Loughborough University

Metrology

23WSC603

Semester 2 2024 | 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.

<u>Help during the exam</u>

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.

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).

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1. On April 15th 1931, the Comité International des Poids et Mesures agreed that henceforth, all length measurements should be referenced to 20°C. This agreement is now detailed and enshrined in ISO 1:2002 *Geometrical Product Specifications (GPS) -- Standard reference temperature for geometrical product specification and verification.*

a) Explain the concept of Thermal Memory in the context of measuring a component. [2 marks]

b) Identify and describe four key aspects of the working/measuring environment that will influence the temperature stability of components and metrology instruments, and explain how you would manage these aspects. [8 marks]

The component shown in Figure Q1A has been machined in aluminium alloy. The component is to be used in a harsh thermal environment, at a cryogenic temperature of -120 °C. The component has an operational tolerance specification of +/-0.0045 inches on all dimensions, when operating at the cryogenic temperature.

The component is measured during production in the manufacturing cell on a warm summers day, with the workplace temperature recorded at 24 °C. The delay between the end of the machining operations and the start of the measurement operations is approximately 4 hours. Assume the measurement operations have no error.

Figure Q1B shows the Thermal Expansion Coefficient (TEC) in SI units with respect to temperature for aluminium alloy. Using Figure Q1B to identify relevant approximate TEC values for the material (with a resolution of 0.5×10^{-6} K^{-1});

c) Calculate the thermal errors of measurement as a function of the manufacturing environment, and identify which dimensions of the component will be in-tolerance, or, out-of-tolerance, when measured in the manufacturing cell. Explain the consequence of the thermal errors with respect to the dimensional tolerances, and any subsequent measurement of the part. [10 marks]

d) With reference to ISO 1:2002, calculate the maximum size change of the component when operating in the operational temperature regime, and identify which dimension will be outside the operational tolerance specification. [5 marks]

2. A 304 austenitic stainless steel prismatic component has been manufactured to the specification shown in Figure Q2. The company inspection team has been requested to assess the conformity to specification using metrology hand tools as defined in Table Q2A.

The resulting data is shown in Table Q2B although the inspection report has grouped measurements together. Measurements have been completed with respect to the datums defined in the specifications noting that multiple repeats of measurement were not completed.

Features X and Y have been measured positionally using the TesaTest DTI in combination with the Mitutoyo Height Master. Feature X used a combination of a spring gauge and an external micrometer. Feature Y required the component to be placed on a pair of 40 mm gauge blocks to allow equipment to correctly access feature Y.

If equipment is used in combination for indirect calculated measurements – then uncertainty statements should be regarded as Type B as defined by the Guide to the Expression of Uncertainty in Measurements (GUM) and are already stated / expressed at a coverage factor of $k = 1$, noting that there are no Type A statements for the data in Table Q2B.

a) Briefly identify what preparatory issues you would consider prior to starting the measurements. [5 marks]

b) Determine and calculate how the measurement process uncertainty statements may change for all of the indirect calculated measurements that require different combinations of measurement tools. [5 marks]

c) Process all data in Table Q2B with respect to dimensions/features with 2 decimal place limit specifications and determine outcome to specification with accompanying recommendations and actions. [7 marks]

d) Process all data in Table Q2B with respect to dimensions/features with 3 decimal place limit specifications and determine outcome to specification with accompanying recommendations and actions. [8 marks]

3. A machined surface has been produced using a DMU 80 FD duoBLOCK 5-axis vertical milling machine on a curved substrate, the radius of curvature being 27.00 mm. The surface displays various surface texture characteristics as a function of the 12.00 mm diameter carbide end mill used during the machining operation.

The surface has been measured using a Taylor Hobson CLI 2000 system with a non-contact 300 µm range Chromatic Length Aberration (CLA) gauge. This gauge produces data in a similar fashion to a contact stylus. The data shown in Figure Q3A has initially been produced in a raw state as a line profile with no further processing, the length of the profile is 16.68 mm.

a) Explain what quantification could be achieved with the data in its raw state as shown in Figure Q3A, and the problems associated with this form of representation and quantification. Using the axes and scale factors provided in the data set in Figure Q3A, calculate numerical values that relate to surface texture parameters which have the *p, v*, *z* and *sm* indicators/notation. [8 marks]

b) The raw dataset requires processing to extract more meaningful data.

