ENGINEERING TRIPOS   PART IB

Friday 6 June 1997   2 to 4

Paper 8

SELECTED TOPICS

Answer not more than **four** *questions.*

Answer questions from **two** *sections only.*

Do not answer more than **two** *questions from any section.*

Do not answer questions from **both** *sections C and D.*

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

Answers to questions in each section should be tied together and handed in separately.

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SECTION A (Civil and Structural Engineering)

1 Figure 1 shows a borehole located adjacent to the side of a proposed 6 m deep excavation. The drillers' log reported the following soil types:

0 - 4 m	silty sand
4 - 8 m	firm clay
8 - 12 m	gravel

Thin-walled "undisturbed" core samples of exactly 4.00 litre volume were taken at locations A and B at 2 m and 6 m depth. Their natural and dried weights were:

	Natural kg	Dried kg
A	7.90	6.63
B	7.28	5.30

Both samples were shown to be comprised of soil grains whose mean specific gravity G_s was 2.65. The eventual rest water level in the bore hole was at 4 m depth.

(a) Calculate the natural bulk density and the degree of saturation of the two samples. [3]

(b) Estimate the vertical total stresses at A and B. [3]

(c) What can be inferred about the pore water pressures at these locations? Explain why negative pore pressures are invariably discounted when calculating the earth pressure acting on the supports in excavations. [4]

(d) Triaxial compression tests were performed on sub-samples taken without disturbance from the cores, as follows: [5]

(cont.

(i) Core A: The sample was saturated, and brought to a confining pressure of 50 kPa. Axial stress was increased slowly while the sample was drained, so that the pore pressure remained atmospheric. The axial stress reached a maximum of 290 kPa before falling back to a plateau at 190 kPa.

(ii) Core B: The sample was sealed, and tested without drainage under a confining pressure of 100 kPa. The axial stress reached a plateau at 220 kPa.

Deduce both the peak and the ultimate angle of friction of the silty sand, and the undrained shear strength of the firm clay.

(e) Perform appropriate earth pressure calculations to deduce the lateral pressures at elevations A and B, for the purpose of designing temporary supports for the excavation. Discuss the level of safety embodied in your estimates. [5]

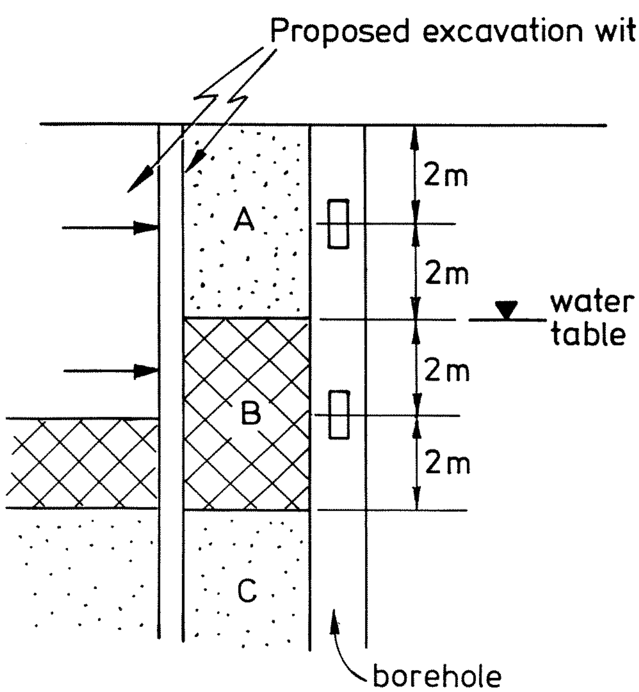

Fig. 1

2 (a) Water is often regarded as the principal cause of problems underground. Explain why, and what can be done about it. [10]

(b) Describe the NATM (New Austrian Tunnelling Method) and TBM-FPB (Tunnel Boring Machine with Full Pressure Balance) tunnelling technologies and list the advantages and disadvantages of each. Give one example each of circumstances for which they are ideally suited. Give one example each of unforeseen ground conditions which would severely compromise their effectiveness. [10]

3 A 12 m high vertical wall retains water whose level can reach the top of the wall. At the bottom, the wall can be idealised as being pinned to its foundation. At a level 4 m below the top of the wall there are horizontal ties at 1 m spacing which ensure that the wall remains in equilibrium, as shown in Fig. 2. The wall is to be made from reinforced concrete with a cube strength of 40 N/mm^2.

