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 AS PER SUBMISSION DEADLINE PUBLISHED ON MOODLE

Open-book take-home examination

Answer ALL questions

You must submit a single pdf document, produced in accordance with the guidelines provided on take-home examinations, that contains all of the work that you wish to have marked for this open-book examination. Your submission file should be named in the format '[Student ID]_MMME2044.pdf'*.*

Write your student ID number at the top of each page of your answers.

This work must be carried out and submitted as described on the Moodle page for this module. All work should have been submitted via Moodle by the due date.
Work submitted after the deadline will be subject to penalty.

No teaching enquiries will be answered by staff during the assessment period Monday 24th August to Tuesday 08th September 2020 and no questions should be raised by students. If you believe there is a misprint note it in your submission but answer the question as written. Contact SS-Programmes-UPE@exmail.nottingham.ac.uk *for any support.*

Plagiarism, false authorship and collusion are serious academic offences *as defined in the University's Academic Misconduct Policy and will be dealt with in accordance with the University's Academic Misconduct Procedures. The work submitted by students must be their own and you must declare that you understand the meaning of academic misconduct and have not engaged in it during the production of your work.*

ADDITIONAL MATERIAL: None

SECTION A

1. Bearings

(a) There are different types of bearings commonly used to support shafts. Explain which type of bearing you would choose for the following applications and briefly state the advantages and disadvantages of the chosen bearing in each case?

i) Power station turbo generator main shaft bearing
ii) Railway carriage wheel bearing
iii) Household lawnmower wheel bearing
iv) Rear differential unit of a 4x4 pickup truck

[4]

(b) A cylindrical roller bearing is subjected to a fluctuating load in operation:

F_1 = 1000 N for 40% of the time
F_2 = 2000 N for 30% of the time
F_3 = 5000 N for 20% of the time
F_4 = 9500 N for 10% of the time

The roller bearing rotates at a constant speed of 1750 rpm and is required to have a L_{10} life of 4500 hours.

i) Calculate the basic dynamic load rating that meets the required bearing life. [5]

ii) Choose a suitable cylindrical roller bearing with two integral flanges on the outer ring and no flanges on the inner ring (NU type) from SKF website (https://www.skf.com/group/products/rolling-bearings) and give a brief justification. [4]

You may find the following equations useful

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

$$L_{10} = \left(\frac{C}{F_{eq}} \right)^q$$

where, F_{eq} = Equivalent dynamic load (N)
U_i = Percentage operational time at load F_i
F_i = Load at percentage time U_i (N)
q = Exponent of bearing life equation for cylindrical roller bearing
L_{10} = Bearing life in 10^6 revolutions
C = Basic dynamic load rating (N)

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(c) Figure Q1-1 shows a rotating shaft supported by a pair of deep groove ball bearings to take a radial load (Fr=2000 N) at the centre of the bearing span and an axial load (Fa =500 N) to the right. The direction of the radial load is stationary to the housing. There are considerable temperature changes in operation.

Answer briefly the following questions:

i) Determine the amount of the radial load (Fr) and the axial load (Fa) taken by each of the pair of ball bearings. [2]

ii) Explain how the axial load (load path from one component to another) is taken from the Shaft to the Housing. [2]

iii) Explain the method used to accommodate the thermal expansion. [1]

iv) Select a suitable fit for both the inner ring of the bearing on the Shaft and the outer ring in the Housing. [2]

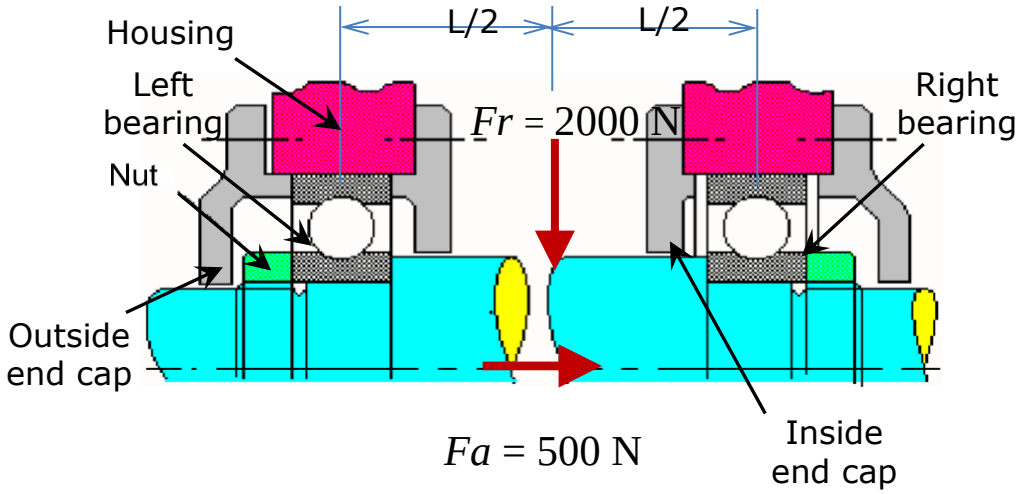

Figure Q1-1

2. Gears

(a) State briefly the main advantages and disadvantages of a helical gear transmission. [2]

