National Examinations - December 2008

07-Mec-A4, Design and Manufacture of Machine Elements

3 Hours Duration

Notes: See Especially Number 6 Below:

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.

2. This is a closed book examination. Candidates may use one of the two Approved calculators, the Casio or Sharp models, and two textbooks of the candidate’s choosing.

3. No notes are allowed, either loose or inscribed into either of the textbooks.

4. There are 7 questions on the following 3 pages, divided into Part A and Part B.

5. All questions are of equal mark value (20%). 5 (five) questions constitute a complete paper. Only the first five questions, as they appear in your answer book, will be marked, subject to #6 below. Clearly cross off any question you do not want marked.

6. Candidates may answer only one or two problems from Part B. Only the first two (2) problems from Part B which appear in your answer book will be marked.

7. You may keep this examination paper.
PART A: Choose any three (3) or four (4) from part A.

1. a) Design a dry multi-disc flat plate clutch to have a torque capacity, when well worn in, of 400 Nm (300 lb-ft). Assume:
   - a frictional coefficient of 0.27
   - a maximum peripheral (tangential) velocity of 30 m/s (100 ft/sec) at the clutch’s top speed of 3000 rev/min.
   Note: this is a design problem, with many correct answers. You will have to make one or more assumptions, such as the ratio of inner-to-outer diameters. Work in either S.I. or English units.

   Required answers:
   - inner and outer diameters
   - number of active clutch surfaces
   - maximum clutch pressure when new, and when well worn in
   - the axial force required.

b) The torque capacity changes as the clutch wears in. Find the minimum torque the laboratory testers should expect, when testing a new clutch.

c) This clutch is designed to be a “slip clutch” (it brings a very large load up to speed slowly) which reduces the motor size required. Find the time required to accelerate a large rotor (I = 16.0 Nm² or 12.0 lb-ft-sec²) up to full speed from rest (0 rev/min).

d) (Bonus of 4 marks for this part).
   How much mechanical energy will be converted into heat during one acceleration period in (c)? Assume that the motor remains at a steady 3000 rev/min during acceleration of the rotor.

2. A cable support is constructed by attaching the cable to a vertical plate. This plate is bolted to the horizontal plate using four class 8.8 bolts of equal diameter. The horizontal plate is welded to a support column by two fillet welds of equal size.

   There is no twisting in the assembly.

   All dimensions are in mm.

   a) (16 marks) For a force P = 10.0 kN, find the required standard bolt diameter. Assume an allowable shear stress of 0.20 of tensile yield strength.

   b) (4 marks) Briefly explain the similarities and differences in solution method to find the required weld size. No calculations are needed, or will be marked.
3. A 400 rev/min shaft subjects a ball bearing to a radial load of 8.00 kN and an axial load of 3.50 kN. The bearing's inner race rotates with the shaft. The design life of the bearing is to be 6.00 years of 7.50 hour per day, 290 working days per year, operation. There is light vibration, and 99.5% reliability is required.

Select a suitable single row ball bearing in the L100 to 300 series. Note: If your text does not show these bearings, but does show other similar bearings, use the information you have to choose a suitable bearing, but indicate clearly which text, and which table you used.

4. This T-shaped support assembly is constructed from solid HR C1020 (G10200) steel of diameter \( d \). Loading is static. Neglect stress concentrations due to the support plate, and consider only stresses at the top of member BD, at D.

a) Draw an element clearly showing all the stresses acting at D (tensile, compressive and/or shear) as functions of \( d \). Identify the longitudinal axis.

b) Using Mohr's Circle or calculation and a factor of safety of 3 on yield, find the required shaft diameter \( d \) at D, based on:
   i) the maximum principal stress,
   ii) the maximum shear stress,
   iii) the maximum distortion-energy theory.

PART B: Choose any one or two problem(s) from Part B.

5. a) (6 marks) In many applications, the designer has the choice of specifying cast iron, or cast steel for a part. For a spoke-type flywheel (heavy hub and rim, relatively lighter spokes), compare the two materials with respect to:
   i) manufacturing (cost, ease of manufacture, etc.), and
   ii) design (various strength properties, ductility, etc.)

b) (7 marks) The bodies and frames of many recently designed vehicles have structural members constructed from closed tubes which have been shaped by hydroforming. These members have complex shapes of varying cross section.
   i) Discuss the advantages of using hydroforming for the designers.
   ii) What construction method(s) would have been used before the introduction of hydroforming?
   iii) Why would the manufacturing engineers specify that an axial compressive load be applied to the tubes during the hydroforming operation?

c) (7 marks) Welding is the preferred attachment method for low alloy steel parts in many applications. However, welding may be difficult, or impossible, with heat-treated, and with high alloy steels. Discuss the problems (and solutions if any) of these two cases.
6. (13 marks)

a) An I-shaped beam is to be manufactured from a carbon fibre-epoxy composite for an expensive aircraft. The carbon fibre is oriented along the longitudinal axis of the beam, and comprises 30% of the volume of the beam.

Data: carbon fibre: $E = 50 \times 10^6$ p.s.i. density $= 0.069 \text{ lb/in}^3$

epoxy: $E = 6.1 \times 10^5$ p.s.i. density $= 0.042 \text{ lb/in}^3$

Find:

i) the density of the composite beam
ii) the modulus of elasticity of the composite beam in the longitudinal direction
iii) as (ii), but perpendicular to the fibres.
iv) The beam has a section modulus of 1.95 in$^3$ and a moment of inertia (second moment of area) of 2.93 in$^4$. Find the maximum tensile stress and the radius of curvature of the beam under pure moment loading of 10,000 lb-ft

b) (7 marks)

Light weight composite brake and clutch pedal arms are being used in many current model year cars. Those pedals with left or right offsets at the pedals (bent near the bottom ends, to clear the steering column, wheel wells, etc.), experience both bending and torsion near the pivot points at their upper ends.

Choose a low cost plastic matrix composite material for these arms, and sketch the cross sections of the arm near the pedal (bottom), and near the pivot point (top). Why did you choose these shapes? Remember that they must be relatively easy to mould.

7. a) (7 marks) When replacing steel parts with aluminum, many engineering properties must be considered. Examples are:

- toughness
- rigidity
- strength
- endurance.

Using the example of the tubular load carrying members in the aluminum chassis of some newer cars, indicate how you would compensate for any changes in the above properties.

b) (5 marks) A flanged steel cup shape is to be deep-drawn.

i) Would you specify a single-acting, or a double-acting die design? Why?

ii) What steel(s) would you expect the designer to specify?

iii) Why is springback a problem?

iv) Why is draft angle important?

c) (4 marks) Commercially-cut gears are heat-treated after machining. Precision gears are cut, hardened, then ground.

i) What hardening method(s) can be used in gear manufacture?

ii) Why do precision gears require grinding after hardening?

iii) Why are all gears not ground after hardening?

d) (4 marks) What machining methods can be used to manufacture:

i) internally-toothed gears?

ii) externally-toothed gears?

iii) Which one of the methods in (ii) is preferred for high volume production?