(a) Determine the force in the tie and the bending moment distribution when the tank is full. [4]

(b) If the wall is to be designed on the basis of ultimate strength alone, calculate a suitable thickness for the wall on the assumption that the section is singly-reinforced, and the same wall thickness is used throughout the height. [5]

(c) Design suitable reinforcement for the wall. (The amount of reinforcement may vary in quantity and location up the height of the wall.) [5]

(d) An alternative design philosophy would be to limit the stresses in the concrete so that crack widths were small.

Discuss, without doing any calculations:

(i) whether this would be a better principle to use, and if so, why? [3]

(ii) whether this would require a thicker or thinner section and more or less reinforcement? [3]

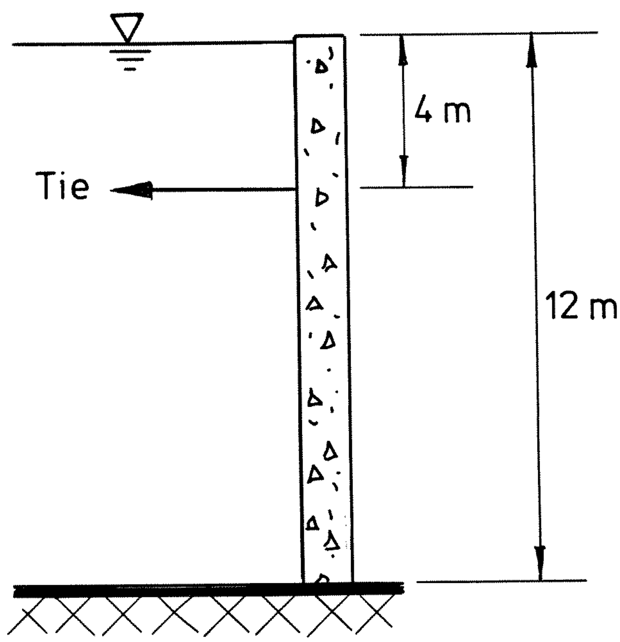

Fig. 2

SECTION B (Mechanical Engineering, Manufacture and Management)

4 An eccentric mass for a vibrating pig is shown in Fig. 3. The mass, of length L, is designed for use in a pipeline of diameter D. The semi-cylindrical section is the eccentric and the cylindrical portion is a flywheel. The mass rotates about an horizontal axis at all times.

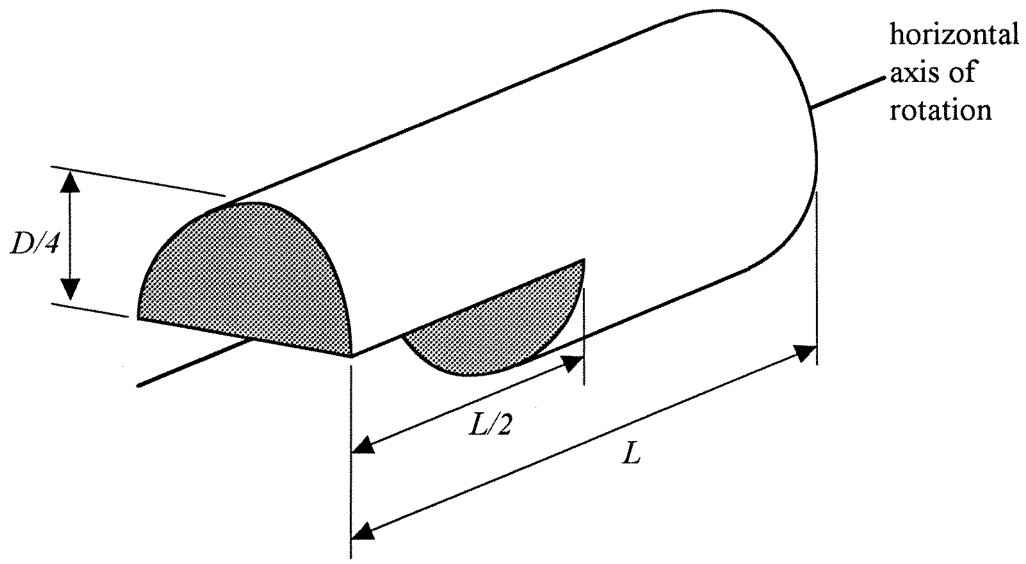

Fig. 3

(a) Show that for this geometry, where $L = D$, the minimum torque required to start rotating the eccentric mass is given by: [8]

$$T_s = \frac{\rho D^4 g}{192}$$

(b) Calculate the starting torque for a steel eccentric mass to fit a pipe with diameter D of 200 mm. [2]

(cont.

