

It continues for to point C.

The vehicle then decelerates to a stop at point D.



- d) What is the total force required to accelerate the vehicle?
- e) What is the distance covered during the acceleration phase?
- f) How much energy is required to accelerate the vehicle?
- g) How much energy is required during the constant speed phase?
- h) How much kinetic energy is in the rail vehicle at the 40kph operational speed?
- i) How much energy is left in the flywheel after completing one journey between the stations?

13 marks

Question 3

Many electric hybrid vehicles utilise regenerative braking to capture all or some of the energy used to decelerate a vehicle.

- a) Explain and contrast the two categories of regenerative braking, series and parallel ?
(5 marks)
- b) Evaluate which of the series or parallel system would be more appropriate for a 24hr Lemans race car ?
(5 marks)
- c) A small front engined front wheel drive petrol internal combustion small car has been hybridised with an additional electrically drive rear axle. Analyse the limitations to recovering energy from the rear axle. Use diagrams and numbers to illustrate your answer.

Typical values:

Mass 1200kg Weight distribution 63% front / 37% rear

Wheel base 2.5m

Height of centre of gravity 0.6m above the ground

Rolling radius 0.26m

(10 marks)

Equations

Potential Energy = mass x gravity x height $PE = m \cdot g \cdot h$

Moment of Inertia = mass x (radius of gyration)squared $I = mk^2$

For a plain disc : radius of gyration = radius/squareroot of 2 $k = \text{outer radius} \times 0.707$

Aero dynamic resistance = $0.5 \times \text{area} \times c_d \times \text{density of air} (1.2 \text{ kg/ m}^2) \times \text{velocity}^2$

	Linear Motion	Rotational Motion	
Position	x	θ	Angular position
Velocity	v	ω	Angular velocity
Acceleration	a	α	Angular acceleration
Motion equations	$x = \bar{v}t$	$\theta = \bar{\omega}t$	Motion equations
	$v = v_0 + at$	$\omega = \omega_0 + \alpha t$	
	$x = v_0t + \frac{1}{2}at^2$	$\theta = \omega_0t + \frac{1}{2}\alpha t^2$	
	$v^2 = v_0^2 + 2ax$	$\omega^2 = \omega_0^2 + 2\alpha\theta$	
Mass (linear inertia)	m	I	Moment of inertia
Newton's second law	$F = ma$	$\tau = I\alpha$	Newton's second law
Momentum	$p = mv$	$L = I\omega$	Angular momentum
Work	Fd	$\tau\theta$	Work
Kinetic energy	$\frac{1}{2}mv^2$	$\frac{1}{2}I\omega^2$	Kinetic energy
Power	Fv	$\tau\omega$	Power

Model Answers

Question 1

Question 1 answer

The vehicle is currently targeted at American commuters that wish to reduce their fuel bills and carbon footprint. The vehicle is cheap with a target \$7,000 sale price, it is expected to be an additional vehicle to the owners current vehicle. Many potential purchasers have expressed interest in a Plug-in Hybrid Electric Drivetrain for the vehicle They hope to gain the following improvements:

Reduced fuel consumption

Lower emissions

Lower running costs

A greener image

Use diagrams, graphs and basic calculations to support your answers. State any assumptions made where information is missing.

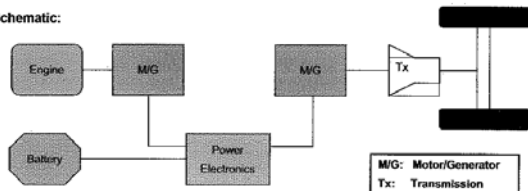
- a) Analyse alternative electric, hybrid and fuel cell vehicle architectures
(4 marks)

The student should explain and contrast :

series hybrid systems (including electric drive with range extender)

Series Hybrid

Schematic:



