

PRIFYSGOL CYMRU : UNIVERSITY OF WALES

**DEGREE EXAMINATIONS 2011
ARHOLIADAU GRADD 2011**

**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*

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

DATE OF EXAMINATION:

EXAMINATION TIMES:

Start Time:
Finish Time:
Time Allowed:

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:

PAGE 1 OF 6

Question 1 – (Rectilinear Dynamics)

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:

- a. 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)

Consider a motorcycle with the following properties:

Mass with rider, $m = 225\text{kg}$

Reduced Mass, $m^* = 245\text{kg}$

Frontal Area, $A = 0.75\text{ m}^2$

Drag Coefficient, $C_D = 0.7$

Wheelbase, $p = 1.4\text{m}$

60/40 front biased weight distribution

CofG height, $h = 0.6\text{m}$

Front spring stiffness $k_f = 10.5\text{ N/mm}$

Rake angle = 23.5°



- b. What is the power required to maintain the motorcycle at a constant velocity of 200 kmh^{-1} along a horizontal flat road?
- c. The power produced is used to overcome both the drag and rolling friction forces. If the motorcycle is climbing a 10° incline, what are the magnitudes if the 3 forces that the motorcycle needs to be overcome?
- d. During braking, this motorcycle logs a deceleration of 7.5 ms^{-2} . Using your understanding and the information given above, determine an approximate value for the suspension compression that you would expect during braking.

(3 marks)

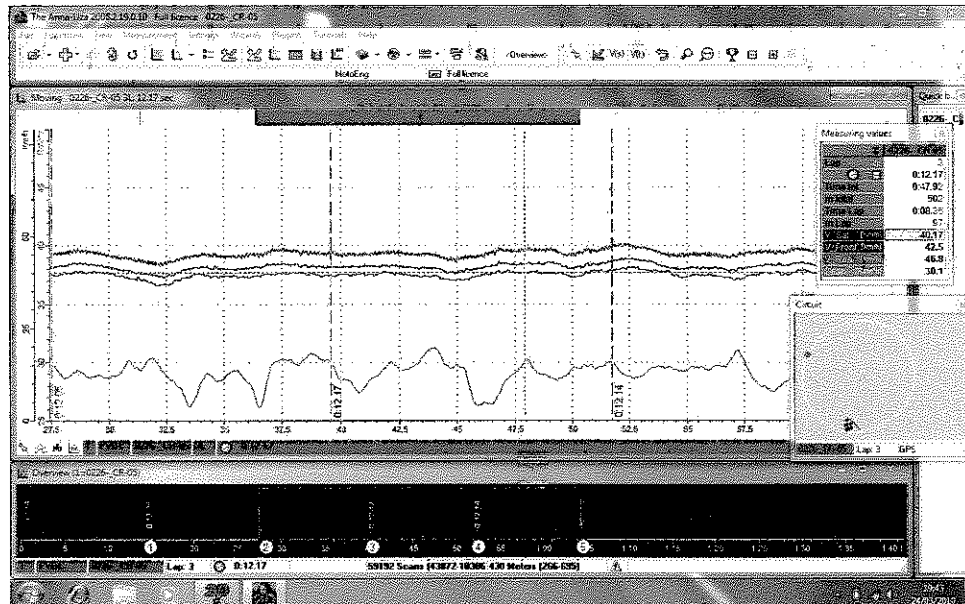
(3 marks)

(6 marks)

Question 2 - (Steady State Cornering)

- a. With the aid of diagrams, derive an equation for the 'ideal' lean angle of a motorcycle in steady state cornering. (5 marks)

- b. With reference to the data trace shown below:



Explain why the 3 recorded velocity traces show different values and explain which of these velocities would be suited to being used as the input to the motorcycles traction control system? (5 marks)

- c. Derive an equation, which expands on the concept of the ideal lean angle to include the motorcycles average tyre thickness into its required lean angle to give a more accurate representation of the required lean angle. (5 marks)