(c) Assuming that the motor torque is constant and the motor rotating mass is small compared to the eccentric mass show that the speed fluctuation $\Delta\omega / \omega$ of the eccentric mass is given by: [8]

$$\frac{\Delta\omega}{\omega} = \frac{32g}{9\pi\omega^2 D}$$

Assume that the mean running speed of the eccentric mass is ω and the maximum and minimum speed during each revolution are $\omega \pm \Delta\omega$.

(d) Calculate the minimum working frequency for the steel eccentric mass defined by (b) assuming a practical value for the speed fluctuation defined in (c). [2]

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5 A steel gas pipe rests partially covered on a coastal sea floor. A vibrating pig is to be used to locate unsupported spans. At midspan, the pig excites the span's resonance at 15 Hz and measures the vibration amplitude with an array of accelerometers. The vibration amplitude provides a measure of the support condition of the pipe.

The output signal of an accelerometer is an electrical charge, the amplitude of which is proportional to acceleration. There is also broad band noise superimposed upon the desired signal which must be removed to leave only that part of the signal due to the 15 Hz excitation.

(a) What are the most common sources of accelerometer signal noise? [3]

(b) The accelerometer output signal is amplified to provide a voltage V_i which may be electronically filtered, using the circuit shown in Fig. 4, to provide a voltage V_o which is proportional to acceleration over a limited frequency band. Sketch the gain versus frequency relationship for this circuit from 0.1 Hz to 1 kHz for R = 10 kΩ, $C_1 = 0.22$ μF and $C_2 = 4.7$ μF. Calculate the 3 dB frequencies for the circuit. [8]

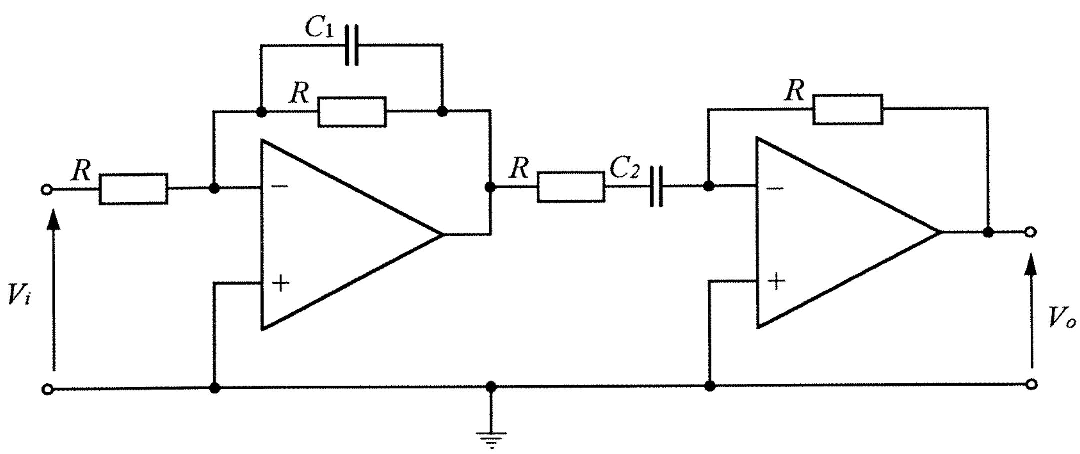

Fig. 4

(cont.

