PM 2K601 METROLOGY & INSTRUMENTATION

Time: 180 minutes Maximum marks: 100

Use of statistical tables is permitted.
Assume suitable data where required and state the same clearly.
Illustrate your answers with neat sketches, wherever applicable.
For numerical problems, define all variables in the equations and explain the logic behind each step
Answer all questions

1. a) Briefly describe the sequential procedure recommended by Montgomery for planning and carrying out a complex experiment.
   b) Derive an expression for the time constant of a liquid in glass bulb thermometer. Explain the assumptions made.
   c) Describe the methods to detect data outliers from measured data.
   d) Describe a digital Data Acquisition System and briefly explain its various components.
   e) Explain the working principle of a heterodyne Laser Interferometer.
   f) Explain what is filter cut-off and how it is selected when measuring surface roughness.
   g) Explain the working of touch trigger probes used in CMMs.
   h) Sketch the section of a piezoelectric pressure transducer and explain how it works.

   (8 X 5 = 40 marks)

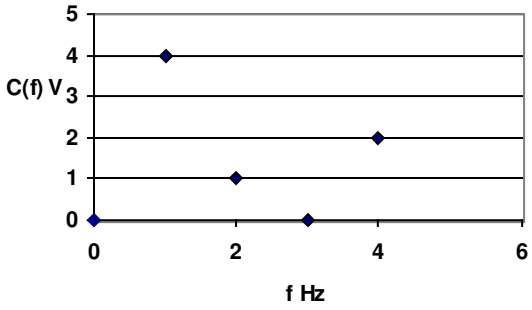
2. a) i) Three micrometers having least counts of 0.01 are each compared with four slip gauges and the following data is obtained:

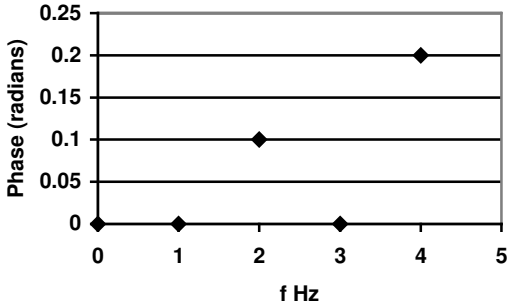
Slip gauge size (mm)	10.000	20.000	30.000	40.000
Micrometer A	10.02	20.04	30.02	40.04
Micrometer B	10.05	19.95	30.05	39.95
Micrometer C	10.10	20.10	30.11	40.11

Identify the most precise, least precise, most accurate and least accurate micrometers. Justify your choices.

(7 marks)

ii) The amplitude spectrum and phase shift of a signal are given below:





Express the signal in terms of a Fourier series. What is the frequency resolution used? Determine the sample time increment.

(8 marks)

OR

b) i) The displacement of a cutting tool is represented by the equation $s = 5 \sin 4\pi t + 0.5 \cos 50\pi t + 0.02 \sin 40\pi t$, where t is the time in seconds. What is the fundamental frequency in Hz? What is the fundamental period in seconds? Rewrite the displacement equation in terms of sine terms only.

(7 marks)

ii) A seismic transducer has a damping ratio of 0.6 and a ringing frequency of 640Hz. Determine the error in magnitude and phase if it is used to measure a vibration with an amplitude of 50μm and frequency of 720Hz.

(8 marks)

3. a) i) The deviations of a surface from an ideal line were measured and recorded as below:

x(mm)	-200	-100	0	100	200
y(μm)	0	2	4	2	10

Determine the best-fit straight line using the method of least squares. What is the straightness error? Show all steps and calculations clearly. (Do not use the regression program in calculators).

(8 marks)

ii) A 0-8V, 4 bit successive approximation A/D converter is used to measure an input voltage of 5.4V. Determine the binary representation and its analog approximation.

(7 marks)

OR

b) i) The output of a UPS is sampled at 40Hz with a signal analyser. What is the maximum frequency component that will be obtained? If the UPS ouput is a sine wave with frequency 50Hz, what will be the frequency indicated by the analyser?

(5 marks)

ii) The diameter of a shaft was measured and the following readings obtained: 10.11, 10.13, 10.09, 10.11, and 10.09mm. Determine the limits of the shaft diameter with 95% confidence.

(5 marks)

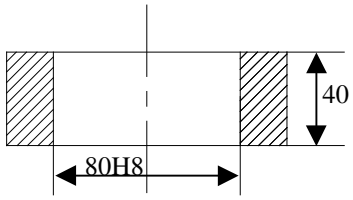
iii) The volume of a cylinder is determined from diameter and length measurements using a vernier caliper. The measured diameter was 50.5mm with an uncertainty of +/-0.02mm (95%). The length was obtained as 80.5mm +/-0.03mm (95%). The vernier caliper was calibrated and found to have an error of +0.4mm due to bending of the jaws with negligible uncertainty. Determine the best estimate of the volume of the cylinder and its uncertainty.

