The University of Nottingham

DEPARTMENT OF MECHANICAL, MATERIALS AND MANUFACTURING ENGINEERING

A LEVEL 2 MODULE, SPRING SEMESTER 2021-2022

DESIGN, MANUFACTURE AND PROJECT

Time allowed TWO hours

Candidates may complete the front cover of their answer book and sign their desk card but must NOT write anything else until the start of the examination period is announced

Answer ALL questions

Only a calculator from approved list A may be used in this examination.

Basic Models	***Scientific Calculators***
Aurora HC133 Casio HS-5D Deli – DL1654 Sharp EL-233	Aurora AX-582 Casio FX82 family Casio FX83 family Casio FX85 family Casio FX350 family Casio FX570 family Casio FX 991 family Sharp EL-531 family Texas Instruments TI-30 family Texas BA II+ family

Dictionaries are not allowed with one exception. Those whose first language is not English may use a standard translation dictionary to translate between that language and English provided that neither language is the subject of this examination. Subject specific translation dictionaries are not permitted.

No electronic devices capable of storing and retrieving text, including electronic dictionaries, may be used.

DO NOT turn examination paper over until instructed to do so

ADDITIONAL MATERIAL: Additional material A1 – Geometry factor Y_J chart for gear bending stress calculation

INFORMATION FOR INVIGILATORS:

Question papers should be collected in at the end of the exam – do not allow candidates to take copies from the exam room.

Turn Over

SECTION A

1. Machine element 1

Bearings

(a) Sketch a Stribeck Curve and name the three lubrication regimes. [3]

(b) *pv* factor is often used in designing a rubbing (sliding) bearing. Briefly state what the limiting factors for *p* (the nominal bearing pressure) and for *v* (the relative sliding speed) are. [2]

(c) Figure Q1-1 shows the GA drawing of a worm gear unit. The radial (F_{radial}) and axial (F_{axial}) forces acted at the meshing points between the worm and gear are indicated in the drawing.

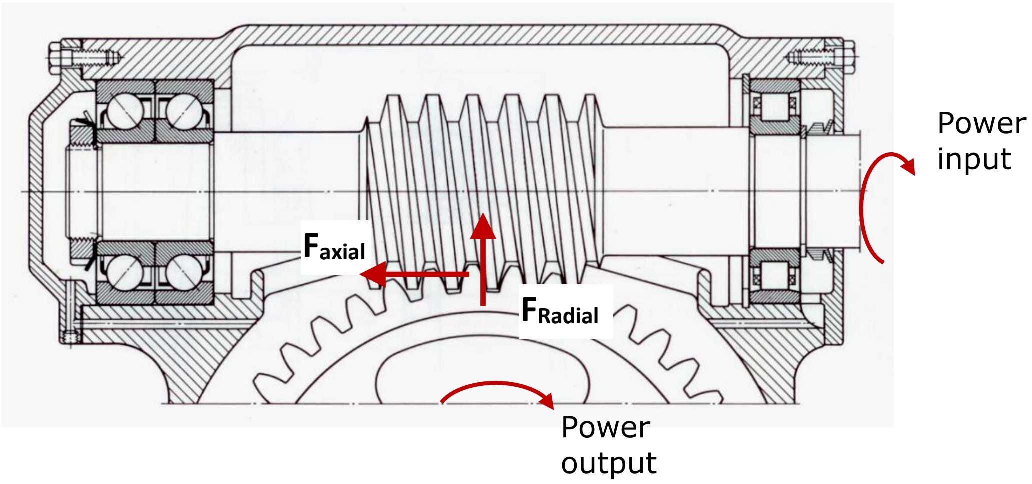

Figure Q1-1

i) Identify the types of the rolling element bearings used to support the worm shaft at both ends. [2]

ii) Briefly explain how the axial force (F_{axial}) is taken from the mesh point of the worm and gear to the casing of the unit. [2]

iii) For proper function of both types of the worm shaft bearings, what fits (clearance, transition or interference fit) would you choose between the inner ring and the worm shaft, the outer ring and the casing? [2]

iv) The rotating speed of the worm shaft is n = 1,950 rpm. The radial force, acted at the middle of the worm shaft span, is F_{radial} = 2,500 N. The chosen bearing on the right hand side has a basic dynamic load rating, C = 20,250 N. Calculate the bearing life at 96% reliability in hours. [4]

