

PRIFYSGOL CYMRU : UNIVERSITY OF WALES

**DEGREE EXAMINATIONS 2008
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**Swansea Metropolitan University
Prifysgol Fetropolitan 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 28th May 2008

EXAMINATION TIMES:

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

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

FACULTY REF: FADE23 OW

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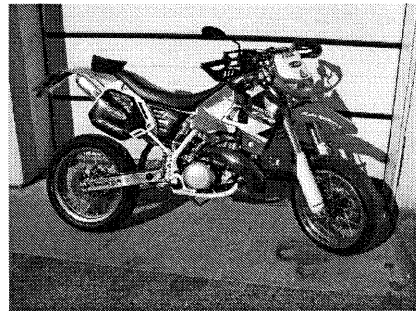
Question 1.

The equations for the forces and loads on a motorcycle enable us to determine the values of the reaction forces N_f and N_r , once the weight force mg , driving force S , and drag force F_D are known:

- Show all these forces, including the standard geometry such as wheelbase, centre of gravity height, etc in a schematic diagram.
(4 marks)
- By equating moments and forces for this system, derive the equation for the dynamic loads on the front wheel, N_f .
(5 marks)

Consider a Supermotard CR500 motorcycle with the following parameters:

Mass with rider, $m = 185 \text{ Kg}$
Reduced Mass $m^* = 200 \text{ Kg}$
Frontal Area, $A = 0.5 \text{ m}^2$
Drag Coefficient, $C_D = 0.55$



- What is the *total* driving force required to maintain the motorcycle at a constant velocity of 120 kmh^{-1} along a horizontal flat road?
(3 marks)
- If the motorcycle now travels at the same velocity, along a road with a constant uphill slope of 20 degrees. What will be the new total driving force and power required?
(4 marks)

The CR500 motorcycle has a wheelbase of, $p = 1.490\text{m}$, a centre of gravity height of $h = 0.8 \text{ m}$ and a longitudinal distance of the centre of gravity, $b = 0.85\text{m}$:

- Calculate its maximum geometry limited deceleration when travelling at a velocity of 100 kmh^{-1} .
(4 marks)

Question 2.

A normal motorcycle front fork system can be represented as an equivalent vertical suspension, which represents the actual vertical wheel rate of the motorcycle.

- a. Using diagrams and calculations, show that the 'reduced stiffness' (k_f) and the 'real stiffness' (k) are related by the equation:

$$k_f = \frac{k}{\cos^2 \varepsilon}$$

Where ε is the rake angle of the motorcycle. (8 marks)

- b. A wheel rate of 12N/mm is required at the front of a motorcycle with a 22° rake angle. What is the required spring stiffness? (3 marks)

Consider yourself riding a Honda RS125R, which weighs 78.5kg with a 50%/50% weight distribution. The fork travel is 103mm and the rake angle is 23.5° .



- c. Select a suitable natural frequency based on the type of motorcycle and its suspension stroke. Use this value to determine a suitable wheel rate if the unsprung front-end weight is 11kg. (6 marks)

- d. From this, determine the required fork spring stiffness. (3 marks)

Question 3.

Consider the case of a rider negotiating 'Hatchets Hairpin' at Pembrey circuit on a Kawasaki ZXR400 motorcycle:

Corner radius, $R_c = 25 \text{ m}$

Forward speed, $V = 50 \text{ km h}^{-1}$

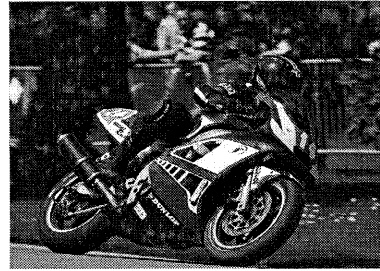
The properties of the motorcycle are:

Mass, $m = 245 \text{ kg}$ (including rider)

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

Wheel radius, $R_f = R_r = 0.3 \text{ m}$

Spin inertia of front and rear wheels, $I_{w_f} = I_{w_r} = 0.63 \text{ kgm}^2$



- Calculate the yaw velocity of the motorcycle. (2 marks)
- Calculate the angular velocity of each wheel. (2 marks)
- Determine the *ideal* roll angle of the motorcycle through this turn. (3 marks)
- Calculate the gyroscopic moment generated by the motion of both wheels. (3 marks)

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 increase the roll angle ($\Delta\phi$).