(5 marks)

4. a) i) Observation of a slip gauge on a flatness interferometer produced fringe counts numbering 8 and 12 for the two observation conditions. Assuming that both faces are flat, calculate the error in parallelism if the radiation wavelength is 0.5893μm.

(5 marks)

ii) Design GO and NO GO gauges to check the following component, conforming fully to Taylor's principles. Provide a wear allowance. IT8 tolerance is 50μm.



(5 marks)

iii) What must be the conversion time period per pixel for an analog to digital converter to be used with a solid state camera having an 896 X 924 pixel matrix. An image processing rate of 20 frames per second must be achieved. The object to be viewed is of size 75 X 75 mm.

(5 marks)

OR

b) i) It is planned to inspect a gear by measuring the base tangent length over three teeth. The involute profile gear with 28 teeth has a module of 1.5mm and pressure angle of 20^o. This gear meshes with another gear having 104 teeth. What is the ideal value of the base tangent length?

(5 marks)

ii) It is required to measure an angle of $29^o15'12"$ using a sine bar of 200mm. Find the length of slip gauges required. Choose the minimum number of gauge blocks to build up the size from the following set:

Range, mm	Steps, mm	No of pieces
1.001 to 1.009	0.001	9
1.01 to 1.09	0.01	9
1.1 to 1.9	0.1	9
1 to 9	1	9
10 to 90	10	9

(5 marks)

iii) Sketch the arrangement of jets on a pneumatic plug gauge to check the bore straightness and explain its working principle.

(5 marks)

5. a) i) The output emf (E) in millivolts of a J type thermocouple with reference junction at 0^oC can be approximated by the equation $E = 0.05T + 0.00003T^2$, where T is the temperature in ^oC. A J type thermopile having four junctions, with reference junction at 30^oC, produced an emf of 33.78mV. Determine the temperature sensed by the thermopile.

(8 marks)

ii) Four strain gauges are used to measure strain in a column subject to uniaxial stress. Sketch how the gauges should be arranged on the column so that temperature and bending effects are compensated. Explain how the compensation is achieved.

(7 marks)

OR

b) i) An inclined tube manometer is used to measure the pressure difference across an orificemeter through which air is flowing. The length of the scale is 200mm and the inclination can be adjusted in steps of 3^o only, from 0^o to 30^o. The manometric fluid has a specific gravity of 0.8. At what angle would you set the inclination, if it is desired to measure a maximum pressure difference of 400Pa with the maximum sensitivity.

(5 marks)

ii) A stroboscope was observed to synchronize at 18,000 flashes per minute on an object rotating with a very high speed. The flash rate was decreased slowly, till synchronisation was achieved. Once again, the flash rate was decreased slowly, and this time synchronisation was achieved at 9000 flashes per minute. Determine the rotational speed of the object.

(5 marks)

iii) What is a "Proving Ring"? Explain its use with the aid of a sketch.

(5 marks)

SCHEME OF VALUATION

1) Each question 5 marks:
   a) Brief explanation of the following steps: Recognition of and statement of problem, Choice of factors, levels, and range, Selection of the response variable, Choice of experimental design, Performing the experiment, Statistical analysis of the data, Conclusions and recommendations.
   b) Derivation of the equation Time constant $\tau = mc_v / hA_s$, where m is the mass of liquid within the thermometer, c_v the specific heat of liquid within the thermometer, h the convection heat transfer coefficient between bulb and environment, and As the thermometer surface area – 3 marks, Assumptions – 2 marks.
   c) Graphical methods– 2 marks, Three sigma test – 3 marks
   d) List DAS components – Filters, Amplifiers, Shunt Circuits, Multiplexers, A/D converters, D/A converter, Microprocessor, Memory, Central Bus, Buffers – 2 marks. Explanation 3 marks
   e) Sketch – 2 marks. Explanation- 3 marks
   f) Description – 3 marks, Selection – 2 marks
   g) Sketch – 2 marks, Explanation 3 marks
   h) Sketch 3 marks, Explanation 2 marks

2)
   a)
      i) Identification - C is most precise but most inaccurate. B is least precise but most accurate (4 marks). Justification of choices (3 marks)
      ii) Fourier series V= 0 + 4 sin2πt + 0.99 sin4πt + 0.1 cos4πt + 1.96 sin 8πt + 0.4 cos 8πt ; (4 marks)
      Frequency resolution = 1Hz;
      Largest frequency obtained = 4 Hz, Hence sampling frequency = 8Hz, sample time increment = 1/8 = 0.125s. (4 marks)

   b)
      i) Fundamental frequency – 2 Hz, Fundamental period – 0.5s, (2 marks)
      Rewrite as s = 5 sin 4πt + 0.5 sin(π/2- 50πt) + 0.02 sin 40πt, (3 marks)

      ii) Natural frequency $\omega_n = \omega_d / \sqrt{1-\xi^2} = 640/\sqrt{1-0.6^2}$ = 800Hz (2 marks)
      ω / ω_n = 720/800 = 0.9
      Magnitude ratio
      $$M(\omega) = 1/\sqrt{\left[1-(\omega/\omega_n)^2\right]^2 + (2\xi\omega/\omega_n)^2} = 1/\sqrt{\left[1-0.9^2\right]^2 + 2*0.6*0.9}$$
      =0.9466 (2 marks)
      Measured amplitude = 47.33μm
      Error in magnitude = -2.672 μm (2 marks)
      Phase shift = tan-1 $\left[\dfrac{-2\xi\omega/\omega_n}{1-(\omega/\omega_n)^2}\right] = \dfrac{-2*0.6*0.9}{1-0.9^2}$ =-80° (2 marks)

