Access Tuition

A-Level Physics

Rotational Motion

Mark Scheme

Time available: 46 minutes
Marks available: 46 marks

Mark schemes

1. (a) To smooth out (fluctuations in) rotational speed ✓

OR to store (rotational kinetic) energy ✓

OR to smooth (fluctuations in) torque/power ✓

Any named form of energy must be (rotational) kinetic

Do not allow an application (eg regenerative braking) unless one of the answers shown alongside is included

1

(b) Use of 0.075 sin 8° **or** 0.075 tan 8° **or** 0.075 (π − 3) to calculate h

$h = 1.04 \times 10^{-2}$ (m) **OR** 1.05×10^{-2} (m) **OR** 1.06×10^{-2} (m) ✓

$mgh = 0.020 \times 9.81 \times 1.04 \times 10^{-2} = 2.04 \times 10^{-3}$ (J) ✓

$T\theta = 2.04 \times 10^{-3}$ (J)

$T = 2.04 \times 10^{-3} / 3.00 = 6.80 \times 10^{-4}$ Nm ✓

1st mark for calculating h

2nd mark for calculating mgh.

3rd mark for dividing mgh by 3.00 rad.

Use of tan gives $h = 1.05 \times 10^{-2}$ *(m)*

Use of arc length gives $h = 1.06 \times 10^{-2}$ *(m)*

3rd mark only awarded for arriving at correct answer to more than 1 sig fig

3

(c) Attempt to use $0 = \omega_1^2 - 2\alpha\theta$ ✓

Or $\theta = 573 \times 2\pi = 3600$ rad ✓

Leading to $\alpha = 0.087$ (rad s^{-2}) ✓

$I = \frac{T}{\alpha} = 7.82 \times 10^{-3}$ kg m^2 ✓

OR

Attempt to use $T\theta = \frac{1}{2} I (\omega_2^2 - \omega_1^2)$ ✓

or $\theta = 573 \times 2\pi = 3600$ rad ✓

($I = 2T\theta/\omega_1^2$)

$= 2 \times 6.8 \times 10^{-4} \times 573 \times 2\pi/25^2$ ✓

$= 7.82 \times 10^{-3}$ kg m^2 ✓

*1st mark for **either** use of equation **or** converting rotations to rad*

ECF for 3rd mark

The value of torque used must be a correctly calculated answer to part (b) or 7×10^{-4} N m

<u>For 2nd method</u>

2nd mark for correct substitution

3rd mark for calculating answer

3

[7]

2. (a) No (net) external torque acts (on the system) ✓

Do not accept force for torque

1

(b) $I_A \omega_A + I_B \omega_B = (I_A + I_B)\omega$ ✓

(taking clockwise as positive)

$(7.2 \times 95) + (11.5 \times -45) = 18.7\omega$

$\omega = (+)8.9$ rad s^{-1} ✓

clockwise ✓

Accept answers with anticlockwise taken as positive.

1st mark for equation or substitution, but condone any incorrect sign for angular velocity.

2nd mark: answer to at least 2 sf

3rd mark for direction, ECF provided direction agrees with sign in calculated answer and sign convention used.

3rd mark is not an independent mark and is contingent on some attempt at calculation using angular momentum

3

(c) Attempts to use Angular impulse $= Tt = \Delta(I\omega)$ ✓

Clutch C: $600\,t = 7.2 \times (95 - 8.9) = 620$ (N m s)

$t = 1.03$ s

OR $\alpha = (95 - 8.9)/t$

$600 = I\alpha = 7.2\,(95 - 8.9)/t$

$t = 1.03$ s

Clutch D: $320\,t = 7.2 \times (95 - 8.9)$

$t = 1.93$ s ✓ (for either or both times calculated)

Compares correct times with 1s < t < 2s and concludes both clutches satisfy criterion. ✓

1st mark: attempts to use idea of angular impulse

Mark not given for just quoting formula.

2nd mark: correct time(s) calculated for either or both clutches

OR torques calculated for 1 s and/or 2 s [620 Nm and 310 Nm]

3rd mark: correct conclusion based on correct times for both clutches

OR based on comparing calculated torques for 1 and 2 s with data in Table 2

Answers may be worked out using shaft B:

$T \times t = 11.5 \times (-45 - 8.9) = (-)620$ *N m s*

Give full marks if 9 rad s^{-1} *is used, giving*

angular impulse = 619 N m s

t for clutch C = 1.03 s

t for clutch D = 1.93 s

3

[7]

3. (a) $T = 6.0 \times 0.036 = 0.22$ (N m) ✓

1

(b) power cannot increase ✓

$P = T\omega$ so if ω is 4x greater, T cannot be more than 1/4✓

OR

Work done by (torque) on C cannot be greater than work done (by torque) on B ✓

$W = T\theta$, if θ is 4x greater, T cannot be more than 1/4✓

Or $T_C \times 4\theta_B = T_B\theta_B$ so $T_C = T_B/4$

OR

Force same on both/force cannot increase/ r_C is ¼ r_B ✓

$F \times r_C = F \times r_B/4$ so TC = $T_B/4$

Or Because radius is ¼, torque on C must be ¼ ✓

Accept other valid argument e.g. using knowledge that radius of C is 1/4 radius of B, or velocity v at point of mesh of gears is the same for both.

