The University of Nottingham

DEPARTMENT OF MECHANICAL, MATERIALS AND MANUFACTURING ENGINEERING

A LEVEL 2 MODULE 2044, SPRING 2021-2022

DESIGN, MANUFACTURE AND PROJECT

Time allowed **TWO hours**

SOLUTIONS

SECTION A

Q1: Machine elements 1

Bearings

(a) Answer: [3 marks]

Figure A1-1 shows a Stribeck Curve to define the three regimes of Boundary, Mixed film and Hydrodynamic lubrications.

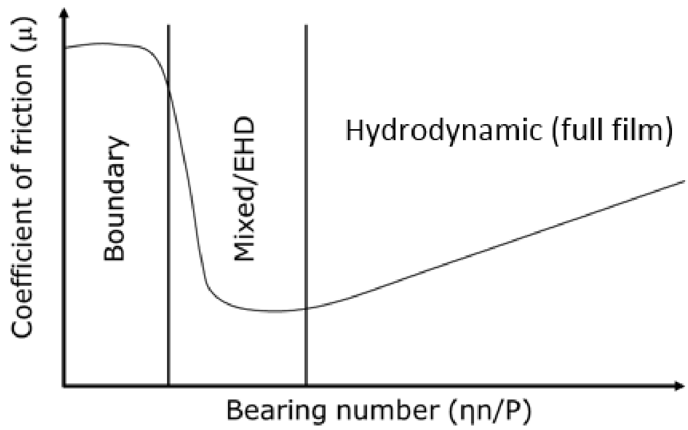

Figure A1-1

(b) Answer: [2 marks]

The limiting factor for *p* is the strength of the bearing material.

The limiting factor for *v* is the maximum operating temperature of the material.

(c) Answer:

(i) LHS are a pair of angular contact ball bearings [2 marks]

RHS is a cylindrical roller bearing

(ii) The axial force (F_{axial}) acted at the meshing points is taken by the pair of the angular contact ball bearings through the worm shaft shoulder to the casing of worm gear unit. [2 marks]

(iii) For both bearing types on the LHS and RHS of the worm shaft,

- An interference fit should be chosen between the inner ring and the worm shaft,
- A clearance fit may be chosen between the outer ring and the casing.

[2 marks]

(iv) For the RHS bearing (cylindrical roller bearing), the equivalent dynamic bearing load is

$$P = \frac{F_{radial}}{2} = \frac{2,500}{2} = 1,250\ (N)$$ [1 mark]

L_{10} bearing life is

$$L_{10} = \left(\frac{C}{P}\right)^q = \left(\frac{20{,}250}{1{,}250}\right)^{10/3} = 10{,}760 \times 10^6 (rev)$$ [2 marks]

Bearing life in hours at 96% is

$$L = \frac{a_1 a_2 a_3 L_{10}}{60n} = \frac{0.53 \times 1 \times 1 \times 1{,}0760 \times 10^6}{60 \times 1950} = 4.87 \times 10^4 (hours)$$ [1 mark]

(d) Answer:

The maximum bending moment of the worm shaft is

$$M = \frac{F_r L}{4} = \frac{2500 \times 0.2}{4} = 125 (Nm)$$ * [1 mark]

$$T = 9549 \frac{P(kW)}{n(rpm)} = 9549 \times \frac{25}{1{,}950} = 122.4 (Nm)$$ [1 mark]

The minimum diameter of the worm shaft is

$$d = \left[\frac{32 n_s}{\pi} \sqrt{\left(\frac{M}{\sigma_e}\right)^2 + \frac{3}{4}\left(\frac{T}{\sigma_y}\right)^2}\right]^{1/3}$$

$$= \left[\frac{32 \times 2}{3.1416} \sqrt{\left(\frac{125}{125 \times 10^6}\right)^2 + \frac{3}{4}\left(\frac{122.4}{500 \times 10^6}\right)^2}\right]^{1/3} = 0.0275 (m) = 27.5 (mm)$$

[2 marks]

Therefore, a worm shaft diameter of $d = 28 \; or \; 30 \; mm$ may be chosen in design.

[1 mark]

* *There was a typo in the bending moment formula for a simply supported beam, $M = \frac{F_r L}{2}$ instead of the correct one, $= \frac{FL}{4}$, in Shaft Design Lecture slides. No deduction of mark is made forusing the incorrect formula to calculate the bending moment ($M = \frac{FL}{2} = 250 \; Nm$) and the minimum shaft diameter (d=34.5 mm).*

2. Machine element 2

Gears

(a) Answer: [3 marks]

Any THREE of the following forms of gear failure:

- Bending fatigue
- Pitting
- Micro-pitting
- Scuffing
- Wear or plastic flow

(b) Answer:

(i) The two stage gearbox is a compound gear train. The overall gear ratio of the gearbox is

$$Z = \frac{n_{motor}}{n_{wheel}} = \frac{N_2}{N_1}\frac{N_4}{N_3} = \frac{31}{17} \times \frac{74}{17} = 7.94$$

[1 mark]

Therefore, the rotating speed of the driven wheels (gear 4) is

$$n_{wheel} = \frac{n_{motor}}{7.94} = \frac{6{,}500}{7.94} = 818.6\ (rpm)$$ [1 mark]

(ii) The pitch diameter of gear 1 is

$$d_1 = mN_1 = 3 \times 17 = 51(mm)$$

Therefore, the transmitted load of the 1st stage of gear pair (gears 1 and 2) is

$$W_T = \frac{60 \times 10^3 P}{\pi d_1 n_1} = \frac{60 \times 10^3 \times 90}{3.1416 \times 51 \times 6{,}500} = 5.19(kN)$$

[2 mark]

(iii) Using the Geometry factor chart, Y_J is found to be Y_J=0.29. [2 marks]

Using AGMA bending stress equation,

$$\sigma = W_T K_O K_V' K_S \frac{1}{Fm}\frac{K_H K_B}{Y_J}$$

$$\sigma = 5.19 \times 10^3 \times 1.5 \times 1.2 \times 1 \times \frac{1}{35\times3}\frac{1.1\times1}{0.29} = 337.5\ (MPa)$$ [2 marks]

As the given allowable bending strength of gear 1 is σ_{all}=290 MPa, the bending strength of gear 1 doesn't meet the design requirement.