(c) Alternatively the motion of the accelerometer y may be derived from the motion of the pipe x using the mechanical system shown schematically in Fig. 5. Calculate the required spring constant k, for an accelerometer mass $m = 10$ g and damping coefficient $\lambda = 3$ Ns/m, if this system is to have the same upper 3 dB frequency as the circuit in (b). Sketch the magnitude of gain versus frequency relationship for this system from 0.1 Hz to 1 kHz. [7]

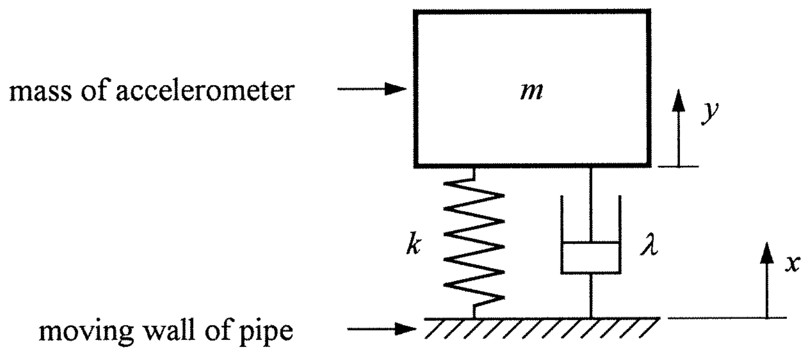

Fig. 5

(d) Discuss the relative merits of the electrical and mechanical filters defined in (b) and (c) for removal of accelerometer signal noise when the pipe is vibrating at resonance. [2]

6 (a) Risk management is a critical part of the product development cycle. Briefly describe the following risk management techniques and their application to product and service development: [12]

(i) Likelihood / impact grids;

(ii) Phased development;

(iii) Hazard and operability (HAZOP) analysis;

(iv) Failure modes and effects analysis (FMEA).

(b) Describe with the aid of a diagram the main development stages for a new pipeline inspection service; for example, depth of cover measurement using a vibrating pig. For each stage describe the key activities and outputs. [4]

(c) How do the development stages of (b) differ from those required for the introduction of a new beer product which includes novel technology; for example, draught beer in a can using a widget? [4]

SECTION C (Aerothermal Engineering)

7 (a) Explain what is meant by propulsive efficiency, cycle efficiency and overall efficiency in the context of aero engine operation. Which, if any, of these quantities remain the same between ground testing and flight at cruise for an engine operating at the same non-dimensional operating point. Justify your answer. [5]

(b) What is meant by bypass ratio? Sketch and label a cross section of an engine with low bypass ratio (less than unity) and an engine with a bypass ratio typical of those now being designed and built for propulsion of a modern civil aircraft. (The sketches only need enough detail to illustrate the different layout of the two engines.) [3]

(c) Explain why it is desirable that the overall pressure ratio (the ratio of compressor delivery pressure to engine inlet stagnation pressure) should be high and indicate a typical value. What is the effect of changing the design value of turbine inlet temperature on the efficiency of the engine? [4]

(d) If the pressure ratio were chosen to be in the range suggested in (c) and the turbine inlet temperature were 1450 K, what drawbacks would there be for an engine with a bypass ratio of unity? [3]

(e) Explain why the engines for propulsion of subsonic passenger aircraft have bypass ratios significantly greater than unity. What factors limit the upper value of the bypass ratio? [5]

(TURN OVER

8 A schematic of one of the stages of a two-stage HP turbine is shown in Fig. 6. The two stages are of identical design and have *purely axial flow* at stage inlet and exit. The stage has design values of

$$\frac{V_x}{U} = 0.55 \text{ and } \frac{W}{U^2} = 1.5 ,$$

where V_x is the axial velocity (which may be assumed uniform throughout the turbine), U is the blade speed and W is the work output per unit mass flow of gas.

(a) Sketch the velocity triangles for a stage. [4]

(b) Find the relative air angle at rotor exit α_3^{rel} . [4]

(c) For a stage the work output per unit mass flow W is given by [3]

$$W = U(V_{\theta 2} - V_{\theta 3}) ,$$

where $(V_{\theta 2} - V_{\theta 3})$ represents the change in the tangential velocity across the rotor. Find the air angle at stator exit α_2 which will achieve the desired value of $\frac{W}{U^2}$.

(d) The two-stage turbine has an inlet stagnation temperature of 1450 K and a blade speed of 350 m/s . If the turbine isentropic efficiency is 0.9 , determine the stagnation temperature of the gas at exit from the turbine and the turbine stagnation pressure ratio. [5]

(e) By assuming that the ratio of densities based on *static* temperature and pressure is equal to the ratio of densities based on *stagnation* properties, estimate the change in the flow cross-sectional area across the two-stage turbine. [4]

You may assume that the gas flowing through the turbine behaves as a perfect gas with the same properties as air.