(b) Explain briefly what the common forms and the causes of failure in a gear system are and how to prevent these gear failures by design. [3]

(c) A shaft carries a 30-tooth spur gear, i.e. N_1= 30, with a module of m=3 (mm). It drives another spur gear N_2, which rotates at a speed of ω_2= 480 rpm. The centre distance between the two gears is 105 mm. Determine the speed of the input gear, ω_1. [3]

(d) Figure Q2-1 shows a planetary gear train of Lego parts. Gear 1 is mounted on the input shaft, which is fixed without rotation, i.e. ω_1= 0 rpm. Gear 5 is mounted on the output shaft.

i) If the output gear or shaft rotates clockwise at a speed of ω_5= 150 rpm, determine the speed and direction of rotation of the Arm. The numbers of teeth of gears are N_1=N_2=N_3=18, N_4=24 and N_5=48. [4]

ii) If Gears 4 and 5 are replaced with two gears of same number of teeth, e.g. N_4=N_5=36, derive the gear ratio equation of this gear train and explain in which way it is similar to a conventional differential unit. [2]

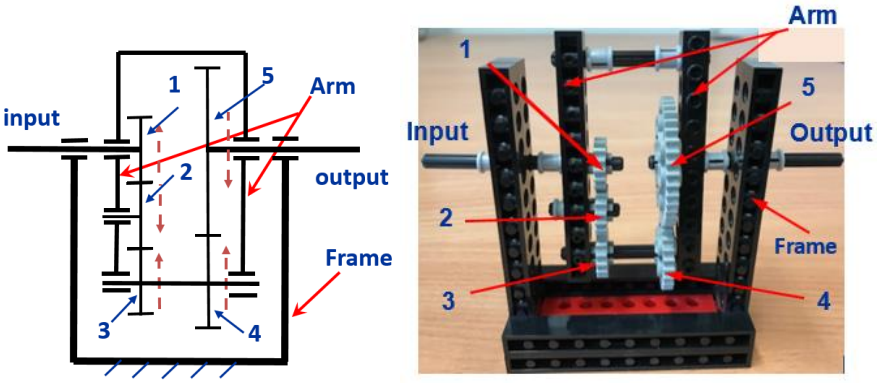

Figure Q2-1

Hints: The dashed arrow lines in the schematic drawing show the direction of rotation of the gears when the Arm is fixed.
You may consider Gear 1 as the first or input gear and Gear 5 as the last or output gear.

You may use the following general gear ratio equation of a planetary gear train in your calculation:

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

where, ω_F = Speed of the first (input) gear
ω_L = Speed of the last (output) gear
ω_A = Speed of the arm or planet carrier

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(e) A parallel spur gear set is used at the high speed section of an offshore wind turbine. Grade 2 through hardened steel is chosen for both gears. Based on AGMA design code, the calculated contact stress of the gear set is σ_C= 450 MPa. To prevent mircopitting surface failure (due to cyclic contact stress), a reserve (or safety) factor, S_H=1.5 is used for a required reliability of 99.9%.

i) Determine the minimum Brinell Hardness (H_B) needed to ensure sufficient contact strength of the gear set. [4]

ii) Explain briefly under what condition that a unit value may be used for the life factor, i.e. Z_N =1. [2]

You may use the following AGMA equations and reliability table (Table Q2-1) in your calculation:

AGMA allowable contact stress:

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

Where, $\sigma_{C,all}$ = Allowable contact stress (MPa)

σ_{HP} = Allowable contact stress tested at 10^7 cycles and 99% reliability (MPa)
S_H = AGMA reserve or safety factor
Y_Z = Reliability factor
Y_θ = temperature factor
Z_N = life factor (stress-cycle factor)
Z_W = hardness ratio factor

You may use the following values for other factors in calculation, Z_N= 1, Z_W= 1 and Y_θ= 1.

Reliability	Y_Z
0.90	0.85
0.99	1.00
0.999	1.25

Table Q2-1: Reliability factor Y_Z

SECTION B

3. General design methods

(a) **Design for sustainability**

You work for a recently founded UK based company in a very competitive sector. Other small companies in this sector often fail within 5 years, but your company has the market advantage of being the first to offer an environmentally sustainable alternative product. So far the capital investment in the company is low, and most of your products are made by a team of skilled manual workers. Your managing director is looking to invest in equipment that would mechanise your manufacturing processes, dramatically increasing the rate of production but also reducing both the financial cost and the greenhouse gas (GHG) emissions for each unit produced. Your chief financial officer is concerned that the capital outlay required to purchase the equipment may put your company at risk of bankruptcy. There is a Government scheme which promises to cover 50% of the cost of investment if your company can demonstrate a net reduction of 250,000 Kg of CO_2 eq. in GHG emissions over the first 3 years from installation. The equipment your company requires is only made by one supplier in Brazil and would need to be transported to your UK site. Between the GHG emissions of making, transporting and installing the equipment, it may not be an environmentally sustainable option, and depending on your rate of production it may not meet the requirements for the Government scheme.

