Version DDS/4 (with answers)

EGT3
ENGINEERING TRIPOS PART IIB

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Monday 27 April 2015 2 to 3.30

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**Module 4C16**

**ADVANCED MACHINE DESIGN**

*Answer **all** questions.*

*All questions carry the same number of marks.*

*The **approximate** percentage of marks allocated to each part of a question is indicated in the right margin.*

*Write your candidate number **not** your name on the cover sheet.*

**STATIONERY REQUIREMENTS**
Single-sided script paper

**SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM**
CUED approved calculator allowed
Attachment: 4C16 Advanced Machine Design data sheet (3 pages)
Engineering Data Book

**10 minutes reading time is allowed for this paper.**

**You may not start to read the questions printed on the subsequent pages of this question paper until instructed to do so.**

1 The stationary pad of an infinitely wide, fixed inclination, plain bearing has the form of a step of height $d$ with parallel inlet and outlet regions. The step is 2/3 along the bearing as shown in Fig. 1. The speed of the lower plane surface, the runner, is $U$ and the bearing is supplied with lubricant of viscosity $\eta$. The outlet film thickness is to be equal to $h_0$.

Reynolds equation as on the data sheet can be quoted and it can be assumed that the viscosity of the lubricant remains constant throughout.

(a) Show that the load supported per unit width $P'$ is given by the expression

$$P' = \frac{2\eta B^2 U d}{(h_0 + d)^3 + 2h_0^3}$$ [30%]

(b) Confirm that if the load carrying capacity of the bearing is to be maximised for a given value of $h_0$ then the value of $D = d/h_0$ should be approximately 0.806. [20%]

(c) Obtain an expression for $F'$, the tangential force per unit width necessary to maintain the motion of the runner, and hence an expression in terms of $D$, $h_0$ and $B$ for the effective coefficient of friction (COF) of the bearing, i.e. the ratio $F' : P'$. If the bearing is running with $D = 0.806$ and $h_0/B = 1/1000$ then what value of COF might be anticipated? [30%]

(d) The linear speed of the bearing of part (c) is now doubled while the load remains unchanged. By what factors would you expect (i) the minimum film thickness, and (ii) the COF to change? [20%]



(cont.

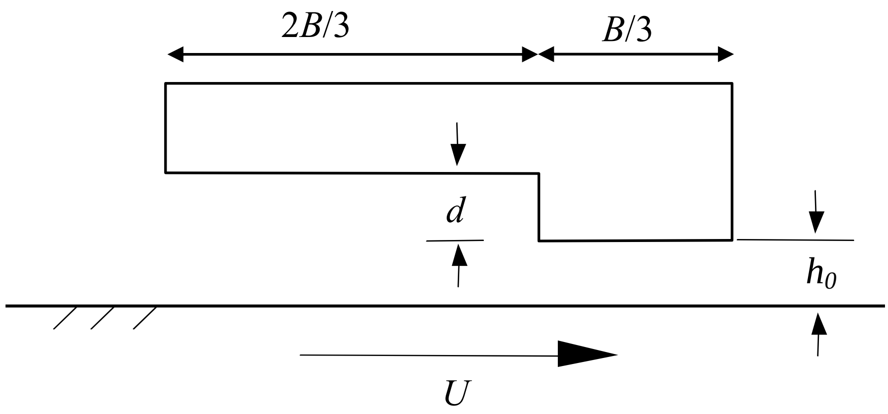


Fig. 1

2 Figure 2 shows a cam which operates a reciprocating follower. The cam has a base circle radius of $3r$ and a tip circle radius $2r$. The follower has end radius $r$. The line of action of the follower is offset by a distance $r$ to the left of the axis of rotation of the cam. The centres of the base circle, tip circle and follower end are O, A and B respectively. The cam rotates anti-clockwise at a constant angular velocity $\dot{\varphi}$ about O. Both cam and follower are prismatic bodies with the cross-sections shown in Fig. 2.