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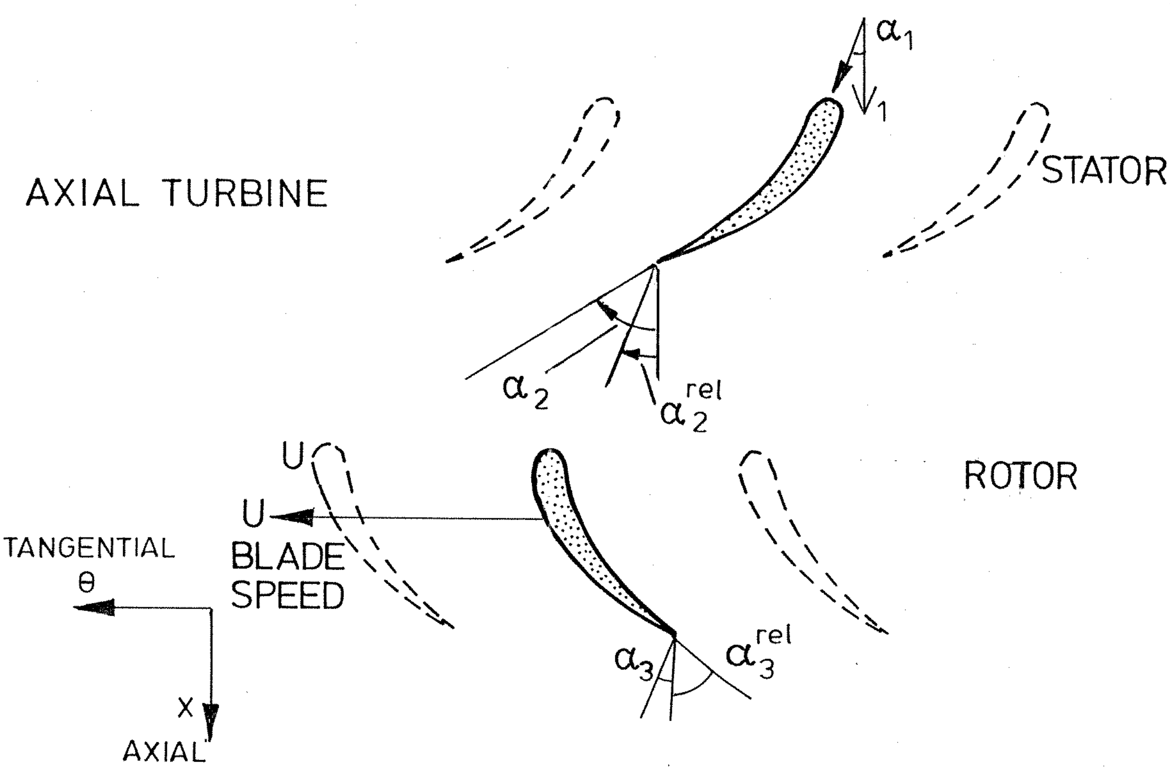

Fig. 6

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9 (a) Describe the factors which influence the choice of design inlet temperature of the HP turbine for modern high-bypass turbofan engines and some of the techniques used to help achieve this choice. [6]

(b) An aircraft cruises at an altitude where the ambient pressure is 28.7 kPa and temperature is 225 K. At entry to the engine the stagnation pressure is measured to be 47.5 kPa. Find the flight Mach number and the stagnation temperature at engine inlet. [3]

(c) During cruise, the stagnation pressure and temperature leaving the fan and entering the core of each engine are 75 kPa and 300 K respectively and the core mass flow is 100 kg/s. The core compressor pressure ratio is 25 while that of the HP turbine is 5.5 and the loss of pressure in the combustion chamber may be neglected. If the core compressor isentropic efficiency is 88% and the HP turbine inlet temperature is 1450 K, find:

(i) The temperature drop across the HP turbine and the turbine isentropic efficiency; [3]

(ii) the fuel flow rate (the fuel is kerosene with a lower calorific value of 43 MJ/kg). [2]

(d) Explain carefully why you would expect the fuel flow rate for the same non-dimensional engine operating point to be proportional to $P_{02}\sqrt{T_{02}}$ where P_{02} and T_{02} are the stagnation pressure and temperature at entry to the engine. Cruise operation, corresponding to parts (b) and (c) above, is simulated in a ground test on a day when the ambient pressure is 100 kPa and the temperature is 288 K. Find the fuel flow rate for the ground test. [6]

You may assume that the combustion products behave as a perfect gas with the same properties as air.

