Loughborough University

Metrology

24WSC603

Semester 2 2025 | 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.

Answer **ALL THREE** questions.

All questions carry equal marks.

Use of a calculator is permitted - 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).

A company called AeroRepair Ltd contacts your company for some contract measurements. With them they have a piece of wing spar (structural component of an aeroplane wing), and they want to measure the object.

During initial discussions, the AeroRepair Ltd representatives are no more informative or descriptive than saying "*we need to measure this component*". For the purposes of this discussion it can be assumed that all potential measurements are related to the metre.

a) Given that AeroRepair Ltd has only provided this limited guiding statement, identify and discuss how you would develop the discussion with the representatives, in order to allow you to implement and complete appropriate measurements.

   Within the discussion, identify what key pieces of further information you require in order to proceed and implement measurement. [12 marks]

b) The AeroRepair Ltd representatives also indicate that they need to have a high level of confidence in the measurement data produced.

   Using diagrams to support your discussion, explain what generic measurement procedures, metrology management procedures, and documentary evidence you have implemented in your company, that will allow you to demonstrate the level of confidence attached to the measurement data. [13 marks]

2. A Global (S) Coordinate Measuring Machine (CMM) manufactured by Hexagon Metrology is being used for shop floor measurements of components within a manufacturing cell. Components are typically removed from 5 axis machining systems, allowed to cool to the point they are only warm and can be manually handled before being put into the CMM. The factory environment experiences temperatures from 15°C to 24°C depending on the time of year, and humidity is not controlled. The factory roof has large southerly facing panel sky lights to aid ambient light levels.

a) The CMM requires periodic verification. Identify what your verification strategy would be for the CMM and the company, in the context of relevant international ISO standards. Make reference to long term and short term processes, explain the benefits and downsides of both the long and short term processes, and identify consequences with the manner in which the CMM is sited and operated. [8 marks]

b) A Renishaw Machine Checking Gauge (MCG) is used periodically in the CMM and is manufactured from stainless steel with ruby spheres. An automated routine has been programmed for operation of the MCG. The MCG is supplied with 101.0017 mm, 150.9927 mm, 225.4539 mm and 380.3448 mm measurement arms. Identify the processes by which the MCG should be used and applied, and the key characteristics of the data that would be required to assess CMM performance. [6 marks]

c) **Table Q2 (page 5)** contains a limited subset of data produced from the use of the MCG on the Hexagon Metrology CMM. This dataset contains one complete cycle of data acquisition, but does not contain repeat cycles. The data set starts with zero degrees being at three o'clock. Determine the maximum volumetric error defined by the MCG data. [6 marks]

d) Using the reference arm length associated with the measurements from Table Q2 - calculate what the range of error of arm measurement would be found across the working year given the information cited above and what impact this error has (if any) on the maximum volumetric error calculated above. [5 marks]

Assume that for the stainless steel, coefficient of thermal expansion is $9.5x10^{-6}$ K^{-1}, density is 7,800 kgm^{-3}, Elastic constant is 215.3 GNm^{-2}, the bulk modulus is 166 GNm^{-2}.

3. PT Grinding Ltd uses a Mitutoyo CS-H5000CNC contact stylus surface texture measuring instrument and a Bruker NPFLEX Elite Scanning White Light Interferometer, both in a dedicated environment controlled Metrology Laboratory. The instruments are installed and calibrated by Mitutoyo and Bruker respectively, and training provided operators.

Two different operators are requested to independently use the contact instrument to measure the 2D surface roughness characteristics of one piece of fine ground austenitic stainless steel casting. Each stylus trace is 15 mm long as shown in **Figure Q3 (page 6)**. The grinding wheel specification was 51-C-240-R-7-V and the stainless steel cast component was 100 mm x 100 mm x 5 mm in size. Each operator produces a range of *R* parameter data shown in **Table Q3 (page 5).**

a) For the two sets of data obtained from the Mitutoyo CS-H5000CNC, identify five possible contributing factors that will cause the operators to produce different results from the same surface, briefly detailing each of the contributing factors. [10 marks]

PT Grinding Ltd then request that Operator 1 uses the Bruker NPFLEX Elite Interferometer on the same cast austenitic steel sample and produce further 2D roughness data for comparison with the contact stylus.