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You may find the following equations and table useful:

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

$$L = a_1 a_2 a_3 L_{10}$$

where, q = 3 for ball bearings, 10/3 for roller bearings
L_{10} = basic bearing life in 10^6 revolutions at 90% of reliability
L = adjusted bearing life in 10^6 revolutions
C = basic dynamic load rating (N)
P = equivalent dynamic bearing load (N)
a1 = reliability factor, a1=0.53 at 96% reliability
a2 = material factor (=1.0)
a3 = operating condition factor (=1.0)

Shafts

(d) As shown in Figure Q1-1, the power input of the worm gear unit is P = 25 kW with worm shaft rotating at n=1,950 rpm. The radial force is F_{radial} = 2,500 N at the middle of the worm shaft span. The span of the worm shaft is L=200 mm.

Use ASME design code to calculate the minimum worm shaft diameter and choose a suitable value in design.

The yield strength and endurance limit of the chosen material for the worm shaft is σ_y= 500 MPa and σ_e =125 MPa, respectively. The design requires a reserve factor of n_s = 2.

You may find the following equations useful:
ASME Design code for shaft diameter

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

$$T = 9549\frac{P(kW)}{n(rpm)}(Nm)$$

where, M = bending moment (Nm)
T = torque (Nm)

Hint: You need to be careful about the unit you use in calculation, e.g. (1 MPa = 10^6 Pa). [5]

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2. Machine element 2

Gears

(a) Name THREE common forms of gear failure. [3]

(b) Figure Q2-1 shows a schematic of the gearbox, a two stage gearbox (a compound train), for Nissan Leaf pure electric cars. The numbers of teeth of the gears are N_1=N_3=17, N_2=31 and N_4=74. A maximum power of P = 90 kW is achieved when the motor rotates at a speed of n_{motor} (n_1) = 6,500 rpm. A module of m=3 mm is chosen for the 1st stage of the gear pair (gears 1 and 2) and the face width of gear 1 is F=35 mm.

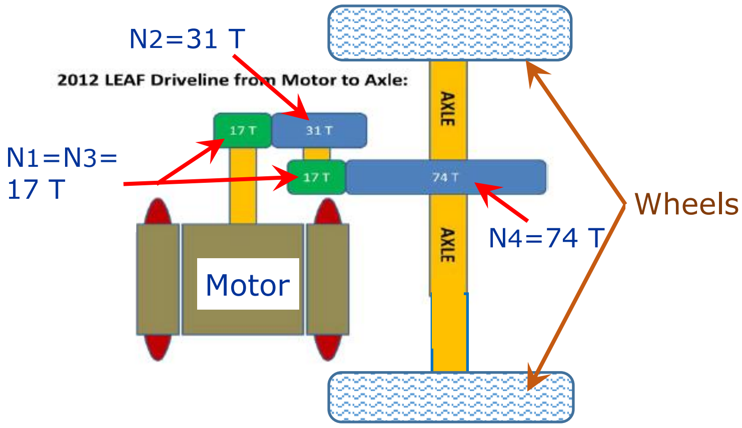

Figure Q2-1

i) Calculate the rotating speed (n_{wheel} or n_4) of the axle of the driven wheels (gear 4). [2]

ii) Calculate the transmitted load of the 1st stage gear pair of the gearbox (gears 1 and 2). [2]

iii) Use the chart in the attached Additional material-A1 to find the value of the Geometry factor Y_J. [2]

iv) The allowable bending stress of grade 1 through hardened steel is σ_{all}=290 MPa. Does the bending strength of gear 1 meet the design requirement? [2]

v) If not, would you be able to suggest TWO possible solutions to improve the bending strength of gear 1? [2]

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You may find the following equations and data useful:

$$Z = \pm\frac{Product\ of\ number\ of\ teeth\ on\ gears}{Product\ of\ number\ of\ teeth\ on\ pinions}$$

$$W_T = \frac{60\times 10^3 P}{\pi d_p n_p}(kN)$$

$$\sigma = W_t K_O K_V^{'} K_S \frac{1}{F\,m}\frac{K_H K_B}{Y_J}(MPa)$$

where, Z = Gear ratio
W_t = Transmitted load (kN)
σ = Bending stress (MPa)
F = Face width (mm)
m = Module (mm)
Y_J = Geometry factor including stress concentration
P = Rated power (kW)
d_P = Pitch diameter of the pinion (mm)
n_P = Rotating speed of the pinion (rpm)

In calculating, the following assumptions may be made:

K_O = 1.5, K'_V = 1.2, K_S = 1, K_H = 1.1, K_B = 1.