SECTION D (Chemical and Process Engineering)

10 For the following pollutants from combustion systems, discuss the impact on the environment and the means of control:

(a) water vapour; [2]

(b) oxides of carbon; [6]

(c) oxides of nitrogen; [6]

(d) oxides of sulphur. [6]

(TURN OVER

11 (a) Define the diffusion coefficient D_{AB} for the diffusive transport of a gas A in the presence of a second gas B. Working in a coordinate frame where there is no net bulk flow, show for a binary mixture of two ideal gases A and B at uniform temperature and pressure, and thus at uniform total concentration, that $D_{AB} = D_{BA}$. [3]

(b) Write down the mass transfer laws which define the gas-side and liquid-side mass transfer coefficients k_g and k_l, and the overall mass transfer coefficient K_g. Show that [4]

$$\frac{1}{K_g} = \frac{1}{k_g} + \frac{H}{k_l}$$

where H is the Henry's Law constant relating equilibrium concentrations in gas and liquid. Define the conditions when the mass transfer is controlled by gas-side or liquid-side resistance.

(c) Describe the Whitman two-film theory for mass transfer between liquid and gas phases of a binary mixture in contact. Find k_g and k_l in terms of the gas and liquid diffusion coefficients D_g and D_l, and film thicknesses δ_g and δ_l. [5]

(d) A wetted wall column with fixed gas and liquid flow rates is used for the absorption of NH_3, CO_2 and SO_2 from a gas stream into a liquid stream. In each case the carrier gas is air, in which the absorbing species is dilute. K_g for the absorption of NH_3 into a dilute acid is 4.0×10^{-2} m/s, and K_g for the absorption of CO_2 into water, under the same hydrodynamic conditions, is 1.9×10^{-4} m/s. Gas-side control (i.e. liquid-side resistance is negligible) may be assumed in the former case, and liquid-side control (i.e. gas-side resistance is negligible) may be assumed in the latter case. Using the data below, estimate [8]

(cont.

(i) the film thicknesses;

(ii) K_g for the absorption of SO_2 into water under the same hydrodynamic conditions.

Comment on your results.

Data

Diffusion coefficients and Henry's Law constants for the given species in air and water.

Gas	$D_g (m^2 / s)$	$D_l (m^2 / s)$	H
NH_3	2.36×10^{-5}	1.7×10^{-9}	4.52×10^{-4}
CO_2	1.64×10^{-5}	1.8×10^{-9}	1.05
SO_2	1.46×10^{-5}	1.9×10^{-9}	9.03×10^{-3}

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12 (a) Describe the operation of a packed column for transfer of a pollutant from an upward-flowing gas to a downward-flowing liquid. [5]

(b) Derive the equation of the operating line relating dilute pollutant concentrations c_g and c_l in the gas and liquid at some point in a packed column, in terms of the gas and liquid volumetric flow rates G and L, and the concentrations $c_{g\mathrm{B}}$ and $c_{\ell\mathrm{B}}$ (B denotes the bottom of the column). Discuss the two cases $L > HG$ and $L < HG$ in the case of long columns, where H is the Henry's Law constant relating equilibrium concentrations in gas and liquid. [6]

(c) An exhaust stream from a process consists of $1.1\ \mathrm{m^3/s}$ of air containing a small amount of SO_2. The gas is passed up a packed column of internal diameter 1.2 m. Water containing no SO_2 is supplied to the top of the column at a flow rate of $0.012\ \mathrm{m^3/s}$. Calculate the height of column required to reduce SO_2 concentration to 10% of its inlet value. Discuss the operation of the column at higher gas flow rates. [9]

