METROLOGY

22WSC603

Semester 2 2023 In-Person Exam paper

This examination is to take place in-person at a central University venue under exam conditions. The standard length of time for this paper is **2 hours**.

You will not be able to leave the exam hall for the first 30 or final 15 minutes of your exam. Your invigilator will collect your exam paper when you have finished.

Help during the exam

Invigilators are not able to answer queries about the content of your exam paper. Instead, please make a note of your query in your answer script to be considered during the marking process.

If you feel unwell, please raise your hand so that an invigilator can assist you.

You may use a calculator for this exam. It must comply with the University's Calculator Policy for In-Person exams, in particular that it must not be able to transmit or receive information (e.g. mobile devices and smart watches are **not** allowed).

METROLOGY

(22WSC603)

Summer 2023 2 Hours

Answer **ALL THREE** questions.

Questions carry the marks shown

Any University-approved calculator is permitted.

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1. Uncertainty Analysis is a key part of Metrology. An aerospace component destined for Boeing Corporation in the USA, is manufactured by Moog Ltd in Wolverhampton (UK). One dimension of the component is measured a number of times by one operator using a Mitutoyo micrometer. A second dimension is measured using a Mitutoyo Vernier Caliper by another operator. Both sets of results are recorded in inches and are shown in Table Q1(A) and Table Q1(B) respectively. A statement of equipment specification is provided by Mitutoyo, and is defined as being (±0.0035 inches at a 95% confidence level) for the Micrometer, and (±0.020 inches) for the Vernier Caliper. Student *t*-distribution coefficients are identified in Table Q1(C).

a) In brief terms, explain why Uncertainty Analysis is important for a measurement process, and identify the primary international standard or framework that underpins Uncertainty Analysis. [4 marks]

b) When completing an Uncertainty Analysis for a measurement process, briefly identify eight elements of the measurement process that may cause uncertainty within the final measurement result, and explain what the initial pragmatic approach should be to further the assessment of these sources. [8 marks]

c) Using diagrams where appropriate, detail the manner in which individual Uncertainties are processed and subsequently combined into a final Expanded Uncertainty statement (U). Reference should be made to appropriate data manipulations that are required, and assumptions made about the probability distributions of the uncertainty sources. [5 marks]

d) Calculate each of the Expanded Uncertainty values (U) for the two measured dimensions defined above, and state your assumptions made for these two different scenarios. [8 marks]

2. Coordinate Measuring Machines (CMM) typically use Touch Trigger Probes to determine data points in Cartesian and/or Polar Coordinates. Like any measurement instrument (simple or complex) application can be made more efficient by the use of Inspection Planning. The National Physical Laboratory have published four Measurement Good Practice Guides concerned with application and use of CMMs, including; CMM Probing, and, Inspection Planning for CMMs.

a) Briefly identify the key elements of a generic Dimensional Inspection Plan, specifically in the context of a CMM, taking into account the requirements from; switching the CMM on, through to data processing. [5 marks]

b) A series of geometric shapes that exemplify typical measurements completed using a CMM are shown in Figure Q2(A). Define the minimum mathematical requirements for probing these features, and, estimate alternative requirements for probing these features, justifying why your answers may be different to the mathematical minimum. [3 marks]

A component is shown in Figure Q2(B) that is required to be measured using a Hexagon Metrology Global Advantage 775 CMM, using a Renishaw PH10MQ Probe Head, with a medium force TP20 TTP. Appropriate Renishaw styli are shown and can be selected from Table Q2(A) and Table Q2(B) using the Renishaw part numbers where relevant. The $E_{L,MPE}$ statement for the CMM is (1.4 + L/450 µm), and the A, B and C component datums are aligned with the X, Y, Z global coordinate system and axes of the CMM respectively.

