Version DDS/4 with answers

EGT3
ENGINEERING TRIPOS PART IIB

Friday 29 April 2016   2 to 3.30

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 (a) Describe briefly the conditions that must be satisfied for hydrodynamic lubrication to be possible. [15%]

(b) Two discs each of radius R are loaded together by a radial force of intensity W/L per unit length in the presence of a lubricant of viscosity η. One disc rotates at speed ω and the other at 2ω so that a film of fluid, with minimum thickness h_0 ($\ll R$), is entrained between them, as indicated in Fig. 1. The film thickness h can be taken to be

$$h = h_0 + \frac{x^2}{R} \quad \text{for} \quad x < 0 \quad \text{and} \quad h = h_0 \text{ for } x \geq 0 .$$

(i) Explain why in this case the entraining velocity is equal to $1.5R\omega$. Verify that $p = Kx/h^2$ is a pressure distribution that satisfies Reynolds' equation and determine the values of K and h^*/h_0, where h^* is the value of the lubricant film thickness where $\frac{\mathrm{d}p}{\mathrm{d}x} = 0$. [25%]

(ii) Sketch the distribution of pressure over the range of values of $x\,(\leq 0)$ for which $h_0 \leq h \leq 3h_0$. Show that pressure has a maximum at $x = -\sqrt{Rh_0/3}$ and evaluate its value at this point. [30%]

(iii) Explain why the specified expression for pressure cannot be considered entirely satisfactory. [5%]

(iv) Indicate how the suggested solution could be used to analyse the situation in which the viscosity of the lubricant obeys the Barus law, i.e.

$$\eta = \eta_0 \exp(\alpha p),$$

by making use of the substitution

$$q = \frac{1 - \exp(-\alpha p)}{\alpha}$$

where η_0 is the base viscosity, α the pressure viscosity index and q the reduced pressure. Hence, or otherwise, deduce a value for the limiting film thickness where the predicted maximum pressure becomes infinitely large. [25%]

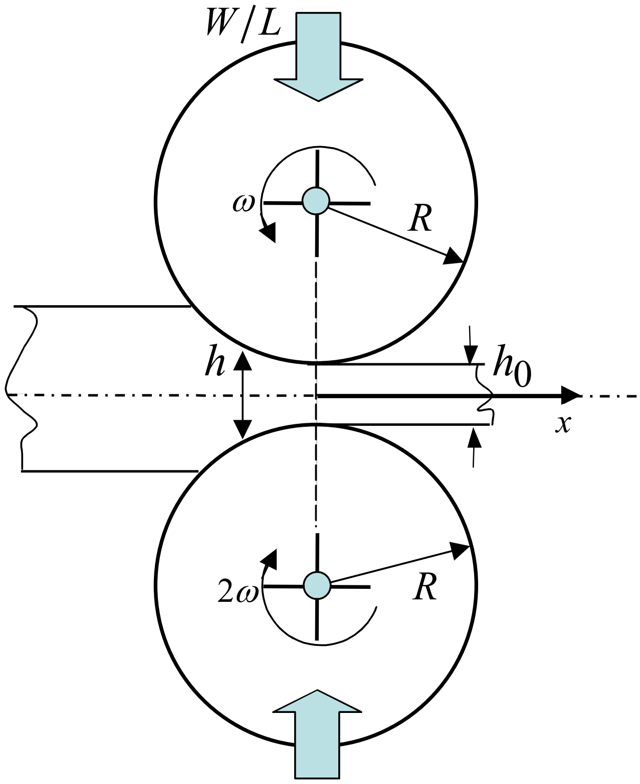

Fig. 1

2 Figure 2 illustrates a simple cam and follower system, in which a cylindrical cam of radius $2a$ and face width L contacts a flat follower of mass m. The cam rotates with constant angular velocity ω about a point O which is offset from the geometric centre of the cam A by a distance a. The follower is constrained to move vertically on an axis which passes through O. A soft spring applies a constant force F to the follower so as to maintain contact with the cam. The contact modulus between the cam and follower is E^*. Gravitational forces can be neglected.

(a) Derive an expression for the contact force between the cam and follower in terms of a, ω, F, m and the cam orientation angle θ, as defined in Fig. 2. Hence find an expression for the critical angular velocity ω at which contact between the cam and follower is first lost. [30%]

(b) Show that the entraining velocity $\bar{U}$ at the point of contact between the cam and follower is given by the expression

$$\bar{U} = \frac{1}{2} a\omega\left(2 + \cos\theta\right)$$

Derive an expression for the sliding velocity at the point of contact. [25%]

(c) Estimate the minimum elastohydrodynamic film thickness between the cam and follower, and the corresponding cam orientation angle θ, for the following conditions: $E^* = 115$ GPa, $\eta_0 = 0.01$ Pa s, $\alpha = 2\times10^{-8}$ m^{2}N^{-1}, $F = 100$ N, $m = 0.2$ kg, $\omega = 1510$ rpm, $a = 10$ mm, $L = 8$ mm. Use the Dowson and Higginson formula to estimate the film thickness; symbols have their usual meanings as used on the datasheet. [30%]

(d) Briefly discuss issues associated with the design of the cam and bucket follower system used in the Ford Zetec valve train, including issues associated with geometry, lubrication, friction and wear. [15%]