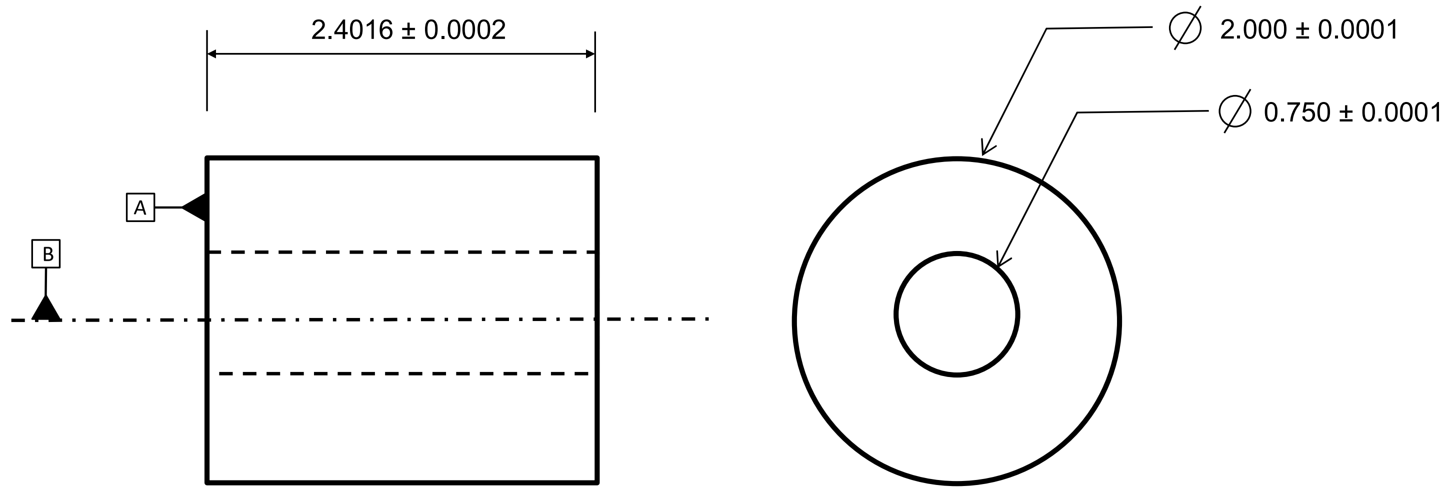
i. Identify why the raw dataset needs to be separated into components [2 marks]

ii. Identify what these components are, and explain in detail, the processes required to transform the raw data set in Figure Q3A as a function of the original curved substrate, to the two final datasets shown in Figures Q3B and Q3C respectively. Within your description, where appropriate, provide numerical examples of typical variables that may be used during the data processing to achieve the final datasets. [8 marks]

c) With respect to the two data sets shown in Figures Q3B and Q3C respectively, calculate and correctly represent the numerical values that relate to surface texture parameters which have the *p, v* and *z* indicators/notation, using the axes scale factors provided in each data set. Calculate the surface texture parameter that has the indicator/notation *sm* for Figure Q3B, and explain why this is not possible (for practical reasons) for the dataset/profile shown in Figure Q3C. [7 marks]

J N Petzing

Dimensions +/- tolerances, identified for all machining operations



Operational tolerance for cryogenic temperature use is +/- 0.0045 inches for all dimensions