• Defining Features

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

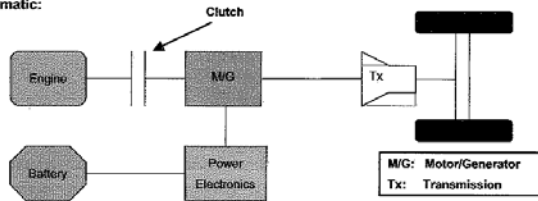
• Examples

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

And parallel hybrid

Full Parallel Hybrid

Schematic:



• Defining Features

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

• Examples

- Audi Duo
- Hino HIMR system (PSV)

The student should also consider electric only drive.
Electric motor direct drive, in hub motors or upstream of a gearbox.

a) Investigate and contrast alternative technologies for 1 Energy storage

Battery technologies

LiON, NiMH, Pb acid

Super Caps

Possible flywheel

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

2. Refueling

Traditional hydrocarbon fuels have a high energy density

Tanks are filled with high power

Electrical recharging is limited by

- Supply . Domestic 240v AC 13 amp socket. (3.1 kw)
10kw dedicated wiring charger

- Power input density of battery chemistry

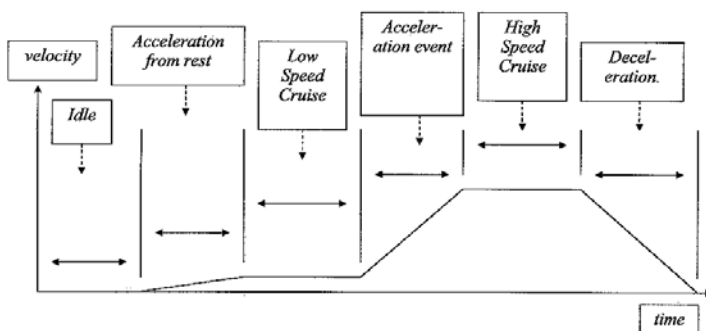
3 Electrical machine ideally placed upstream of gearbox to ensure operation over a wide speed range and gain torque multiplication benefits

Typically Ac or BLDC technologies.

(6marks)

b) Develop a brief typical drive cycle

(3marks)



The student should note

- Variable speeds, low speed accel and low speed running
- Frequent stop – start function, urban driving and US grid systems.

- Low average power requirement
- High peak power demand under accel and gradability
- Fairly consistent vehicle mass

- a) Recommend Elio Motors a elec / hybrid solution and demonstrate how it may meet the requirements
(7 marks)

Students should (hopefully) use information above.

Series hybrid a good option. (but not the only solution,)

Essentially a full elec vehicle with range extender ICE

Low power ICE with optimised single point operation

KERS can be used to charge storage but modest decel rates so not much available

Limited storage batt capacity required as range extender can cut in if required

Batt must be sized to take rate of charge provided by ICE

Low speed operation, therefore motors and final drive ratio require careful selection.

Question 2 answer

- a) Calculate flywheel thickness 2 marks

$$\text{Volume} = \text{mass} / \text{density} = 300 \text{ kg} / 7820 \text{ kg/m}^3 = 0.03856 \text{ m}^3$$

$$\text{Thickness} = \text{volume} / \text{area} = 0.03856 / \pi * 0.5 * 0.5 = 0.0245 \text{ m} = 24.5 \text{ mm}$$

- b) Rotational inertia of the flywheel 2 marks

$$2500 \text{ rpm} = 2500 \text{ rpm} / 60 \text{ secs} * 2 * \pi \text{ rads/sec} = 262 \text{ rads/sec}$$

$$\text{Plain section flywheel radius of gyration } k = 0.707 * \text{radius} = 0.707 * 0.5 = 0.3535$$

$$I = mk^2 = 300 * 0.3535 * 0.3535 = 37.489 \text{ kg.m}^2$$

- c) Torque to charge the flywheel 3 marks

$$262 \text{ rads/sec} / 30 \text{ secs} \text{ gives a rotational acceleration of } 8.73 \text{ rads/sec}^2$$

$$\text{Torque} = \text{inertia} * \text{rotational accel} = 37.5 * 8.73 = 327 \text{ Nm}$$

