9210-222
Level 7 Post Graduate Diploma in Mechanical Engineering
Mechanical engineering design

Sample Paper

You should have the following for this examination
- one answer book
- non-programmable calculator
- pen, pencil, drawing instruments

A Reference booklet is attached
A copy of BS 1440 is provided

General instructions
- Answer four out of **seven** questions including all parts of **Question 1 (Compulsory)** and any other **three** questions.
- It is advisable that the parts of Question 1 are attempted in the given order.
- Use clearly drawn and labeled diagrams, or sketches in place of written presentations, wherever these will help to present your ideas, views and answers clearly. Do not use red ink.
- Any missing data can be rationally and reasonably assumed, provided that such data is clearly stated with justifications.
- Show sufficient steps to justify answers.
- Any result obtained from calculations should stand with their relevant units, unless those are dimensionless.
- Necessary design data, abstracts of catalogues and any other special information are provided in the question paper.
- Question 1 carries 55 marks and the remainder 15 marks each. The maximum marks for each section within a question are shown.

1 The elevation of a belt conveyor, which is used to transport coal at a 150 MW power plant, is shown schematically in Figure Q1a. This figure does not show the drive mechanism of the conveyor. The belt is made out of a rubber sheet of 0.6 m width wrapped around a set of rollers as shown. The bottom roller and the top roller are spaced 15 m apart as shown. The conveyor belt is driven by the bottom roller, while the other rollers are free to rotate in their bearings. Crushed coal falls on to the belt from a chute (which is not shown) at a point close to the bottom of the conveyor. The power train of the belt conveyor is shown schematically in Figure Q1b. Figure Q1a and Figure Q1b are given in the Reference Booklet.

The performance specifications and the relevant design details of the machine described above are given below.

- The conveyor has to satisfy the following performance specifications.
  Rate of transfer of coal = 1000 kg/min
  Inclination of the conveyor belt to the horizontal = 20 degrees
- The bottom roller is driven by an induction motor through a V belt drive and a gearbox as shown in Figure Q1b. The outer diameter of the bottom roller is 200 mm. The output shaft of the gearbox is coupled to the bottom roller through a sleeve or muff coupling.
- The gearbox which has a two stage gear reducer consists of two pairs of spur gears in mesh as shown. All gears are spur gears of 20 degree pressure angle, full depth, and involute profile.
- The speed ratio of the V belt drive as well as that of the gear pair ***A*** and ***B*** is 4.
- Gear pair **C** and **D** should be designed to satisfy a speed ration between 3.5 and 5.0.
- The power train has to be designed so that the linear speed of the conveyor belt is as close as possible to 0.2 m/s. The outer diameter of the bottom roller is 200 mm. Assume that slip and creep of the conveyor belt over the bottom roller is negligible. Neglect speed losses due to slip and creep in the V belt drive.
- When estimating the numbers of teeth on gear drives, you are advised to make the number of teeth as low as possible, provided interference of gear teeth is avoided. The relevant modeling equations are provided in the Reference booklet.
- Fifteen percent (15%) of the mechanical power that is supplied to the bottom roller of the belt conveyor is lost due to friction at the bearings and the belt.
- The conveyor belt operates 24 hours per day for 340 days per year.
- BSS for belt drives, an extract from a motor catalogue, information required to design gears, an extract from a bearing catalogue, etc. are provided in the Reference Booklet.

In order to design the belt conveyor and the associated power train, answer the following questions.

a) Estimate the power that is required to drive the belt conveyor. Also estimate the power of the electric motor, considering the losses in the power transmission system. Hence propose a suitable electric motor for this purpose. (7 marks)

b) Design the V belt drive that Is used in the power train. Determine the cross section of the V belts to be used and the number of belts. Also estimate the diameters of the two pulleys. You may consider that the center distance between the two pulleys is approximately 1.3 times the larger pulley diameter. (6 marks)

c) Completely design the gear pair ***C*** and ***D*** from the point of bending, dynamic tooth load and surface wear.