Data

Overall mass transfer coefficient $K_g = 8.4 \times 10^{-3}\ \mathrm{m/s}$

Specific contact area of packing $a = 194\ \mathrm{m^2/m^3}$

Henry's Law constant $H = 9.03 \times 10^{-3}$

The log mean driving force formula for mass transfer is

$$\text{rate of mass transfer (kmol/s)} = K_g A \left\{ \frac{\left(c_{g\mathrm{B}} - Hc_{l\mathrm{B}}\right) - \left(c_{g\mathrm{T}} - Hc_{l\mathrm{T}}\right)}{\ln\left[\left(c_{g\mathrm{B}} - Hc_{l\mathrm{B}}\right) / \left(c_{g\mathrm{T}} - Hc_{l\mathrm{T}}\right)\right]} \right\}$$

where A is the contact area for mass transfer, and T denotes the top of the column.

SECTION E (Electrical Engineering)

13 Explain, with the aid of diagrams, what is meant by: [4]

(a) positive resist technology;

and

(b) negative resist technology.

Explain what is meant by the terms *Depth of Field* and *Resolution* as applied to lithographic systems. [4]

Describe the lithographic processes currently used in the manufacture of transistors and discuss the relative merits of *UV optical lithography, x-ray lithography* and *electron beam lithography* for the manufacture of next generation fast transistors. [6]

A VLSI designer wishes to use whole-wafer exposure for a silicon wafer of 300 mm diameter and a flatness of $\pm$ 7 microns. The smallest device feature is to be 0.3 micrometers. A projection exposure system of wavelength 0.25 microns and Numerical Aperture of 0.3 is available. Discuss the suitability of such a system for this application and discuss techniques for overcoming any difficulties that the designer may encounter. [6]

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14 (a) Outline the key evidence that electrons can behave like waves. [4]

(b) Calculate the wavelength of an electron of kinetic energy 0.1 eV, when its effective mass is 0.1 times the free electron mass. [4]

(c) Contrast the classical and quantum behaviour of an electron of kinetic energy 0.1 eV when it meets a barrier of height 1 eV and length L. [4]

(d) Write down the form of the wavefunction in each of the three regions of (c) shown in Fig. 7 for an electron approaching from the left. Without detailed mathematics, describe how the transmission probability varies with width L, giving an estimate of the length for the transmission probability to fall by a factor of e^2. Explain how these wave properties would affect the design of very high speed Field Effect Transistors. [8]

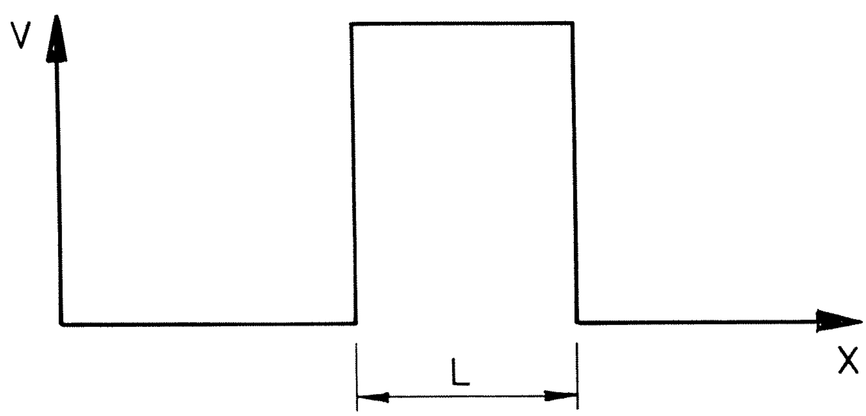

Fig. 7

15 (a) Sketch the electron velocity versus electric field dependence for silicon, assuming its mobility is $0.1\ \mathrm{m^2\ V^{-1}s^{-1}}$ and its scattering-limited velocity is $10^5\ \mathrm{ms^{-1}}$. [3]

(b) You desire to design a fast MOSFET from a thin $1\ \mu\mathrm{m}$ layer of n-type silicon on an insulating substrate, using a supply voltage of 2 V. Calculate the source to drain length L and electric field which would give a transit time of 10 ps, justifying any assumptions you make. [3]

(c) Sketch the charge distribution in the MOSFET when turned off, when the donors in the source-drain channel are fully ionised.