For this measurement task, a standard 5X Michelson objective lens is used with the camera resolution set at 640 x 480 (horizontal x vertical) pixels, producing an image array size of 1.41 mm x 1.05 mm. Fifteen images are stitched together in a line as shown in Figure Q3 with a 0% data field overlap. The Bruker DigitalSurf software is used to produce a line cross-section down the length of the stitched data with data shown in Table Q3.

b) For the Operator 1 data only using the contact and non-contact instruments, identify and detail reasons why the data will be different, based only on instrument mechanics and physics. [6 marks]

c) Using diagrams where appropriate, identify one type of surface feature more typical of a casting operation that both types of measuring instrument will mis-interpret or not correctly identify. [3 marks]

d) In recognition of these differences, PT Grinding Ltd implement the ISO 21920-1:2021 specification that identifies rules for conformance to surface texture specification. Identify and detail the three core surface texture conformance rules identified in this specification. [6 marks]

J N Petzing

X (mm)	Y (mm)	Z (mm)
225.4646	0.0000	0.0005
159.4209	159.4210	0.0004
0.0008	225.4522	0.0006
-159.4198	159.4206	0.0001
-225.4554	-0.0006	0.0001
-159.4182	-159.4185	0.0001
0.0010	-225.4518	0.0005
159.4188	-159.4192	0.0003
159.4218	0.0009	159.4167
112.7286	112.7288	159.4152
0.0009	159.4203	159.4145
-112.7273	112.7291	159.4169
-159.4207	0.0000	159.4184
-112.7273	-112.7274	159.4174
0.0010	-159.4207	159.4175
112.7287	-112.7261	159.4175
172.7162	0.0002	-144.9138
122.1296	122.1293	-144.9128
0.0008	172.7120	-144.9128
-122.1272	122.1286	-144.9124
-172.7132	-0.0003	-144.9135
-122.1253	-122.1261	-144.9114
0.0011	-172.7126	-144.9126
122.1292	-122.1286	-144.9117

Table Q2

Equipment	Operator 1	Operator 2
Mitutoyo CS-H5000CNC	*Ra* 0.746 µm	*Ra* 0.721 µm
Bruker NPFLEX Elite	*Ra* 0.693 µm	----

Table Q3

 /continued

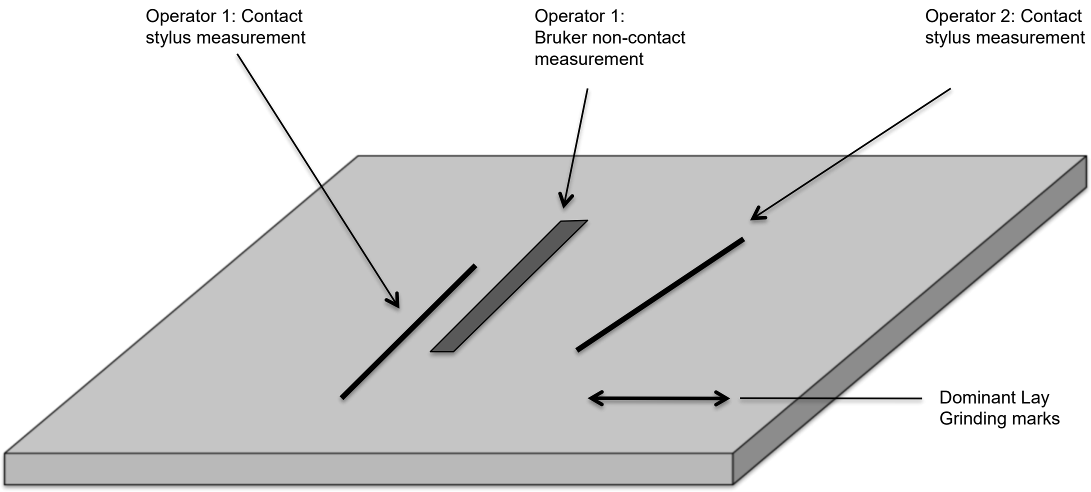
Operator 1: Contact
stylus measurement
Operator 1:
Bruker non-contact
measurement
Operator 2: Contact
stylus measurement
Dominant Lay
Grinding marks

Figure Q3