(a) (i) Draw an equivalent mechanism for the case of follower contact on the tip circle. What is the value of the cam angle $\varphi$ when the follower lift $y$ is a maximum? [30%]

(ii) Find the follower accelerations at maximum and minimum lift. [30%]

(b) (i) Draw an equivalent mechanism for the case of follower contact on the cam flank (the case shown in Fig. 2). [20%]

(ii) Hence find an expression for the follower lift $y$ as a function of the flank angle $\theta$. [20%]

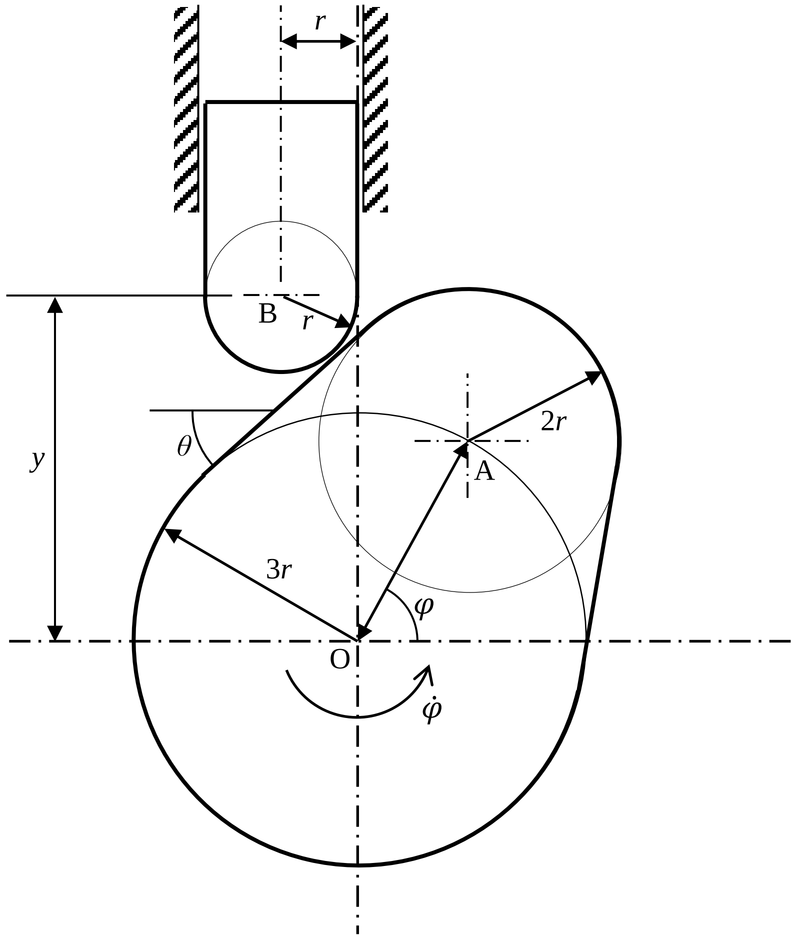


Fig. 2

3 A vehicle with a mass $m$ of 1000 kg is to be designed for urban operation over flat terrain with a standard 20 second drive cycle of: (1) uniform acceleration to a speed of 10 m $s^{-1}$ over a period of 4 s; (2) cruising at a constant speed of 10 m $s^{-1}$ for 10 s; (3) deceleration to a stop in 2 s; and (4) remaining stationary for another 4 s. The vehicle has a frontal cross-sectional area $A$ of 2 $m^2$, an aerodynamic drag coefficient $C_D$ of 0.4 and a coefficient of rolling resistance $C_{RR}$ of 0.01. The density of air is 1.2 kg $m^{-3}$. The vehicle will be powered by a hybrid transmission consisting of an internal combustion (IC) engine supplemented by a flywheel energy storage system.

(a) (i) Determine the maximum driving power required. [10%]

(ii) Calculate the energy consumed during each phase of the drive cycle. [30%]

(iii) Hence calculate the power of the IC engine if it is only required to meet the mean power over the whole drive cycle. [10%]

(iv) How much energy must the flywheel be capable of storing? [10%]

(v) For how long must the IC engine be run with the vehicle stationary at initial start-up? [10%]

(b) The flywheel is to be manufactured from a composite material with a maximum operating tensile stress of 1 GPa and a density of 1600 kg $m^{-3}$. Determine the mass of flywheel necessary for the vehicle. [30%]

**END OF PAPER**

**ANSWERS**

1

(c) Coefficient of friction = 0.0034

(d) (i) The minimum film thickness increases by a factor of 1.39

(ii) The coefficient of friction increases by a factor of 1.56

2

(a) (i) $\varphi$ = 99.6°

(ii) The follower acceleration is $\frac{36}{\sqrt{35}} r\dot{\varphi}^2$ downwards at maximum lift and zero during the period of minimum lift.

(b) (ii) $y = r(4\sec\theta - \tan\theta)$

3

(a) (i) 26.5 kW

(ii) Energy consumed in: Acceleration phase = 52.4 kJ, Cruise phase = 14.6 kJ, Deceleration phase = -48.8 kJ, Stopped phase = 0 J

(iii) 914 W

(iv) 54.3 kJ

(v) 59.4 s

(b) 0.174 kg