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

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ii) To determine the Environmental sustainability of the new equipment, you have been asked to conduct a Life Cycle Assessment of your company's options using the data in Table Q4-1 and Equations Q4.1 and Q4.2

	[Kg of CO_2 eq.]
GHG emitted per unit produced by current methods	37
GHG emitted per unit produced by new equipment	24.5
GHG emitted making, transporting and installing the new equipment	17,300

Table Q4-1 Green-house gas (GHG) emissions

Calculate the number of units that are required to be produced to achieve a GHG emissions Return on Investment (GHG ROI) ≥1. [2]

$$GHG\ ROI = \frac{GHG\ emissions\ saved}{GHG\ released\ to\ change\ practices}$$

Eq. (Q4.1)

iii) Calculate the number of units that your company would have to produce per year to meet the requirements of the Government scheme. [2]

iv) Assuming your company is able to receive support from the Government, the final cost of the new equipment to your company would be £300,000. If the new equipment produces 120,000 units in its working life, what is the cost effectiveness of this environmental benefit? [1]

$$Cost\ effectiveness = \frac{GHG\ emissions\ saved\ [Kg\ \text{of CO2 eq.}]}{financial\ investment\ [£GBP]}$$

Eq. (Q4.2)

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(b) **Design for Assembly (DfA)**

You have been asked to evaluate ways to redesign a low cost, low duty, single-acting pneumatic actuator for a reduced assembly time, see Figure Q4-1. The current assembly process takes 140 seconds. The pneumatic actuator must retain the push-fit connector and exhaust port as individual components as they are safety critical components provided by an external supplier, and the piston "O"-ring must remain accessible for regular replacement due to wear.

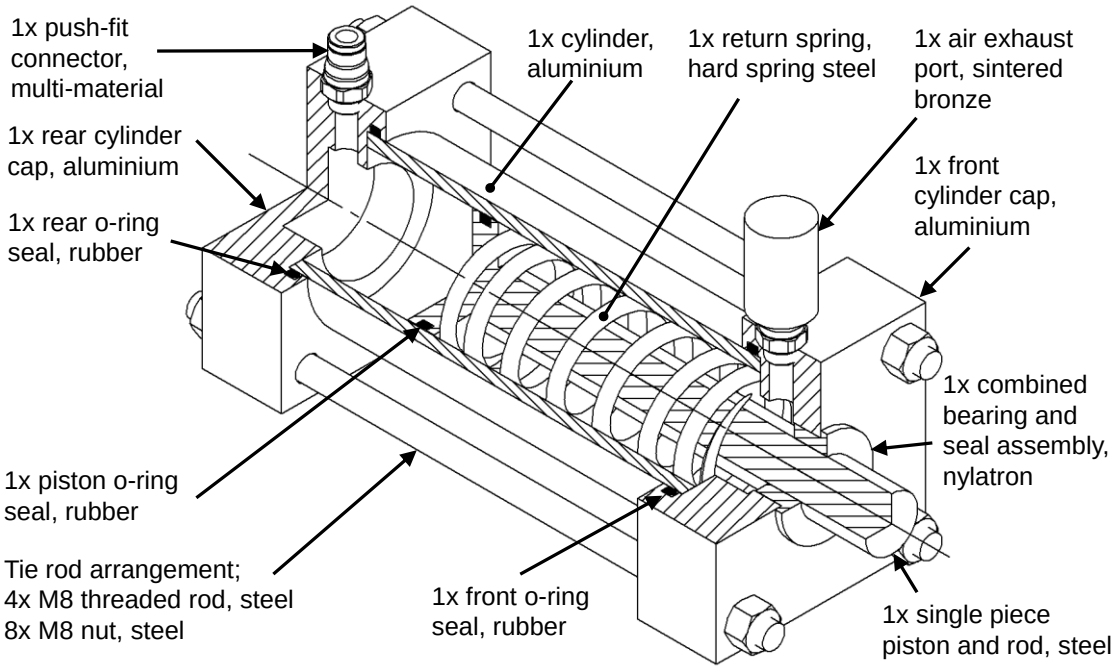

Figure Q4.1 Illustration of pneumatic cylinder assembly

i) Identify which components, or combination of components, 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]

ii) Calculate the design efficiency based on the assembly time of the current design and the theoretical essential part number. [1]

$$Design\ efficiency = \frac{3\ seconds \times the\ minimum\ number\ of\ parts}{total\ assembley\ time\ in\ seconds}$$