Linkage mechanisms

(c) What is a crank rocker linkage? Briefly explain its main characteristics accompanied with a simple sketch. [4]

(d) Figure Q2-2 shows a schematic of a retractable landing gear of aircraft. Its retraction mechanism is a four bar linkage (O_1ABO_2) actuated by a hydraulic cylinder D pivoted at E. Piston F is actuated to enable the extension and retraction of the landing gear.

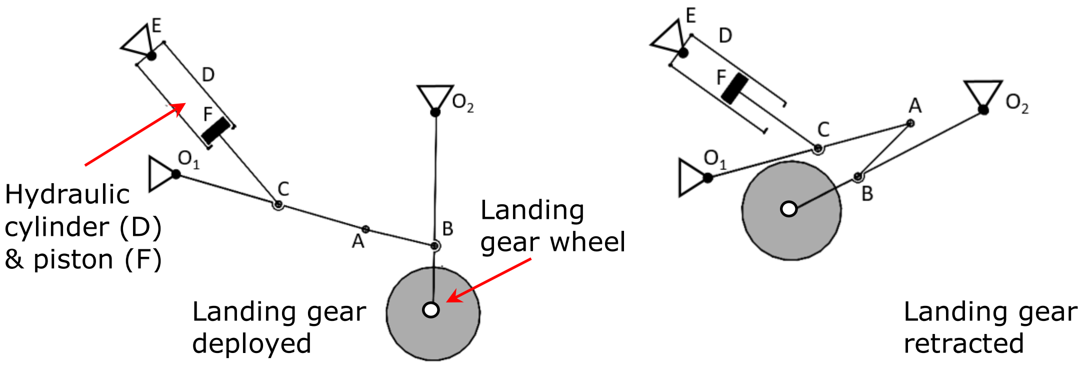

Figure Q2-2

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Use Gruebler's equation, calculate the numbers of DoF (Degree of Freedom) of the landing gear four bar linkage. [3]

You may find the Gruebler's equation useful:

$$M = 3(L - 1) - 2J$$

where, M is degree of freedom (DoF)
L is number of links
J is number of joints

Hint: You should exclude the joint of landing gear wheel from your calculation.
You may count the cylinder (D) and piston (F) as two links.

SECTION B

3. General design methods

Design for inclusivity

(a) Identify any FOUR of the seven objectives of inclusive design and describe how they might be used to improve any of the example products provided in Table Q3-1.

For each objective make sure to state clearly how current design limits inclusivity and how your proposed change would correct that. You may use an example product to illustrate more than one objective. [8]

Table Q3-1		
Home automation touch panel controller	Rugged child pushchair	Shower cubicle system for sale to sports facilities
Controller is wall mounted. Manufacturer's warranty requires panel be mounted >1.3 metres above floor 'to prevent damage by children'. Panel provides visual feedback when option is selected.	Pushchair is 8kg heavier than the market average. Marketed as 'Tough enough for days out with Dad'. Folding the pushchair requires a particular sequence of actions, otherwise the mechanism can jam.	Cubicle is a complete integrated system with fixed hardware. Door to cubicle opens outwards. Shower controls are very minimal and sleek, users have complained they struggled find the control for water temperature.

