ENGINEERING TRIPOS PART IIB

Tuesday 8 May 2012 2.30 to 4

Module 4C16

ADVANCED MACHINE DESIGN

*Answer **all** questions.*

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

Attachment:
Module 4C16 data sheet (3 pages).

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS
Engineering Data Book
CUED approved calculator allowed

You may not start to read the questions printed on the subsequent pages of this question paper until instructed that you may do so by the Invigilator

djc03

1 (a) A thin film of incompressible lubricant fills the gap between two smooth solid surfaces at distance h apart. The upper surface is stationary while the lower moves with speed U as shown in Fig. 1(a). The lubricant is Newtonian with viscosity η. Coordinates x and z are in the entraining and normal directions respectively.

(i) By considering the equilibrium of an element of the fluid within the film, show that shear stress τ and pressure p are related by the equation

$$\frac{\partial \tau}{\partial z} = \frac{\mathrm{d}p}{\mathrm{d}x}.$$ [15%]

(ii) The upper surface is chemically treated so that it offers no resistance to slip of the fluid, whereas on the lower surface the usual no-slip conditions apply. Show that shear stress, pressure gradient and location within the fluid film are related by the equation

$$\tau = \frac{\mathrm{d}p}{\mathrm{d}x}(z-h).$$ [15%]

(b) Figure 1(b) shows a fixed pad bearing of breadth B in which the film thickness h falls from h_1 at inlet to h_0 at exit so that

$$\frac{h}{h_0} = 1 + K - K\frac{x}{B} \quad \text{where} \quad K = \frac{h_1 - h_0}{B}.$$

In this bearing, the upper surface at $z = h$ has been similarly treated so that it too offers no resistance to slip whereas, on the lower surface, the usual no-slip condition applies.

(i) By considering continuity of flow, or otherwise, show that fluid pressure is governed by the equation

$$\frac{\mathrm{d}}{\mathrm{d}x}\left(h^3 \frac{\mathrm{d}p}{\mathrm{d}x}\right) = 3\eta U \frac{\mathrm{d}h}{\mathrm{d}x}.$$ [35%]

(ii) The effective friction force F offered by the bearing can be determined by integrating the shear stress acting on the lower moving surface, so that

$$F = \int_0^B \tau\big|_{z=0} \mathrm{d}x \,.$$

Use this equation to find the relation between the effective coefficient of friction of the bearing (the ratio of F to W) and its geometry. Confirm the validity of your solution by simply considering the equilibrium of the stationary element of the bearing. [35%]

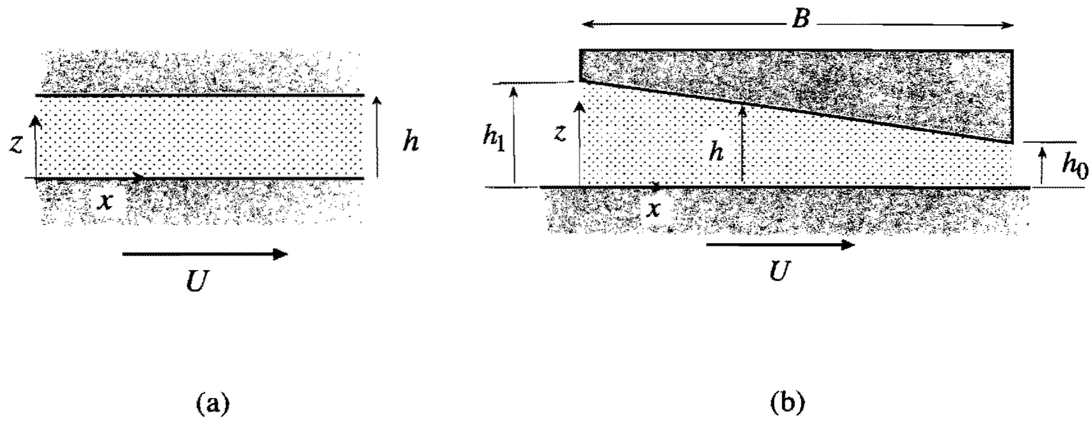

Fig. 1

2 (a) Discuss why cams are generally used for operating the inlet and exhaust valves on car internal combustion engines. What are the critical design issues? [15%]