- Determine the increase in roll angle needed to achieve equilibrium? (4 marks)

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

- Calculate by how much the mass centre must move ' d ' in order to achieve equilibrium? (3 marks)
- What would be the effect on the effective roll angle if the motorcycle used tyres of a larger cross sectional area? (2 marks)
- What effect does the centre of gravity height have on the effective roll angle? (1 mark)

Question 4.

Consider a motorcycle with the following properties, leaning from right to left:

Moment of inertia, front wheel, $I_{w_f} = 0.6 \text{ kgm}^2$

Roll velocity, $\dot{\delta} = 0.5 \text{ rad s}^{-1}$

Spin velocity of wheel, $\omega = 100 \text{ rad s}^{-1}$

Rake angle, $\varepsilon = 25^\circ$

Normal trail, $a_n = 0.1 \text{ m}$

- a. Calculate the gyroscopic moment M_g that acts on the front frame around an axis lying in the plane of the motorcycle perpendicular to the longitudinal roll axis.
(3 marks)
- b. Calculate the gyroscopic moment around the steering axis of the motorcycle due to its roll motion from right to left.
(3 marks)

In a similar way, turning the handlebars from right to left generates a gyroscopic moment around an axis perpendicular to both the steering head axis and the rotational axis of the front wheel.

$$M_g = I_{w_f} \omega_f \dot{\delta}$$

- c. What effect does this gyroscopic moment have on the motorcycle?
(4 marks)
- d. If the gyroscopic moment created was 22Nm, what was the rotational velocity seen at the handlebars about the motorcycles steer axis?
(4 marks)

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.

- e. For a motorcycle speed of 10 ms^{-1}
(3 marks)
- f. For a motorcycle speed of 50 ms^{-1}
(3 marks)

Equation Data Sheet

Dynamic Loadings:

$$N_f = mg \frac{b}{p} - S \frac{h}{p}$$

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

Aerodynamic Drag:

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

Maximum Acceleration

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

Maximum Deceleration

$$\ddot{x} = -\frac{g(p-b)}{h} - \frac{F_D}{m}$$

Ideal Roll Angle

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

Tyre Correction

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

Change in Roll Angle

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

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

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

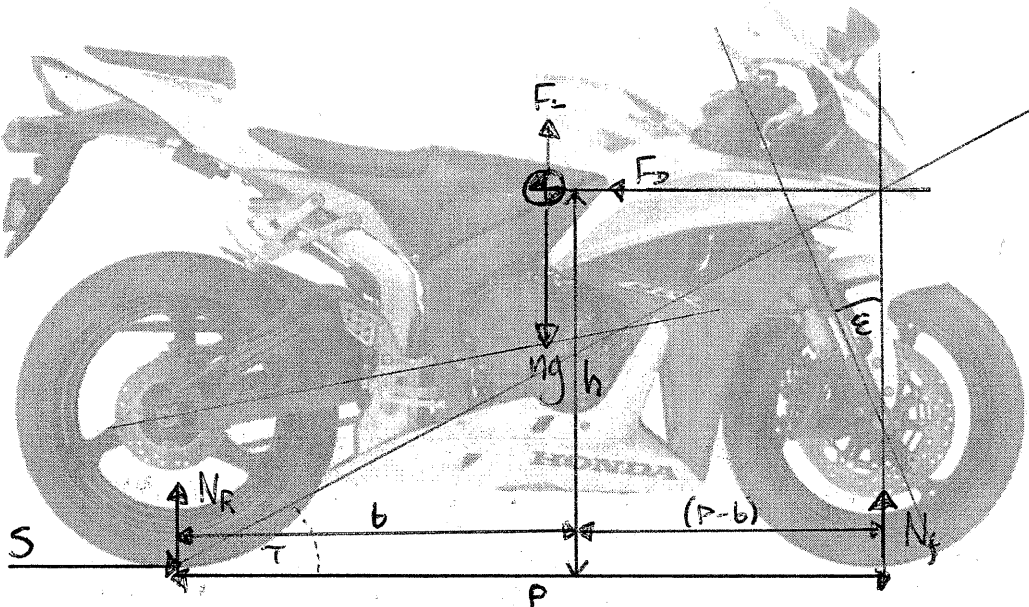
Natural Frequency

$$f = \frac{1}{2\pi} \sqrt{\frac{k}{M}}$$



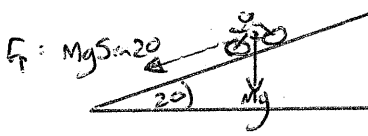
EXAMINATION SOLUTIONS : SESSION 2007/08

Programme:	BEng Motorcycle Engineering	Year:	Level 5
Module/Unit:	Motorcycle Dynamics and Power Transmission		
Author:	Dr Owen Williams	Page:	1 of 6