Do not allow 'it is not possible' (WTTE) unless backed up by valid argument.

2

(c) α = 76/2.1 = 36 (rad s^{-1}) (36.2 rad s^{-1}) ✓

$I = T/\alpha = \frac{0.054}{36} = 1.5 \times 10^{-3}$ (kg m^2) ✓

ECF for 2nd mark for AE or transposing error.

2

(d) angular impulse = ang. momentum change = $T\Delta t$ ✓

1st mark for statement defining angular impulse

Reference to (large) $\Delta(I\omega)$ in small Δt gives large T ✓

2nd for relating momentum change in small t to high T

($T = F \times r$) so large F on gear teeth. ✓

3rd for relating high T to high force

3

[8]

4. (a) $F = 0.11 \times \cos 45$ (= 0.078 N) ✓

$T = F \times 0.12$ on each arm = 9.4×10^{-3} N m

Total $T = 3 \times 9.4 \times 10^{-3} = 0.028$ N m ✓

Do not allow sin 45 instead of cos 45 but give CE for 2nd mark.

No CE for 2nd mark if no attempt to resolve force i.e. no cos or sin.

2

(b) (i) Initially friction torque < applied torque so spinner accelerates / frictional torque increases with speed ✓
Eventually applied torque = friction / resistive torque and spinner angular speed remains constant ✓

For a full answer is in terms of 'force' rather than 'torque' give max 1 mark.

2

(ii) 240 rev min^{-1} = 25 rad s^{-1} OR use of $P = T\omega$ with attempt to convert rev min^{-1} to rad s^{-1} ✓
$P = T\omega$
$P = 0.028 \times 25 = 0.70$ W ✓

Accept attempt such as multiplying by π or dividing by π or 2π, or dividing 240 by 60 and not using 2π.

No CE for incorrect ω

T must be either 0.028 or 0.03 Nm

0.75 W if 3×10^{-2} used

2

(c) (i) Use of $\theta = ½(\omega_1 + \omega_2)\,t$ OR $\theta = 13 \times 2\pi$ ✓
$= 0.5 \times 25 \times t$
$t = 6.5$ s ✓

CE for ω^1 from b ii

2

(ii) E_K = mean power × time
= 0.35 × 6.5 = 2.3 J
OR
$E_K = T\theta = 0.028 \times 26\pi = 2.3$ J ✓

CE for values of θ and t from c i and P from b ii

Allow use of $E_K = ½ I\omega^2$ with I from part c iii

If T = 0.03 N m used, E_K = 2.4(5) J

1

(iii) $E_K = ½ I\omega^2$
$I = 2 E_K / \omega^2 = 7.3 \times 10^{-3}$ kg m^2 ✓

If 2 J used for E_K, $I = 6.3 \times 10^{-3}$ kg m^2

Alternative: use of $I = T / \alpha$

Where α = 25/ans c i

When $T = 3 \times 10^{-2}$, $I = 7.76 \times 10^{-3}$ kg m^2

CE for ω

1

[10]

5. (a) T = power/ω

Torque = 2500/0.47

5320 N m value to 2 or more sf needed

3

(b) (i) Deceleration= 0.47/34= 0.0138 (rad s^{-2})

moment of inertia = torque / angular deceleration
=5000/0.0138 = 3.57 × 10^5

kg m^2 (Allow N m s^2)

3.8 × 10^5 if 5320 used

3

(ii) Suitable equation of motion used with correct data but omitted minus sign

8.0 radian Allow (their $\omega/2\pi$)

1.27 revolutions

Condone 1 revolution

(allowed for thinking question refers to complete revolutions)

3

(c) (i) F = 65 × 2.2 × 0.47^2

32(31.6 N)

2

(ii) Force produced by friction between the feet and the roundabout

Centripetal force has to act through the centre of mass of the operator
or
The resultant of the frictional force and normal reaction has to pass through the centre of mass

Any indication (eg on diagram) of wrong direction = 0

2

(iii) Ticks 4th box

1

[14]