c) Develop and detail a brief Dimensional Inspection Plan using the CMM for the component shown in Figure Q2B, specifically taking into account all features that are labeled (*V, W, X, Y* and *Z* respectively). Identify what are the measurement issues when dealing with the measurement of the ensemble of features, what appropriate styli should be chosen using Tables Q2(A) and/or Q2(B), and what additional equipment you might need to cause successful measurement of these features. [9 marks]

d) Measurement data from the component is shown in Table Q2(C) for a limited number of the component features. Process the data and identify the status of each feature with respect to the specification, noting that object orientation may have changed as a function of measurement requirement. Note that reference to the MPE_E statement should be made where relevant. [8 marks]

3. Many *R* surface texture parameters exist for surface roughness measurement. One such parameter is known as the "*arithmetic mean of the absolute departures of the profile from the mean line*".

a) Using diagrams where appropriate, explain how this parameter is derived, and how it may be manually calculated from a profile trace. In addition, identify what additional information is required to supplement the parameter value to allow confidence in understanding and use of the final result, and why this parameter may lead to ambiguity when measuring different types of surface. [8 marks]

b) Two other similar variants of this parameter exist and are described using the capital letters *P* and *W*. Explain what the differences are between *P, R* and *W* based parameters for this specific example, in what circumstances they may be applied, and how the information they generate should be interpreted. [4 marks]

c) Figure Q3 shows a section of a trace profile that has been recorded from an object surface using a Form Talysurf Intra with a 50 mm long stylus and a stylus tip with a radius of 0.5 μm. The object is manufactured from magnesium alloy. Calculate the approximate value of the primary quantifier of the "*arithmetic mean of the absolute departures of the profile from the mean line*", for the trace shown in Figure Q3. A section spacing of approximately 2 μm would be appropriate. [9 marks]

d) The object has been measured at a temperature of 299 K. With respect to the vertical direction and the mean line through the trace, identify what would be the maximum change of peak height and valley depth if thermal compensation was applied with reference to the International Temperature for Measurement, and identify what influence this would have on the previously calculated "*arithmetic mean of the absolute departures of the profile from the mean line*" value. [4 marks]

Magnesium alloy properties:

Elastic Modulus; 45×10^9 Nm^{-2}, Shear Modulus; 17×10^9 Nm^{-2}, Coefficient of Thermal Expansion; 24.8×10^{-6} K^{-1}, Poisson Ratio; 0.290.

J N Petzing

1.375	1.372	1.374
1.378	1.376	1.376
1.377	1.377	1.373
1.374	1.375	1.375
1.373	1.375	1.377
1.376	1.378	1.374
1.375	1.374	1.375
1.378	1.373	1.372

Table Q1(A)

4.21	4.18
4.25	4.23
4.19	4.20
4.17	4.21
4.20	4.19

Table Q1(B)

Data Points	**Student t-factor**		
(n)	**(k = 1)**	**(k = 2)**	**(k = 3)**
3	1.32	2.27	---
4	1.20	1.66	3.07
5	1.14	1.44	2.21
6	1.11	1.33	1.84
7	1.09	1.26	1.63
8	1.08	1.22	1.51
9	1.07	1.19	1.43
10	1.06	1.16	1.36
11	1.05	1.14	1.32
12	1.05	1.13	1.28
13	1.04	1.12	1.25
14	1.04	1.11	1.23
15	1.04	1.10	1.21
16	1.03	1.09	1.20
17	1.03	1.09	1.18
18	1.03	1.08	1.17
19	1.03	1.08	1.16
20	1.03	1.07	1.15

Table Q1(C)

Ruby ball / Tungsten Carbide stem									
Ball diameter (mm)	**0.5**	**0.7**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**4.0**	**5.0**
Length 10 mm	A-5000-7805	A-5000-7801	A-5003-1325	–	–	–	–	–	–
20 mm	A-5003-1345	A-5003-0577	–	A-5003-0034	A-5003-3822	A-5003-1896	A-5003-0938	A-5003-1029	A-5003-0046
30 mm	–	–	A-5000-8663	A-5003-0035	A-5003-0036	A-5003-0038	A-5003-0040	A-5003-0043	A-5003-0047
40 mm	–	–	–	–	A-5003-0037	A-5003-0039	A-5003-0041	A-5003-0044	A-5003-0048
50 mm	–	–	–	–	–	–	A-5003-0042	A-5003-0045	A-5003-0049