You may use the following data in the design of the gear drive.
The face width of the gears is 8 times the module.
Service Factor = 1.4
You may use a module of 4.0 mm for this gear drive, provided the number of teeth on the pinion is the minimum needed to avoid interference.
If the module is 4.0 mm, tooth error in action (e) = 0.05 mm
Allowable static stress of pinion ***C*** (steel) = 180 MPa
Allowable static stress of wheel ***D*** (steel) = 140 MPa (22 marks)

d) Design the intermediate shaft of the gear box. Determine a suitable minimum diameter for this shaft. Assume that the pitch circle diameter of gear wheel ***B*** is 192 mm. All three shafts in the gear box are coplanar. (10 marks)

e) Choose a suitable anti friction bearing to carry the intermediate shaft at $\boldsymbol{B_1}$. The bearing is expected to last 8 years. (5 marks)

f) A three stage speed reducer is used in the power train of this belt conveyor. The speed reduction of the gear pair ***C*** and ***D*** is greater than that in the other stages of the power train. Explain with reasons the advantage of having the highest speed reduction in the third stage of a power train of this type. (3 marks)

g) What improvements to the conveyor belt design would you propose, in order to prevent coal from falling off the sides of the belt? (2 marks)

2 The left half of the operating spindle of a lifting jack that is shown schematically in Figure Q2a is threaded and is inserted through a nut to which the side links AB and AC are hinged at point A. The single start thread which is of the trapezoidal type that is shown in Figure Q2b has a thread angle of 30 degrees and 3 mm pitch. The outer diameter of the thread is 13.6 mm and the height of the thread is half the pitch. The right end of the operating spindle is inserted through a bush to which the side links ***DE*** and ***DF*** are hinged at point ***D***. The bush rests against a collar attached to the shaft. The thrust bearing between the bush and the collar has an inner diameter of 13.6 mm and an outer diameter of 28.6 mm. The lower plate of the jack rests on the ground and is used to lift a load of 2000 N, which acts on the upper plate as shown. The coefficient of friction at the screw as well as at the thrust bearing is 0.1. All four side links are inclined to the horizontal by angle θ. ***AB*** = ***AC*** = ***DE*** = ***DF*** = 150 mm. Figure Q2a, Figure Q2b and the mathematical model of the friction torque at the thrust bearing are given in the Reference Booklet.

a) Determine the torque which should be exerted on the operating spindle in order to lift the load, as a function of θ. (12 marks)

b) The base of the thread on the screw is equal to the gap between a pair of threads at the top. The first thread carries 35% of the total load. Estimate the safety factor in the shear mode of failure of the most severely stressed thread of the screw at its root when angle θ is equal to 25 degrees. The allowable shear stress of the material of the screw is 80 MPa. (3 marks)

See next page

3 Figure Q3 shows a part of a power transmission system. The solid shaft of 60 mm diameter overhangs the bearing at section ***A*** – ***A*** and carries a gear wheel at its end ***B*** as shown. The distance from section ***A*** – ***A*** to ***B*** is 60 mm. Under steady operating conditions, the resultant radial force ***P*** acting on the gear wheel is 12 kN and the resisting torque on the shaft *T* is 0.8kNm.

a) Mark the various types of stresses with <u>their numerical values</u> in a square shaped element located on the surface of the shaft at section ***A*** – ***A*** as shown. Two sides of this element are parallel to the shaft axis. Also estimate the magnitude of the maximum principal stress at this section. (8 marks)

b) If the allowable shear stress of the material of the shaft is 80 MPa, estimate a minimum diameter for the shaft at section ***A*** – ***A***. (7 marks)

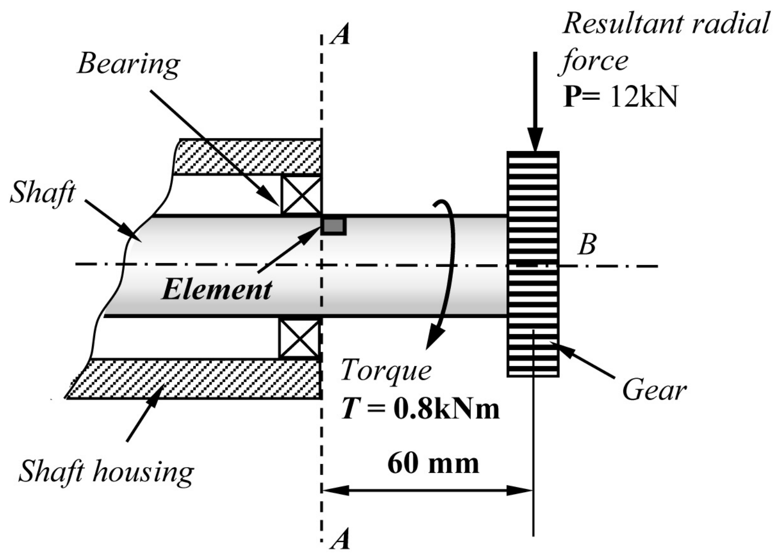
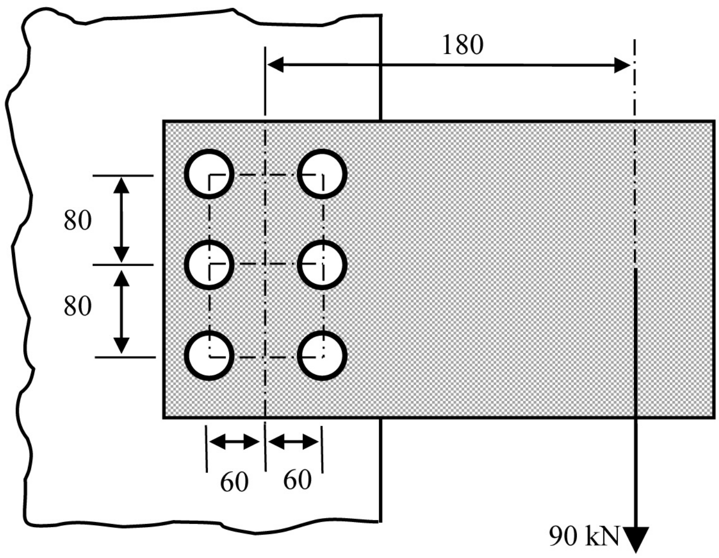