Design for assembly

(b) You have been asked to redesign a lens adjustment assembly to improve its assembly efficiency, see Figure Q3-1 on the next page for an illustration, a full parts list and descriptions of the requirements of the parts.

i) Identify how many components there are in the current assembly? And how many of those components are fasteners? [1]

ii) Calculate the assembly time of the current design. You may assume that it takes 10 seconds to seat the lens, 10 seconds for each fastener to be placed and tightened, 10 seconds to insert the pinion and align with the rack, and an additional 40 seconds to adjust the tightness of both top-plates. [1]

iii) Identify which of these components are theoretically essential to a redesigned assembly that has the minimum possible number of parts, while still providing the essential functions of the device. Your answer must make explicit reference to the design for assembly guidelines on what constitutes a theoretically essential part. [6]

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iv) Using your answers to ii) and iii) and the equation below calculate the design efficiency of the current design. [1]

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

v) Produce a description and/or set of sketches for a revised design of the lens focussing device which minimises the assembly time. Make sure to state clearly the reduced assembly time and how it was achieved. You will not be assessed on the quality of your drawings, and they do not need to be isometric, but they should be clear and well annotated to convey your design intent. [3]

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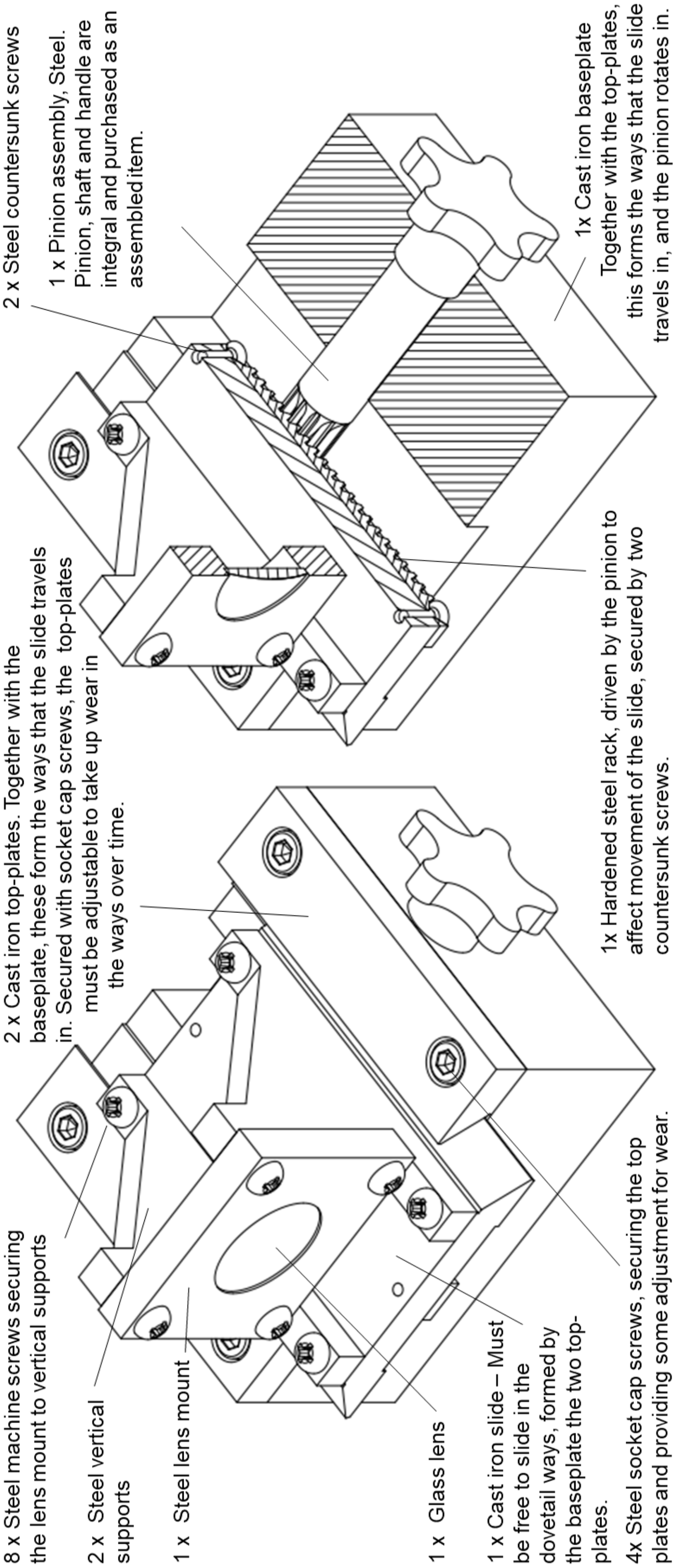
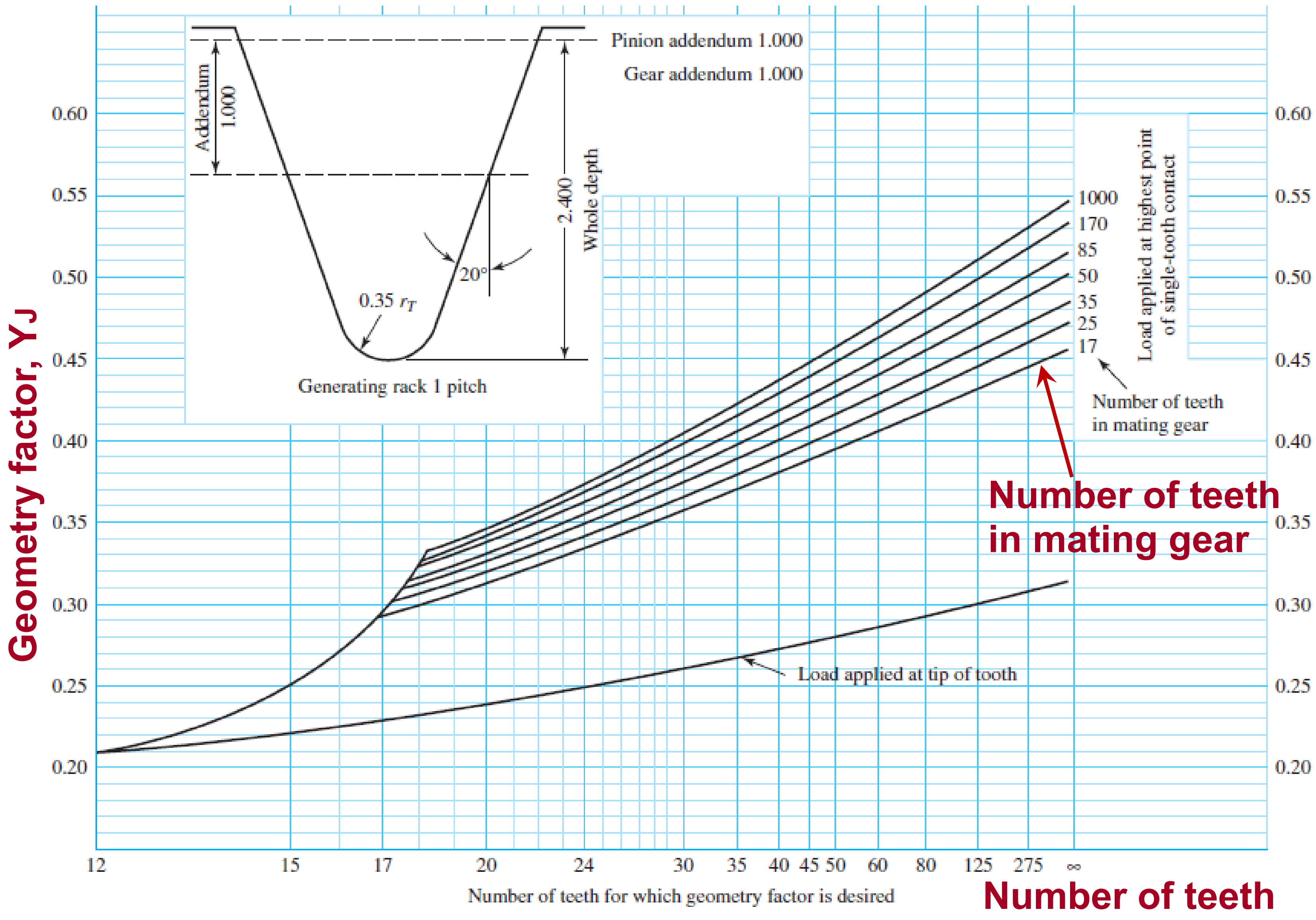


Figure Q3-1

END



Additional material A1 Geometry factor Y_J of gear bending stress