ENGINEERING TRIPOS PART IIB

Thursday 25 April 2013 2 to 3.30

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

1 Summarize briefly the essential features of a hydrodynamically lubricated bearing. [20%]

Figure 1 shows a 'hump' on an upper fixed surface separated by an oil film from a lower flat surface which moves at constant speed U. The thickness of the gap between the surfaces is given as a function of x by

$$h = h_0 \exp(-\alpha x) \quad \text{for} \quad x \le 0 \quad \text{and}$$
$$h = h_0 \exp(+\alpha x) \quad \text{for} \quad x > 0$$

where α is a real positive quantity. The oil separating the surfaces can be assumed to have constant viscosity η and there is no flow out of the plane of the figure.

(a) The inlet side of the bearing may be assumed to be full of oil within which pressure p is equal to zero at $x = -\infty$. Indicate by a sketch the way in which the hydrodynamic pressure in the oil film might be expected to build up and decay with position x. [10%]

(b) By applying Reynolds' equation, obtain an expression which describes the way in which the pressure in the oil film varies with position x $(x \le 0)$ in terms of U, η, α, h_0 and h^* where this is the value of h at which p has a turning point, i.e. where $\mathrm{d}p/\mathrm{d}x = 0$. [20%]

(c) Show that if $p = p_0$ at $x = 0$ then

$$p_0 = \frac{U\eta}{\alpha h_0^2}\{3 - 2H\} \quad \text{where} \quad H = \frac{h^*}{h_0} \quad .$$ [10%]

(d) On the outlet side it can be assumed that the pressure falls monotonically from a value of p_0 at position $x = 0$ in such a way that at position $x = x_1$ both pressure p and pressure gradient $\mathrm{d}p/\mathrm{d}x$ are simultaneously zero. By equating the expressions for p_0 within the inlet and outlet regions, or otherwise, find the numerical value of the ratio H noting that $H > 1$. [40%]

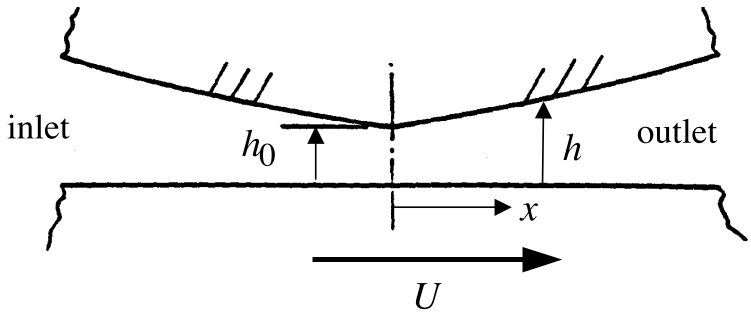

Fig. 1

2 An earth-moving vehicle performs the operating cycle shown in Fig. 2(a). The vehicle is driven forwards with constant tractive force of 10 kN so that the vehicle accelerates from rest to 5 m s^{-1} in 5 s with constant acceleration. The vehicle then encounters a constant resistance force due to earth in front of the vehicle and decelerates to rest in 1 s with constant deceleration; the tractive force remains at 10 kN during this time. Once the vehicle has come to rest it is reversed at low speed for 9 s consuming negligible energy. The operating cycle then repeats indefinitely. The vehicle's tractive force is provided by a hybrid drive, which includes an internal combustion engine providing constant power and an energy store.

(a) (i) State the advantages of a hybrid drive over an internal combustion engine alone. [10%]

(ii) Suggest a suitable technology for the energy store, and sketch a schematic block diagram of a suitable hybrid drive arrangement, showing the major components and the flows of energy between the components. [10%]

(b) (i) Sketch the power required by the vehicle as a function of time. Hence or otherwise calculate the minimum mean power required of the internal combustion engine of the hybrid drive, and the peak power required of the energy store. [25%]

(ii) Sketch the energy required by the vehicle as a function of time. Hence or otherwise calculate the minimum required capacity of the energy store. [35%]

(c) Six different technologies are being considered for the energy store, denoted A to F. The specific power and specific energy (in Watt-hours per kg) of the technologies are shown in Fig 2(b). Using your results from (b) select the best technology if mass is to be minimised. Explain your reasoning. [20%]