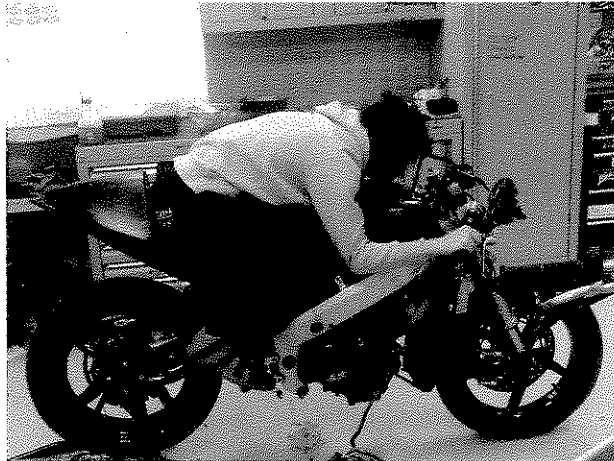
- d. For the motorcycle show in the above data trace, calculate the ideal lean angle and the 'real' lean angle assuming the test track diameter to be 45m and realistic values for the required motorcycle geometry and compare your solution to the data on the trace and discuss your results. (5 marks)

Question 3 – (Suspension Analysis)

- a. A motorcycle suspension can be represented by an equivalent 'vertical stiffness' or 'wheel rate'. Using both diagrams and calculations, show how the 'wheel rate' and the 'spring rate' are related.

(8 marks)

- b. The TeamV4 – Bike 2 weighs 145kg and has a 58/42 front biased weight distribution with rider. The fork travel is 90mm, the rear wheel travel is 112mm, the rake angle is 21.5° , the front unsprung mass is 11kg and the rear unsprung mass is 14.5kg.



- i. Advise a suitable ride frequency assuming Andy weighs 65kg.
- ii. Assuming both tyres have a stiffness of 200N/mm, determine a suitable fork spring stiffness.

(2 marks)

(4 marks)

- c. The rear suspension can also be analysed in a similar manner. If the 'link ratio' for the motorcycle is 2.5:1 and the damping coefficient in compression at the wheel is 1200 Ns/m, calculate the required stiffness of the rear spring and comment on the suitability of the damping coefficient and its corresponding value at the shock.

(6 marks)

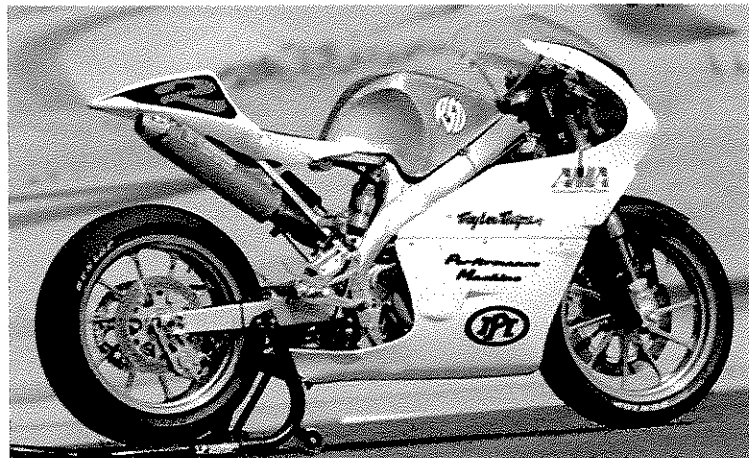
Question 4 – (Dynamics and Handling)

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)

The New CsR500R Super2T motorcycle has a total mass of 144kg and a 52/48 forward weight distribution with a 70kg rider. It has a front unsprung mass of 9.4kg and a rear unsprung mass of 12.4kg. The rake angle is 22.5 degree and the rear link ratio is an average of 2.5:1. Determine the following:



- c. Determine the vertical wheel stiffness's that are needed to satisfy a ride frequency of 2.0 Hz for the front and 2.2Hz for the rear. (3 marks)
- d. Determine the critical damping that would be needed for these vertical stiffness's? (3 marks)
- e. Given the suspension geometry for the motorcycle, determine the damping required at the fork and the shock for the sprung mass for both the front and rear of the motorcycle if the damping ratio for the sprung mass is to be $\zeta = 0.4$. (6 marks)

Equation Data Sheet

Dynamic Loadings:

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

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

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

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

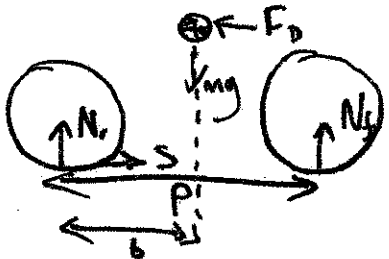
Natural Frequency

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



EXAMINATION SOLUTIONS : SESSION 2010/11

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

Question No	Question	Marks
Q1a	 $F_D = S$ (1) $mg = N_f + N_r$ (2) Take moments about C of G $N_f(p-b) + Sh = N_r b$ Substitute (2) for N_r $N_f(p-b) + Sh = mg - N_f b$ $N_f p - \cancel{N_f b} + Sh = mg - \cancel{N_f b}$ $N_f p + Sh = mg b$ $N_f = \frac{mg b}{p} - \frac{Sh}{p}$ Now for N_r $(mg - N_r)(p-b) + Sh = N_r b$ $mgp - N_r p - mgb + \cancel{N_r b} + Sh = \cancel{N_r b}$ $N_r p = mgp - mgb + Sh$ $N_r = \frac{mg(p-b)}{p} + \frac{Sh}{p}$	(8)
b	$200 \text{ kmh}^{-1} = 55.5 \text{ ms}^{-1}$ $F = \frac{1}{2} \rho C_D A V^2 + 0.02 mg$ $= 943.6 + 44.145 \text{ N}$ $\text{Power} = F \times v = 987.75 \times 55.5 = 54.8 \text{ Kw}$	(3)

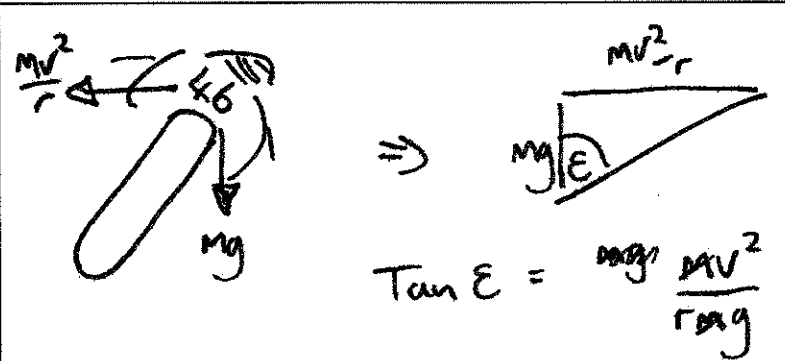
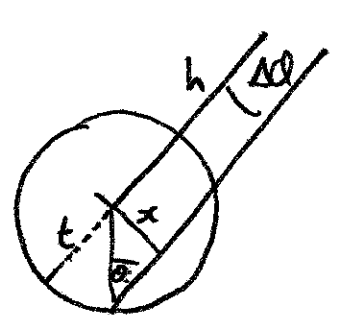
Continuation Sheet

Module/Unit:	Motorcycle Dynamics	Page:	2 of 6
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Question No	Question	Marks
1c	Aerodynamic = ~~987~~ 943.6 N Rolling friction = 44.145 N Now need force due to incline. $F = mg \sin \theta = 225g \times \sin 10 = \underline{383.3 \text{ N}}$	(3)
d	During braking $N_f = mg \frac{b}{p} + S_b \frac{h}{p}$ (S_b = brake force) $N_f = 225g \left(\frac{0.6 \times 1.4}{1.4} \right) + 7.5 \times 225 \times \left(\frac{0.6}{1.4} \right)$ $N_f = 1324.35 + 723.21 = \underline{2047.6 \text{ N}}$ Now using $F = kx$ and $k = k' \times \cos^2 \alpha$ $2047.6 = \left(\frac{21000}{\cos^2 23.5} \right) \times x$ $x = \underline{82 \text{ mm}}$	(6)
Total		20

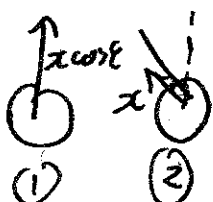
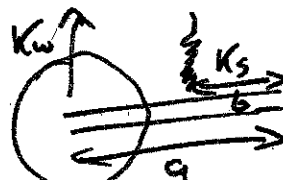
Continuation Sheet

