The University of Nottingham

DEPARTMENT OF MECHANICAL, MATERIALS AND MANUFACTURING ENGINEERING

A LEVEL 2 MODULE, SPRING 2020-2021

DESIGN, MANUFACTURE AND PROJECT

Time allowed **TWO hours**

SOLUTIONS

Turn over

SECTION A

Q1: Machine elements 1

Bearings

(a) Answer: [6 marks]

i) A pair of deep groove ball bearings or tapered roller bearings can be used as they are good to take combined radial and axial load.

ii) Hydrodynamic bearings would be a suitable choice as hydrodynamic lubrication condition can be established easily to achieve low friction and wear at high speed operation.

iii) Plain journal (sliding) bearings would be a suitable option due to the low speed condition and low cost benefit. (Use of deep groove ball bearings is also acceptable)

[Note: 2 marks are allocated to each case with a possible varying mark given based on level of clarity and precision]

(b) Answer: [3 marks]

The use of a pair of angular contact ball bearings (back to back) is to take both the radial and axial load. The cylindrical roller bearing is used to take a large proportion of the radial load close to the pulley.

Both the angular contact ball and cylindrical roller bearings are located by using an endcap and a circlip for the outer rings. Shaft shoulders and spacer plates/bushes are used to locate the inner rings of the bearings.

(c) Answer:

i) Calculate the nominal pressure of the plain bearing [3 marks]

Note the bearing load for each bearing is F = 1800/2 = 900 N.

$$p_{nom} = \frac{F}{\emptyset D \times b} = \frac{900}{16 \times 20} = 2.813\ (MPa)$$

which is smaller than the allowable pressure, P_{max}= 5 MPa, so it is acceptable.

Calculate the PV value

$$V = \frac{2\pi n}{60} \times \frac{\emptyset D}{2} = \frac{2 \times 3.1416 \times 800}{60} \times \frac{20}{2} = 837.8\ (mm/s) = 0.84 (m/s)$$

$$PV = p_{nom} \times V = 2.813 \times 0.84 = 2.36 (MPa\ m/s)$$

which is larger than the 50% PV_{max}= 2.5 MPa m/s. Therefore, it is NOT acceptable.

ii) The maximum wear depth in operation is [3 marks]

$$y = y_{max} - Clearance = 0.2 - 0.02 = 0.18(mm)$$

The maximum allowable wear volume is

$$W_{max} = y \times b \times \emptyset D = 0.18 \times 16 \times 20 = 57.6\ (mm^3)$$

Therefore, the predicted operating life may be calculated as

$$t = \frac{W_{max}}{KFV} = \frac{57.6 \times 10^{-9}}{0.01 \times 10^{-15} \times 900 \times 0.84} = 7.62 \times 10^6 (s) = 2{,}116\ (hours)$$

Brakes and clutches

(d) Answer:

i) Design #2 would be the correct choice. This is because both shoes are leading shoes, which are self-energising and therefore can generate the maximum possible braking torque. [2 marks]

ii) Figure A3-1 shows the free body diagram of the normal and friction forces as well as their moments to the pivots on both shoes. [3 marks]

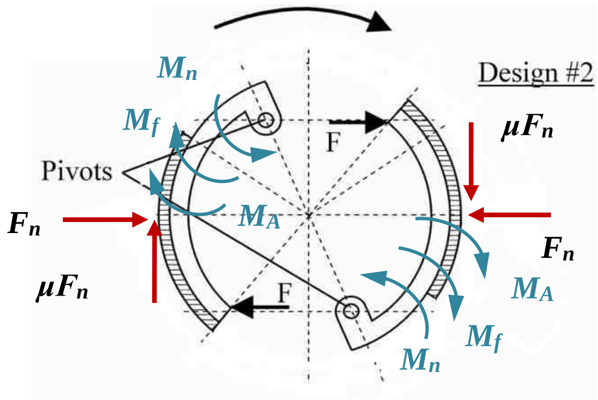

Figure A3-1

2. Machine element 2

Bolted joints

(a) Answer:

i) To use necked bolts and to increase the length of the bolts are two feasible options to achieve a 'hard' joint in the engine assembly. [2 marks]

ii) According to BS 3692, the tensile strength and the yield strength of the 9.8 M6x1.0 bolts are

$$\sigma_{UTS} = 9 \times 100 = 900\ (MPa)$$

$$\sigma_Y = 0.8\sigma_{UTS} = 0.8 \times 900 = 720(MPa)$$

The proof strength is

$$\sigma_P = 0.85\sigma_Y = 0.85 \times 720 = 612\ (MPa)$$

As this is a case of a permanent joint, the required pre-tension force is

$$F_i = 0.9A_s\sigma_P = 0.9 \times 20.1 \times 612 = 11{,}071\ (N)$$

Using the tightening torque equation, the tightening torque should be

$$T = KF_id = 0.2 \times 11{,}071 \times 6 \times 10^{-3} = 13.3(Nm)$$ [3 marks]

It is acceptable to use the proof load F_P ($A_s\sigma_P$) = 13,100 N from Table 5 (BS EN ISO 898 1: 2009) in Lecture Slides to calculate the required pre-tension force,

$$F_i = 0.9A_s\sigma_P = 0.9 \times 13{,}100 = 11{,}790\ (N)$$

Therefore, in using the proof load F_P =13,100 N, the tightening torque would give a slightly different value,

$$T = KF_id = 0.2 \times 11{,}790 \times 6 \times 10^{-3} = 14.15(Nm)$$

(b) Answer:

i) From the schematic diagram, there are 5 links plus the ground link (also considered as a link), i.e., L=6. There are 7 joints including the sliding joint of the piston and cylinder D and the pivot joint E, i.e., J=7.

Use the Gruebler's equation, the number of DoF of the landing gear can be calculated as

M=3×(6-1)-2×7=1 [3 marks]

ii) The sum of the lengths of the shortest and longest links

$$S + L = O_1O_2 + O_1A = 650 + 275 = 925\ (mm)$$

The sum of the lengths of the remaining two links

$$P + Q = AB + O_2B = 500 + 450 = 950\ (mm)$$

Based on Grashof condition,

$$S + L < P + Q$$

Therefore, it is a Grashof linkage. As the longest link O1O2 is grounded, it is a crank-rocker mechanism. [3 marks]

(c) Answer:

i) A key functional requirement for the wind turbine gearbox is to increase the speed of the rotor (by 50~100 times) so the generator can rotate at a higher speed to generate electricity. [2 marks]

ii) Gear ratio of the planetary gear stage

Using the gear ratio equation of the planetary gear train

$$Z = \frac{\omega_F - \omega_A}{\omega_L - \omega_A} = \pm \frac{product\ of\ number\ of\ teeth\ on\ wheels}{product\ of\ number\ of\ teeth\ on\ pinions}$$

and assume the Ring (3) is the first (input) gear so the Sun (1) is the last gear (output) of the low speed stage.

(Note: If the Sun (1) is assumed the first gear and the Ring (3) the last gear, the inverse of the gear ratio equation is true.)

$$Z_{planetary} = \frac{\omega_3 - \omega_{Arm}}{\omega_1 - \omega_{Arm}} = -\frac{N_2}{N_3} \times \frac{N_1}{N_2} = -\frac{N_1}{N_3}$$

Note the "-" sign indicates that the direction of rotation of the Sun (1) should be opposite to the Ring (3) if it is not fixed. As the Ring (3) is fixed, ω_3=0, rearranging the above equation gives

$$Z_{planetary} = \frac{\omega_A}{\omega_1} = \frac{1}{\frac{N_3}{N_1}+1} = \frac{1}{\frac{99}{21}+1} = \frac{1}{5.714}$$ [3 marks]

