ENGINEERING TRIPOS PART IIB
ELECTRICAL AND INFORMATION SCIENCES TRIPOS PART II
ENGINEERING TRIPOS PART IIA

Thursday 24 April 2003 9 to 10.30

Module 4C4

DESIGN METHODS

*Answer not more than **three** questions.*

All questions carry the same number of marks.

*The **approximate** percentage of marks allocated to each part of a question is indicated in the right margin.*

You may not start to read the questions printed on the subsequent pages of this question paper until instructed that you may do so by the Invigilator

1 A mounting bracket assembly for a car roof box is shown in Fig. 1. The plate, which is integral to the floor of the box, is clamped to the roof bar using a threaded U-bolt. The nominal pitch between the centres of the two 8 mm holes in the plate is 100 mm. The nominal pitch between the centres of the two arms of the U-bolt is also 100 mm. Manufacturing tolerances are such that there is a variation of ± 0.5 mm in the plate-hole centre-to-centre pitch and ± 0.1 mm in the plate-hole diameter. The U-bolt arm diameter is known to be 7 mm ± 0.1 mm and the variation in the U-bolt arm centre-to-centre distance can be up to ± 1 mm.

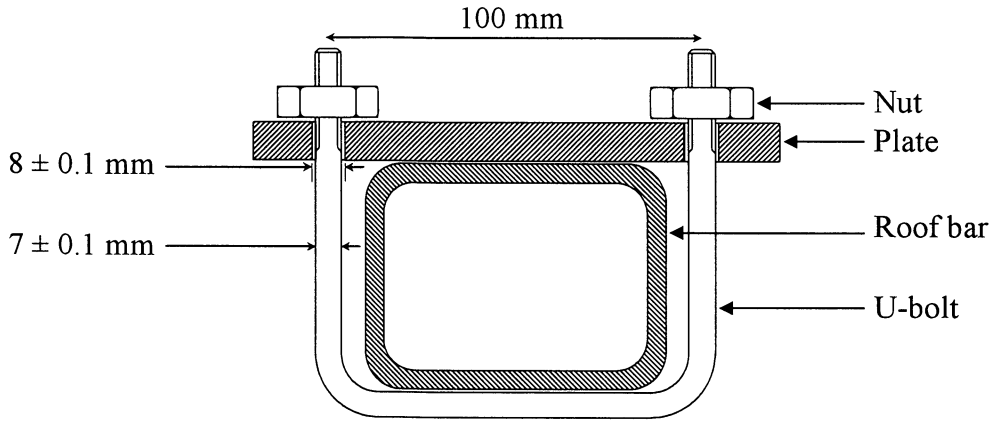

Fig. 1

(a) Define the meaning of the terms 'safety-factor' and 'safety-margin', and state how they may be applied to the U-bolt fitting through the plate. [20%]

(b) Calculate the safety-factor for the U-bolt fitting through the plate, for nominal and 'worst case' conditions. [20%]

(c) Calculate the percentage of U-bolt / clamp plate sets that will not fit together for the following cases:

(i) assuming no bending of the U-bolt;
(ii) assuming that bending of the U-bolt allows relative movement of the arm centres by up to 1 mm.

Assume that all probability distributions are normal and that the range from minimum to maximum is equivalent to two standard deviations. [40%]

(d) By how much should the diameter of both holes in the plate be increased to reduce the clamp failures to less than one set per 1000? Assume all other conditions are as for Part (c) (ii) above. [20%]

2 (a) The iterative step in a general optimisation descent algorithm can be defined as:

$$\boldsymbol{x}_{k+1} = \boldsymbol{x}_k + \alpha_k \boldsymbol{s}_k .$$

State the principal stages of a general descent algorithm including a definition for each term above and its significance. Under what circumstances will a gradient descent method always converge to a global minimum? [30%]

(b) Given the following objective function:

$$f(\boldsymbol{x}) = x_1^3 + 2x_2^2 + 5x_3^2$$

and a starting point of $\boldsymbol{x}_0 = (1,1,1)^T$, perform one iteration of both the Steepest Descent Method and the Conjugate Gradient Method, up to and including the calculation of $\boldsymbol{s}_1$. [40%]

(c) (i) What is the primary difference between the $\boldsymbol{s}_k$ terms used in the Steepest Descent Method and the Conjugate Gradient Method for $k > 0$, and what mathematical relationship would you expect to find between $\boldsymbol{s}_0$ and $\boldsymbol{s}_1$ for each of these two methods?

(ii) Evaluate these two relationships for the values of $\boldsymbol{s}$ that you have obtained in Part (b), and explain why they do not quite yield the expected values.

(iii) Explain why these two descent methods usually converge at different rates, and state which method you would expect to converge more rapidly for the function given in Part (b). [30%]

3 (a) Explain, with the aid of a diagram, the meaning of the terms *verification* and *validation*. Why is validation so critical for medical device design? [10%]

(b) A pen injector is to be used to inject an anti-migraine drug. The injection sequence is defined as follows:

(i) Remove rear of pen;
(ii) Insert drug cartridge;
(iii) Replace rear of pen;
(iv) Select drug dose;
(v) Remove pen cap;
(vi) Attach sterile needle to pen;
(vii) Insert needle into forearm;
(viii) Press button to release drug;
(ix) Remove needle from forearm;
(x) Discard used needle from pen;
(xi) Replace pen cap.

It is critical that the drug be injected correctly for the dose to be effective. Sketch a fault tree for the situation where the patient does not receive an effective dose of the drug. For each initiating event in the fault tree, indicate the relative likelihood of the event occurring as high (H), medium (M) or low (L). [30%]

(c) Identify the high-risk steps in the sequence given in Part (b) and suggest modifications to the pen design that may reduce the risk. [40%]

(d) Describe appropriate verification and validation approaches for a pen injector of this type. [20%]

4 A farmer living in the Mendips (a range of hills to the south of Bristol) would like to acquire a portable ski-lift to use on the rare occasions that there is sufficient snow for skiing. He has it in mind to use the lift in a particular field behind the farm that has a run of 200 m with a 20% gradient. The run is approximately 50 m wide.

(a) Derive a solution-neutral problem statement for the ski-lift. [10%]

(b) Define a suitable set of requirements for the device. [20%]

(c) Sketch an overall function and function structure(s) for the proposed device. [30%]

(d) Identify and describe two possible concepts for the device. Clearly identify features that will ensure safe use of the lift. [40%]

END OF PAPER