3)
   a)
      i) Regression equation is y = 3.6 + 0.02 x (6 marks)
      Straightness error = 3.6 + 2.4 = 6μm (2 marks)
      ii) Resolution = $E_{FSR}/2^M = 8/2^4 = 0.5$V
      Binary representation 1010 (5 marks)
      Analog approximation 5.0V (2 marks)

   b)
      i) Max frequency component Nyquist frequency $f_N = f_m/2$ = 20 Hz (2 marks)
      10Hz. (3 marks)
      ii) Mean = 10.106, Sample standard deviation = 0.0167332 (2 marks)
      From statistical tables, $t_{0.025,4}$ = -2.77
      Confidence interval = 10.106 +/-2.77*0.0167332 = 10.06 to 10.153 (3 marks)
      iii) Corrected d =50.1mm, h = 80.1mm
      $V=\pi d^2h/4$ = 157905.7mm^3 (2 marks)

$$\theta_d = \frac{\partial V}{\partial d} = 2\pi dh/4 = 6304$$

$$\theta_h = \frac{\partial V}{\partial h} = \pi d^2/4 = 1971$$

$$\delta V = \sqrt{(\theta_d \delta d)^2 + (\theta_h \delta h)^2} = 139.2 \text{ mm}^3 \text{ (3 marks)}$$

OR By sequential perturbation,

d	h	V				
50.1	80.1	157905.7				
50.12	80.1	158031.8	126.0976	126.0976		
50.08	80.1	157779.7	-126.047	126.0473	126.0724	
50.1	80.13	157964.9	59.14072	59.14072	59.14072	139.2547
50.1	80.07	157846.6	-59.1407	59.14072		

4)

a)

i) (0.5893/2)*(12-8)/2= 0.5893 μm (5 marks)

ii) GO – Plain cylindrical plug gauge with OD 80+0.0025/+0.005 and length at least 40.
NO GO – Two point gauge (but not cylindrical) with OD 80+0.045/+0.05 (5 marks)

iii) Pixels per frame = 896 * 924 = 827904
Hence bits per frame = 827904 * 20 = 16558080 bits per second (5 marks)

b)

i) $$BTL = Nm\cos\phi\left[\tan\phi - \phi - \frac{\pi}{2N} + \frac{\pi S}{N}\right]$$

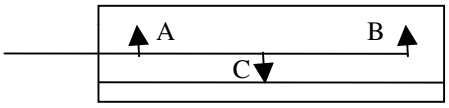
$$= 28 * \cos 20\left[\tan 20 - 0.34906 - \frac{\pi}{228} + \frac{\pi * 3}{28}\right] = 11.65\text{mm (5 marks)}$$

ii) h=L sinθ = 200 sin29.2533 = 97.734mm (2 marks)
1.004 + 1.03 + 1.7 + 4 + 90 = 97.734mm (3 marks)

iii)

Sketch 2 marks, explanation 3 marks

Jets A and B are equal and jet C has a flow equal to A + B

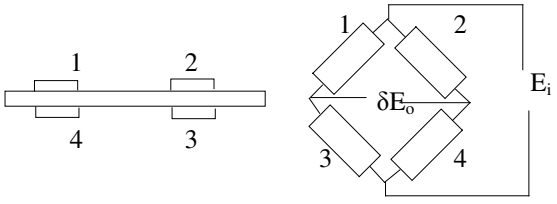


5)

a)

i) Emf per thermocouple = 33.78/4 = 8.445mV (2 marks)
$E_{30,0}$ = 0.05 * 30 + 0.00003 * 30 * 30 = 1.527mV
From the law of intermediate temperatures,
$E_{T,0} = E_{T,30} + E_{30,0}$ = 8.445 + 1.527 = 9.972mV (2 marks)
Solving for T in $0.05T + 0.00003T^2 = 9.972$
$T^2 + 1666.66\,T - 332400 = 0$
T = 180°C (4 marks)

ii)



Sketch 4 marks, explanation 3 marks

b)

i) $\theta = \sin^{-1}\{P_1 - P_2 /[(\rho_m - \rho) g L]\} = \sin^{-1} \{ 400/[800*9.81*0.2]\} = 14.76^o$
Hence choose 12^o (5 marks)

ii) $$R = \frac{R_1 R_N (N-1)}{R_1 - R_N} = \frac{18000*9000*2}{18000-9000}$$ = 36000rpm (5 marks)

iii) Sketch 2 marks, Explanation 3 marks