Gear ratio of intermediate speed stage

$$Z_{interm-speed} = \frac{\omega_4}{\omega_5} = \frac{N_5}{N_4} = \frac{23}{82} = \frac{1}{3.565}$$ [1 mark]

Gear ratio of the high speed stage

$$Z_{high-speed} = \frac{\omega_6}{\omega_7} = \frac{N_7}{N_6} = \frac{22}{88} = \frac{1}{4}$$ [1 mark]

iii) The total gear ratio of the gearbox is

$$Z_{total} = \frac{\omega_{Arm}}{\omega_7} = Z_{planetary} \times Z_{interm-speed} \times Z_{high-speed}$$
$$= \frac{1}{5.714} \times \frac{1}{3.565} \times \frac{1}{4} = \frac{1}{81.5}$$

Therefore, the speed of the high speed shaft (Pinion 7) is

$$\omega_7 = \frac{\omega_{Arm}}{Z_{total}} = \frac{20}{1/_{81.5}} = 1630\ (rpm)$$ [2 marks]

3. General Design Methods

(a) Answer:

Provide any logical examples based on these products. Answers should include a correct R being considered, a rationale argument for an area of poor sustainability in the original product, a reasonable modification to make and a clear indication of how the change addresses a sustainability domain.

Possible answers might include;

Rethink: [up to 2 marks]

- Suggest a change in design to facilitate a shared ownership scheme for the personal electric bike.
- Connect the low cost laptop to a cloud based service that performs the more difficult computing.

Reduce: [up to 2 marks]

- Move production of any of these products closer to the market to reduce energy expenditure on transport, for example of the electric scooter which is sold exclusively in the UK.
- Change the design of the coffee jar so as to reduce the material used or the energy used in shipping.

Replace: [up to 2 marks]

- Eliminate chrome plating from the lamp design to avoid the use of hexavalent chrome.
- Replace the non-bio-degradable material of the coffee can with one that is biodegradable.

Recycle: [up to 2 marks]

- Redesign the laptop for easier disassembly to ease separation of valuable metals for recycling. Also applies to the front-loading dishwasher or kettle.
- Identify that the coffee jar materials are recyclable and make sure that it is clearly labelled as such.

Reuse: [up to 2 marks]

- Adapt laptop design to allow for upgrades and extended usage.
- Introduce a buy back scheme for the laptop or electric bike and then introduce them to new customers in new markets.

Repair: [up to 2 marks]

- Adapt the washing machine to make it easy to replace the control screen when it fails.

(This list is not intended to be exclusive. So long as the answer is logical it should be awarded up to 2 marks.)

[Total up to 12 marks]

(b) Answer:

Provide FOUR of the following objectives with any logical examples based on these products. Answers should include a clear statement of the principle/objective, a rationale argument for an area of poor inclusivity in the original product, a reasonable modification to make and a clear indication of how the change addresses inclusivity.

FOUR of the following objectives. [up to 2 marks each, total of 8 marks]

- Equitable Use
    - Remove the marketing of the electric bike towards the younger audiences, as this may exclude or stigmatize users.
- Flexibility in Use
    - Make the positions of the electric bikes controls adjustable.
- Simple and Intuitive Use
    - simplify the washing machine controller.
- Perceptible Information
    - replace washing machine control panel with dedicated buttons or add sound indications for visually impaired users.
- Tolerance for Error
    - Add a visual indicator to the lamp switch so that the user need not risk electrocution when replacing a bulb.
- Low Physical Effort
    - Reposition the switch on the kettle to make it easier to access, or reduce the weight of the lamp to make it easier to handle.
- Space & Size for Approach & Use
    - Sell the washing machine with a riser kit to increase the height of the door improving access for those with limited range of motion.

(This list is not intended to be exclusive. So long as the answer is logical it should be awarded up to 2 marks.)

[Total marks for Question 3 is 20]

END