Table Q2(A)

Ruby ball / Carbon Fibre stem			
Ball diameter (mm)	**4.0**	**5.0**	**6.0**
Length 30 mm	A-5003-4241	A-5003-4781	A-5003-4782
50 mm	A-5003-2285	A-5003-2286	A-5003-2287
75 mm	A-5003-4784	A-5003-4785	A-5003-4786
100 mm	A-5003-2289	A-5003-2290	A-5003-2291

Table Q2(B)

Feature X	(61.00, 42.097, 4.002)
	(49.003, 42.102, 3.998)
	(61.014, 23.108, 4.001)
	(48.994, 23.084, 4.003)
	(47.507, 36.614, 4.000)
	(47.510, 28.598, 4.002)
	(66.512, 36.603, 3.999)
	(66.511, 28.598, 3.997)
Feature Y	(70.414, 15.001, -10.497)
	(84.408, 15.002, -10.501)
	(77.393, 15.000, -3.488)
	(77.421, 15.002, -17.504)
	(70.409, 56.999, -10.503)
	(84.402, 57.001, -10.493)
	(77.413, 57.000, -3.472)
	(77.394, 56.998, -17.494)

Table Q2(C)

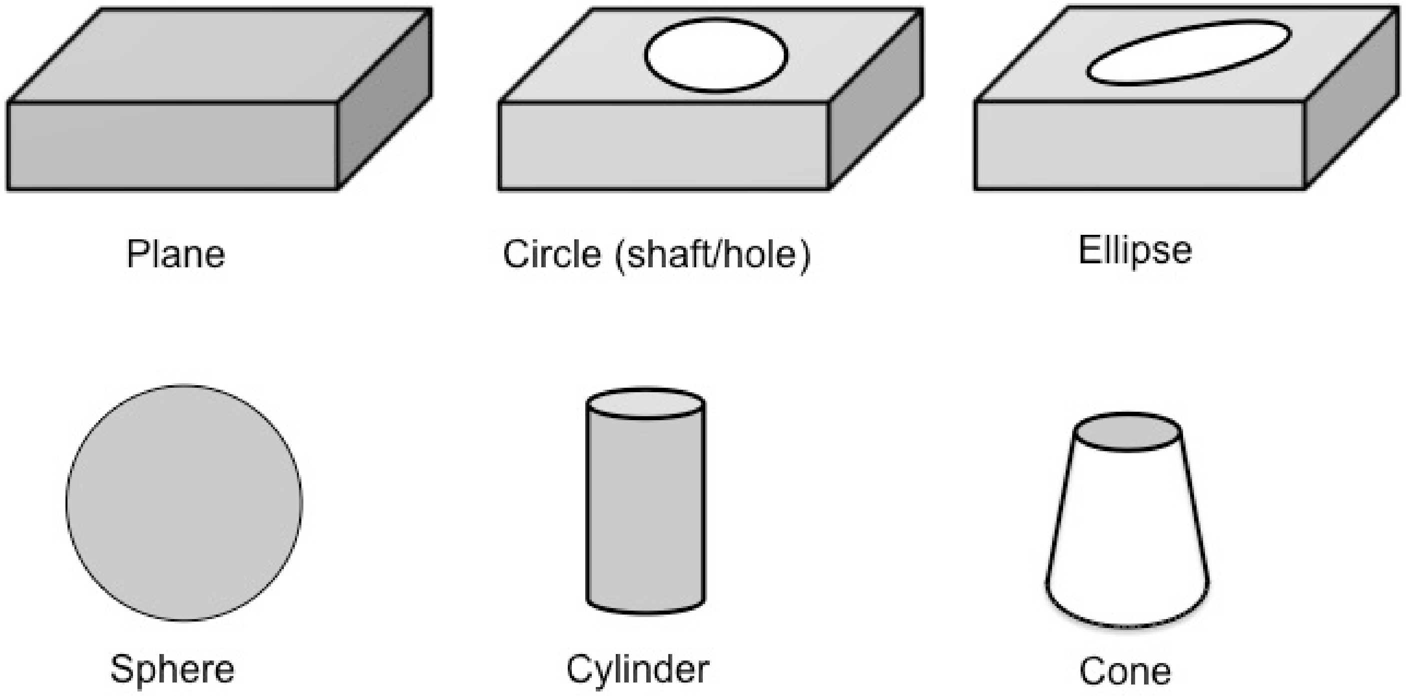
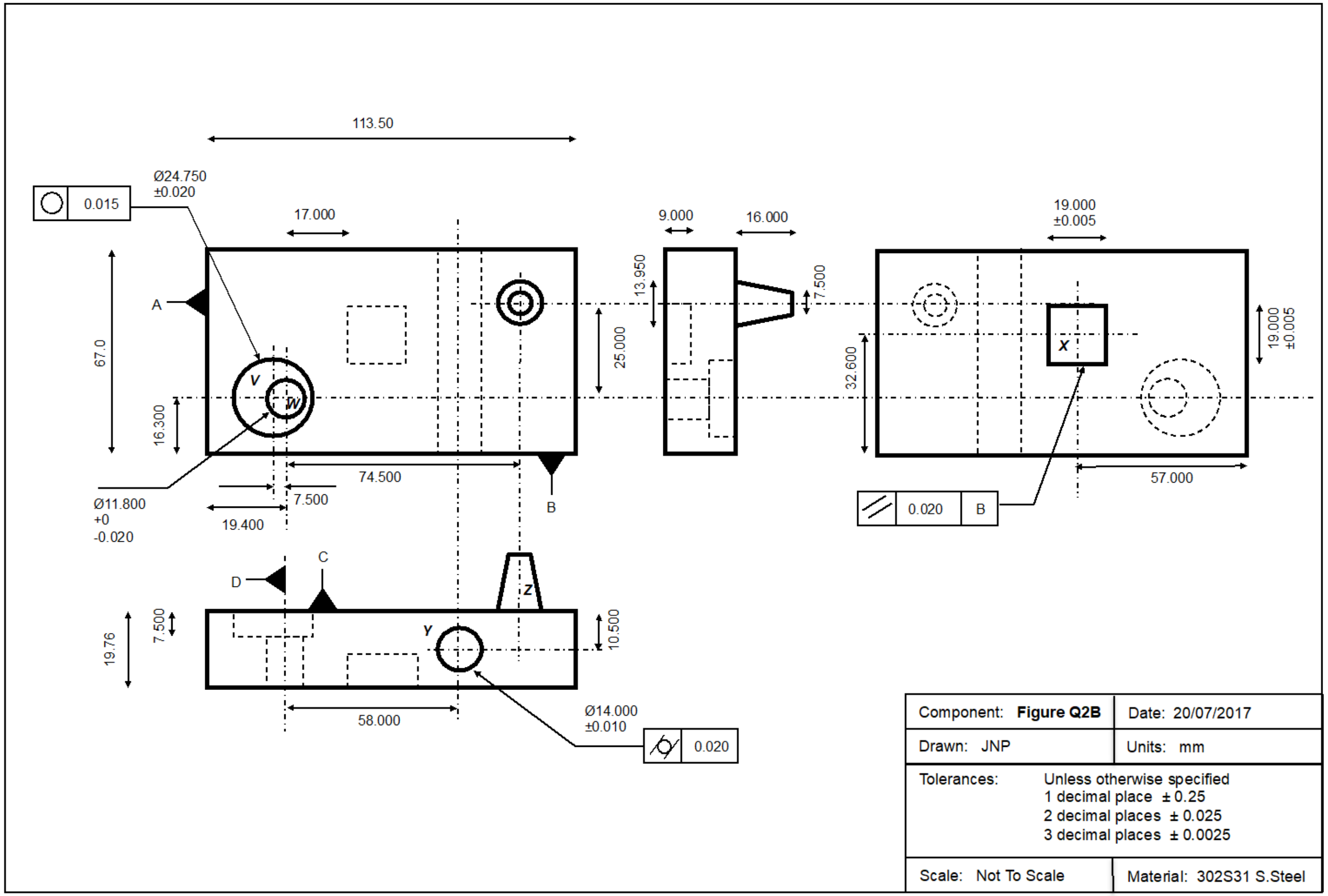