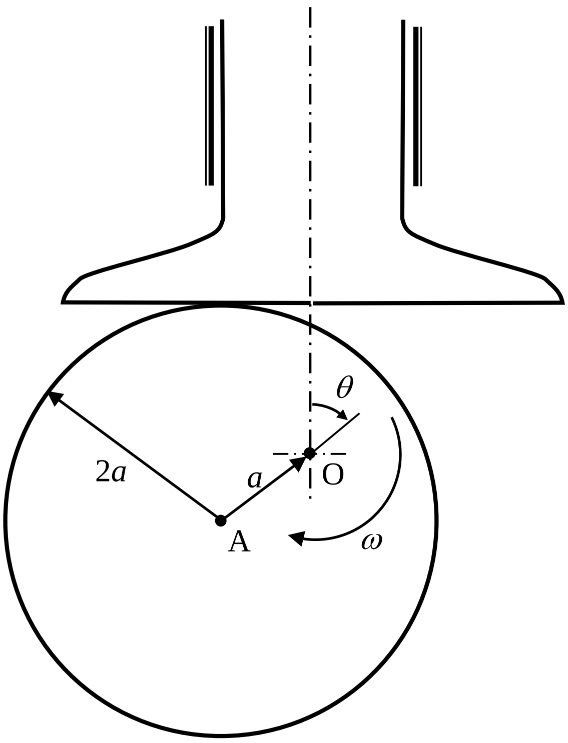

Fig. 2

3 Figure 3 shows a schematic diagram of a hybrid transmission for a road vehicle consisting of a 3 cylinder internal combustion engine (ICE), an epicyclic gearbox and two electric motor/generators (MG). The crankshaft of the ICE is directly connected to the planet carrier of the epicyclic, and has angular velocity ω_C. MG1 is connected to the sun gear of the epicyclic, and has angular velocity ω_S. MG2 is connected to the annulus of the epicyclic, and also to the road wheels via reduction gears, and has angular velocity ω_A. Electronics control the flow of electrical energy between MG1, MG2 and a battery (not shown).

(a) List the different modes of operation of the hybrid transmission with a brief description of each. [30%]

(b) If there is no energy flow to or from the battery then MG1 and MG2 can function as a continuously variable transmission (CVT) with a speed ratio V and an efficiency η. The ratio of annulus to sun diameter is R. For this case:

(i) Draw a block diagram of the transmission. [15%]

(ii) Is the transmission input or output coupled? [5%]

(iii) Find an expression for the ratio of the speeds of MG2 and the ICE as a function of V and R. [25%]

(iv) Find an expression for the overall efficiency of the transmission as a function of η, V and R. [25%]

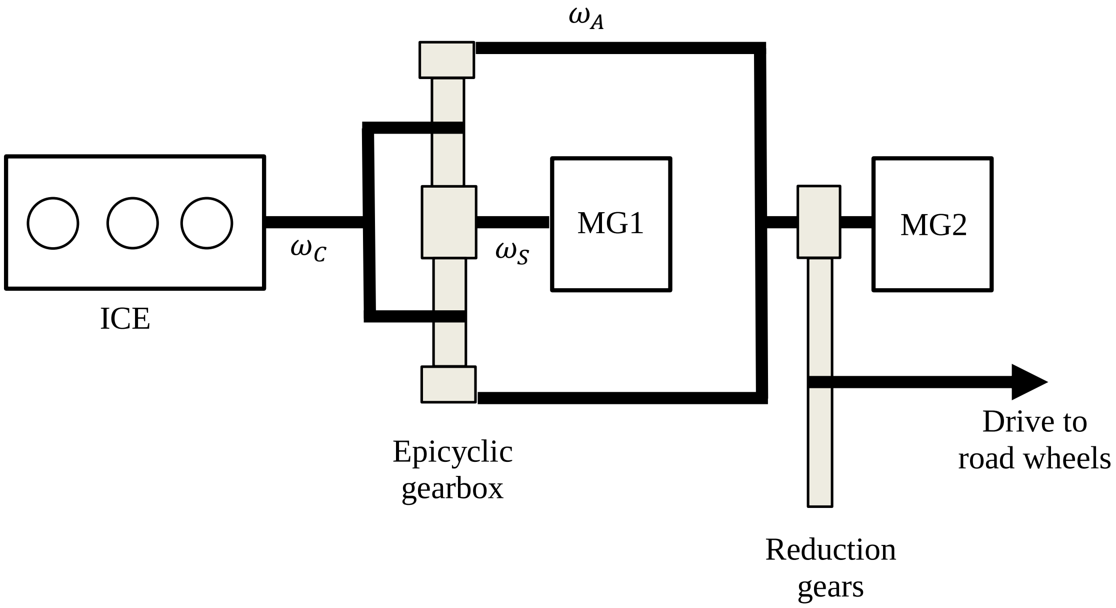

Fig. 3

END OF PAPER

ANSWERS

1 (a) For hydrodynamic support, need: convergent geometry, positive entraining velocity, viscous lubricant.

(b) (i) $K = -6\eta R\varpi \quad \frac{h^*}{h_0} = 4/3$

(ii) $p_{max} = \frac{9\sqrt{3}}{8}\eta\varpi\sqrt{\frac{R^3}{h_0^3}}$

(iv) ${h_0}^3 \simeq \frac{243}{64}(\alpha\eta_0\varpi)^2 R^3$

2 (a) $P = F + m\varpi^2 a\cos\theta,\ \varpi = \sqrt{F/ma}$

(b) $a\varpi(2-\cos\theta)$

(c) 0.17 µm

3 (b) (ii) Output coupled.

(iii) $\frac{\varpi_a}{\varpi_c} = \frac{V(1+R)}{1+VR}$

(iv) $\bar{\eta} = \frac{\eta+VR}{1+VR}$