

PRIFYSGOL CYMRU : UNIVERSITY OF WALES

**DEGREE EXAMINATIONS 2007
ARHOLIADAU GRADD 2007**

**Swansea Institute of Higher Education
Athrofa Addysg Uwch Abertawe**

Faculty of Applied Design and Engineering

NAME OF COURSE/PROGRAMME: BEng Motorcycle Engineering

YEAR or LEVEL (state which): Year II

NAME OF MODULE/UNIT: Motorcycle Dynamics and Power
Transmission

**NAME OF EXAM PAPER:
(if different to module name)**

DATE OF EXAMINATION: Wednesday 30th May 2007

EXAMINATION TIMES:

Start Time:	12.00 pm
Finish Time:	2.00 pm
Time Allowed:	2 hrs

INSTRUCTIONS TO CANDIDATES:

For all questions, take $\rho_{air} = 1.167 \text{ kg m}^{-3}$

An equation sheet is provided with this exam paper

Answer 3 from 4 Questions

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1.

Consider a motorcycle with the following properties:

750cc Transversely mounted engine, with a forward spinning crankshaft.

Total mass with rider, $m = 255$ kg

Height of centre of gravity, $h = 0.65$ m

Wheel radius, $R_f = R_r = 0.3$ m, Tyre Width = 180mm

Spin inertia of the front and rear wheels, $I_{wf} = I_{wr} = 0.65$ kgm²

Total angular momentum of the engine, $I\omega_m = 16$ kgm² s⁻¹

The motorcycle is traversing a 200 m radius corner with a velocity of 40 ms⁻¹

- (i) Calculate the ideal roll angle. (2 marks)
- (ii) Calculate the increase in roll angle due to the tyre thickness. (3 marks)
- (iii) Calculate the gyroscopic moment due to the engine rotation. (3 marks)
- (iv) Calculate the increase in roll angle due solely to the gyroscopic effect generated by the engine. (4 marks)
- (v) Calculate the gyroscopic moment due solely to the wheels and the corresponding change in roll angle (6 marks)
- (vi) Taking into account the gyroscopic contribution from the wheels and engine, and the contribution due to tyre thickness, determine the overall roll angle. (2 marks)

2.

Consider a motorcycle about to negotiate a left turn...

Explain in detail the process by which the rider gets from steady state straight line motion, to steady state cornering

- a. For a motorcycle speed of 10 ms^{-1} (4 marks)
- b. For a motorcycle speed of 50 ms^{-1} (4 marks)

Consider the case of a rider negotiating a constant radius corner:

Turning radius, $R_c = 220 \text{ m}$

Forward speed, $V = 40 \text{ ms}^{-1}$

The properties of the motorcycle are:

Mass, $m = 180 \text{ kg}$

Height of centre of gravity, $h = 0.65 \text{ m}$

Wheel radius, $R_f = R_r = 0.32 \text{ m}$

Spin inertia of front and rear wheels, $I_{wf} = I_{wr} = 0.6 \text{ kgm}^2$

- c.
 - (i) Calculate the yaw velocity of the motorcycle. (1 marks)
 - (ii) Calculate the angular velocity of each wheel. (1 marks)
 - (iii) Determine the *ideal* roll angle of the motorcycle through this turn. (2 marks)
 - (iv) Calculate the gyroscopic moment generated by the motion of both wheels. (2 marks)
- d. The case described above is not in equilibrium. There are two ways in which the rider will be able to achieve equilibrium.

The first method is to displace the mass centre toward the centre of the turn.

- (i). Calculate by how much the mass centre must move (d) in order to achieve equilibrium. (3 marks)

The second method is to increase the roll angle ($\Delta\phi$).

- (ii) Determine the increase in roll angle needed to achieve equilibrium. (3 marks)

3.

a. The equations of equilibrium of a motorcycle enable us to determine the values of the reactive forces N_f and N_r , once the weight force mg , driving force S , and drag force F_D are known:

(i) Show all these forces, including standard geometry (Wheelbase, CofG height, etc) in a schematic diagram.