Scale: Not to scale	Units: inches	Figure Q1A

/continued

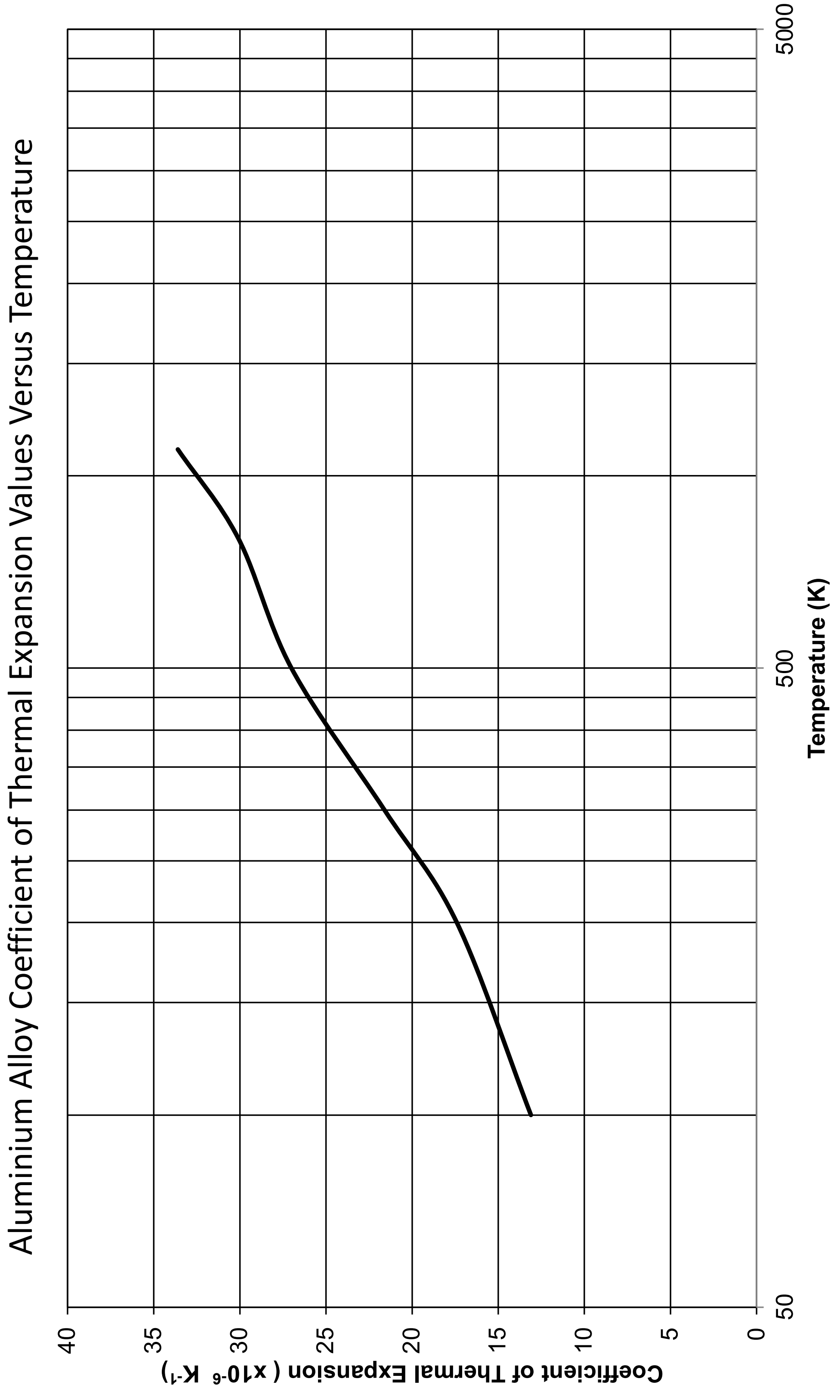


Figure Q1B

/continued

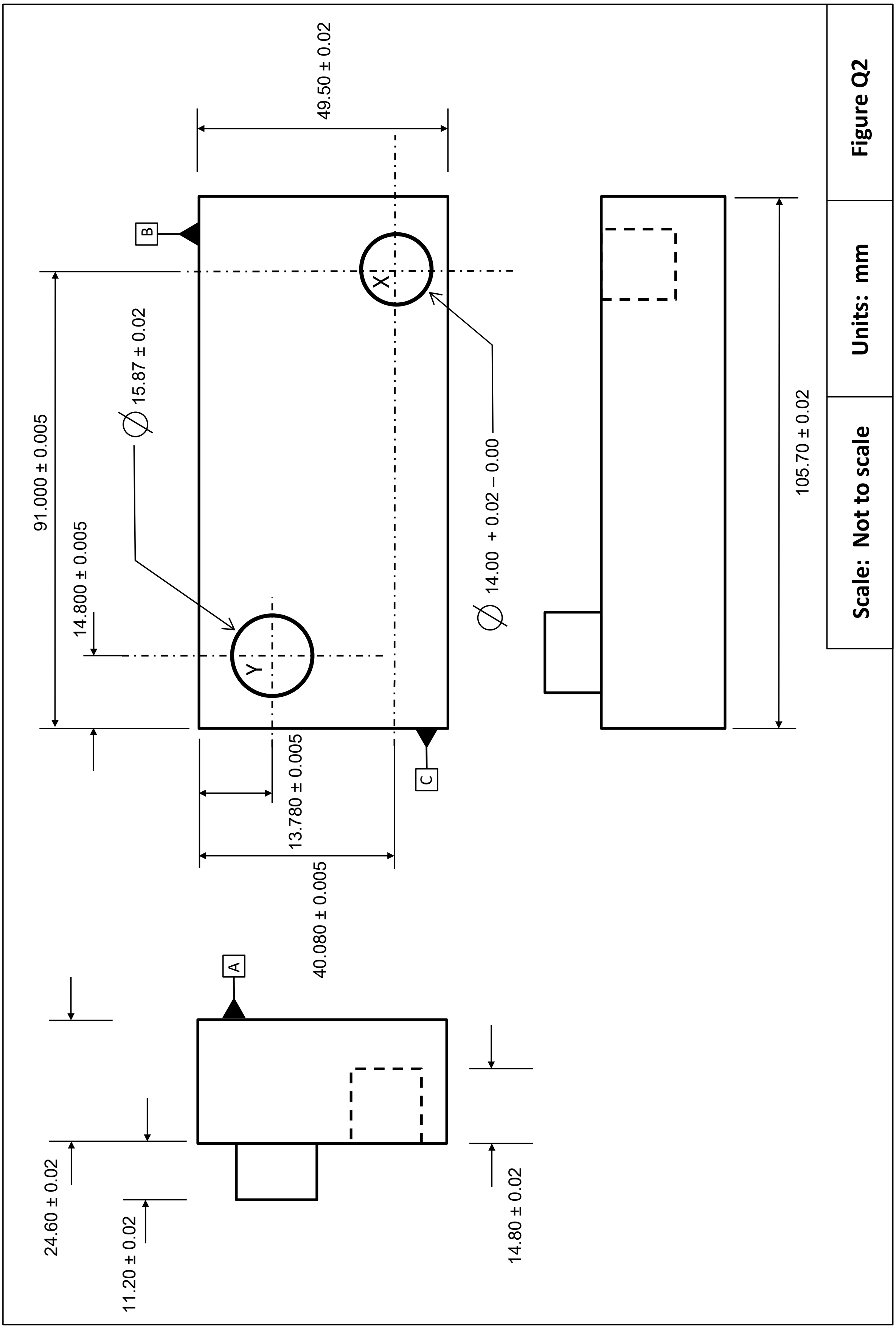


Figure Q2
Units: mm
Scale: Not to scale
49.50 ± 0.02
B
C
A
X
Y
∅ 15.87 ± 0.02
∅ 14.00 + 0.02 – 0.00
91.000 ± 0.005
14.800 ± 0.005
13.780 ± 0.005
40.080 ± 0.005
105.70 ± 0.02
24.60 ± 0.02
11.20 ± 0.02
14.80 ± 0.02

/continued

Measurement Instrument	**Instrument Resolution (μm)**	**Manufacturer's Uncertainty Statement @ k=1 (μm)**	**Instrument Output (decimal places)**
Mitutoyo Micrometer (0 – 25 mm)	10	$\pm$2	2
Mitutoyo Micrometer (25 – 50 mm)	10	$\pm$2	2
Mitutoyo Micrometer (100 – 125 mm)	10	$\pm$3	2
Mitutoyo Spring Gauge	---	---	---
TesaTest Level Dial Test Indicator (DTI)	2	$\pm$2	3
Mitutoyo Digital Height Master (0 – 300 mm)	2	$\pm$2	3
Mitutoyo Grade 0 Gauge Block (40 mm)	---	$\pm$0.1	---

Table Q2A

Component Feature	**Measurement Data (mm)**
Component substrate	24.62
	49.45
	105.69
Feature X Hole	13.94
	14.80
Feature X Position	33.071
	83.980
Feature Y Pin	15.92
	35.809
Feature Y Position	61.739
	62.771