Another similar vehicle with larger flywheel

- d) What is the total force required to accelerate the vehicle?

$$\text{Rolling resistance} = 0.005 * 7500 * 9.81 = 368 \text{ N}$$

$$\text{Road speed } 40 \text{ kph} = 11.111 \text{ m/s}$$

$$\text{Aero resistance} = 0.5 * \text{density of air} * C_d * \text{frontal area} * \text{velocity squared}$$

$$AR = 0.5 * 1.2 * 0.7 * (2 * 3) * 123.5 = 310 \text{ N}$$

$$\text{Total resistance force } RF = 368 + 310 = 678 \text{ N}$$

Total resistive power $RP = RF \times \text{Velocity} = 678 \times 11.111 = 7525 \text{ watts}$
(for information only)

- e) What is the total distance covered during the acceleration phase?

Acceleration phase

Initial velocity 0 final velocity 11.1m/s at 1m/s^2 takes 11.1 secs

Distance = (initial velocity + final velocity) $11.1 \text{ secs}/2 = 61.6\text{m}$

- f) How much energy is required to accelerate the vehicle?

KE from above = 462Kj

Rolling resistance $368\text{N} \times 61.6\text{m} = 22.67 \text{ kj}$

Total energy = $462 + 22.7 = 484.7 \text{ kj}$

Then allow for transmission inefficiency @ 85%

$484.7/0.85 = 570\text{kj}$ from the flywheel

- g) How much energy is required during the constant speed phase?

Steady 40 kph phase

$1500\text{m} - (2 \times 61.6\text{m}) = 1376.8\text{m}$

Workdone = force x distance = $678\text{N} \times 1376.8\text{m} = 933.47 \text{ kj}$

Then allow for trans inefficiency $933.47/0.85 = 1098\text{kj}$ from the flywheel.

- h) What is the Kinetic energy?

$40 \text{ kph} = 11.1 \text{ m/s}$

Mass – 5000kg plus $(20 \times 100\text{kg}) = 7500\text{kg}$

$Ke = 0.5 \times 7500 \times (11.1 \times 11.1) = 462 \text{ kj}$

- i) How much energy is left in the flywheel after completing one journey?

Deceleration phase

KE in vehicle = 462kj

KE in flywheel

Inertia = 62.5 kgm^2

$KE = 0.5 \times 62.5 \times 262 \times 262 = 2145\text{kj}$

Total use of flywheel = accel phase + steady 40kph phase = $570 + 1098 \text{ kj} = 1668.2 \text{ kj}$

Residual energy in flywheel = $2145 - 1668 = 477\text{Kj}$

KE in vehicle = 462kj

Rolling resistance during decel = 22.67kj (same as accel)

KE available for regen = $462 - 22.67 = 439.33 \text{ kj}$

Allow for trans inefficiency $439.33 \times 0.85 = 373.4 \text{ kj}$ going back into the flywheel.

Hence total energy in flywheel at end of the journey = $477 + 373 = 850 \text{ Kj}$

Question 3

Many electric hybrid vehicles utilise regenerative braking to capture all or some of the energy used to decelerate a vehicle.

- a) Explain and contrast the two categories of regenerative braking, series and parallel ?
(5 marks)

The student should draw the diagrams below and highlight the differences with cost and feel
Examples, parallel Honda Civic and Insight

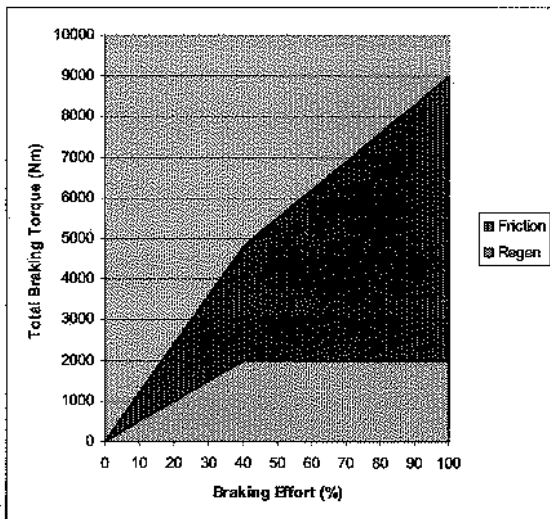
Series Toyota products/ Ford /GM

The student may mention:

the difficulty with series reliable brake blending
Active brake boosters and the Toyota recall.

