ENGINEERING TRIPOS PART IIA

Wednesday 7 May 2003 2.30 to 4.00

Module 3C4

MACHINE DESIGN - TRANSMISSIONS

Answer not more than ***three*** *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.*

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 Figure 1 shows schematically a compound epicyclic gearbox. The input shaft is connected to the sun wheels S_1 and S_2, the planet carrier C_1 is connected to the annulus A_2, and the planet carrier C_2 is connected to the output shaft. A third shaft N is connected to the annulus A_1 as shown. The tooth ratios A_1/S_1 and A_2/S_2 are denoted by R_1 and R_2, respectively.

(a) For the case where $\omega_N = 0$, show that the ratio of output to input speeds ω_o/ω_i is given by

$$\frac{\omega_o}{\omega_i} = \frac{1 + R_1 + R_2}{(1 + R_1)(1 + R_2)}$$

and find a corresponding expression for ω_o/ω_i when ω_N/ω_i is equal to –0.2. [50%]

(b) If the input torque equals 100 Nm , $R_1 = 3$ and $R_2 = 4$, find the output torque for the following cases:

(i) $\omega_N/\omega_i = 0$, where friction can be neglected; [15%]

(ii) $\omega_N/\omega_i = -0.2$, where friction can be neglected; [10%]

(iii) $\omega_N/\omega_i = -0.2$ with a gearbox efficiency of 95%. [25%]

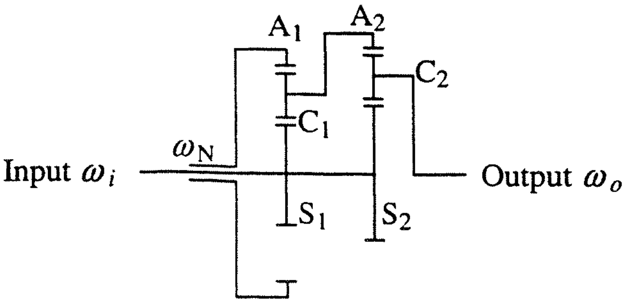

Fig. 1

2 (a) Describe the operation of a swash plate pump. Sketch and comment on the form of typical characteristic performance curves (that is, efficiency and speed as a function of output flow rate and output pressure). [35%]

(b) Figure 2 illustrates a rocking lever mechanism. The cam, which rotates at a constant angular velocity ω about a fixed centre O, has a base circle radius R and straight flanks. The contacting arc of the lever has the same radius R and the centre of its arc at P is a distance $3R$ from the pivot of the lever at Q. When contact is on the base circle, PQ is horizontal and OP is vertical, as sketched.

For the case when contact has just started on the straight flank:

(i) sketch the equivalent mechanism; [20%]

(ii) show that the angular velocity of the lever is equal to zero and find an expression for the angular acceleration of the lever in terms of ω. [45%]

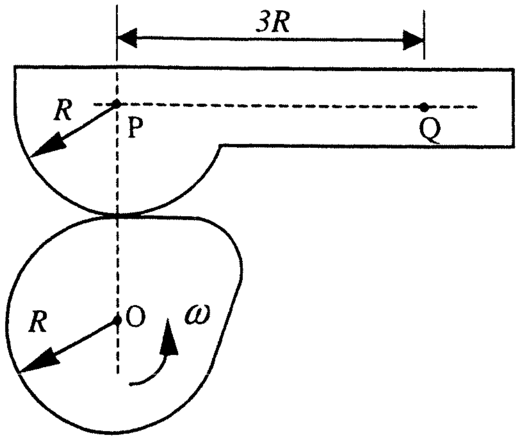

Fig. 2

3 (a) In the form of a table, compare the performance of dry/rubbing bearings, rolling element bearings and hydrodynamic bearings, in terms of their relative cost, speed range, force capacity, and axis alignment accuracy. Give a typical application of each type of bearing. [25%]

(b) Figure 3 shows schematically a design requirement for a shaft, bearings and housing assembly. Forces F_1, F_2 and F_3 act on the rotating shaft. The forces on the shaft are reacted by two rolling element bearings, one at A and one at B.

Bearings are to be selected. The shaft rotates at 3000 revolutions per minute. The inner diameter of each bearing must be 45 mm. The required life is 1000 hours with a reliability of 95%. No correction for viscosity is required, and there is no need to use the minimum radial load equation in the Data Sheet. Assume that the equivalent radial force on a bearing is equal to the sum of the magnitudes of the radial force and the axial force on the bearing. The axial force should be reacted by either bearing A or bearing B, not both.