Figure Q2(A)



Component: **Figure Q2B**	Date: 20/07/2017
Drawn: JNP	Units: mm
Tolerances:	Unless otherwise specified 1 decimal place ± 0.25 2 decimal places ± 0.025 3 decimal places ± 0.0025
Scale: Not To Scale	Material: 302S31 S.Steel

Figure Q2(B)

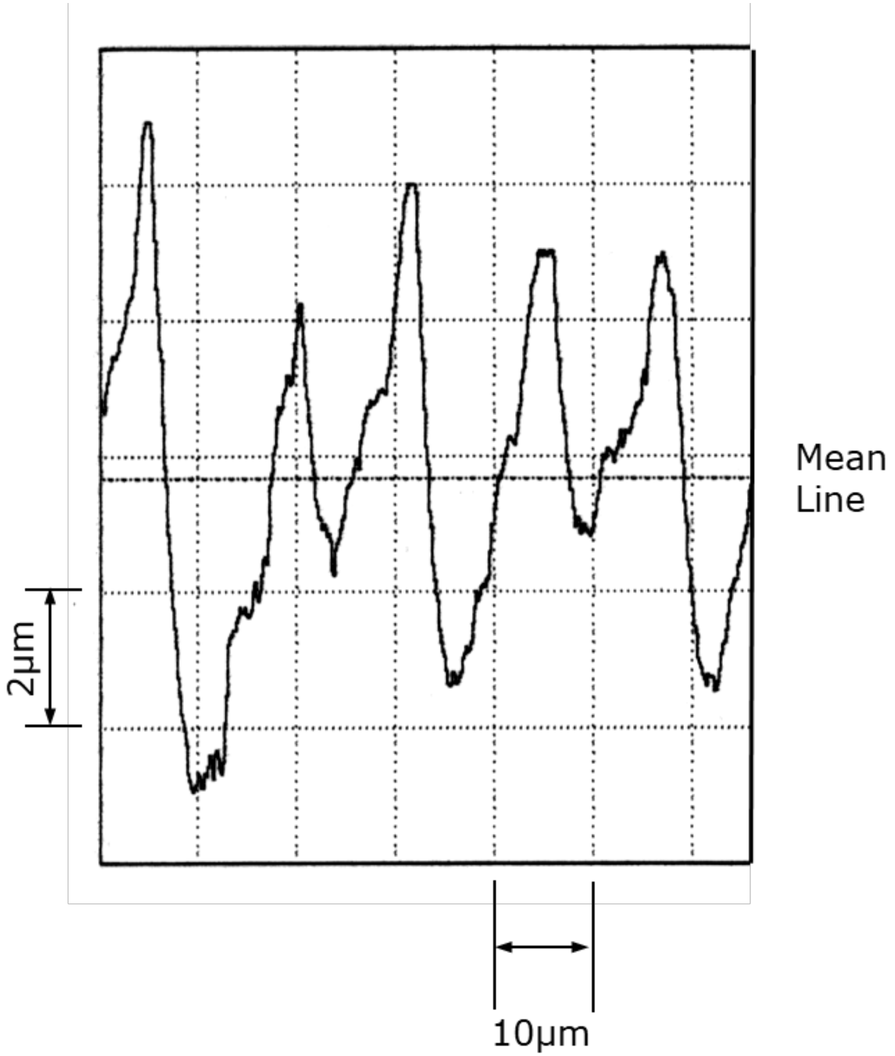


Figure Q3