The University of Nottingham

DEPARTMENT OF MECHANICAL, MATERIALS AND MANUFACTURING ENGINEERING

A LEVEL 2 MODULE, RESIT/SUMMER 2019-2020

DESIGN, MANUFACTURE AND PROJECT

Time allowed **ONE hour and 30 minutes**

SOLUTIONS

SECTION A

Q1: Bearings

(a) Answer: [4 marks]

1 mark is given to the selection of correct bearing type and a couple of reasonable advantage and disadvantage features.

i) Hydrodynamic bearing

Advantages:	High load capacity Operation at high speed Long service life
Disadvantages:	Needs of complex oil system High cost

ii) Ball or roller bearing

Advantages:	High load capacity Able to withstand frequent stops and starts Cheap and easy to replace
Disadvantages:	Modest life

iii) Plain journal bearing

Advantages:	Low cost Dry lubrication Suitable to operate at modest to low loads and speeds
Disadvantages:	inevitable wear

iv) Tapered roller or angular contact ball bearing

Advantages:	Low cost Large load capability in radial and in axial (from one side) directions Suitable for bevel gear arrangement of a differential unit
Disadvantages:	Care is needed for adjustment of the tapered roller bearing in assembly of the whole unit

(b) Answer:

i) Calculate the equivalent dynamic load [3 marks]

$$F_{eq} = \left(\frac{{F_1}^q U_1 + {F_2}^q U_2 + {F_3}^q U_3 + \cdots}{U_1 + U_2 + U_3 + \cdots} \right)^{1/q}$$

$$= \left(\frac{1000^{10/3} \times 0.4 + 2000^{10/3} \times 0.3 + 5000^{10/3} \times 0.2 + 9500^{10/3} \times 0.1}{0.4 + 0.3 + 0.2 + 0.1} \right)^{3/10}$$

$$= 5096.2\ (N)$$

Determine the required bearing life in 10^6 cycles [1 mark]

$$L_{10} = 1750 \times 4500 \times 60 = 472.5 \times 10^6\ (revolutions)$$

Using bearing life equation, the Dynamic Load Rating is

$$C = \left(\frac{L_{10}}{10^6}\right)^{1/n} F_{eq} = \left(\frac{472.5 \times 10^6}{10^6}\right)^{3/10} \times 5096.2 = 32{,}326.8\ (N)$$ [1 mark]

ii) By searching in the section of roller bearings on SKF website (https://www.skf.com/group/products/rolling-bearings/roller-bearings/cylindrical-roller-bearings/single-row-cylindrical-roller-bearings#cid-464726), NU 2204 ECP is obviously the most suitable cylindrical roller bearing. [2 marks]

The reasons for this choice are as follows

1) The NU2204 cylindrical roller bearing has a dynamic load rating of C=34.5 kN, which is larger than the calculated value of C= 32.3 kN and has the smallest possible outer ring diameter D=47 mm. A similar cylindrical roller bearing is also acceptable.
2) The chosen bearing is NU type as required from the briefing. [2 marks]

(c) Answer:

i) Each ball bearing takes half of the total radial load, i.e. 0.5XFr =1000 N. [1 mark]

As the Left bearing is fully constrained for axial location, it takes all the amount of the axial load, Fa =500 N. [1 mark]

ii) The axial load from the shaft is first taken by the Lock Nut, then the Left side deep groove ball bearing (inner ring, rolling balls and outer ring), the Inside end cap on the Left side and finally to the Housing by the bolted joints. [2 marks]

iii) The thermal expansion is accommodated by the gap or clearance of the Right bearing in the Housing. [1 mark]

iv) Use an interference fit for the inner ring on the Shaft and push or clearance fit for the outer race in the Housing. This push fit also allows any thermal expansion. [2 marks]

Q2: Gears

(a) Answers: [2 marks]

Advantages (any 3 of the following are acceptable)

- Progressive and longer contact between two teeth
- Less noisy
- Carries higher loads
- Can be mounted at various angles if cut at appropriate angle

Disadvantages (Any 1 of the following is acceptable)

- Generation of axial force due to the helical angle
- More expensive for manufacturing

(b) Answers: [3 marks]

The first two are expected answers of this question. Answer iii) is also acceptable.

i) Bending fatigue is caused by bending stress at tooth root under cyclic loading conditions. Sufficient bending strength reduces the possibility of bending fatigue failure by choosing suitable Module (m) value and through hardened materials.

ii) Pitting or micropitting surface failure is due to cyclic contact stress. Sufficient contact strength reduces the possibility of failure by limiting contact stress level and using suitable surface hardening or nitriding heat treatment.

iii) Scuffing is another form of failure causing adhesive wear on gear surface often occurring in high speed gearbox due to temperature rises. Separate standard can be used to design against this type of failure assisted by sufficient lubrication and cooling measures.

(c) Answers: [3 marks]

Using the centre distance equation $C = \frac{1}{2}m(N_1 + N_2)$, the number of teeth of the gear N_2 may be calculated as

$$105 = {}^{1}/_{2} \times 3 \times (30 + N_2)$$

$$N_2 = \frac{105}{1.5} - 30 = 40$$

Using gear ratio equation, $Z = \frac{\omega_1}{\omega_2} = \frac{N_2}{N_1}$, the rotating speed of the input gear ω_1 may be calculated as

$$\omega_1 = \frac{40}{30} \times 480 = 640\ (rpm)$$

(d) Answers:

i) Using the general gear ratio equation for planetary gear train, [4 marks]

$$\frac{\omega_1 - \omega_{Arm}}{\omega_5 - \omega_{Arm}} = -\frac{N_3 N_5}{N_1 N_4}$$

It is noted that Gear 2 is an idler gear so it doesn't contribute to the overall gear ratio. The " – " sign shows that the direction of rotation of Gear 5 should be opposite to that of Gear 1 if the Arm is fixed.