Question No	Question	Marks
Q1a		4
1b	Horizontal forces $F_D = S$ Vertical forces $N_R + N_f = mg$ (*) Moments about C of G $N_f(P-b) + Sh = N_R b$ use (*) $N_f(P-b) + Sh = mgb - N_f b$ $N_f P - \cancel{N_f b} + Sh = mgb - \cancel{N_f b}$ $N_f P + Sh = mgb$ $N_f P = mgb - Sh$ $N_f = mgb \frac{1}{P} - S \frac{h}{P}$	5

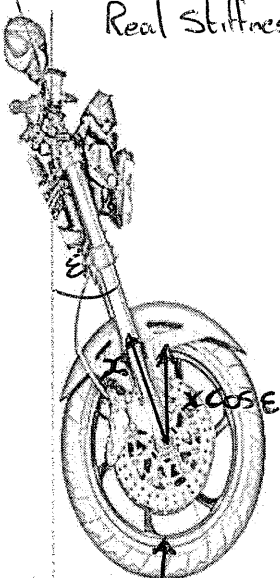
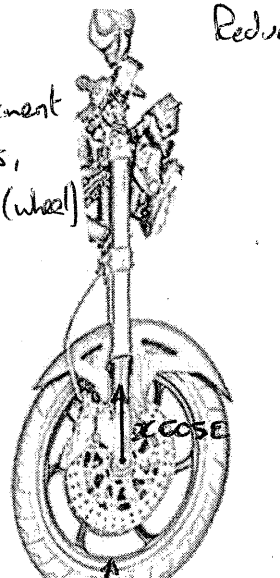
Continuation Sheet

Module/Unit:	Motorcycle Dynamics and Power Transmission	Page:	2 of 6
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Question No	Question	Marks
<u>Q1c</u>	Total Driving force = Drag force + Rolling Resistance Rolling Resistance considered to be 2% of mg $F_D = \frac{1}{2} \rho C_D A V^2 = \frac{1}{2} \times 1.167 \times 0.55 \times 0.5 \times 33.3^2$ $F_D = 178.3 \text{ N}$ $F_w = 0.02 \times 185g = 36.3 \text{ N}$ So $S = F_D + F_w = 178.3 + 36.3 = \underline{215 \text{ N}}$	(3)
<u>Q1d</u>	For uphill ---  $F_r = Mg \sin 20$ $F_r = 185g \times \sin 20$ $F_r = 620.7 \text{ N}$ Total Driving force $S = F_D + F_w + F_r = 215 + 620.7 = \underline{835 \text{ N}}$ Power required = $S \times V = 835 \times 33.3$ Power required = $\underline{27.8 \text{ kW}}$	(2)
<u>Q1e</u>	$\ddot{x} = -\frac{g(r-b)}{h} - \frac{F_D}{M}$ (Not M^* as deceleration) $\ddot{x} = -\frac{g(0.64)}{0.8} - \frac{\frac{1}{2} \times 1.167 \times 0.5 \times 0.55 \times 27.7^2}{185}$ $\ddot{x} = -7.8 + 8 - 0.665$ Max deceleration $\ddot{x} = \underline{-8.5 \text{ ms}^{-2}}$	(4)
Question Total		20 Marks

Continuation Sheet

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Question No	Question	Marks
Q2a	Real Stiffness K  For a fork displacement x for real forks, Reduced system (wheel) moves $x \cos \epsilon$ N_f (Real) $N_f \cos \epsilon = Kx$ ④ $N_f = \frac{Kx}{\cos \epsilon}$ Reduced Stiffness K_f  $F = Kx$ N_f (Reduced) $N_f = K_f x \cos \epsilon$ ④ equating equations for N_f $\frac{Kx}{\cos \epsilon} = K_f x \cos \epsilon$ $K_f = \frac{Kx}{x \cos^2 \epsilon}$ so $K_f = \frac{K}{\cos^2 \epsilon}$	④ ④