(5 marks)

(ii) By equating moments and forces for this system, derive equations for the dynamic loads on the front and rear wheels N_r and N_f .

(8 marks)

b. In conditions approaching front wheel lift, the front load of the motorcycle tends to zero. This can be represented by the equation:

$$F_D \frac{h}{p} + F_L \frac{b}{p} = mg \frac{b}{p}$$

If the motorcycle has the following properties:

Mass (plus rider) = 220 Kg

The drag area $C_D A = 0.4 \text{ m}^2$

The lift area $C_L A = 0.1 \text{ m}^2$

The longitudinal distance of the centre of gravity is $b = 0.71 \text{ m}$

The height of the centre of gravity is $h = 0.62 \text{ m}$

The wheelbase of the motorcycle is $p = 1.38 \text{ m}$

Calculate the maximum velocity attainable before front wheel lift occurs.

(7 marks)

4.

Answer the following questions:

a. What power is required to drive a motorcycle of $C_D A = 0.3$, to a velocity of:

- (i) 250 kph
- (ii) 320 kph
- (iii) Comment on your results.

(4 marks)

b. Consider a motorcycle with the following parameters:

Mass, $m = 240 \text{ Kg}$
Reduced Mass $m^* = 285 \text{ Kg}$
Frontal Area, $A = 0.6 \text{ m}^2$
Drag Coefficient, $C_D = 0.7$

- (i) What is the *total* driving force required to maintain the motorcycle at a constant velocity of 200 kph along a horizontal road?
(3 marks)
- (ii) If the motorcycle now travels at the same velocity, but along a road with a constant uphill slope of 12 %. What will be the total driving force required?
(4 marks)
- (iii) If this motorcycle has a wheelbase of, $p = 1.3 \text{ m}$, a centre of gravity height of $h = 0.6 \text{ m}$ and a longitudinal distance of the centre of gravity, $b = 0.55 \text{ m}$: Calculate its maximum geometry limited acceleration when travelling at a velocity of 35 ms^{-1} .
(4 marks)

c. Assuming the front un-sprung mass of a 200kg motorcycle to be 19kg with an angle of inclination of the steering head to be 22° .

- (i) Calculate the stiffness of the reduced spring so that with a load equal to the weight of the motorcycle the fork compresses by 60 mm.
(2 mark)
- (ii) From this, calculate the overall stiffness of one fork spring.
(3 marks)

Equation Data Sheet

Dynamic Loadings:

$$N_f = mg \frac{b}{p} - S \frac{h}{p} \qquad N_R = mg \frac{(p-b)}{p} + S \frac{h}{p}$$

Aerodynamic Drag

$$Force = \frac{1}{2} \rho C_D A V^2$$

Maximum Acceleration

$$\ddot{x} = \frac{mg}{m^*} \frac{b}{h} - \frac{F_D}{m^*}$$

Reduced Spring Stiffness

Overall Stiffness

$$k_f = \frac{mg}{y \cos \varepsilon}$$

$$k = k_f \cos^2 \varepsilon$$

Ideal Roll Angle

Tyre Correction

Change in Roll Angle

$$\varphi_i = \tan^{-1} \left(\frac{R_c \Omega^2}{g} \right)$$

$$\frac{\sin \Delta \varphi}{t} = \frac{\sin \varphi_i}{h-t}$$

$$\sin(\Delta \varphi) = \frac{I_w \omega \Omega \cos \varphi}{h \sqrt{(mg)^2 + (m R_c \Omega^2)^2}}$$

Gyroscopic Moment

$$M_g = I_w \omega \Omega \cos \varphi$$

$$M_g = d \sqrt{(mg)^2 + (m R_c \Omega^2)^2}$$

Gyroscopic Moment on Front Frame due to Roll Motion

$$M_{g_u} = I_{w_f} \omega_f \dot{\varphi} \cos \varepsilon$$



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Programme:	BEng Motorcycle Engineering	Year:	2
Module/Unit:	Motorcycle Dynamics and Power Transmission		
Author:	Dr Owen Williams	Page:	of