(b) Figure 2 illustrates a cylindrical cam mechanism used to lift a roller follower of radius R. The base and tip circles of the cam both have radius R and the tip circle centre O' is a distance $2R$ from the base circle centre O. The centre of the follower C is height h above the base circle centre O. The line of action of the follower is offset by a horizontal distance of $\sqrt{3}R$ from the centre of the base circle. Smooth transitions between the flank circles and the base and tip circles occur at points A, A', B and B'. Angles AOB and A'O'B' equal 120°. The cam rotates about O at a constant angular velocity ω.

(i) Show that the radius of the flank circles equals $3R$. [10%]

(ii) Sketch equivalent mechanisms for contact on the base, flank and tip circles. [15%]

(iii) Find the maximum and minimum values of height h during the cam motion and show that O' is vertically below C when contact occurs at A'. [15%]

(iv) Find expressions for the velocity and acceleration of the follower when contact is on the tip circle at A'. [35%]

(v) Would such a cam mechanism be appropriate for an automotive valve train? Justify your answer. [10%]

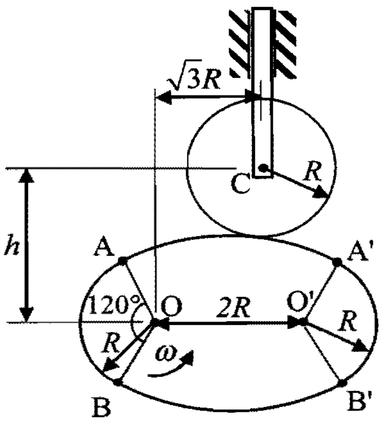

Fig. 2

3 (a) List the significant criteria by which the performance of energy storage devices is assessed. Outline the strengths and weaknesses of chemical batteries as energy storage devices for use in automotive hybrid drive applications. [15%]

(b) A passenger car is equipped with a series hybrid drive. An internal combustion engine is connected to a generator. The engine-generator delivers constant electrical power P or is turned off. Energy can be stored in a battery with energy capacity E. The vehicle's wheels are driven by an electric motor. The driving force f required to move the vehicle forward on horizontal ground is given by

$$f = m\frac{\mathrm{d}v}{\mathrm{d}t} + cv^2 + a$$

where m is the vehicle mass, v is the vehicle speed, c is a constant coefficient, and a is the rolling resistance force. The vehicle travels at constant speed v_0. Assuming that P is greater than the power required to drive the vehicle at this speed, show that the ratio of engine off-time to on-time is given by

$$\frac{P}{\left(cv_0^2 + a\right)v_0} - 1$$

and find the required energy storage capacity E of the battery in terms of the on-time t_{on} and P, c, v_0 and a. [25%]

(c) The engine-generator in (b) is now permanently on, and the vehicle is required to reach a speed greater than the speed v_p that can be sustained by power P. This is achieved by fully discharging the battery at constant rate P_d. The discharging phase is followed by a charging phase, where the battery is fully charged at constant rate P_c (less than P). The cycle then repeats.

(i) Sketch the vehicle speed as a function of time, indicating the charging and discharging phases. [15%]

(ii) Assume that the vehicle spends a large fraction of each phase travelling at near constant speed. If a is small, derive approximate expressions for the minimum and maximum speeds. [20%]

(iii) Derive expressions for the acceleration and deceleration of the vehicle at speed v_p. [25%]

END OF PAPER

4C16 2012 Answers

1 (b) (ii) $\frac{F}{W} = \frac{Kh_0}{B} = \frac{h_1 - h_0}{B}$

2 (b) (iii) $h_{\max} = \sqrt{13}R, \quad h_{\min} = R$

(iv) velocity $\sqrt{3}R\omega$ upwards

acceleration $3\omega^2 R/2$ downwards

3 (c) (ii) $v_{\max} = \sqrt[3]{\frac{P + P_d}{c}}$, $v_{\min} = \sqrt[3]{\frac{P - P_c}{c}}$

(iii) $\frac{P_d}{mv_p}$, $\frac{-P_c}{mv_p}$