As Gear 1 is fixed without rotation, i.e. $\omega_1 = 0$,

$$\frac{0 - \omega_{Arm}}{\omega_5 - \omega_{Arm}} = -\frac{18 \times 48}{18 \times 24}$$

Rearranging the above equation gives $\frac{\omega_5}{\omega_{Arm}} = \frac{3}{2}$

Therefore, $\omega_{Arm} = \frac{2}{3}\omega_5 = \frac{2}{3} \times 150 = 100\ (rpm)$ and the Arm should rotate in the same direction as Gear 1 (i.e. in clockwise direction).

ii) As Gears 4 and 5 have the number of teeth, i.e. $N_4 = N_5 = 36$, the gear ratio equation becomes [2 marks]

$$\frac{\omega_1 - \omega_{Arm}}{\omega_5 - \omega_{Arm}} = -\frac{N_3 N_5}{N_1 N_4} = -\frac{18 \times 36}{18 \times 36} = -1$$

Thus, $\omega_1 + \omega_5 = 2\omega_{Arm}$

The above equation is identical to the basic equation of a differential unit using bevel gears. Therefore, this planetary gear train is able to provide the same kinematic function as the conventional differential unit.

(e) Answers:

i) From Table Q2-1, the reliability factor should be $Y_Z = 1.25$. Using the AGMA allowable contact stress equation, the minimum allowable contact stress at the test condition [4 marks]

$$\sigma_{HP} = \sigma_{C,all} S_H \frac{Y_\theta Y_Z}{Z_N Z_W}$$

$$= 450 \times 1.5 \times \frac{1 \times 1.25}{1 \times 1} = 843.75\ (MPa)$$

Using the grade 2 steel gear, $\sigma_{HP} = 2.41 H_B + 237\ (MPa)$

The minimum Brinell hardness may be calculated by using the given equation

$$H_{B,min} = \frac{\sigma_{HP} - 237}{2.41} = \frac{843.75\ - 237}{2.41} = 251.8$$

ii) The life factor Z_N is used to account for the effect other than 10^7 cycles. So Z_N =1 may be used if the designed life is 10^7 cycles. [2 marks]

SECTION B

Q3: General Design Methods

(a) Design for sustainability

i) With reference to the scenario above, identify one positive impact and one negative impact for each of the three domains of sustainability; Social, Economic, and Environmental. [6 marks]

Some possible examples;

- Positive Social: If the company is successful they will grow in size and increase employment in the local area.
- Negative Social: current skilled work force may no longer be required and lose their jobs. Reducing social mobility in the area.
- Positive Environmental: If the company that produces environmentally sustainable products gains market share, the total environmental impact will likely be reduced.
- Negative Environmental: Upfront environmental impact may not be offset if the company is unsuccessful and fails before it is able to recoup the benefits of the investment.
- Positive Economic: If the company is successful they will grow and increase their market share.
- Negative Economic: Upfront financial cost represents a real risk to the success of the company.

[1 mark for any complete and reasonable answer for each condition]

ii) Emissions saving per unit produced = 37 – 24.5 = 12.5

Emissions released in investment 17,300

GHG ROI ≥ 1 the number of units produced = 17,300/12.5 = 1384 units.

[2 marks]

iii) Required net reduction = 250,000 Kg of CO2 eq.

Required reduction = 250,000 + 17,300 = 267,300 Kg of CO2 eq.

Period to achieve reduction is 3 years, so required reduction per year is 267,300/3 = 89100 Kg of CO2 eq. per year

At a saving of 12.5 Kg of CO2 eq. per unit, that makes the number of units the company would have to produce per year = 89100/12.5 = 7128 units.

[2 marks]

iv) Calculate total saving, 120,000 units * 12.5 Kg of CO2 eq. per unit
= 1,500,000 Kg of CO2 eq. saved

Cost efficiency = total saved / total cost =1500000 / 300000
= 5 Kg of CO2 eq. per £GBP invested [1 mark]

(b) Design for Assembly (DfA)

i) The following gives a list of components, which are theoretically essential to this product. For each component that you consider essential you should clearly identify the criteria or product requirement that makes it essential. [8 marks]

- Push-fit connector (stated as an essential separate part)
- Exhaust connector (stated as an essential separate part)
- Combined cylinder body and one cylinder cap (functional requirement to contain air pressure)
- Single piece piston and rod (requires motion relative to cylinder)
- Spring (requires relative motion and has fundamental requirement to be made of a different material)
- Piston "O"-ring (requires relative motion when it is replaced during maintenance and has fundamental requirement to be made of a different material)
- Second cylinder cap (required for assembly and disassembly)

[1 mark each for all of the above]

[1 bonus mark for either identifying that the combined bearing and seal assembly in the front cylinder cap should be considered essential as it has fundamental material properties, or 1 mark for suggesting that it could be incorporated into the front cylinder cap if the material of the cap were to be changed]

ii) The design efficiency based on the assembly time of the current design and the theoretical essential part number can be calculated as [1 mark]

$$Design\ efficiency = \frac{3\ seconds \times 7\ or\ 8\ (see\ above)}{140}$$

$$Design\ efficiency = 15\%\ or\ 17.2\%$$

END