(iv) Any two of the following answers:

1) Using the same grade steel (grade 1 through hardened steel), increase the Brinell hardness hence the allowable bending strength.

2) Choosing grade 2 nitrided through hardened steel would generally increase the Brinell hardness hence the allowable bending strength.

3) It is also possible to choose a larger module value (m) or face width (F) of the pinion and gear. However, this would increase the size of whole gearbox, which is less favourable in design but acceptable in answer. [2 marks]

Linkage mechanisms

(c) Answer:

Crank rocker is a four bar linkage, where the input link (the crank) is capable of full revolution of rotation and the output and the other links (the rockers) oscillate. [2 marks]

The crank rocker linkage satisfies Grashof condition, i.e. the sum of the shortest and longest links are less than the sum of the other two links. [1 mark]

A sketch of crank rocker linkage showing the shortest link as the crank as shown in Figure A2-1 is acceptable. [1 mark]

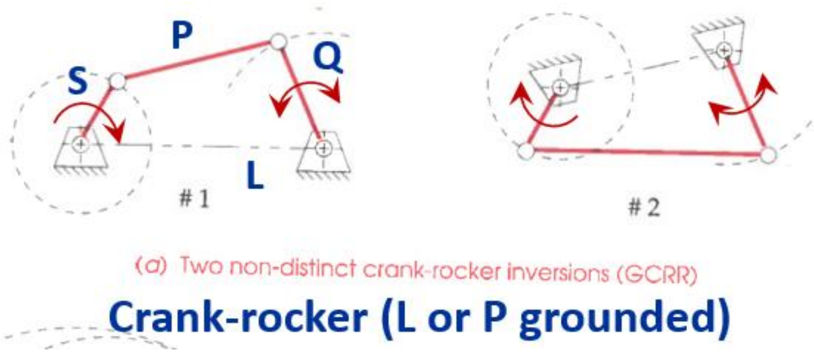

Figure A2-1

(d) Answer:

There are 4 links of the four bar linkages plus two links of the cylinder (D) and piston (F), i.e., L=6. There are 7 joints including the sliding joint of the piston (F) and cylinder (D) and the pivot joint C, i.e., J=7.

Use the Gruebler's equation, the number of DoF of the landing gear is

$$M=3\times(6-1)-2\times7=1$$ [3 marks]

3. General design methods

(a) Answer: [8 marks]

Four of the following objectives. With suitable examples

1) A home automation touch panel controller:

Perceptible Information – only visual feedback

Space & Size for Approach & Use – wall height requirement make it inaccessible to wheelchair users.

Equitable Use – potentially exclusionary as warranty assumes status as parent.

2) A rugged child's pushchair:

Low Physical Effort – heavier than comparable products

Equitable Use – gendered advertising

Tolerance for Error – prone to jam when not following fixed steps

3) A shower cubicle system for sale to sports facilities:

Flexibility in Use – fixed hardware, not adjustable to needs

Space and size for approach – outwards opening door could limit access

Perceptible Information – difficult to see controls

Simple and Intuitive Use – Unintuitive controls

[1 mark for identifying a inclusivity need in a produce with specific reference to the named objective. 1 mark for a reasonable adjustment to the product] Any reasonable example will be accepted, not just the ones listed above.

(b) Answer:

(i) 24 parts [1/2 mark] , 14 fasteners [1/2 mark]

(ii) 14 fasteners, each taking 10 seconds. 10 seconds to insert lens, 10 seconds to insert the pinion, and 40 seconds to adjust both of the top plates. Total time 200 seconds. [1 mark]

(iii) The fundamental components are [6 marks]

- a base (relative motion to slider/mount/rack),
- a combined slider/mount/rack (relative motion to slider/mount/rack)
- Pinion (relative motion to base and slider/mount/rack)
- Lens (essential difference in material)

Note that the requirement for a hardened rack and pinion has been removed from when this example has been used in the past.

2 marks for the correct number, 1 mark for each currently identified justification. Marks to be deducted for the inclusion of non-essential parts, or incorrect justification.

This solution assumes that the requirement for adjustment of wear in the ways can be made integral to the slider or the base. If the students have additional parts to accommodate wear, then the answer could acceptably be up to 6 marks.

(iv) 3 seconds x 4 parts = 12 seconds.

15/220 = 0.068

However if the calculation is consistent with the minimum number of parts they have identified above, they get the mark. [1 mark]

(v) Design should integrate the lens mount, vertical supports and slider, eliminating 8 fasteners. An excellent design should eliminate the top-plates by allowing some integral adjustment, removing a further 4 fasteners and 40 seconds of adjustment.

Total assembly time with top plates retained 4 fasteners, 10s lens, 10s pinion, 40s adjustment of top plates - total time 100 seconds.

Total assembly time with integrated top plates as little as total time 20 seconds, 10s lens, 10s pinion. [3 marks]

[Up to 3 marks available for clear descriptions of how they would combine elements of the design without breaking the essential requirements of the device. Marks to be awarded for the completeness and clarity of their solution, 1 mark for correctly identifying the new total assembly time of their concept]