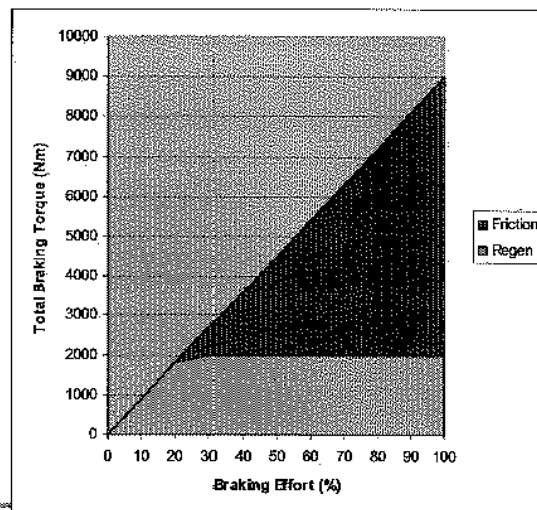
Parallel

- ☐ Cheap
- ☐ Poor pedal feel
- ☐ Poor brake feel
- ☐ Lower energy recovery



Series

- ☐ Expensive
- ☐ Consistent pedal and brake feel
- ☐ Maximum energy recovery



- b) Evaluate which of the series or parallel system would be more appropriate for a 24hr Lemans race car ?
(5 marks)

The student should evaluate the application

Rear wheel drive and regen

Vehicle brakes at maximum decel

Therefore capturing power at low speeds not required

Assuming max decel both regen and friction brakes required

If energy store full, rear breaking reduced leading to a stable vehicle

Could employ active brake balance to maintain balance for max decel if store full.

Series braking much simpler and just as effective

- c) A small front engined front wheel drive petrol internal combustion small car has been hybridised with an additional electrically drive rear axle. Analyse the limitations to recovering energy from the rear axle. Use diagrams and numbers to illustrate your answer.

Typical values:

Mass 1100kg Weight distribution 63% front / 37% rear

Wheel base 2.5m

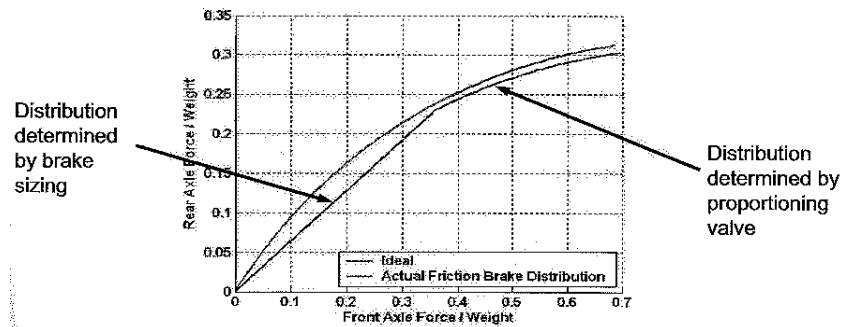
Height of centre of gravity 0.6m above the ground

Rolling radius 0.26m

(10 marks)

The student should discuss

1. longitudinal weight transfer
2. Rear braking torque maximum limited by wheel lock, rear instability.



3. Rear brake or regen torque constant for decel
4. But power = Torque x omega therefore power that can be removed reduces as speed reduces. Therefore need to reduce regen power at lower speeds
5. In reality on the road most people brake at less than 0.3g therefore braking takes longer and there is more opportunity to use regen and avoid friction brakes.
6. Regen should be stopped before the vehicle is stationary to avoid driving the vehicle backwards.