Question No	Question	Marks
I (i)	Ident Roll angle $\phi_i = \tan^{-1} \left(\frac{D_c \Omega^2}{g} \right) = \tan^{-1} \left(\frac{200 \times 0.2^2}{g} \right)$ $\phi_i = 39.2^\circ$	2
(ii)	$\frac{\sin \Delta \phi}{l} = \frac{\sin \phi_i}{(h-l)}$ $\sin \Delta \phi = l \left(\frac{\sin \phi_i}{h-l} \right)$ $\sin \Delta \phi = 0.18 \times (1.344)$ $\Delta \phi = 0.24^\circ$	3
(iii)	Gyroscopic couple engine $M_g = I_{\omega} \Omega \cos \phi = 16 \times 0.2 \times \cos(39.2 + 0.24)$ $M_g = 2.47 \text{ Nm}$	3
(iv)	$\sin \Delta \phi = \frac{M_g}{h \sqrt{(m g)^2 + (m l \Omega^2)^2}} = \frac{2.47}{2098.2}$ $\sin \Delta \phi = 0.001177$ $\Delta \phi = 0.067^\circ$	4
(v)	$M_g = I_{\omega} \Omega \cos \phi = 2 \times 0.65 \times \left(\frac{40}{0.3} \right) \times 0.2 \times \cos(39.2 + 0.24)$ $= 26.772 \text{ Nm}$ $\sin \Delta \phi = \frac{M_g}{2098.2} = 0.0128 \Rightarrow \Delta \phi = 0.73^\circ$	6
(vi)	$\phi_{\text{cent}} = 39.2 + 0.24 + 0.73 + 0.067$ $\phi_{\text{cent}} = 40.24^\circ$	2
		<u>20</u>

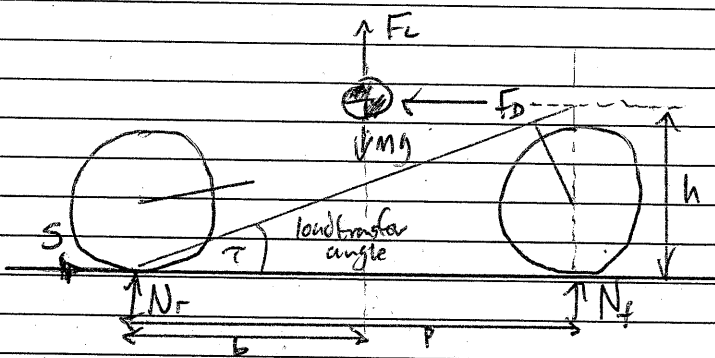
Continuation Sheet

Module/Unit:	Mobycle Dynamics + Power Transmission	Page:	of
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Question No	Question	Marks
2a	Turn bars, bike begins to fall opposite way (mg) Correct for fall (turn bars into turn), follow constant radius	4
b	Attempt to turn bars (apply torque) Gyro reaction causes roll in opposite direction Roll rate determined by steer torque Steady state achieved as $m\dot{\theta} = \frac{mv^2}{r}$	4
(i)	Yaws $\Omega = \frac{v}{R_c} = \frac{40}{220} = 0.182 \text{ rad/sec}$	1
(ii)	Wheel Angular $\omega = \frac{v}{R_s} = \frac{40}{0.32} = 125 \text{ rad/sec}$	1
(iii)	$\phi = \tan^{-1}\left(\frac{R\omega^2}{g}\right) = \tan^{-1}\left(\frac{220 \times 0.182^2}{9.81}\right)$ $\phi = \tan^{-1} 0.743 = 36.6^\circ$	2
(iv)	$M_g = I\omega\Omega \cos\phi \times 2 = 2 \times 0.6 \times 0.125 \times 0.182 \times \cos 36.6$ $M_g = 21.92 \text{ Nm}$	2
d(i)	$M_g = d\sqrt{(m\dot{\theta})^2 + (mR\omega^2)^2} = d \times 2200$ $d = \frac{21.92}{2200} = 10 \text{ mm}$	3
(ii)	$\Delta\phi = \sin^{-1}\left(\frac{d}{h}\right) = \sin^{-1}\left(\frac{0.01}{0.65}\right)$ $\Delta\phi = \sin^{-1}(0.0154)$ $\Delta\phi = 0.88^\circ$	3
		<u>20</u>