By considering a cylinder of height x and cross-sectional area A, with its base at the bottom of the silicon where the field and voltage are zero, use Gauss's theorem to work out the electric field at its top surface due to the enclosed charge of density q per unit volume. [5]

Calculate the voltage at the gate by integrating the field over x. Hence obtain the formula for capacitance per unit area of the gate. Calculate the gate capacitance of this MOSFET assuming a permittivity for silicon of $10^{-10}\ \mathrm{Fm^{-1}}$ and a source width to source-drain length ratio, W/L, of 10. [4]

(d) In the structure detailed in part (c), if the resistivity of the silicon is $0.01\ \Omega\mathrm{m}$, calculate the source-drain resistance, and compare the RC time constant with the transit time given in part (b), to show which factor would appear to control the device speed. [5]

SECTION F (Information Engineering)

16 Describe what is meant by hashing and explain how hashing can be used to give efficient access to large tables of information. State the criteria which should be used in designing the hash function for a specific application. [5]

In a high security network, every packet contains a source address (SA), a destination address (DA) and a security code (SC) which is unique to every pair of source and destination addresses. A security unit monitors all network traffic and for each packet, it uses the SA/DA pair to access a look-up table of security codes. If there is no entry for SA/DA or the retrieved SC does not match the code stored in the packet, then it raises an alarm.

Write a LookUp function with heading

FUNCTION LookUp(sa: Address; da: Address) : SecurityCode

which uses hashing to allow rapid retrieval of stored SCs given an SA/DA pair. Include in your answer the design of a suitable data structure for the hash table entries and the design of the hash function. It may be assumed that addresses and security codes are simple integers and that source and destination addresses are random and uncorrelated. An address can lie anywhere within the integer range and a code of 0 is returned by LookUp if the given SA/DA pair is not in the table. [12]

If it is subsequently discovered that the least significant 8 bits of SA/DA pairs are often identical, what would be the effect on the retrieval performance of your design? [3]

17 (a) Explain what is meant by *connection oriented* and *connectionless* protocols in the context of computer networks. Briefly discuss the relative merits of the two types of protocol. [6]

(b) Show how a transport layer packet is constructed from various layers' protocol headers and from the data being transferred by the transport layer. Describe what essential information you would expect to find in each of the protocol headers in a system where each layer up to and including the transport layer is connectionless, explaining the purpose of each of these information fields. [7]

(c) A network monitor is to be used on an Ethernet to investigate poor performance caused by an excessive number of packets being generated. The aim is to classify the packets into groups, count the number in each group and hence identify the source of the problem by finding which groups contain a very large number of packets. The problem is thought to be caused by one of the following: [7]

(i) a few computers generating spurious packets;

(ii) a misconfigured computer retransmitting each broadcast packet it receives;

(iii) a single malfunctioning application on some computer.

Explain in each case how the packet header information should be used to group packets and what filtering, if any, might be done in the hardware.

(TURN OVER

18 Explain briefly what is meant by polled-mode and interrupt-mode input/output and list the benefits of each approach. [3]

A portable network monitor unit is to be designed using a display with a touch-screen to replace the keyboard. The touch-screen uses a simple controller chip which has an 8 bit control/status register and an 8 bit data register as follows:

Name	Address	Function
Data	0FE000	Read only data register
Cont	0FE001	Write only control reg:
	Bit 0	- set to reset device
	Bit 1	- set to enable interrupts
	Bits 2-4	- X resolution (num pixels-1)
	Bits 5-7	- Y resolution (num pixels-1)
Stat	0FE001	Read only status reg:
	Bit 0	- set when data ready
	Bits 1-3	- 3 bit error code (0=no error)

The resolution determines the number of pixels per bit in the position values read from the data register. In operation, pressing on the touch screen causes bit 0 of the status register to be set and, if enabled, an interrupt is generated at vector address 0200H. The corresponding screen position can then be obtained from the data register using two successive reads to get the X position and then the Y position.

Write suitable type and variable definitions to describe these registers using Pascal notation. [6]

(cont.

The interface to this device is to be a circular buffer of (X,Y) positions which is filled by an interrupt service routine and emptied by the application program. Design a suitable module interface and implement the interrupt service routine using Pascal notation. [9]

In a multi-process environment, what additions would be needed to allow a process to sleep waiting for the screen to be touched? [2]

END OF PAPER