Module/Unit:	Motorcycle Dynamics	Page:	3 of 6
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Question No	Question	Marks
2a	 $\tan \epsilon = \frac{mv^2}{r \cdot mg} = \left(\frac{v^2}{rg} \right)$	(5)
b	There are differences in the traces due to the different tyre thicknesses on the motorcycle which affects the wheels rotational speeds. V Rear is best suited to traction control, referenced to V Front. GPS Not suitable due to signal dropout.	(5)
c	 $\sin Q = \frac{x}{t} \quad \sin \Delta Q = \frac{x}{h-t}$ $t \sin Q = (h-t) \sin \Delta Q$ $\frac{\sin Q}{h-t} = \frac{\sin \Delta Q}{t}$	(5)
d	$Q_i = \tan^{-1} \left(\frac{v^2}{rg} \right) \Rightarrow Q_i = 29.2^\circ$ $\sin \Delta Q = 0.0629 \text{ so } \Delta Q = 3.61^\circ$ So real lean angle $Q = \underline{32.8^\circ}$ This is similar to dater brace, but slight inaccuracies due to one selected tyre thickness etc ...	(5)
Total		20

Continuation Sheet

Module/Unit:	Motorcycle Dynamics	Page:	4 of 6
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Question No	Question	Marks
3a	 $(1) N_s = K_s x \cos \epsilon$ $(2) N_s \cos \epsilon = K x$ ~~① is ②~~ $K_s x \cos \epsilon \cos \epsilon = K x$ $K_s \cos^2 \epsilon = K$  $F_s = \frac{b}{a} F_w \quad x_s = \frac{a}{b} x_w$ $K_s = \frac{F_s}{x_s} = \frac{F_w \frac{b}{a}}{x_w \frac{a}{b}} = K_w \left(\frac{b}{a}\right)^2$	(8)
b(i)	Suitable mode frequency $\approx 2.1 \text{ Hz}$ (Andy not relevant yet)	(2)
(ii)	Vertical stiffness $= (2\pi f)^2 \times M$ $= (4.2\pi)^2 \times 110.8$ (% front mass - unsprung) $= 19.29 \text{ N/mm}$ $K = \frac{K_t K'_s}{K_t + K'_s}$ re-arrange for $K'_s \dots K'_s = \frac{K K_t}{(K_t - K)} = 21.349 \text{ N/mm}$ $K_s = K'_s \cos^2 \epsilon = 18.48 \text{ N/mm}$ So each spring $K_s = 9.25 \text{ N/mm}$ (assuming 0.25 increments)	(4)

Continuation Sheet

Module/Unit:	Motorcycle Dynamics	Page:	5 of 6
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Question No	Question	Marks
3c	$f = \frac{1}{2\pi} \sqrt{\frac{k}{m}}$ $k_w = m(2\pi f)^2$ $k_w = 73.7(4.2\pi)^2$ $k_w = 12.83 \text{ N/mm}$ So at shock $k_s = 12.83 \times 2.5^2 = \underline{80 \text{ N/mm}}$ Critical damping at wheel $= 2\sqrt{kM} = \underline{1944 \text{ Ns/m}}$ Damping ratio $\zeta = \frac{c}{c_{crit}} = \frac{1200}{1944} = 0.62$ This is underdamped, but suitable for suspension Value at shock $= 1200 \times 2.5^2 = \underline{7500 \text{ Ns/m}}$	(6)
Total		20

Continuation Sheet

Module/Unit:	Motorcycle Dynamics	Page:	6 of 6
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Question No	Question	Marks
4a	low speed steering works like the 'bicycle model' so a turn of the bars to the right causes instability and the vehicle begins to 'fall' to the left, this is corrected by the steering and corner thrust to regain control, this situation continues through corner, so no true steady state.	(4)
b	at high speed, gyroscopic effects allow steering to be done by another mechanism. A turn of the bars to the right causes the gyro (front wheel) to lean to the left. steering moves to allow wheel to follow path. $\rightarrow$ steady state	(4)
c	front $K_f = m(2\pi f)^2 = 101.8(4\pi)^2 = 16.1 \text{ N/mm}$ Rear $K_r = 90.32 \times (4.44\pi)^2 = 17.25 \text{ N/mm}$	(3)
d	front $C_c = 25 \text{ km} = 2560 \text{ Ns/m}$ Rear $C_c = 25 \text{ km} = 2496 \text{ Ns/m}$	(3)
e	front $C = 0.4 C_c = 1024 \text{ Ns/m}$ at fork $C = 1024 \times \cos^2 22.5 = 874 \text{ Ns/m}$ each fork = 437 Ns/m Rear $C = 0.4 C_c = 998.4 \text{ Ns/m}$ at shock = 998.4×2.5^2 = 6240 Ns/m	(6)
Total		20