Table Q2B

/continued

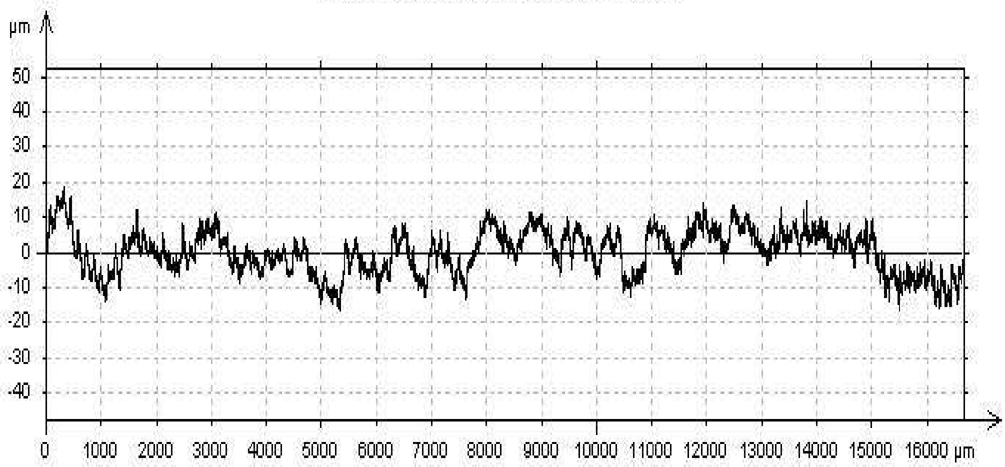


Figure Q3A

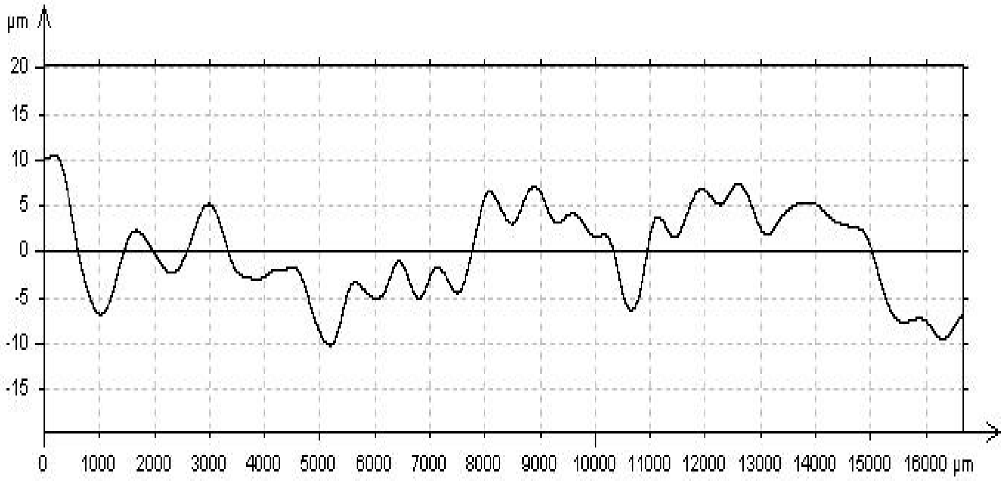


Figure Q3B

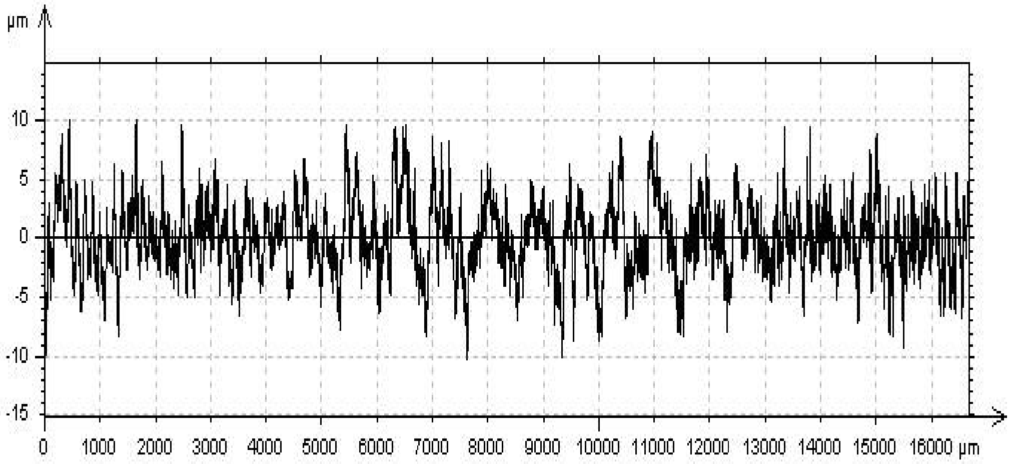


Figure Q3C