Figure Q3

4 A bracket in the form of a plate is attached to a column by means of six bolts of equal size as shown in Figure Q4. The allowable shear stress of the bolt material is 120 MPa. Determine the diameter of the bolts in order to withstand a load of 90 kN which acts as shown. (15 marks)



All dimensions are in mm

Figure Q4: Eccentrically loaded bracket

5 a) A double riveted lap joint is used in a particular machine. You are expected to estimate the strength of the joint. State three (3) common modes of failure of the joint that have to be considered when estimating the strength. (3 marks)

b) A beam of rectangular cross section is welded to a column by means of a fillet weld around the circumference of the beam as is shown in Figure Q5. The beam which is 1000 mm in length carries a vertical load of 25 kN at its end as shown. Calculate the leg length of the weld. The allowable shear stress in the weld is 70 MPa. The cross section of the beam is 200 mm *x* 300 mm as shown.
The second moment of area of the fillet weld about the ***x*** axis is: $\boldsymbol{I_x} = \boldsymbol{t}\,\boldsymbol{b}^2(3\boldsymbol{l} + \boldsymbol{b})/6$
where **t** is the throat thickness of the weld and the dimensions ***b*** and ***l*** are illustrated in Figure Q5 of the Reference Booklet. (12 marks)

6 A helical gear drive is to be designed to transmit 2.2 kW of power and produce a speed ratio of 2.5. The helical gears have involute profile stub teeth with a normal pressure angle of 20 degrees. The helix angle is 25 degrees and the face width is 12 times the normal module. The pinion runs at 800 rpm. The normal module is 3.0 mm. Use a service factor of 1.5. The forces acting on the teeth of a helical gear are shown in Figure Q6 of the Reference Booklet.

a) Design the gear drive, so that the number of teeth on the pinion is the minimum required to avoid interference. Estimate the numbers of teeth on the gear pair. (4 marks)

b) Compute a lower bound estimate for the allowable static stress of the material of the pinion. Also estimate the axial force exerted on the pinion teeth. (11 marks)

7 a) State under what conditions the choices given below are preferred.

i) Cylindrical roller bearings are preferred over deep groove ball bearings.

ii) Angular contact ball bearings are preferred over deep groove ball bearings.

iii) Self aligning ball bearings are preferred over deep groove ball bearings. (3 marks)

b) A deep groove ball bearing supports one end of a shaft that is used in a gear box. The bearing is subjected to the loads that are given below.

i) A radial load of 2800 N combined with an axial load of 550 N and runs at a speed of 800 rpm, over 60% of the operating time.

ii) A radial load of 3600 N combined with an axial load of 720 N and runs at a speed of 600 rpm, over 40% of the operating time.

If the expected life of the bearing is 14,000 hours, choose a suitable deep groove ball bearing for this application. The bore of the bearing (i.e. inner diameter of the inner race) should be 40 mm. Assume that the bearing is supposed to have 96% reliability. (12 marks)

The adjusted rating life of a bearing (L_a) is given by: $L_a = \mathbf{a} (L_{10})$; where L_{10} is the basic rating life of the bearing in millions of revolutions for 90% reliability.

Life adjustment factor (**a**) for reliability:

Reliability %	90	96	98	99
a	1.0	0.53	0.33	0.21