(i) To simplify the design, the bearings at A and B are required to be identical deep groove ball bearings. Select one bearing from the Data Sheet that meets the life requirement, has 45 mm inner diameter and minimises the outer diameter. State whether the axial force should be reacted at A or at B. [40%]

(ii) The requirement for identical bearings at A and B is removed and an alternative design requirement is introduced: the outer diameter of the larger of the two bearings must be minimised. Bearing selection can be made from the deep groove ball bearings and the cylindrical roller bearings listed in the Data Sheet. Select bearings for A and B that meet the life requirement, have 45mm inner diameter and minimise the outer diameter of the larger bearing. [35%]

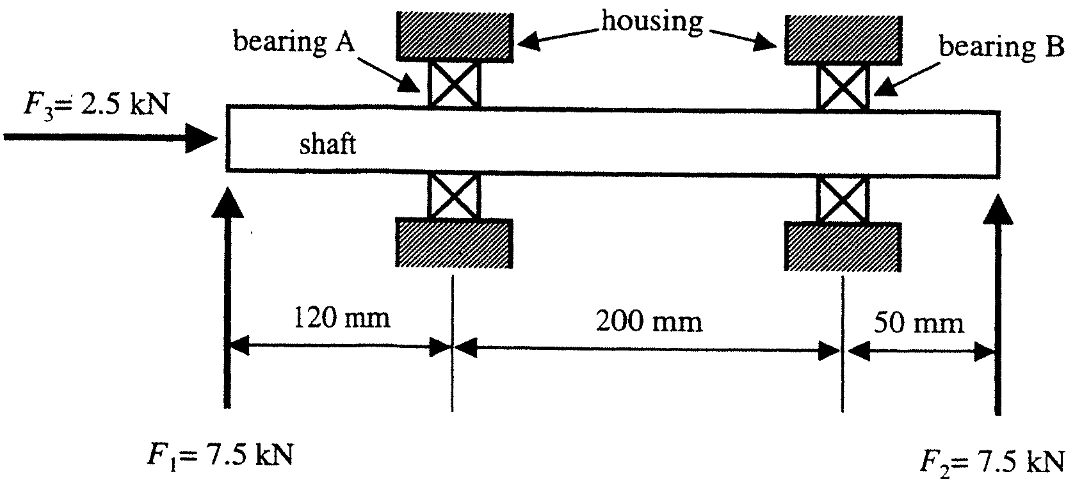

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Fig. 3

(TURN OVER

4 An input coupled split transmission system with a variable speed unit and an epicyclic gear is shown schematically in Fig. 4. The speed ratio of the variable speed unit is $V = \omega_2/\omega_1$ and its efficiency is η. There are no losses in the epicyclic gear. The speed equation for the epicyclic gear is

$$\omega_3 = \rho\omega_1 + (1-\rho)\omega_2$$

where ρ is the uncoupled speed ratio, defined as $\rho = \omega_3/\omega_1$ when $\omega_2 = 0$.

a) For a road vehicle application, state the potential benefits of a split transmission system over the use of a variable speed unit alone. [10%]

b) Derive an expression for the speed ratio V of the variable speed unit in terms of ρ, that gives zero output speed ω_3. [5%]

c) When power flow through the variable speed unit is left to right, show that the ratio of power P_V input to the variable speed unit to the total input power P_1 is given by

$$\frac{P_V}{P_1} = \frac{V\alpha}{\eta + V\alpha} \qquad \text{where } \alpha = \frac{1-\rho}{\rho}$$

[40%]

and derive an expression for the overall efficiency P_0/P_1. [15%]

d) If power is input at P_1, $\eta = 0.7$ and $\rho = -0.25$, find the range of overall speed ratio ω_3/ω_1 for which power flows from *right* to *left* through the variable speed unit (negative recirculation). [30%]

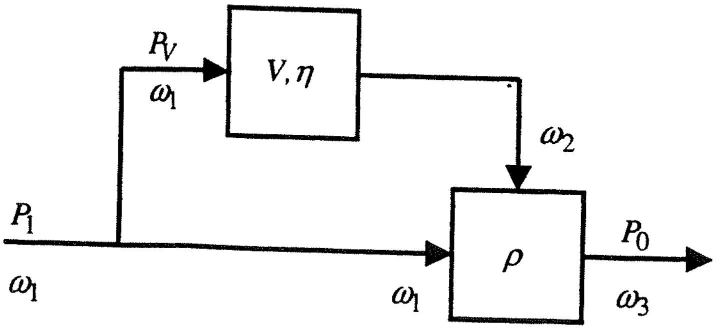

Fig. 4

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Engineering Tripos Part IIA 2003

Module 3C4

Machine Design – Transmissions

1. (a) $$\frac{\omega_o}{\omega_i} = \frac{1 + R_1 + R_2 - 0.2R_1R_2}{(1 + R_1)(1 + R_2)}$$

   (b) (i) 250 Nm
   (ii) 250 Nm
   (iii) 240 Nm

2. (b) (ii) $\frac{2}{3}\omega^2$

3. (b) (i) C=67 kN, bearing 6409, outer diameter 120 mm
   (ii) roller bearing at A, C=55.5 kN, bearing 209, outer diameter 85mm
   deep groove ball bearing at B, C=48.8 kN, bearing 6309, outer diameter 100 mm

4. (b) $$V = \frac{\omega_2}{\omega_1} = \frac{\rho}{\rho - 1}$$

   (c) $$\frac{P_0}{P_1} = \frac{\eta(V\alpha + 1)}{\eta + V\alpha}$$

   (d) $$0.107 > \frac{\omega_3}{\omega_1} > -0.25$$