Continuation Sheet

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Question No	Question	Marks
<u>Q2b</u>	Using $k_s = \frac{k}{\cos^2 \epsilon}$ $12 = \frac{k}{\cos^2 22}$ $k = 12 \cos^2 22$ $k = \underline{10.32 \text{ N/mm}}$	(3)
<u>Q2c</u>	for a race motorcycle with this suspension stroke, a suitable fork natural frequency is 2.2 Hz Using $f = \frac{1}{2\pi} \sqrt{\frac{k_s}{M}}$ Total motorcycle + Rider weight = 78.5 + 80 = 158.5 kg (Student can use any weight) with a 50/50 weight distribution, front weight = 79.25 kg Motorcycle Spring front weight = 79.25 - 11 = 68.25 kg. $2.2 = \frac{1}{2\pi} \sqrt{\frac{k_s}{68.25}}$ $13.82^2 = \frac{k_s}{68.25}$ $k_s = 13.040 \text{ N/mm}$	(3)
<u>Q2e</u>	again $k_s = \frac{k}{\cos^2 \epsilon}$ so $13.04 = \frac{k}{\cos^2 23.5}$ $k = 13.04 \times \cos^2 23.5$ $k = \underline{10.97 \text{ N/mm}}$	(3)
Question Total		20 Marks

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Question No	Question	Marks
Q3a	From $V = r\omega$, $V = R_c \Omega$ so $\Omega = \frac{V}{R_c} = \frac{13.88}{25} = 0.55 \text{ rad/s}$	(2)
Q3b	From $V = r\omega$, $V = R_f \omega$ so $\omega = \frac{V}{R_f} = \frac{13.88}{0.3} = 46.3 \text{ rad/s}$	(2)
Q3c	$\phi_i = \tan^{-1}\left(\frac{R_c \Omega^2}{g}\right) = \tan^{-1}\left(\frac{25 \times 0.55^2}{9}\right) = 37.7^\circ$	(3)
Q3d	$M_y = I \omega_f \omega_f \Omega \cos \phi_i = 0.63 \times 46.3 \times 0.55 \times \cos 37.7$ $M_y = 12.7 \text{ Nm}$	(3)
Q3e	$\sin \Delta \theta = \frac{M_y}{h \sqrt{(mg)^2 + (m R_c \Omega^2)^2}} = \frac{12.7}{0.65 \sqrt{(245g)^2 + (245 \times 25 \times 0.55^2)^2}}$ $\sin \Delta \theta = \frac{12.7}{1972.6}$ $\Delta \theta = \sin^{-1} 0.0064$ $\Delta \theta = 0.37^\circ$	(4)
Q3f	$M_y = d \sqrt{(mg)^2 + (m R_c \Omega^2)^2}$ so $12.7 = d \times 3034.77$ (From above) $d = 0.00418 \text{ m} = 4.18 \text{ mm}$	(3)
Q3g	larger tyres will require greater lean angles for same radius + speed.	(2)
Q3h	Lower CofG pos. bikes need greater lean angles for same radius corners + speeds.	(1)
Question Total		20 Marks

Continuation Sheet

Module/Unit:	Motorcycle Dynamics and Power Transmission	Page:	6 of 6
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Question No	Question	Marks
<u>Q4a</u>	This is the gyroscopic effect from the wheel rotation and lean rate $M_g = I_{wz} \omega_f \dot{\phi} \quad \text{Neglecting Rake angle}$ $M_g = 0.6 \times 100 \times 0.5$ $M_g = \underline{30 \text{ Nm}}$	(3)
<u>Q4b</u>	This is the same effect but acting at an incline equal to rake angle $M_g = I_{wz} \omega_f \dot{\phi} \cos \epsilon$ $M_g = 30 \cos 25$ $M_g = \underline{27.2 \text{ Nm}}$	(3)
<u>Q4c</u>	In this case, the effect will result in the body of the motorcycle leaning to the RIGHT, due to the gyroscopic reaction of the front wheel and steer torque. This is called Countersteering	(4)
<u>Q4d</u>	Using $M_g = I_{wz} \omega_f \dot{\delta} \cos \epsilon$ $22 = 0.6 \times 100 \times \dot{\delta} \times \cos \epsilon$ $\dot{\delta} = \frac{22}{54.4}$ Steer rate $\dot{\delta} = \underline{0.4 \text{ rad/s}}$	(4)
<u>Q4e</u>	Rider applies torque to left, wheel turns to left, the lateral force at tyre ~~causes~~ causes yaw to left which causes lean to Right - Steer now to the Right - yaw to Right.	(3)
<u>Q4f</u>	Apply torque to left, gyro reaction leans bike to the Right correct steering for desired path - yaw to the Right.	(3)
Question total		(20 marks)