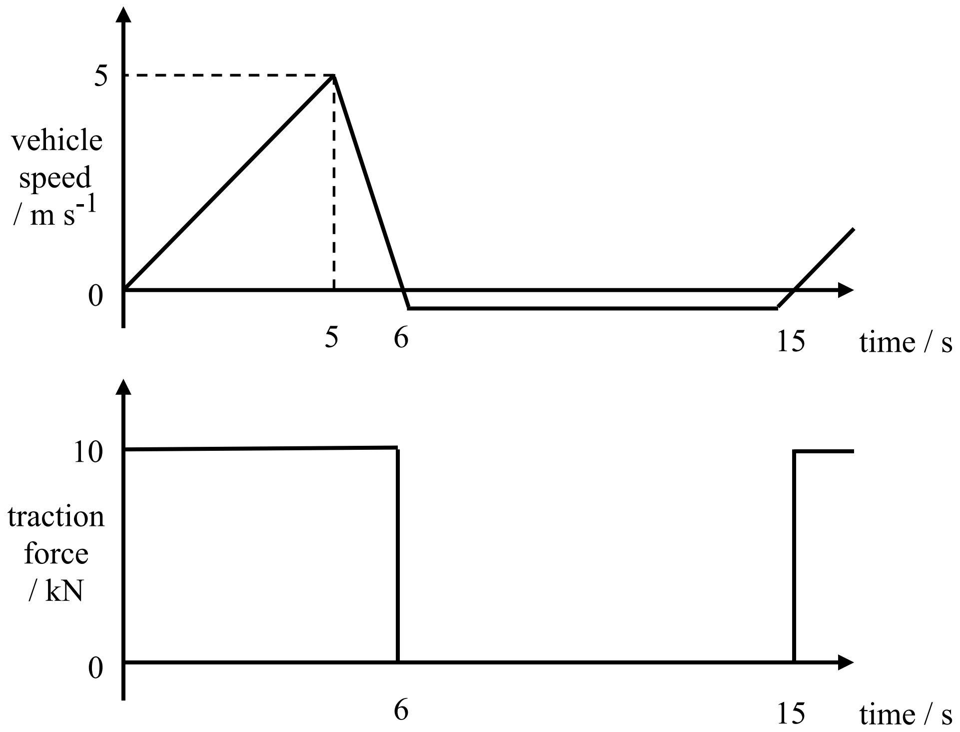
5
vehicle
speed
/ m s-1
0
5
6
15
time / s
10
traction
force
/ kN
0
6
15
time / s

Fig. 2(a)

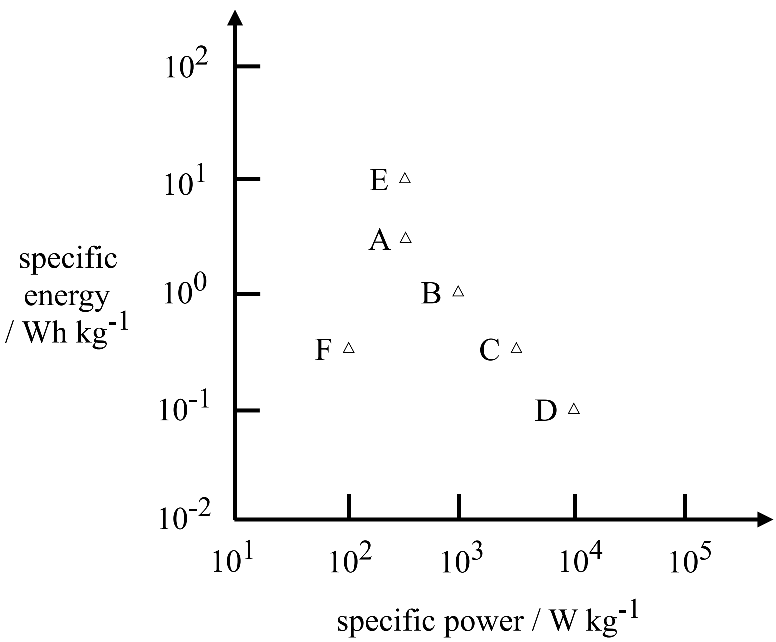
10^2
10^1
10^0
10^-1
10^-2
specific
energy
/ Wh kg-1
E
A
B
F
C
D
10^1
10^2
10^3
10^4
10^5
specific power / W kg-1

Fig. 2(b)

3 (a) A high speed cam rotating at constant angular velocity ω is required to give lift L over a cam rotation of 60° with the follower stationary at the beginning and end of the lift. The first design proposed is a power-law cam profile which takes the form

$$y = \frac{L}{2}\left(\frac{\theta}{30}\right)^3 \qquad 0 \le \theta \le 30°,$$

$$y = L - \frac{L}{2}\left(\frac{60-\theta}{30}\right)^3 \qquad 30° < \theta \le 60°$$

where y is the cam profile and θ is the cam rotation in degrees. (Another part of the profile lowers the follower by L.)

(i) Sketch the way in which the displacement, velocity and acceleration of the follower vary over the interval $0 \le \theta \le 60°$. [25%]

(ii) A modified design is proposed for which the lift starts early and finishes late, with lift errors of no more than $0.0135L$ at 0° and 60°. By what factor could the maximum acceleration of the follower be reduced, compared to the first design? [25%]

(iii) Compare the maximum acceleration of the modified design, measured as a multiple of $L\omega^2$, with a sinusoidal profile that satisfies the original requirement (lift L over a cam rotation of 60° with the follower stationary at the beginning and end of the lift.) [25%]

(b) Discuss briefly the difficulties associated with the lubrication of high speed cams and followers. [25%]

END OF PAPER