Continuation Sheet

Module/Unit:	<i>Motorcycle Dynamics + Power Transmission</i>	Page:	
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Question No	Question	Marks
3a(i)	 From diagram Horizontal forces $S = F_0$ Vertical forces $mg - N_r - N_f = 0$ (1) Moments about C of G $Sh - N_r b + N_f (P - b) = 0$ (2) Solve (1) and (2) for N_r $Sh - N_r b + (mg - N_r)(P - b) = 0$ $Sh + MgP - Mgb - N_r P = 0$ $N_r P = mg(P - b) + Sh$ $N_r = \frac{Mg(P - b)}{P} + S \frac{h}{P}$ Now Find N_f $Sh - (mg - N_f)b + N_f(P - b) = 0$ $Sh - mgb + N_f P = 0$ $N_f = Mgb/P - S h/P$ From $F_0 h/P + F_r b/P = mg b/P$ use $F_0 = \frac{1}{2} \rho C_D A V^2$ and $F_r = \frac{1}{2} \rho C_r A V^2$ -- rearrange to get $V = \sqrt{\frac{mgb}{(\frac{1}{2} \rho C_D A h/P + \frac{1}{2} \rho C_r A b/P)P}}$ Solve using given parameters to give $V = \sqrt{\frac{1532.32}{\sqrt{(0.105 + 0.09)P}}} = \sqrt{\frac{1532.32}{0.186}} \quad 90.7 \text{ m/s}$	5
		5
		3
		4
		3
		30

Continuation Sheet

Module/Unit:	Motorcycle dynamics + Power transmission	Page:	of
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Question No	Question	Marks
4(a)(i)	at 250 kph $\approx 69.4 \text{ ms}^{-1}$ $\text{Power} = \frac{1}{2} \rho C_D A V^3 = \frac{1}{2} \times \rho \times 0.3 \times 69.4^3$ $\text{Power} = 58.62 \text{ kW}$	1
(ii)	at 320 kph $= 88.89 \text{ ms}^{-1}$ $\text{Power} = \frac{1}{2} \rho \times 0.3 \times 88.89^3$ $\text{Power} = 123 \text{ kW}$	1
(iii)	for a 28% Speed increase, Power needed increases 112%	2
6(a)	Driving force = Rolling Resistance + Aero resistance (assume rolling resistance to be 2% of weight force) $= (0.02 \times 240 \times 9.81) + (\frac{1}{2} \rho \times 0.6 \times 0.7 \times (200 \times \frac{3}{3.6})^2)$ $= 47.088 + 756.39$ $= 803.5 \text{ N}$	3
(ii)	When going uphill Force $= 803.5 + mg \sin \alpha$ $\alpha = \tan^{-1} 0.12$ for a 12% gradient $\text{Force} = 803.5 + (240 \times 9.81 \times 0.119)$ $= 1084 \text{ N}$	4
(iii)	$\ddot{x} = \frac{Mg}{m^*} \times \frac{b}{h} - \frac{F_D}{m^*} = \left(\frac{240g}{285} \times \frac{0.55}{0.6} \right) - \frac{\frac{1}{2} \rho C_D A V^2}{m^*}$ $\ddot{x} = 7.57 - 1.05 = 6.52 \text{ ms}^{-2}$	4
(c)(i)	$K_f = \frac{81g}{60 \times \cos 22} = 14.28 \text{ N/mm}$ $K = K_f \cos^2 22 = 12.27 \text{ N/mm}$ So each fork spring $= \frac{1}{2} \times 12.27 = 6.14 \text{ N/mm}$	2 3
	<u>20</u>	